ACDI African Climate & Development Initiative

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Climate Change and Impacts on Crop Suitability in the *Planalto* region of Angola

Climate Risk Analysis

Study undertaken in support of the Smallholder Agricultural Development and Commercialisation Project (SADCP) project in Angola

Summary report and Recommendations

May 2017

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Executive Summary

The Smallholder Agricultural Development and Commercialisation Project (SADCP) is expected to be implemented over a 7 year period (2017-2024) in the central highlands *Planalto* region of Angola, including the provinces of Benguela, Bié, Cuanza Sul, Huambo, Huíla and Malanje. The SADCP will be implemented by the Angolan Government in participation with several development partners, including the International Fund for Agricultural Development (IFAD) and the World Bank (WB). In support of the project development process, a Climate Risk Analysis study was undertaken to determine *inter alia* i) the current and future climate characteristics of the project area; ii) the current and future suitability of various crop species to the project area; and iii) identify risks related to climate change, as well as potential adaptation options and opportunities to increase climate resilience.

The Climate Risk Analysis was undertaken in two phases, the first of which was a Preliminary Climate Risk Analysis (PCRA) undertaken in October 2016. The latter study provided a brief summary of baseline climate in the project area, observed and predicted climate change impacts in Angola, and an assessment of the agricultural value chains and primary commodities in the project area. In addition, the PCRA provided a summary of the baseline distribution of crop suitability index scores (i.e. the relative suitability or production potential for a given crop) across the project area. Consequently, the latter information is not presented in detail in this report, which represents the second phase of the Climate Risk Analysis study – readers are encourage to refer to the PCRA report (October 2016) for a detailed description of the baseline climate and crop suitability zones in the project area.

The following report, henceforth referred to as the Climate Risk Analysis (CRA) provides an updated analysis of the baseline situation described in the PCSA. The updated CRA includes *inter alia*:

- A brief summary of climate, as well as observed and predicted climate changes, in Angola. The latter summary is based on past studies and literature reviewed and is presented for background context in Section 1.
- Analysis of regional-level and provincial-level climate changes predicted in the period from 'Baseline', to 'Near Term Future in the Year 2030' (NT2030) and 'Mid Century Future in the Year 2050' (NT2050), respectively. The results of the latter analyses are summarised in Section 2 (Baseline Climate), Section 3.1 (Predicted climate changes and anomalies at a regional level) and Section 3.2 (Predicted climate changes and anomalies within each respective province).
- Analysis of predicted changes to crop suitability (list of crops assessed below) as a result of climate change, in the period from 'Baseline' to NT2030 and MC2050 timepoints, respectively. The results of the latter analyses are summarised in Section 4 for each individual crop or cultivar assessed.
- Summarised climate change impacts, climate risks, opportunities and adaptation options in each of the six provinces of the study region. The latter summaries are presented in Section 5.

The predicted effects of climate change are not consistent across the full extent of the study area. However, several general observations can be made for all six of the studied provinces. For example, all provinces in the study area are predicted to experience increasing temperatures throughout the year, indicated by increased average monthly 'Mean Temperature' as well as average 'Minimum Temperature'. Furthermore, all provinces are predicted to experience increasing delays or inconsistencies in the onset of rainfall, where the months of September, October and in some cases November are characterised by deficits in rainfall.

The study assessed the effect of climate change on the relative suitability of the project area for various agricultural crops, detailed in the table below.

Summary table: Crop varieties assessed in EcoCrop analyses of future suitability under climate change

Crop	Species and varieties assessed	Number varieties assessed
Cassava	*Manihot esculenta*	1
Bananas	*Musa acuminata* (Cavendish table banana) *M. balbisiana* (cooking plantain) *M. balbisiana* x *M. acuminata* (hybrid plantain)	3
Sweet potato	*Ipomoea batatas*	1
Maize	*Zea mays* Ls. *mays* *Z. mays* v. *indurata; indentata* (flint and dent maize varieties) *Z. mays* v. *amylacea; everta*; *tunicate* (soft, pop and pod maize varieties)	3
Sugarcane	*Saccharum officinarum*	1
Sorghum	*Sorghum bicolor* (low-altitude and high altitude varieties)	2
Millet	*Pennisetum glaucum*	1
Coffee	*Coffeea arabica* (arabica coffee); *C. robusta* (robusta coffee)	2

The combined effects of reduced precipitation and increased temperatures are likely to have negative effects on climate-sensitive crops such as maize, sweet potato and coffee. However, despite these common trends, there are also several province-specific effects on climate variables and resultant crop suitability that will necessitate the development of local-level adaptation plans and strategies for agricultural development.

Of all the provinces assessed, Huíla is considered to be particularly vulnerable to climate change, where the suitability index scores and total suitable area of several important crops (*inter alia* cassava, maize, sorghum, banana) are predicted to decrease as a result of climate change. Huíla is predicted to be particularly negatively affected by reduced rainfall as well as increased temperatures, and as a result the suitable range of several crop types is predicted to be reduced in the southern and western lowlands of the provinces. Certain other provinces may enjoy both negative and positive effects as a result of climate change, where it is predicted that increased temperatures may improve the production potential of several crops. For example, in the northern extent of the study area, including much of Huambo, Bié, Malanje and Cuanza Sul provinces, it is predicted that climate change will result in increased suitability for staple crops such as maize and cassava as well as valuable cash crops such as banana and coffee.

It is important to note that these analyses are based on consideration of a narrow range of modelled variables and the resultant effects on crop suitability. This study cannot account for local-level factors such as differences in performance, climatic suitability and yield potential between local land races or improved cultivars. In addition, the study cannot consider or predict the effect of different cultivation methods and technologies that may be practiced within the study area. Finally, in terms of predicting the likely effects of climate change and resultant risks to crop production, this study cannot account for indirect effects of climate change on crop production, such as increased vulnerability to pests and disease, soil degradation or flooding/waterlogging. However, the study does find that climate change is likely to result in multiple negative effects on smallholder farmers in the study area through disruption of familiar seasonal trends, increased water and heat stress and reduced growing season. Potential opportunities for adaptation and crop diversification have been identified for each of the six provinces and are described in the contents of this report.

1. Climate and Climate Change in Angola

1.1 Baseline Climate and Weather of Angola

The country has two distinct seasons – hot, humid and rainy season (October to May) and dry and cool (June to September). Rainfall decreases from north (1800mm) to south (50mm, particularly in desert areas) in the country as the cooling effects of the Benguela current become pronounced. Temperatures in Luanda average 25°C in January and 21°C in the winter month of July. With less rain along the coast, the capital (Luanda) receives an average of ~300mm annually (GoA, 2012). Angola's meteorological records are notoriously unreliable and inconsistent as a result of the disrepair of the country's monitoring network, and as a result there are large geographic and historical gaps in data. For example, rainfall data is based on a monitoring network of 500 station of which only ~20 are considered to be fully functional, which provides an inadequate level of detail to inform accurate and downscaled analysis and forecasts of Angola's climate.

1.2 Observed Climate Change Trends in Angola

According to Angola's Initial National Communication (INC, GoA 2012) surface temperature increases of 0.2 to 1.0 °C were observed from 1970 and 2004 within the coastal areas and northern regions of Angola; and an increase of between 1.0 and 2.0 °C in the central and eastern regions of the country. Air temperature data in Luanda indicated an increase of ~0.2 °C per decade, totalling an increase of 2.1 °C between 1911 and 2016 with greater increases observed during the cool season. Meteorological data extracted from the central plateau of Angola, where data sets are more reliable relative to the majority of the country, do not indicate any clear change in seasonal precipitation trends. (GoA 2012).

The sectors which are considered to be particularly vulnerable to climate change in Angola include natural resources/biodiversity, human health, infrastructure, fisheries, and agriculture and food security. Given the uncertainties in projected trends in precipitation, specific impacts are difficult to predict. However it is anticipated that climate change will increase the severity of existing vulnerabilities (Lotz-Sistika and Urquhart, 2014), notably extreme events such as droughts and floods. The entire SADC region, including Angola, has been severely impacted by the disruptions of the El Nino effect. The country experienced a severe drought during the 2013-2014 agricultural cycle which resulted in widespread food insecurity in the country's southern provinces. The drought affected 1.8 million people in six provinces, particularly Cunene (543,000), Huíla (583,000) and Namibe (162,092), where production losses of cereals and legumes were ~100% (UNICEF, 2014). The subsequent agricultural cycle in 2015–2016 was similarly impacted such that the United Nations Office for Coordination of Humanitarian Affairs reports that drought "affected 1.4 million people in seven of Angola's provinces, of which 78% are located in Cunene, Huíla and Namibe. Cunene being the greatest affected province, 800 000 people residing in rural communities were affected in 2016 compared to 500 000 affected in the previous year" (OCHA, 2015). The Office of the UN Resident Coordinator reports that the heavy downpours and flash floods that typify the rainy season are expected to exacerbate the food security situation in the 2016–2017 season (UNORC, 2016).A brief summary of the scale and frequency of climate-related disasters (droughts and floods) in Angola in the period 1976–2014 is presented in Table 1, below.

Table 1. Recorded impacts of drought and flood in Angola (1976–2014) (UNICEF, 2014).

Disaster type	Disaster subtype	Events count	Total deaths	Total affected	Total damage ('000 US$)
Drought	Drought	7	58	444,3900	0
Flood	Riverine flood	24	468	108,8608	10,000
Flood	--	9	74	11,6228	0
Flood	Flash flood	4	134	5,755	0

1.3 Projected Climate Change

Considering the limited availability of observational data to inform analytical models, there is a relatively wide range of uncertainty of the likely effect of climate change in Angola. Projections of average annual rainfall over the country from a number of models illustrate a wide range of changes in rainfall patterns for Angola (RoA, 2015). IPCC scenarios (SRES A1B scenario as shown in the IPCC 4th Assessment Report) project an increase of mean annual temperature ranging between 1.2 to 3.2°C by the 2060s, and 1.7 to 5.1°C by the 2090s (IPCC, 2014). However, in general all climate models project that Angola will experience increased temperatures, more extreme weather events, an expansion of arid and semi-arid regions, seasonal shifts in rainfall, localized floods, increased wildfires, sea level rise, increased rainfall in the northern parts of the country, changes in river flows and changes in sea and surface water body temperatures over the coming 100 years (RoA, 2015).

Existing climate-related hazards such as drought and floods are likely to become more frequent and severe, particularly in the southern regions. The National Adaption Programme of Action 2011 (NAPA) emphasises the likelihood of negative impacts on sectors including agriculture and food security, as well as natural resources and biodiversity, fisheries, water resources, human health, infrastructure, and energy (RoA, 2011). The agriculture sector is considered to be particularly vulnerable to the impacts of hazards such as drought and flood, in addition to which it is predicted that changes in the onset and duration of the growing season will further exacerbate food insecurity. Possible shifts in the growing season are likely to include reduced duration of the growing season in Southern and coastal regions, and a shift from two seasons towards one annual growing season in the Northern regions (Lotz-Sistika and Urquhart, 2014).

In addition to the climatic variables which directly influence crop performance (primarily temperature and precipitation), there are a number of other hazards related to climate change that may result in negative impacts on the most climate-vulnerable communities. For example, the widespread disrepair and underdevelopment of Angola's road network is already recognised as a barrier to market access for rural communities, resulting in large transport costs, high rates of spoilage and poor quality in the marketplace. It is likely that these negative impacts on agricultural households are likely to be exacerbated as a result of the increased frequency and severity of floods predicted for Angola. Another existing barrier to the development of the agricultural value chain which may be exacerbated by the effects of climate change is the high rates of food spoilage and limited capacity for post-harvest storage that characterises many subsistence farming households. In certain cases, particularly storage of cereal crops, inadequate drying or storage of grain promotes growth of the *Aspergillus* fungus, which results in contamination of food with the carcinogenic aflatoxin and severely exacerbates existing food insecurity and malnutrition. Baranyi et al. (2015) found that the range of areas characterised by aflatoxin was likely to increase as a result of increased temperatures and humidity, but that this increase would largely occur in temperate climates – it was not clear from the latter study whether sub-tropical and tropical climates would similarly be increasingly vulnerable to aflatoxin outbreaks (Baranyi et al., 2016).

2. Baseline Climate and Weather in Angola's '*Planalto*' provinces

The provinces prioritised for inclusion in this climate risk analysis include the coastal provinces of Benguela and Cuanza Sul and the inland provinces of Malanje, Bié, Huambo and Huíla, encompassing an area ranging in altitude from 0 to ~1,600m above sea level. The majority of the contiguous area between these provinces is covered by the *Planalto* midland plateau region, which extends from the escarpment ~30-50km inland from the semi-arid coastal zone towards the interior highlands of the country. Figure 1 (below) depicts the provinces assessed.

Figure 1. Map of provinces selected for analysis of climate risks.

Baseline climate data for the project area was derived from Worldclim historical data[1] WorldClim Version 1 provides average monthly climate data for minimum, mean, and maximum temperature and for precipitation for the period 1960-1990. Data is provided at a resolution of ~1km^2 (a resolution grid of 30 arc-seconds). Detailed information on the methods used to generate WorldClim climate layers, units and formats of data etc. is provided by Hijmans et al. (2005). Interpolations of observed data representative of the period 1960-1990 are henceforth referred to as the 'historical' or 'baseline' period.

2.1 Summarised temperature and precipitation across study area

The coastal zone and interior *planalto* varies widely in climate, soil type and topography and consequently supports a wide variety of subsistence and cash crops. The three following figures depict the average variation in monthly precipitation, monthly minimum temperature and monthly mean temperature, respectively, across the six provinces assessed. Firstly, Figure 2, below, depicts the average of all provinces in the *Planalto* region by month. Figure 3, further below, indicates the individual provincial averages of temperature and precipitation across all 12 months. Finally, Figure 4 depicts the spatial variability in Temperature and Precipitation across the full extent of the study area.

[1] http://www.worldclim.org/version1

Despite the annual and spatial differences in climate within the study area, Figures 2-4 broadly depict the onset of a bi-modal rainy season which begins in ~October and peaks in December, before a second 'late' rain at the end of the season in March-April. The winter months of May to August/September are dry and characterised by a mean temperature of ~17^{o}C, ~4-5^{o}C lower than the mean temperatures in summer. The baseline climate of each individual province is described further in Sections 2.2–2.7.

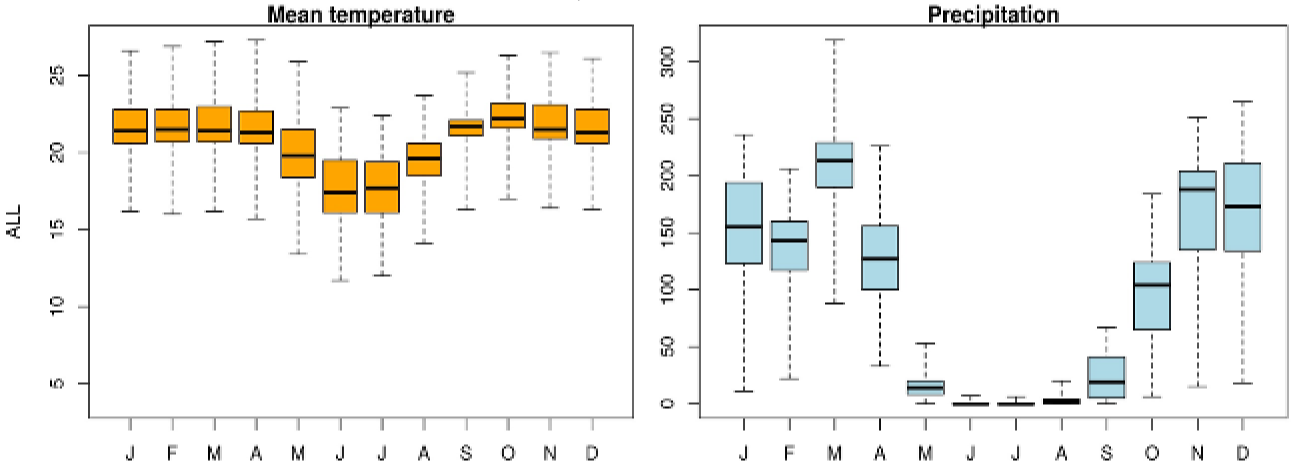


Figure 2. Mean monthly temperature and precipitation across the central planalto region of Angola

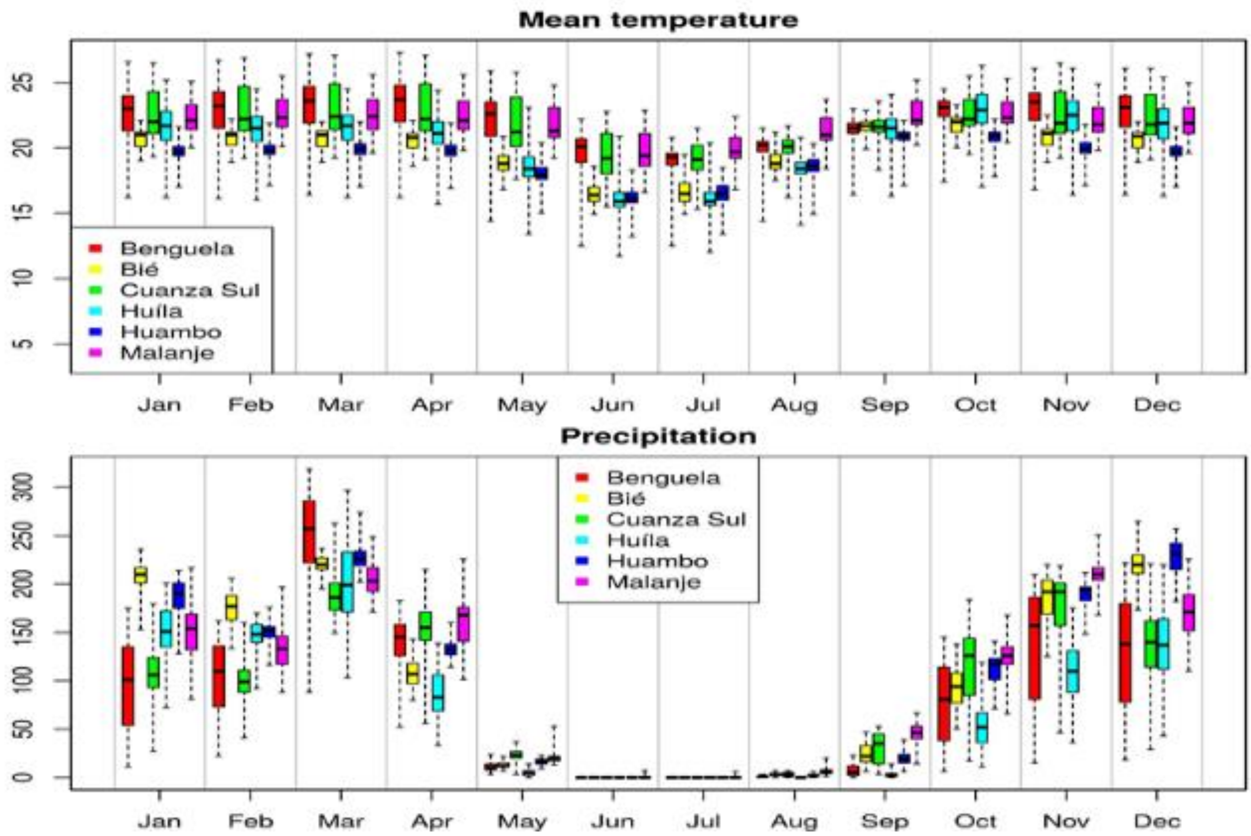


Figure 3. Mean monthly temperature and precipitation for each of six individual provinces in the planalto region of Angola

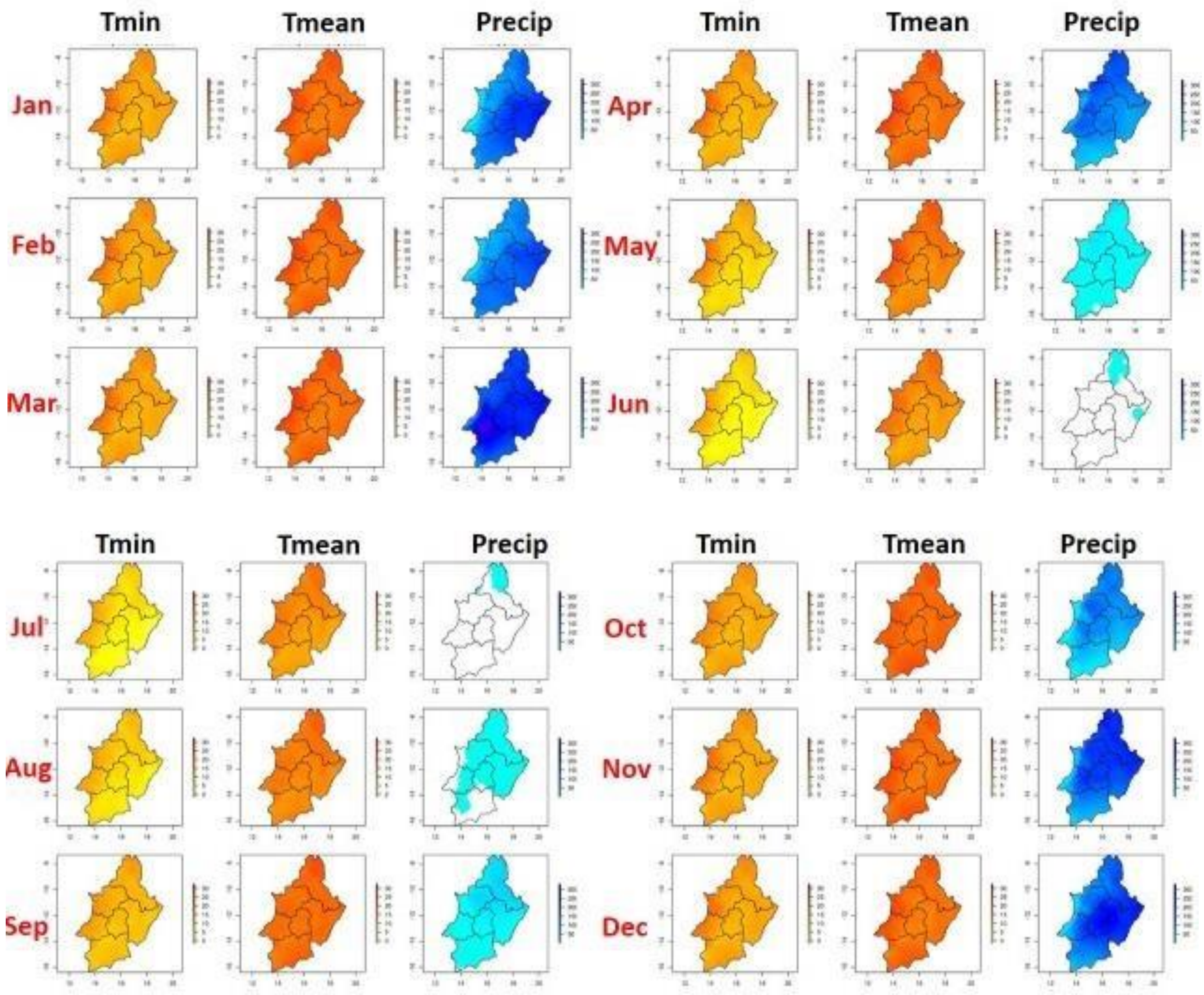


Figure 4. Seasonal variation in minimum temperature, mean temperature and mean precipitation across the planalto study region in Angola

2.2 Mean annual temperature and precipitation in Benguela province

Benguela province, similar to Cuanza Sul (below) is one of the hottest and most climatically variable of the six provinces assessed. The wide variability in mean temperature and precipitation within individual months (Figure 5, below) is consistent with the heterogeneity of the landscape from the semi-arid coastal plains eastwards to the interior plateau. The coastal lowlands of Benguela are particularly prone to drought and water shortages as a result of the high temperatures, extended winter dry season and erratic rainfall. The interior uplands of Benguela to the east of the coastal escarpment are comparatively cooler with higher rainfall, and are markedly different from the coastal plans in terms of suitability for different crops.

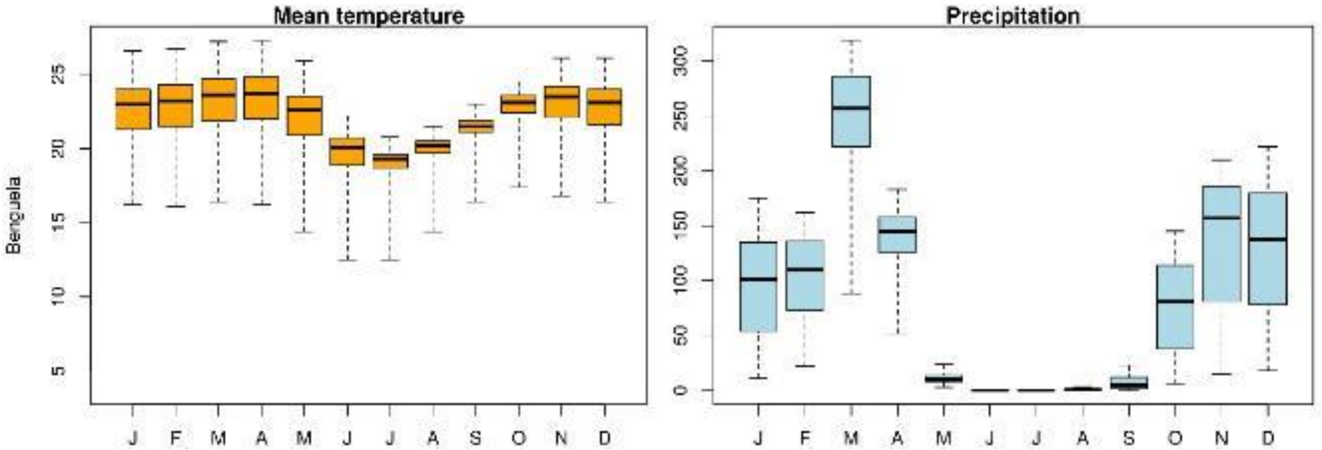


Figure 5. Mean monthly temperature and precipitation in Benguela province.

2.3 Mean annual temperature and precipitation in Bié province

Bié's climate is relatively stable and homogenous with small deviation in monthly average temperature compared to the geographically heterogeneous provinces such as Benguela and Cuanza Sul. The province is characterised by an extended dry season during the winter months from May to August, after which the planting season for rainfed agriculture begins with the onset of rains in September and October.

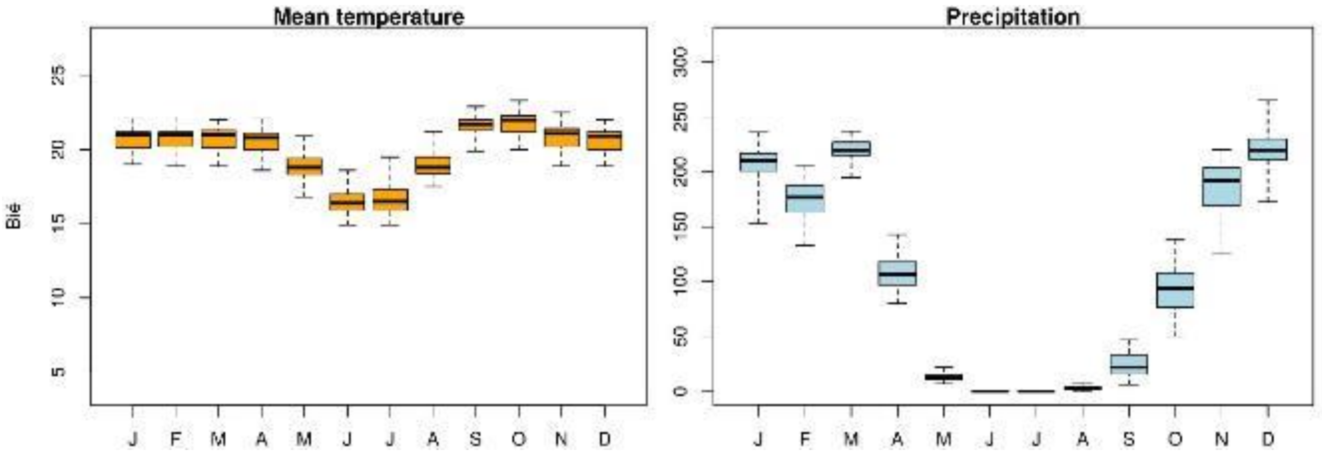


Figure 6. Mean monthly temperature and precipitation in Bié province.

2.4 Mean annual temperature and precipitation in Cuanza Sul province

The climate of Cuanza Sul province is comparable to Benguela province, and is similarly defined by the heterogeneous topography of the region extending from the coastal plains inland towards and beyond the coastal escarpment towards the *planalto* highlands. The primary difference between the climates of the two provinces is that the rainy season in Cuanza Sul begins slightly early (in September) in the northern latitudes of the province, allowing for comparatively earlier planting and longer growing seasons for rainfed crops.

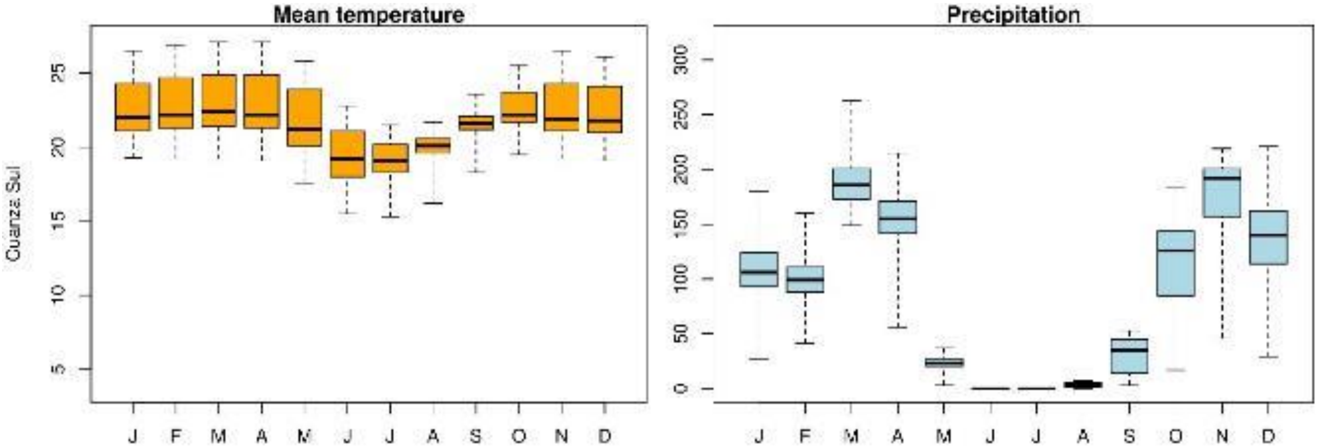


Figure 7. Mean monthly temperature and precipitation in Cuanza Sul province.

2.5 Mean annual temperature and precipitation in Huambo province

The climate of Huambo is relatively consistent across the geographic extent of the province compared to the more heterogeneous provinces such as Benguela and Cuanza Sul. The onset of the rainy season in this central province and neighbouring Huíla province begins in October and extends until April, declining sharply during the dry season from May to August.

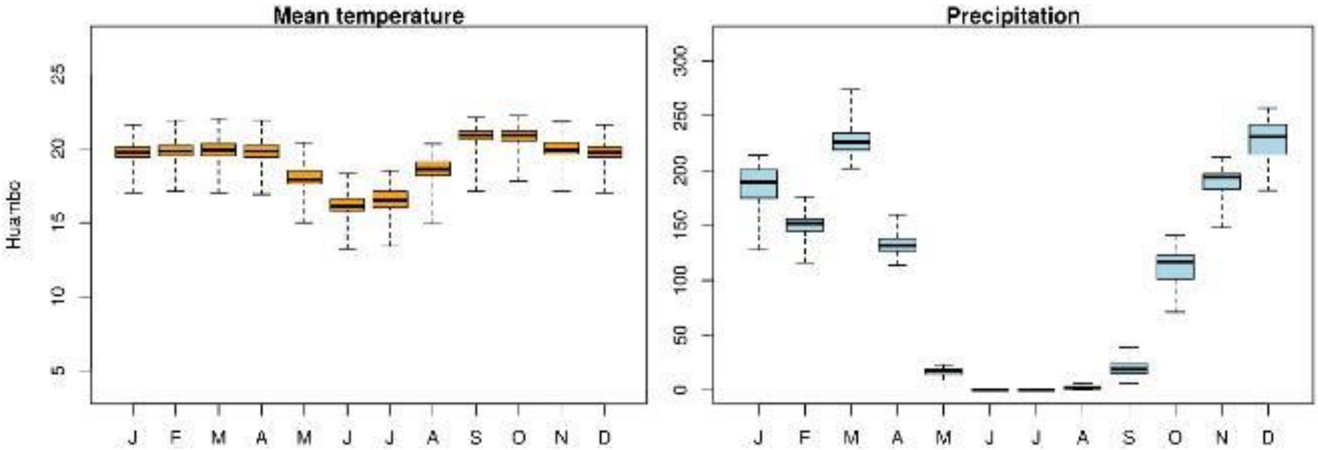


Figure 8. Mean monthly temperature and precipitation in Huambo province.

2.6 Mean annual temperature and precipitation in Huíla province

Huíla is the most southerly of the provinces in the study area and is also the most arid. In the months at the onset of the rainy season, Huíla is the only province which receives an average precipitation of less than 50 mm in the month of October. Similar to Huambo province and the interior of Bié, the winter months of June-July in Huíla province are cooler (winter average of ~15-16 ^{0}C) than the coastal plains and particularly arid in the period from May–September.

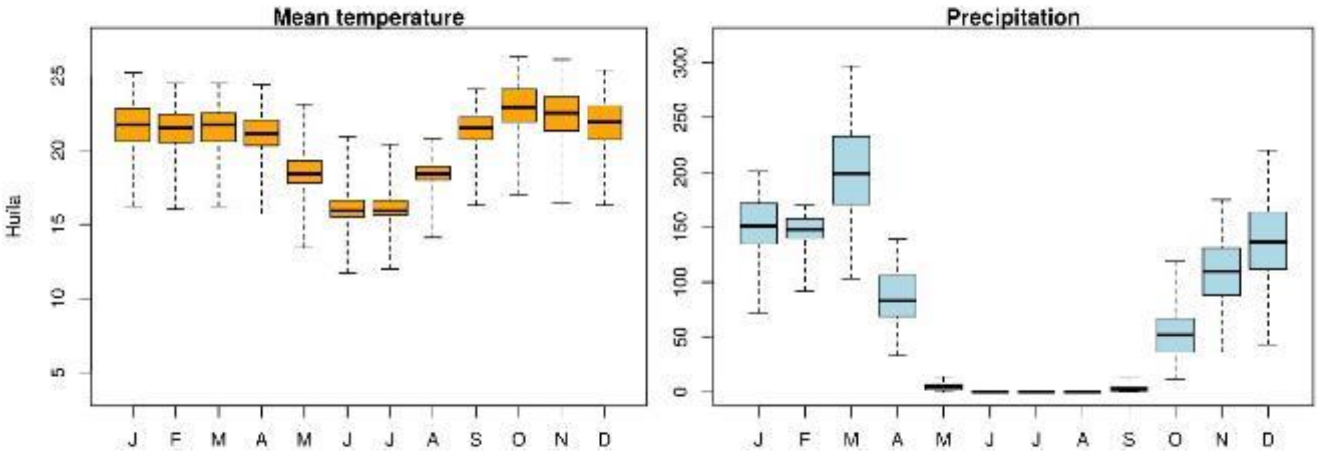


Figure 9. Mean monthly temperature and precipitation in Huíla province.

2.7 Mean annual temperature and precipitation in Malanje province

Malanje, the northernmost of the six provinces assessed, has the highest mean annual precipitation and the wettest winter months relative to other provinces. Typical of a humid sub-tropical climate, the average temperature in Malanje is above 20ºC all year around, even in winter months, and averages ~23ºC for the rainy period from September to April.

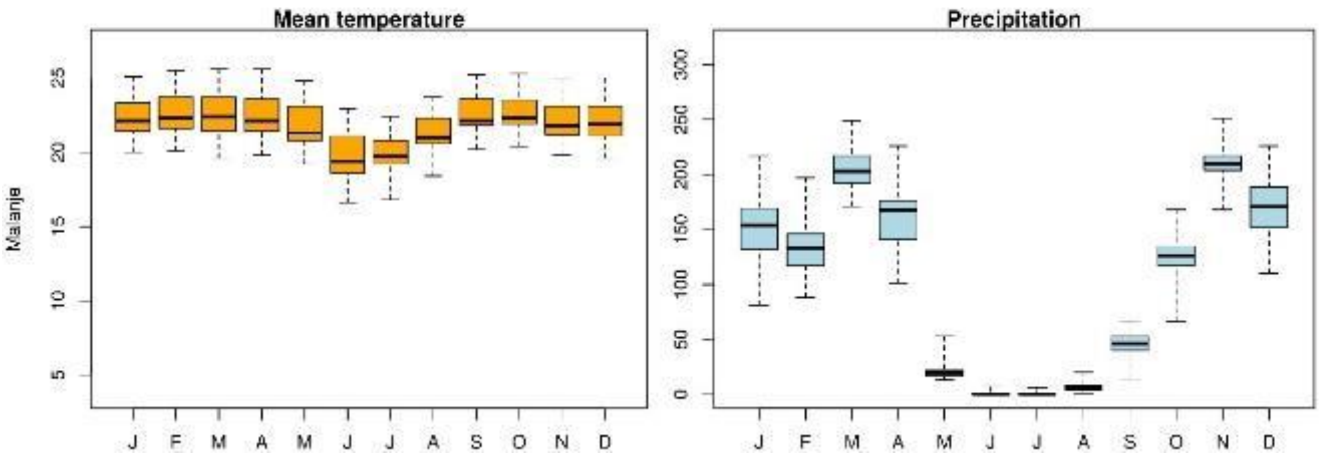


Figure 10. Mean monthly temperature and precipitation in Malanje province.

3. Predicted effects of climate change in Angola's 'Planalto' provinces

The baseline climate and weather of the studied provinces – Benguela, Bié, Cuanza Sul, Huambo, Huíla and Malanje – are described in the previous chapter. The future effects of climate change on the historical 'baseline' climate in the study area were computed based on analysis of 29 General Circulation Models (GCMs) downloaded from the AgMERRA dataset[2]. Analyses were based on the methods described by Ramirez-Villegas et al (2013). Future climate changes were computed assuming the scenario of 'RCP 8.5' (where 'RCP 8.5' refers to one of four hypothetical scenarios for future global greenhouse gas emissions proposed by the Intergovernmental Panel on Climate Change). This analysis was used to generate predictions of the effect of climate change in the *planalto* region of Angola, with a particular emphasis on the following three variables: i) Monthly Mean Temperature (Tmean); ii) Monthly Minimum Temperature (Tmin); and iii) Mean Monthly Precipitation (Precip.). The changes in each of these three variables were computed for two time periods, specifically:

- a near term (NT) change (henceforth 'NT 2030'), which is the monthly mean change for: i) Tmin; ii) Tmean; and iii) rainfall, based on each GCM in the periods 1980-2010 relative to 2010-2039 periods.
- a mid-century (MC) change (henceforth 'MC 2050', which is the monthly mean change for: i) Tmin; ii) Tmean; and iii) rainfall, based on each GCM in the periods 1980-2010 relative to 2040-2069 periods.

The results of these analyses are first described in terms of the predicted spatial changes and anomalies in each variable within the study area (Section 3.1, immediately below), and then subsequently in terms of the predicted average change in climate within each province in the study area (Section 3.2, following section). It should be emphasised the reader must be cautious when making direct comparisons between the analyses in the latter two sections, for the reason that map plots allow for the visualisation of spatial variability, whereas barplots and scattergraphs do not (for example, a boxplot for a given province represents an aggregate of all provincial outcomes and removes the effect of spatial variability). Therefore, two identical values could be the result of a condition which is homogenous across a wide spatial extent, or alternatively could be the result of a heterogeneous situation varying across a continuous range of variables. A further note on the representation of GCMs in spatial map plots and bar plots is the complexity of representing: i) spatial variability within a province; and ii) variation between and within each GCM. While there is only 1 value per month for 1 grid point under historical conditions, there are 29 values per month for 1 grid point under future conditions. Therefore, all analyses depicted show the median GCM output when presenting climate variables, and the median EcoCrop suitablility outcome when presenting the suitability of various crops in Section 4 (where the latter is not necessarily the result of the median GCM).

[2] https://data.giss.nasa.gov/impacts/agmipcf/agmerra/

3.1 Predicted changes and anomalies in the Planalto region of Angola in the period from 'Baseline' to 'Mid-Century 2050' timepoints

3.1.a Predicted changes and anomalies in Monthly Mean Temperature (Tmean)

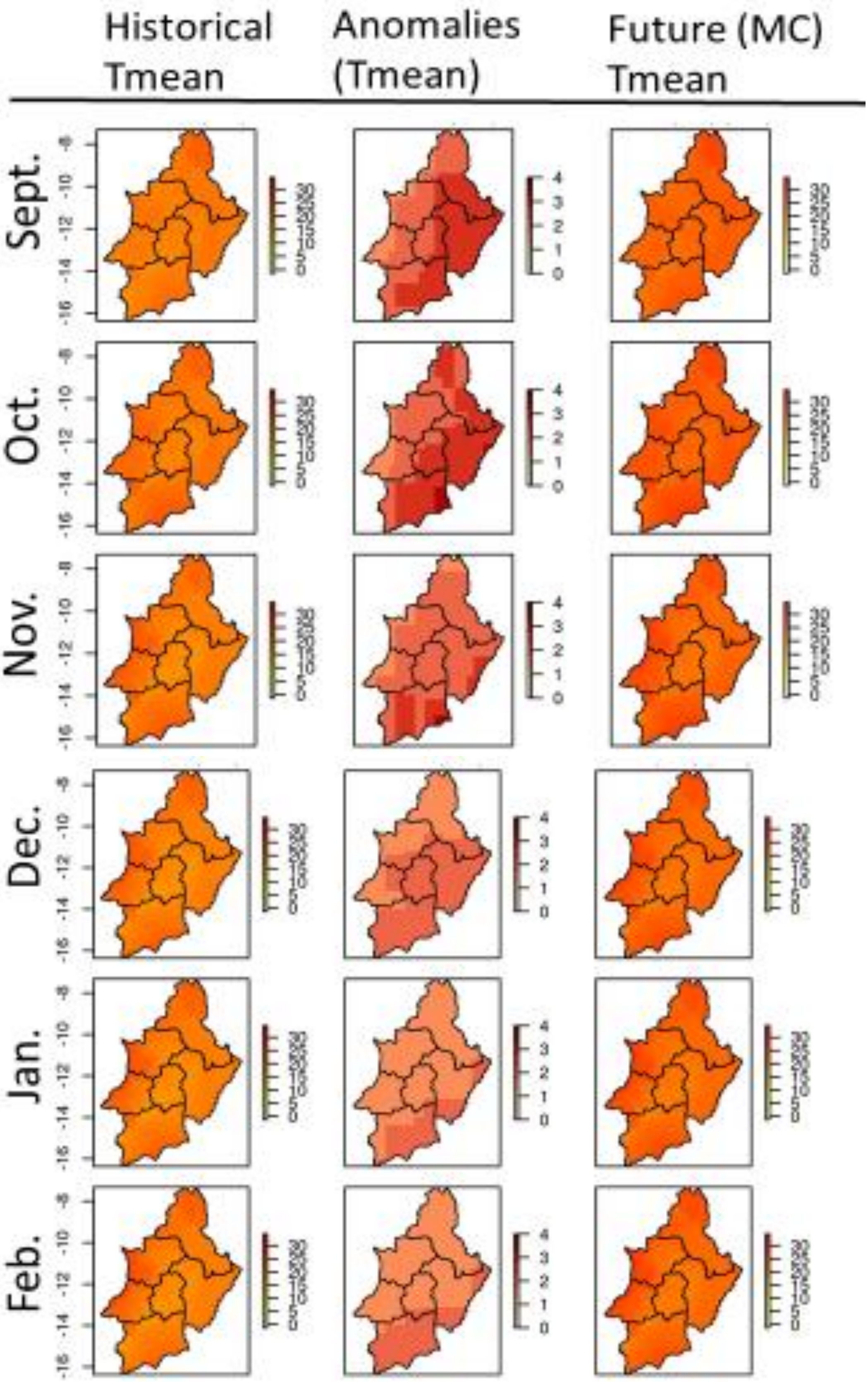
The figures presented below (Figure 11) depict the spatial distribution of mean temperature (Tmean) across the study area in all 12 months of the year. Included in the figures are graphical depictions of: i) Tmean at 'Baseline' time period, presented in the columns on the left of Figure 11;
ii) Anomalies between Tmean values predicted for the 'Baseline' and 'Future Mid-Century 2050' time periods, presented in the columns at the centre of Figure 11; and
iii) Tmean at 'Future Mid-Century 2050' time period, presented in the columns at the centre of Figure 11.

In general, a clear trend of warming is predicted across the entire study region. The eastern and southern interior of the country is predicted to experience the largest total increases in Tmean, particularly during the first months of the agricultural growing season (~onset of rains in September to December). However, the coastal and central regions of the country are also anticipated to experience significant increases in Tmean in the period between 'baseline' and 'MC 2050'. Furthermore, the autumn and winter months in the *planalto* region are also predicted to be characterised by increasingly large anomalies in Tmean, where the months of May to August are characterised by moderate-to-large anomalies across the entire region. The predicted warming trends are further described on a quarterly basis below.

In the months of September to November, it is predicted that large areas of Bié, Huambo, Huíla and Malanje provinces will experience major anomalies (+-1.5 – 2^{o}C) in average monthly mean temperature (Tmean). The majority of the remaining study area, including Cuanza Sul and Benguela provinces are predicted to experience moderate (~1^{o}C) anomalies in Tmean.

In the summer months of December to February, increased average Tmean values are predicted for the entire study area. In particular, the central and eastern interior of the study region and the entirety of Huíla province is predicted to experience most significant increases in Tmean, relative to the baseline. The months at the end of the rainy growing season, from March to May, are also characterised by predictions of widespread increases in Tmean. Finally, the dry winter months of June to August are characterised by the largest (and most geographically widespread) increases in Tmean relative to the baseline, during which period it is predicted that Tmean will increase across the majority of the study area by ~+-1.5^{o}C, relative to baseline.

The predicted changes to Tmin in each of the studied provinces are described further in Section 3.2.


Historical Tmean
Anomalies (Tmean)
Future (MC) Tmean
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.

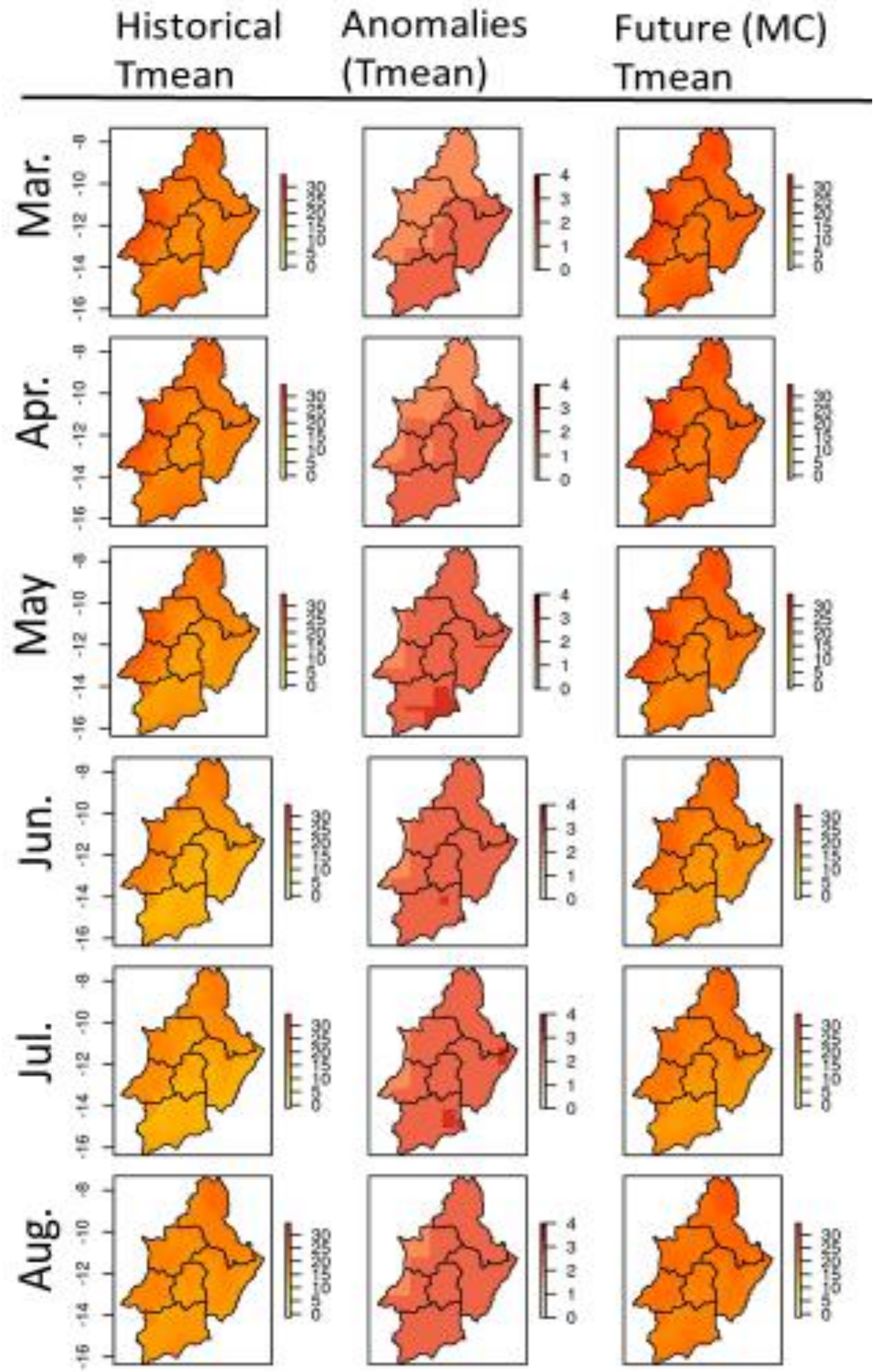


Figure 11. Predicted changes and anomalies in mean monthly temperature in the Planalto region of Angola in the period from 'Baseline' to 'Mid-Century 2050' timepoints.

3.1.b Predicted changes and anomalies in Minimum Temperature (Tmin)

Figure 12, below, depict2 the spatial distribution of mean 'Minimum Temperature' (Tmin) across the study area in all 12 months of the year. Included in the figures are graphical depictions of: i) Tmin at 'Baseline' time period, presented in the columns on the left of Figure 12;
ii) Anomalies between Tmin values predicted for the 'Baseline' and 'Future Mid-Century 2050' time periods, presented in the columns at the centre of Figure 12; and
iii) Tmin at 'Future Mid-Century 2050' time period, presented in the columns at the centre of Figure 12.

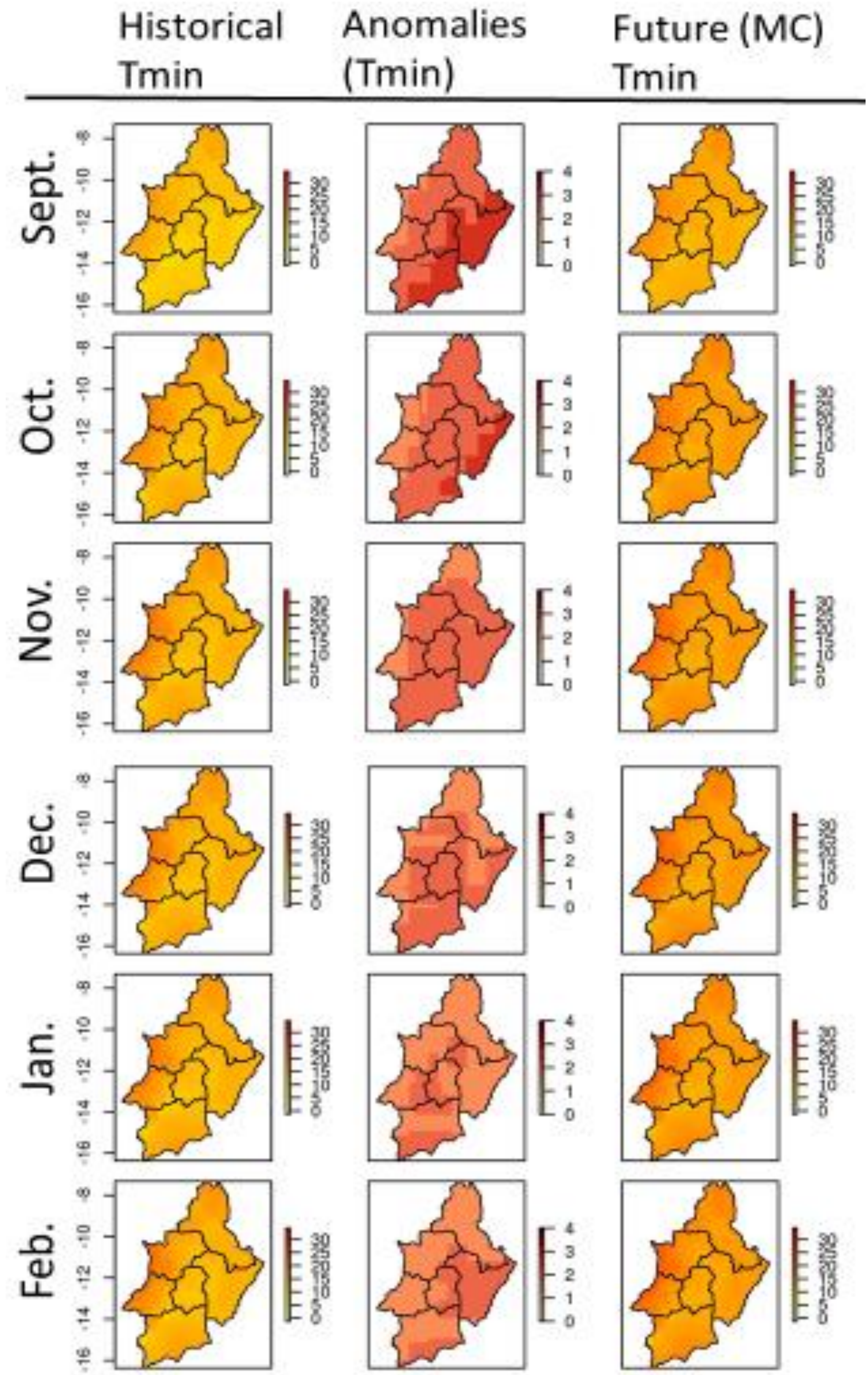
In general, the trends predicted for 'Tmin' are well aligned with those predicted for 'Tmean' (described above). In general, a clear trend of warming is predicted across the entire study region throughout all months of the year.

The eastern and southern interior of the country is predicted to experience the largest total increases in Tmin, particularly the provinces of Huíla, Huambo and Bié. However, the coastal, central and northern regions of the country are also anticipated to experience significant increases in Tmin in the period between 'baseline' and 'MC 2050'. Furthermore, the autumn and winter months in the *planalto* region are predicted to be characterised by increasingly large anomalies in Tmin, where the months of May to August are characterised by moderate-to-large anomalies across the entire region. The period from May to September, just before the onset of the rainy season, is characterised by the largest and most widespread sustained increases in Tmin. The predicted warming trends are further described on a quarterly basis below.

In the months of September to November, it is predicted that large areas of Bié, Huambo, Huíla will experience major anomalies (+-1.5 – 2^{o}C) in average monthly minimum temperature (Tmin). The majority of the remaining study area, including Malanje, Cuanza Sul and Benguela provinces are predicted to experience moderate (~1^{o}C) anomalies in Tmin.

In the summer months of December to February, moderate increased Tmin values are predicted for the entire study area. The months at the end of the rainy season, from March to May, are characterised by predictions of widespread increases in Tmin, of which the south, central and eastern regions are predicted to experience the largest anomalies in Tmin. The dry winter months of June to August are characterised by the largest (and most geographically widespread) increases in Tmin relative to the baseline, during which period it is predicted that Tmin will increase across the majority of the study area by ~+-1–1.5^{o}C, relative to baseline.

The predicted changes to Tmin in each of the studied provinces are described further in Section 3.2.


Historical Tmin
Anomalies (Tmin)
Future (MC) Tmin
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.

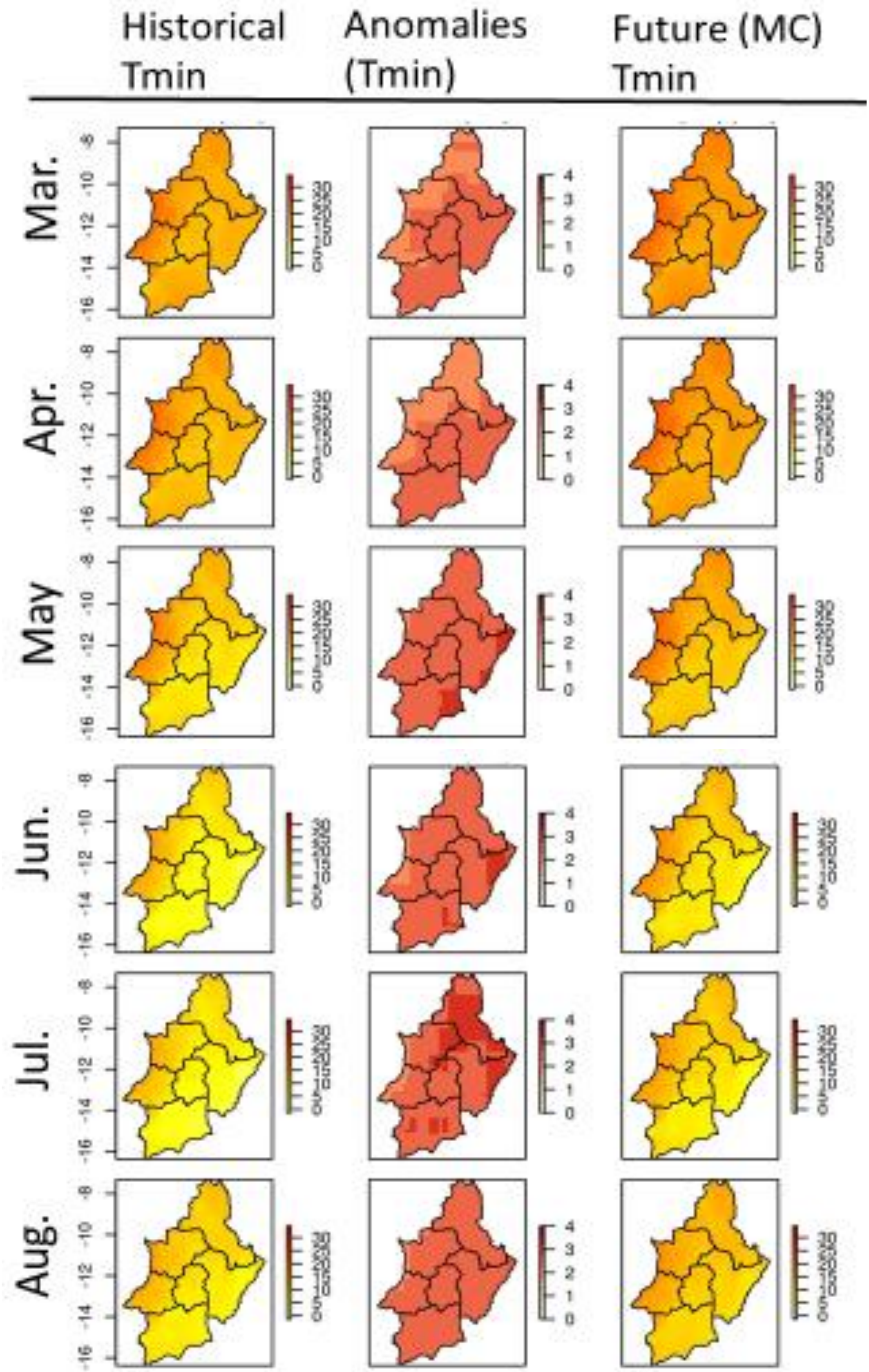


Figure 12. Predicted changes and anomalies in minimum monthly temperature in the Planalto region of Angola in the period from ‘Baseline’ to ‘Mid-Century 2050’ timepoints.

3.1.c Predicted changes and anomalies in Monthly Total Precipitation (Precip.)

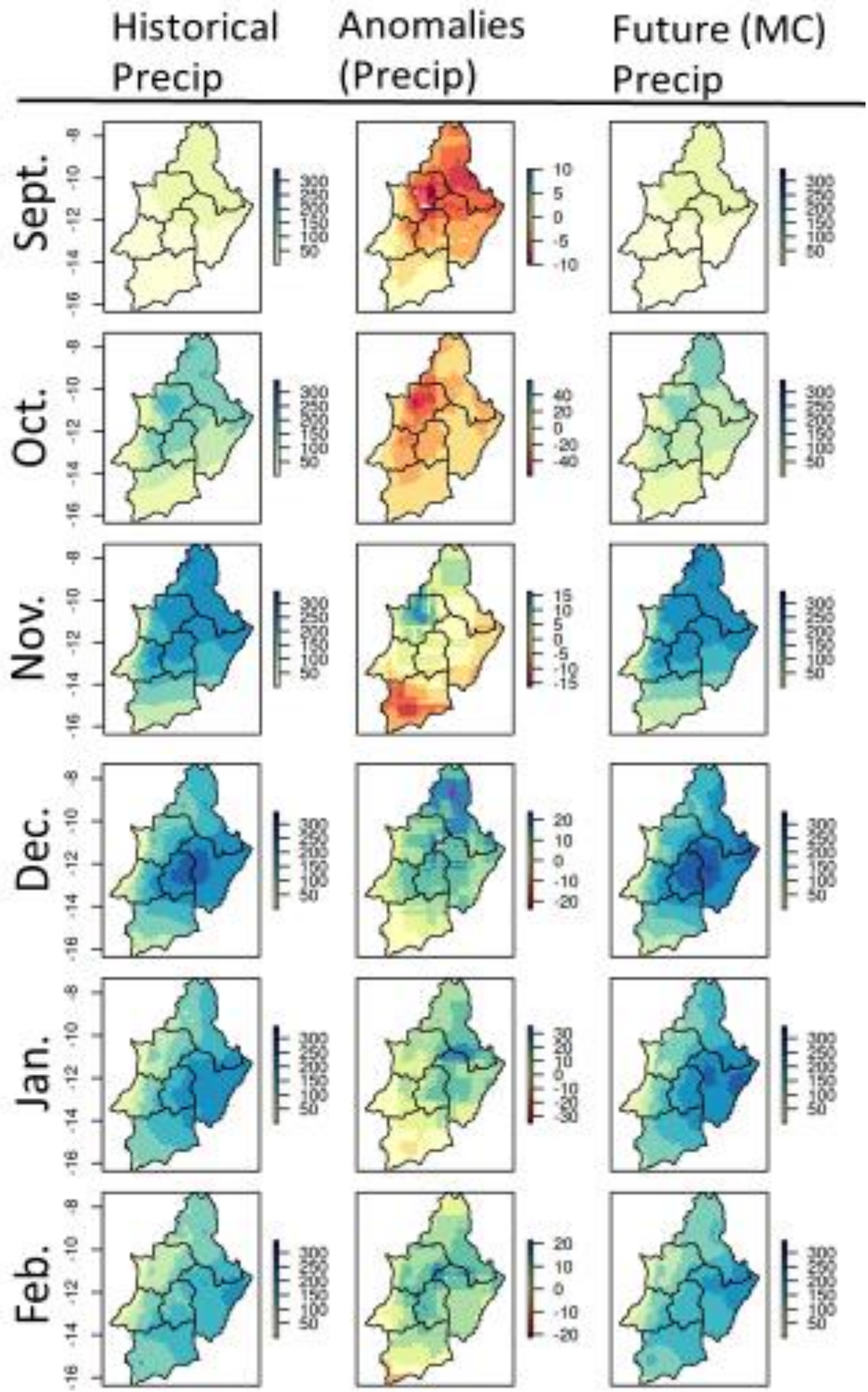
Figure 13, below, depicts the spatial distribution of mean 'Monthly Precipitation' (Precip.) across the study area in all 12 months of the year. Included in the figures are graphical depictions of:
i) Precip. at 'Baseline' time period, presented in the columns on the left of Figure 13;
ii) Anomalies between Precip. values predicted for the 'Baseline' and 'Future Mid-Century 2050' time periods, presented in the columns at the centre of Figure 13; and
iii) Precip. at 'Future Mid-Century 2050' time period, presented in the columns at the centre of Figure 13.

The predicted changes in mean monthly precipitation during the period from 'baseline' to 'MC 2050' timepoints indicate that climate change will result in complex spatial and temporal changes in precipitation in the *planalto* region. A common prediction for all six target provinces is that mean monthly precipitation at the onset of the rainy season, in the months of September and October, will be reduced in all provinces during the period from 'baseline' to 'MC 2050' timepoints. Anomalies in monthly rainfall, indicated by red shading in Figure 13, below, are particularly acute in the northern, central and western extents of the study area. In the month of November, the central and southern extent of the study area – including the entire extent of Huíla province and majority of Bié and Huambo – is predicted to experience further deficits in rainfall by 'MC 2050' time period, relative to baseline. In contrast, the majority of Cuanza Sul and Malanje provinces are predicted to benefit from increased rainfall in November by 'MC 2050', relative to 'baseline' mean monthly rainfall.

In the mid-summer months from December to February, the majority of the study area is predicted to benefit from increased rainfall by 'MC 2050 relative to 'baseline' mean monthly rainfall, with the exception of the southernmost extent of Huíla province. In March and April, the last months of the traditional maize-growing season, rainfall anomalies across the study area are predicted to follow two distinct trends, specifically: i) reduced rainfall in the southern and eastern areas, particularly Huíla, Bié and the south-eastern extent of Huambo; and ii) increased rainfall in the central, western and northern areas, particularly Malanje, northern Huambo, and the highland interior of Cuanza Sul and Benguela provinces. No major changes to rainfall are predicted for the dry winter months of May to August.

These analyses indicate that climate change will delay the onset of rainfall, in turn resulting in changes to the timing of various agricultural activities such as field preparation and sowing of seed. In the case of the southern and eastern extents of the project area, notably Huíla and south-east Bié, the majority of the agricultural growing season is characterised by monthly rainfall deficits and is likely to result in fundamental changes to local crop choices and agricultural practices by the year 2050. Drought-sensitive crops such as maize are likely to be increasingly unreliable or poor in yield, which will be further exacerbated by the predicted increases in temperature described previously. However, certain regions within the study area, notably the central and northern areas, are expected to benefit from surplus rainfall during the middle and late summer months which may have the effect of extending the growing season or improving the yield potential of certain crops.

The predicted changes to mean monthly rainfall in each of the studied provinces are described further in Section 3.2.


Historical Precip
Anomalies (Precip)
Future (MC) Precip
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.

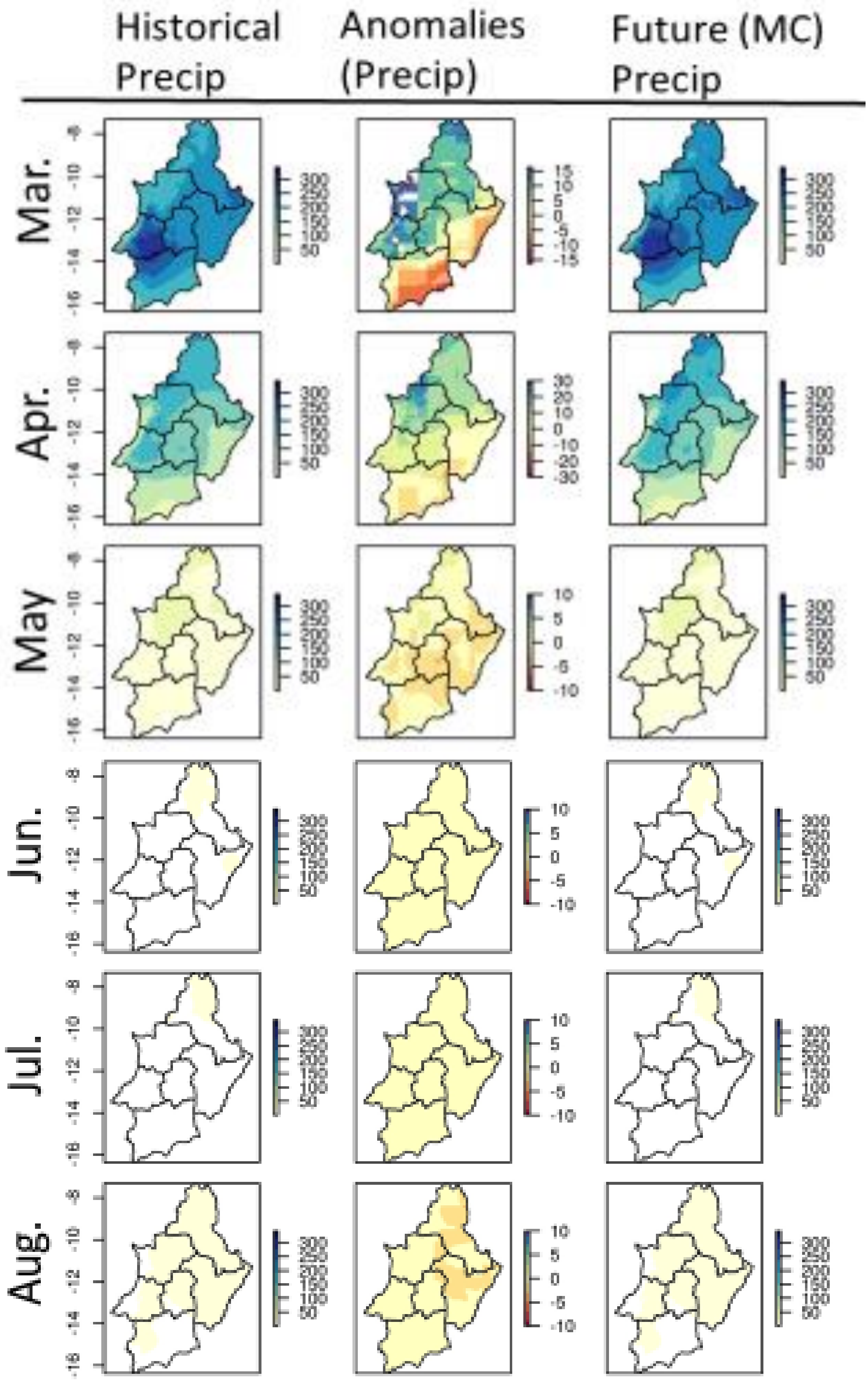


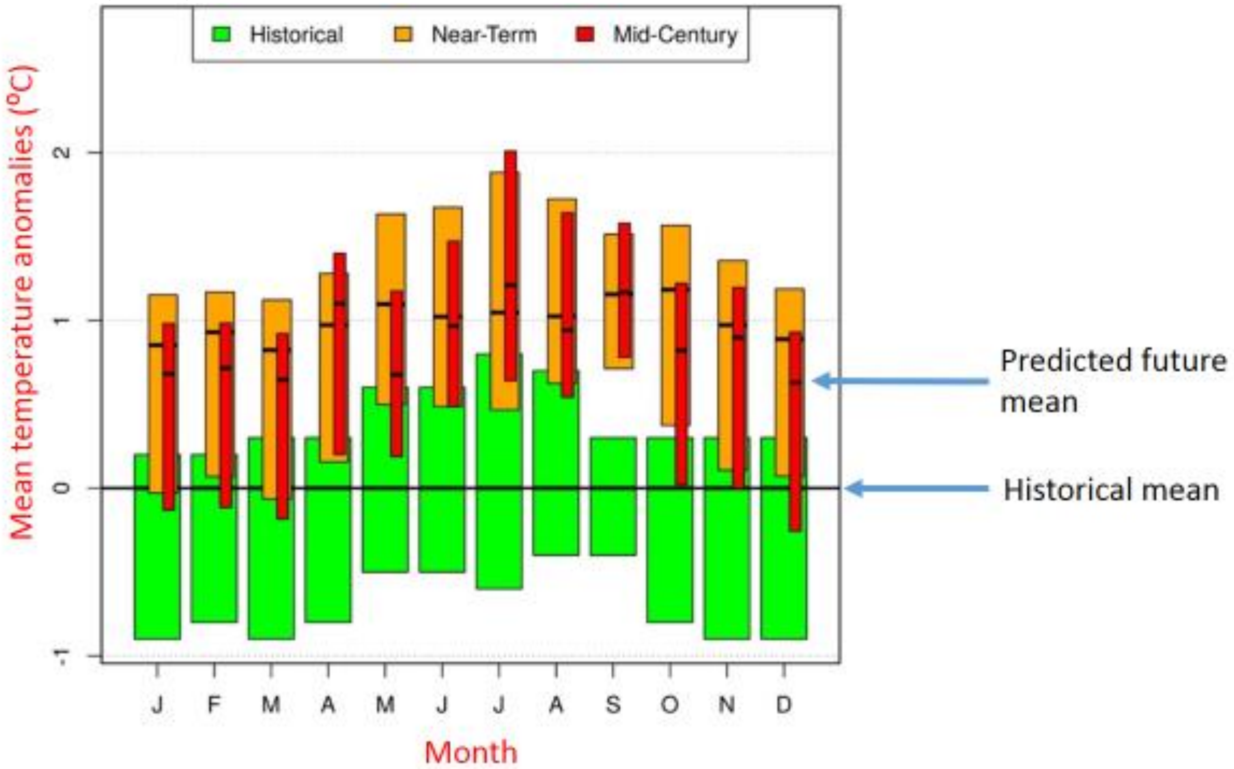
Figure 13. Predicted changes and anomalies in mean monthly precipitation in the Planalto region of Angola in the period from 'Baseline' to 'Mid-Century 2050' timepoints.

3.2 Predicted monthly changes in precipitation and temperature in the Planalto region of Angola, in the period from 'Baseline' to 'Mid-Century 2050' timepoints

The figures presented below (Figure 14 onwards) depict the predicted monthly variation in Tmean, Tmin and Precipitation in each of the six provinces at 'Baseline', 'NT2030' and 'MC2050' time points. Included in the following figures for each time point are: i) mean monthly averages for Tmean, Tmin and Precipitation, respectively; and ii) anomalies (i.e. total change) in Tmean, Tmin, and Precipitation between 'Baseline' and future periods.

To assist in the interpretation of these figures, an explanatory example is presented and discussed below. The example histogram below represents 'mean temperature anomalies' for each month, where an anomaly is the size of change from the provincial average for 'Tmean'. Green bars represent the 'historical' Tmean, orange represents the predicted 'NT2030' Tmean and red represents the predicted 'MC 2050' Tmean. The black line through the centre of each bar represents the 'monthly mean' of each month and time point, while the upper and lower extent of each bar represents the lowest and highest value reported for that month. Therefore, the height of each coloured bar represents the total variability in temperature anomalies within the whole province, relative to the provincial average for Tmean i.e. the taller the bar, the greater the spatial variability in temperature relative to the provincial average.

In the case of the example below, the histogram indicates that monthly 'Tmean' values are predicted to increase relative to the 'Historical' mean by ~0.75-1 ^{o}C, with the largest anomalies observed in the period ~May to September.



The following sections describe the predicted changes in climate for each of the six provinces, including Tmean, Tmin and Precipitation.

3.2.a Predicted monthly changes in precipitation and temperature in Benguela in the period from 'Baseline' to 'Mid-Century 2050' timepoints

Results indicate that average monthly minimum temperatures (**Tmin**) in Benguela will increase in the near term (NT 2030) during the summer months of December, January, February, and March by ~1 °C from ~23 to ~24 °C. A similar trend of a ~1 °C increase is observed during the winter months of June, July, and August from ~20 to ~21° C for NT 2030 projections.

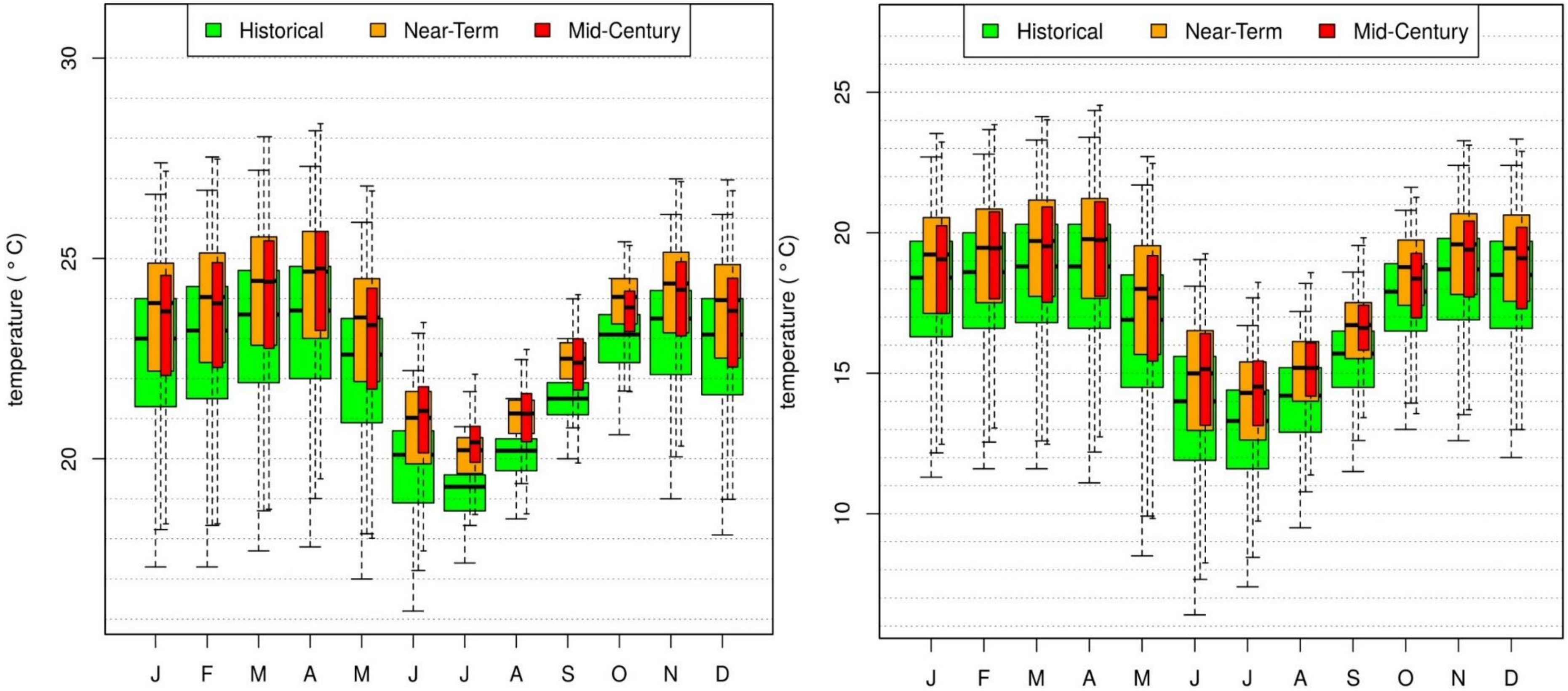


Figure 14. Average monthly anomalies in Minimum Temperature (left) and average monthly Minimum Temperature (right) in Benguela, at Historical, Near-term and Mid-Century periods.

Predicted change in Mean Temperature in Benguela

Average monthly mean temperature (**Tmean**) changes in Benguela for the NT 2030 indicate an increase of ~1 °C, from ~23 to ~24 °C during the summer months of December, January, and February. A similar increase of ~1 °C is observed during the winter months of June, July, and August from ~20 to ~21 °C.

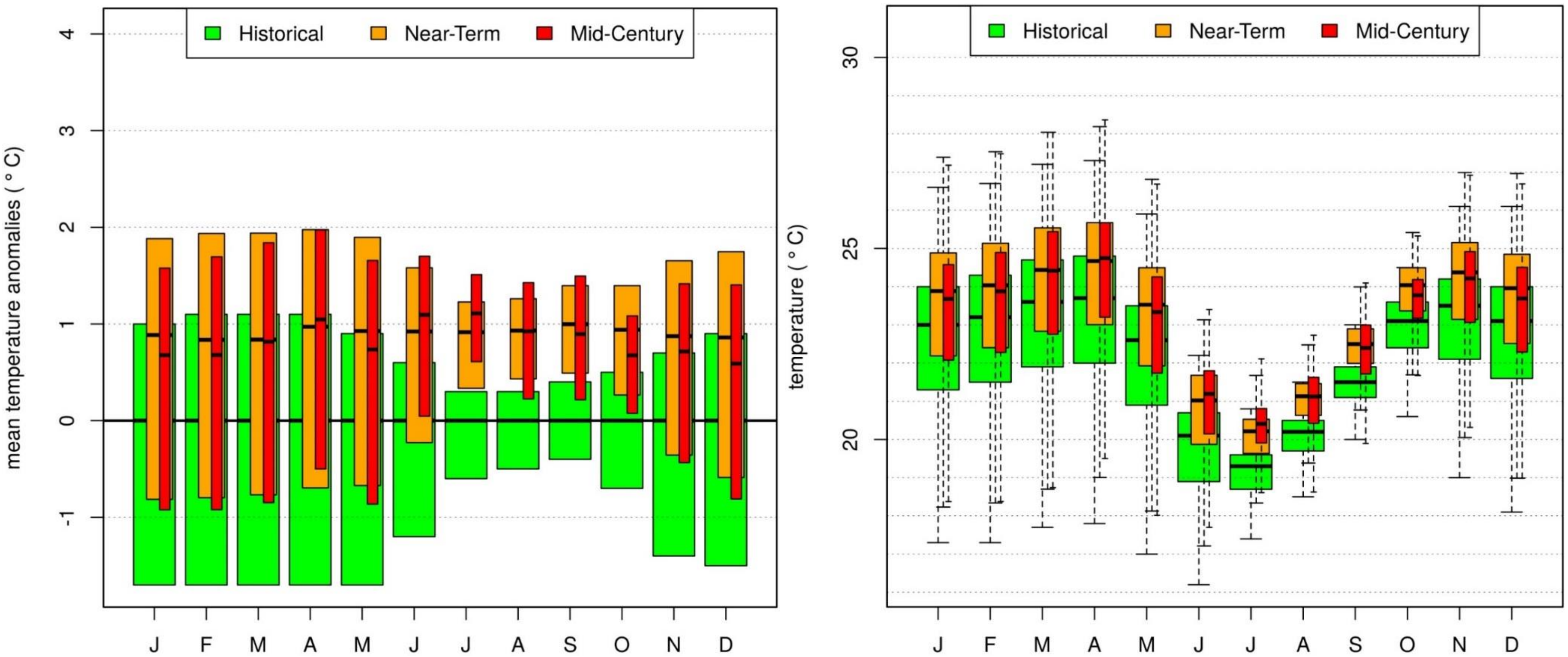


Figure 15. Average monthly anomalies in Mean Temperature (left) and average monthly Mean Temperature (right) in Benguela, at Historical, Near-term and Mid-Century periods.

Predicted change in Mean Precipitation in Benguela

The rainy season in Benguela begins in October and ends in April, peaking in March. Mean monthly precipitation illustrates a substantial increase from February to March and decreases drastically from the end of March to April. Results for change in mean monthly precipitation within the rainy season in Benguela predict a small increase from 995 mm (Historical), 1005 mm (NT 2030), to 1050 mm (Mid-Century 2050).

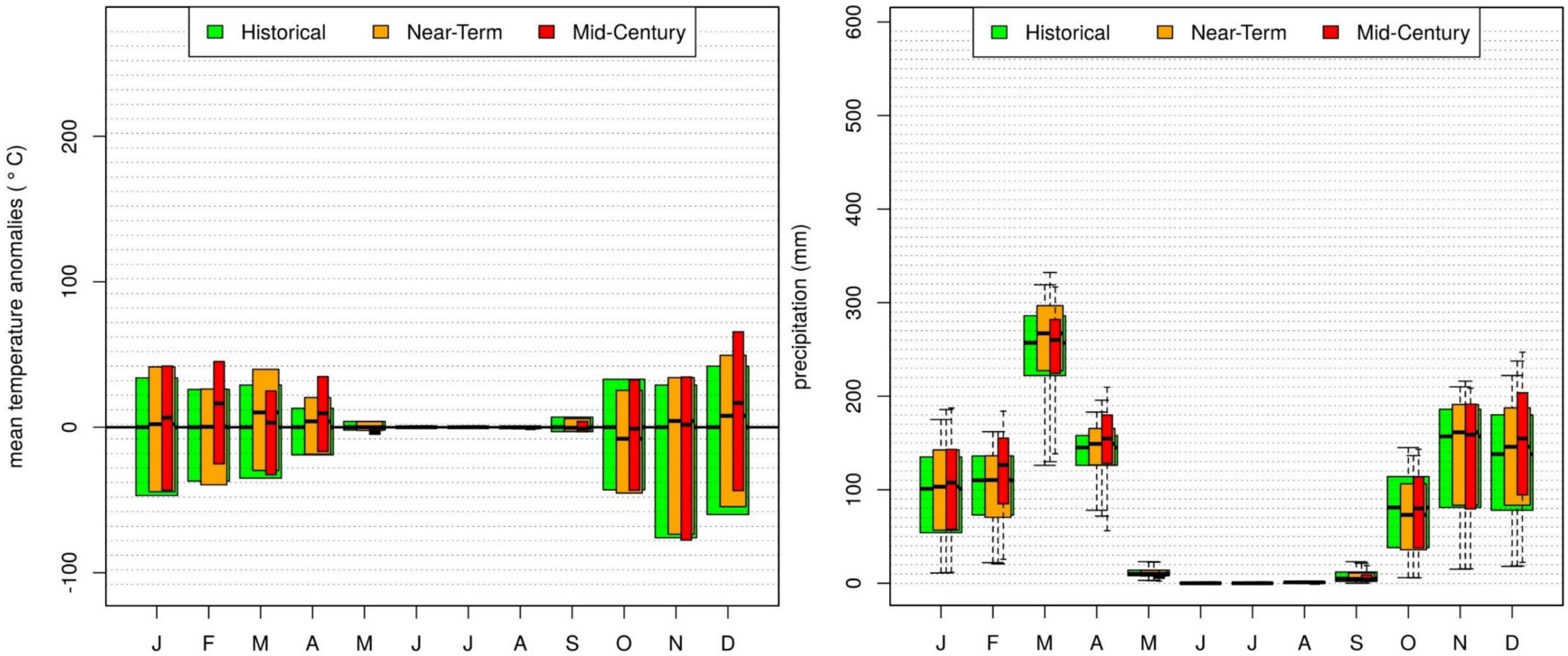
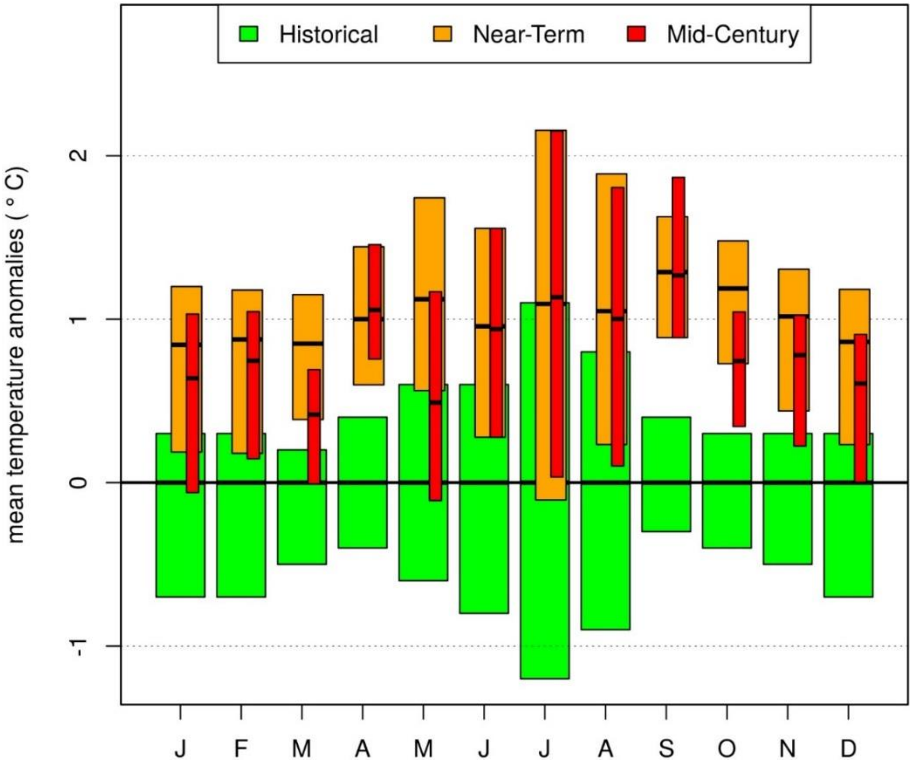


Figure 16. Average monthly anomalies in Mean Monthly Precipitation (left) and average Mean Monthly Precipitation (right) in Benguela, at Historical, Near-term and Mid-Century periods.

3.2.b Predicted monthly changes in precipitation and temperature in Bié in the period from 'Baseline' to 'Mid-Century 2050' timepoints

Tmin in the province of Bié is projected to increase by ~1 °C during the summer months of December, January, February, and March from ~15.5 TO ~16.5 °C during the period from 'Baseline' to 'NT 2030' timepoints. Similarly it is predicted that during the period from 'Baseline' to 2030 **Tmin** will increase during the winter months of June, and July project from ~7 to ~8 °C, as well as a ~1 °C increase during the month of August from ~9.5 to ~10.5 °C.



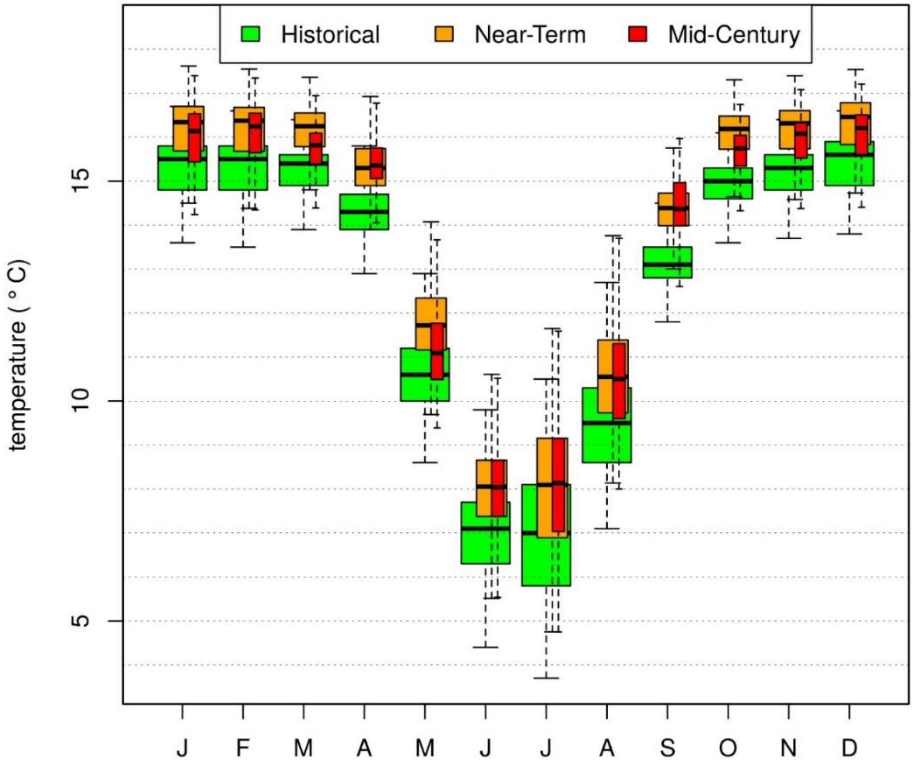


Figure 17. Average monthly anomalies in Minimum Temperature (left) and average monthly Minimum Temperature (right) in Bié, at Historical, Near-term and Mid-Century periods.

Predicted change in Mean Temperature in Bié

Projections for **Tmean** at time period 'NT 2030' suggest an increase of ~1 °C during the summer months of December to March from ~21 to ~22 °C. The winter months of June, July, and August illustrate a similar increase of ~1 °C, June and July increasing from ~16.5 to ~17.5 °C, and August increasing from ~19 to ~20 °C.

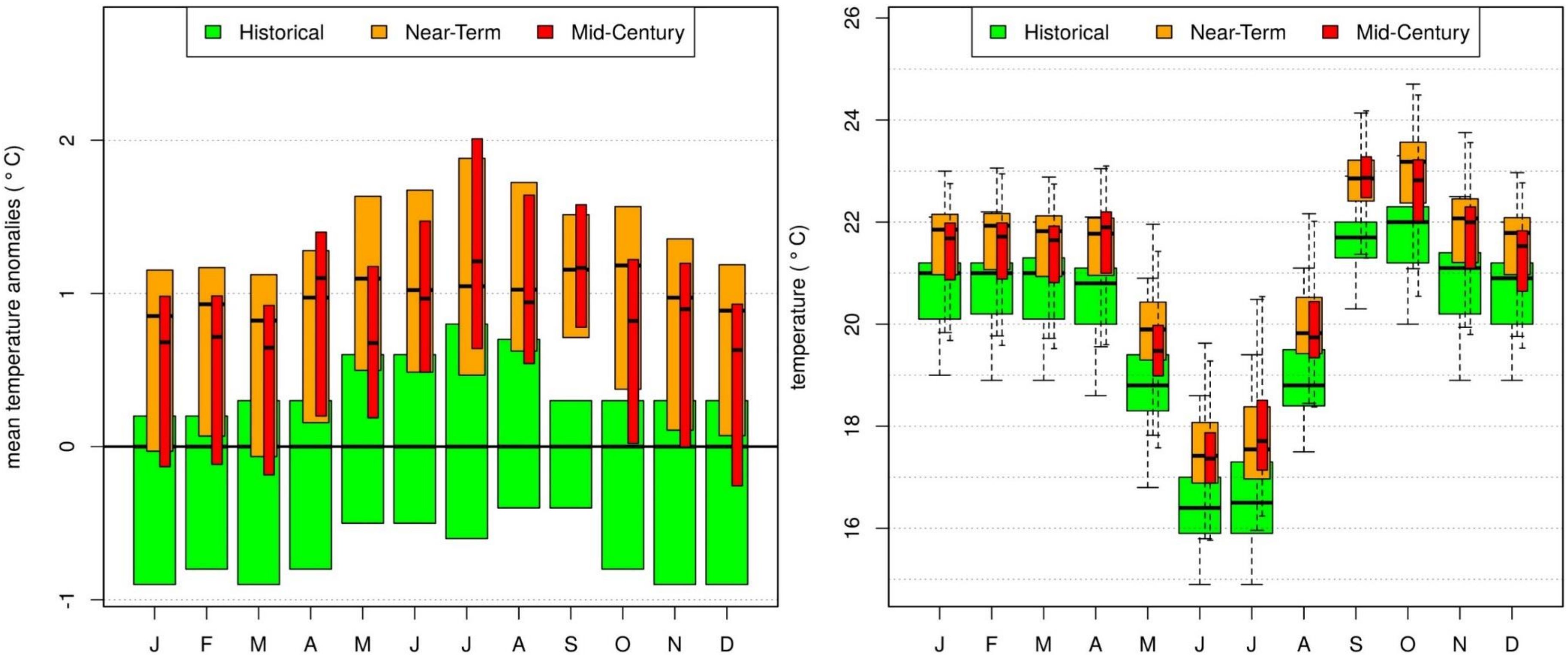
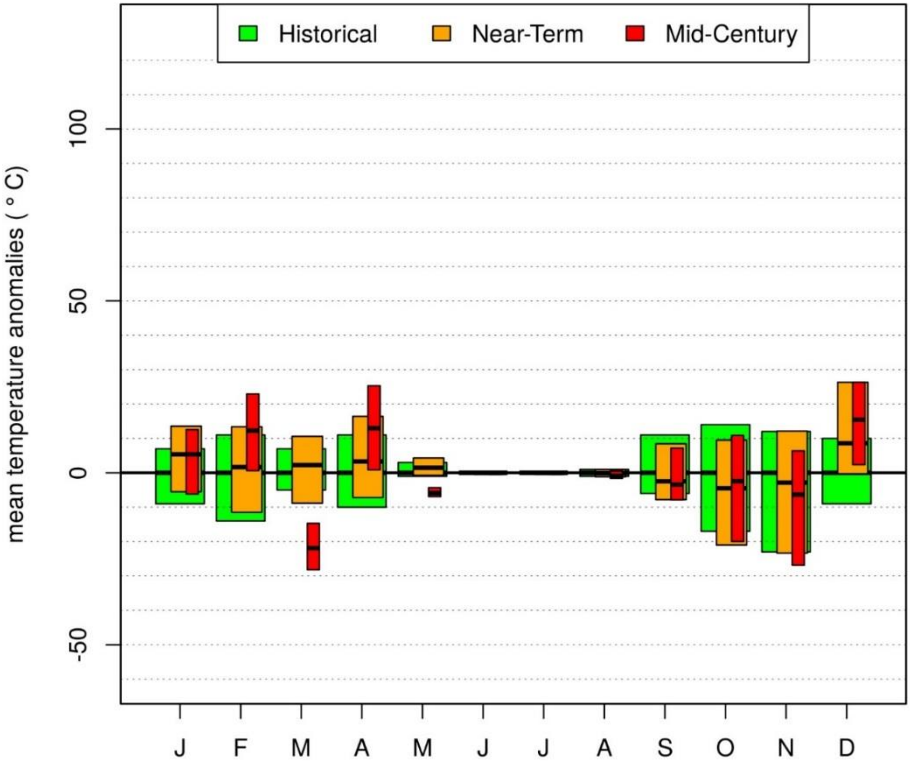


Figure 18. Average monthly anomalies in Mean Temperature (left) and average monthly Mean Temperature (right) in Bié, at Historical, Near-term and Mid-Century periods.

Predicted change in Mean Precipitation in Bié

It is predicted that mean monthly precipitation will not change significantly during the period from 'Baseline' to 'NT 2030' and 'MC 2050' timepoints. The rainy season in Bié begins in October and ends in April, peaking in March. Cumulative precipitation projections for the rainy season illustrate a small increase from 1225 mm (Historical) to 1240mm for NT 2030, and MC 2050 projections.



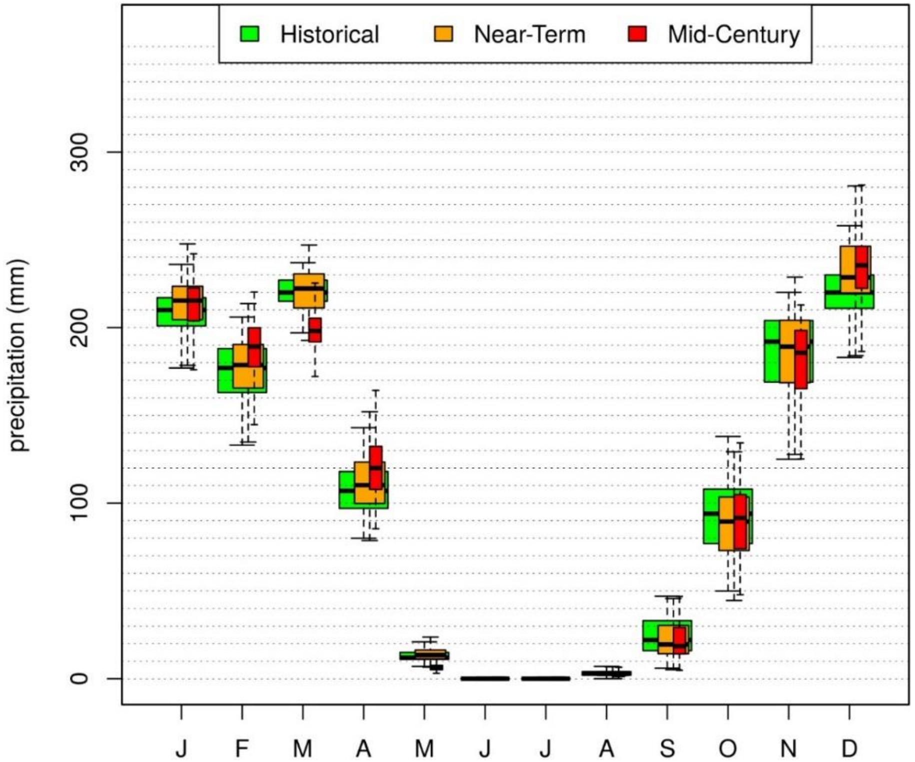


Figure 19. Average monthly anomalies in Mean Monthly Precipitation (left) and average Mean Monthly Precipitation (right) in Bié, at Historical, Near-term and Mid-Century periods.

3.2.c Predicted monthly changes in precipitation and temperature in Cuanza Sul in the period from 'Baseline' to 'Mid-Century 2050' timepoints

In the province of Cuanza Sul, **Tmin** is predicted to increase by ~1 °C ~17 to ~18 °C during the summer months of December, January, February, and March by 2030 compared to baseline year. It is also predicted that by 2030, **Tmin** for the winter months of June and, July will increase by ~1 °C from ~12 to 13 °C.

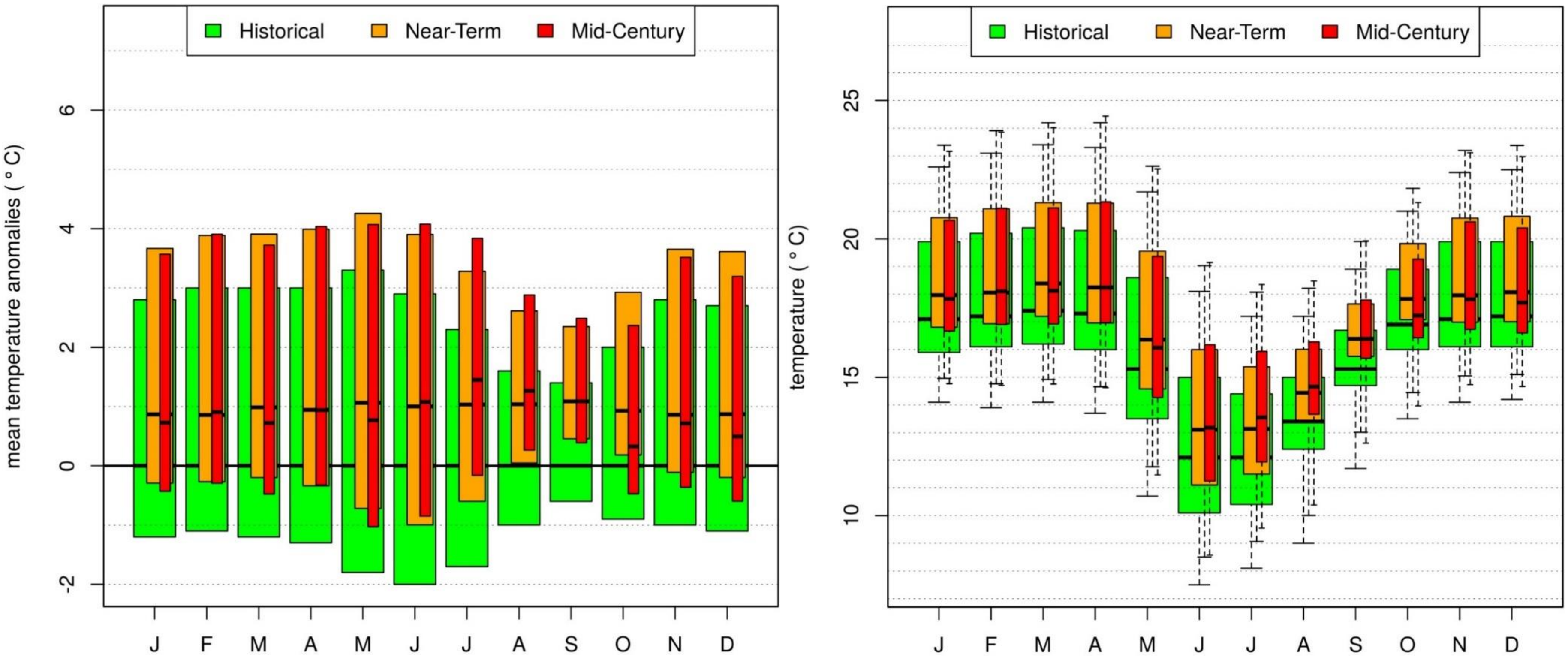


Figure 20. Average monthly anomalies in Minimum Temperature (left) and average monthly Minimum Temperature (right) in Cuanza Sul, at Historical, Near-term and Mid-Century periods.

Predicted change in Mean Temperature in Cuanza Sul

Tmean projections for NT 2030 suggest a ~1 °C increase during the summer months of December, January, February and March, from ~22 to ~23 °C. The **Tmean** for the winter months of June and July are predicted to increase by ~1 °C from ~19 to ~20 °C, as well as a ~1 °C increase in August from ~20 to ~21 °C, in the period from 'Baseline' to 'NT 2030'.

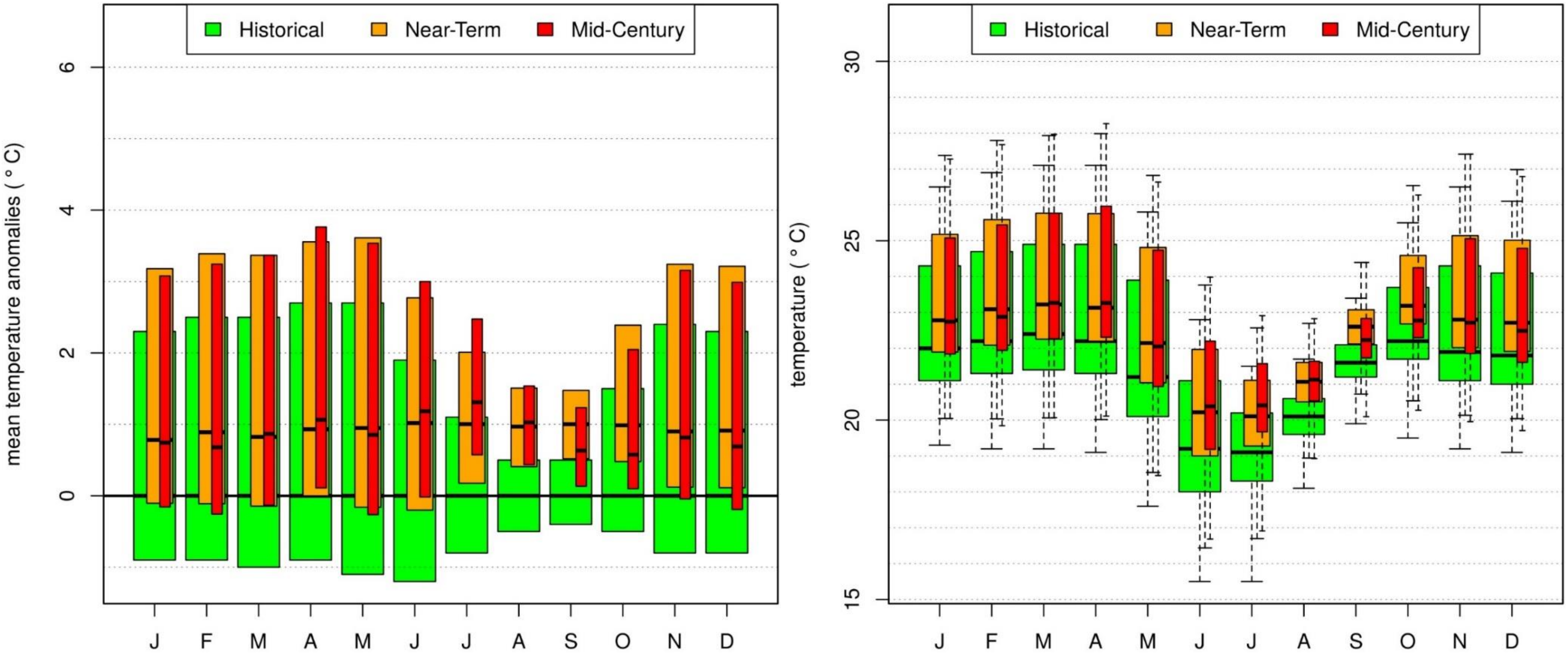


Figure 21. Average monthly anomalies in Mean Temperature (left) and average monthly Mean Temperature (right) in Cuanza Sul, at Historical, Near-term and Mid-Century periods.

Predicted change in Mean Precipitation in Cuanza Sul

The rainy season in Cuanza Sul begins in October and ends in April, peaking in November. Monthly cumulative precipitation projections for the rainy season show a small increase from Historical (1005 mm) to NT 2030 (1030 mm) and MC 2050 (1025 mm) projections.

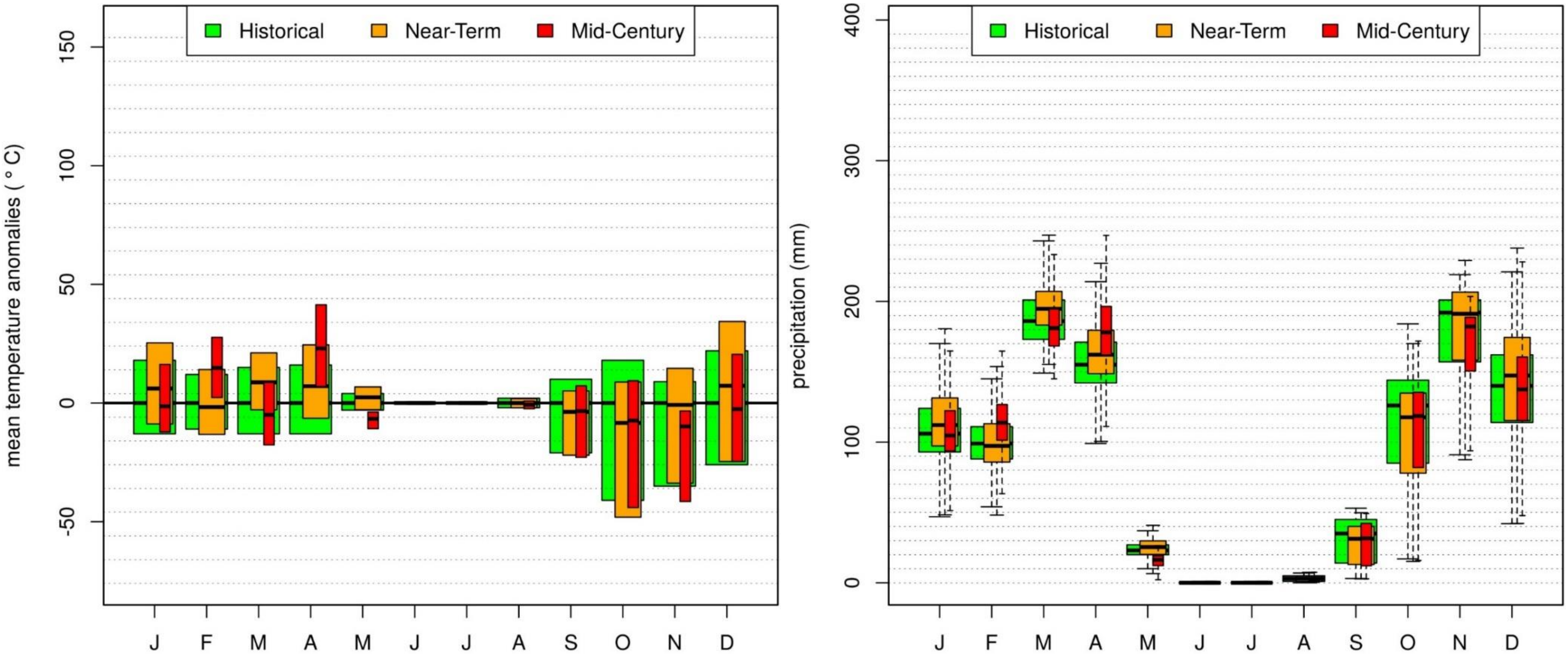


Figure 22. Average monthly anomalies in Mean Monthly Precipitation (left) and average Mean Monthly Precipitation (right) in Cuanza Sul, at Historical, Near-term and Mid-Century periods.

3.2.d Predicted monthly changes in precipitation and temperature in Huambo in the period from 'Baseline' to 'Mid-Century 2050' timepoints

It is predicted that **Tmin** in the province of Huambo will increase during the period from 'Baseline' to 'NT 2030' timepoints by ~1 °C during the summer months of December, January, February, and March from ~14.5 TO ~15.5 °C. It is furthermore predicted that **Tmin** will increase during winter months in the period from 'Baseline' to 'NT 2030' – an increase of ~1 °C from ~8 to ~9 °C are predicted in June and July, and an increase from ~10 to 11°C in the month of August.

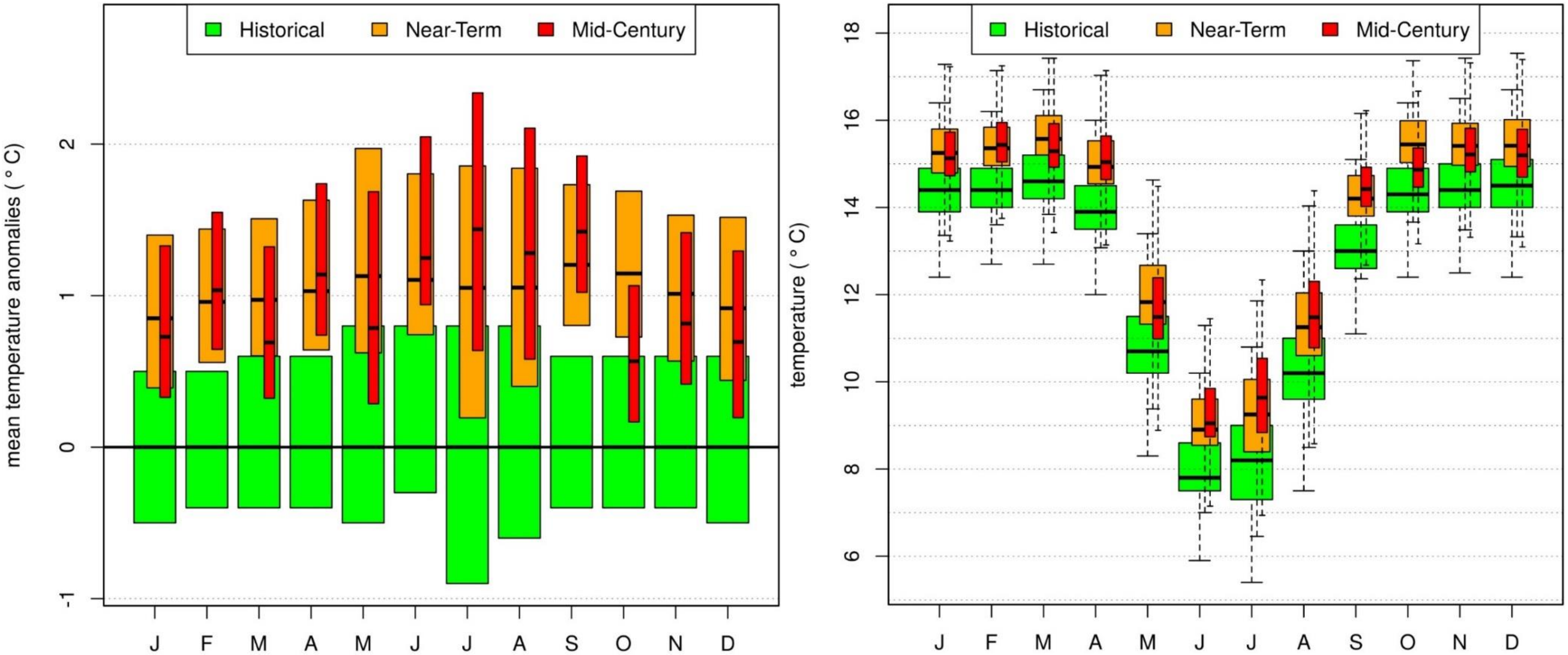


Figure 23. Average monthly anomalies in Minimum Temperature (left) and average monthly Minimum Temperature (right) in Huambo, at Historical, Near-term and Mid-Century periods.

Predicted change in Mean Temperature in Huambo

Similar to Tmin (described above), the mean temperature (**Tmean**) is also predicted to increase in the period from baseline to NT 2030 by ~1 °C for the summer months of December, January, February, and March from ~19.5 to ~20.5 °C. **Tmean** for the winter months of June, July, and August is predicted to increase by ~1 °C in the period from 'Baseline' to 'NT 2030', from ~16 to ~17 °C in June, ~16.5 to ~17.5 °C in July, and ~18.5 to ~19.5 °C in the month of August.

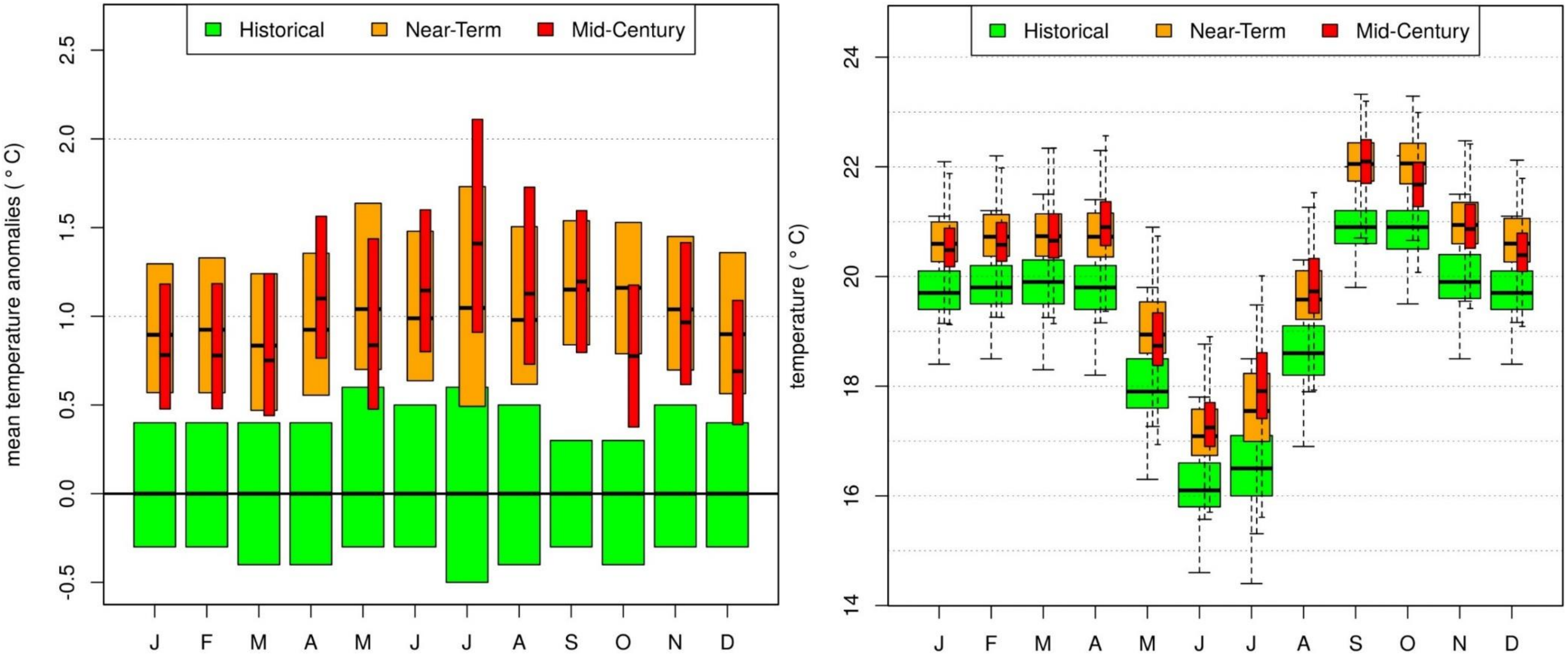


Figure 24. Average monthly anomalies in Mean Temperature (left) and average monthly Mean Temperature (right) in Huambo, at Historical, Near-term and Mid-Century periods.

Predicted change in Mean Precipitation in Huambo

The rainy season in Huambo begins in October and ends in April. Monthly cumulative precipitation projections for the rainy season illustrate a small increase in rainfall from 1230 mm (Historical) to 1270 mm (NT 2030), and 1325 mm for MC 2050.

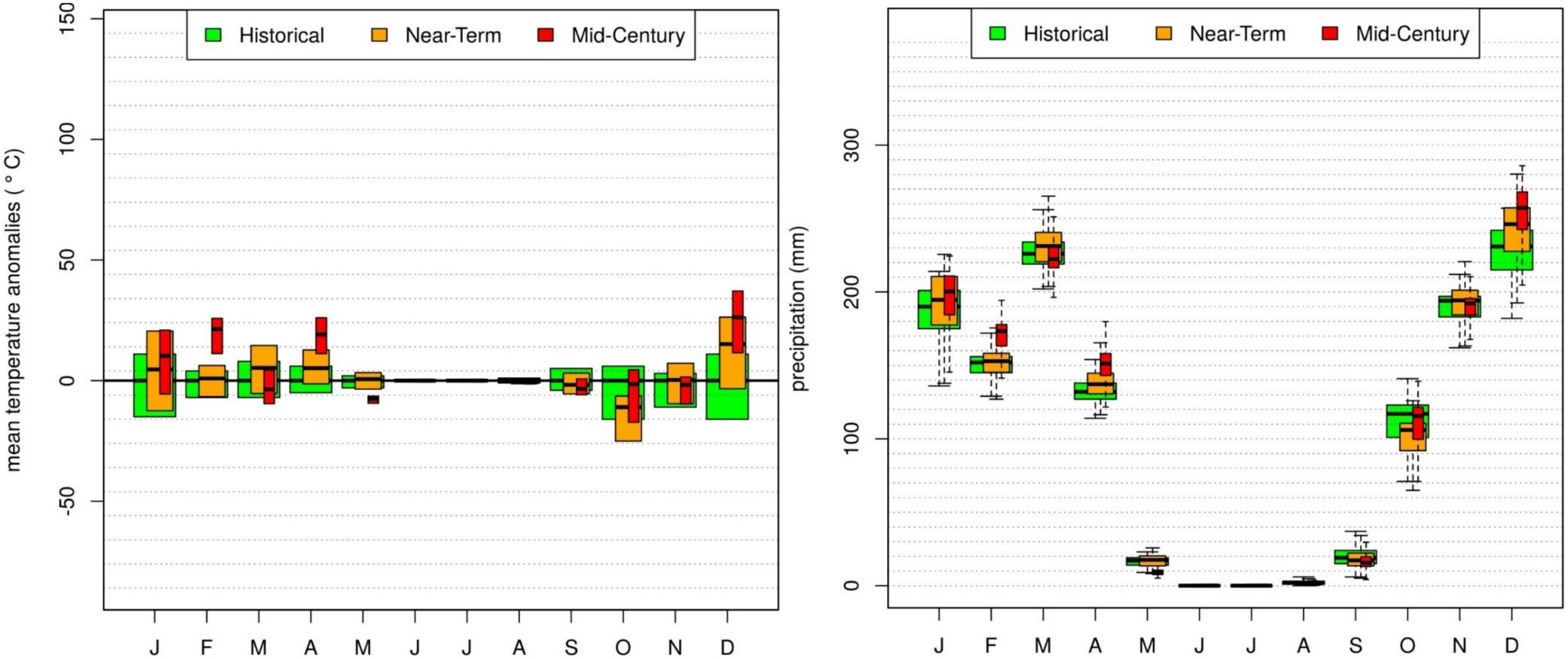


Figure 25. Average monthly anomalies in Mean Monthly Precipitation (left) and average Mean Monthly Precipitation (right) in Huambo, at Historical, Near-term and Mid-Century periods.

3.2.e Predicted monthly changes in precipitation and temperature in Huíla in the period from 'Baseline' to 'Mid-Century 2050' timepoints

The province of Huíla is predicted to experience an increase of ~1 °C in **Tmin** during the period from 'Baseline' to 'NT 2030' in the summer months of December, January, February, and March, increasing from ~15.5 to ~16.5 °C. A similar ~1 °C increase in **Tmin** is predicted for the timepoint 'NT 2030' during the winter of months of June, July, and August – **Tmin** is predicted to increase from ~7 to ~8 °C in June and July and 9.5 to 10.5 °C for the month of August by the year 2030.

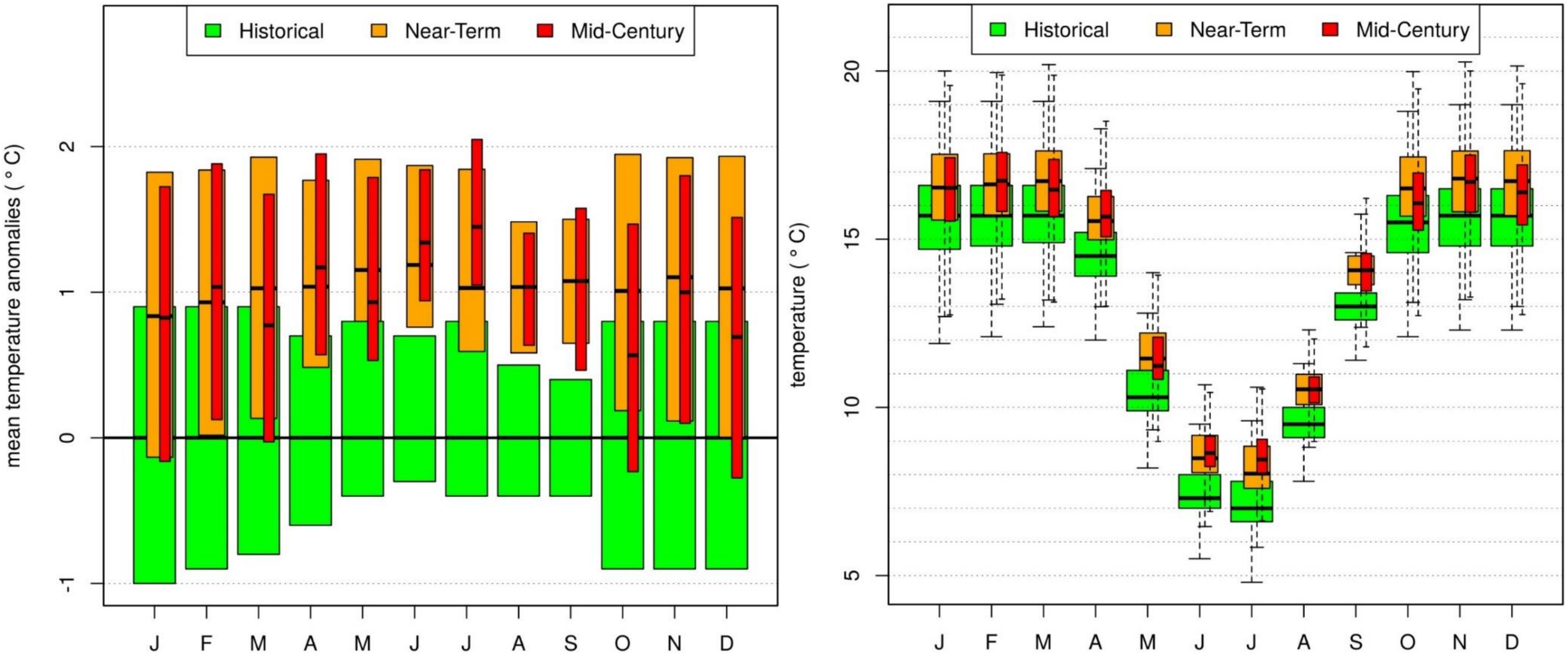


Figure 26. Average monthly anomalies in Minimum Temperature (left) and average monthly Minimum Temperature (right) in Huíla, at Historical, Near-term and Mid-Century periods.

Predicted change in Mean Temperature in Huíla

Mean temperature (**Tmean**) is expected to increase during the period from 'Baseline' to 'NT 2030' including an increase of ~1°C for the summer months of December (~22 to~23 °C), January (~21.5 to ~22.5 °C), and February (~21.5 to ~22.5 °C)

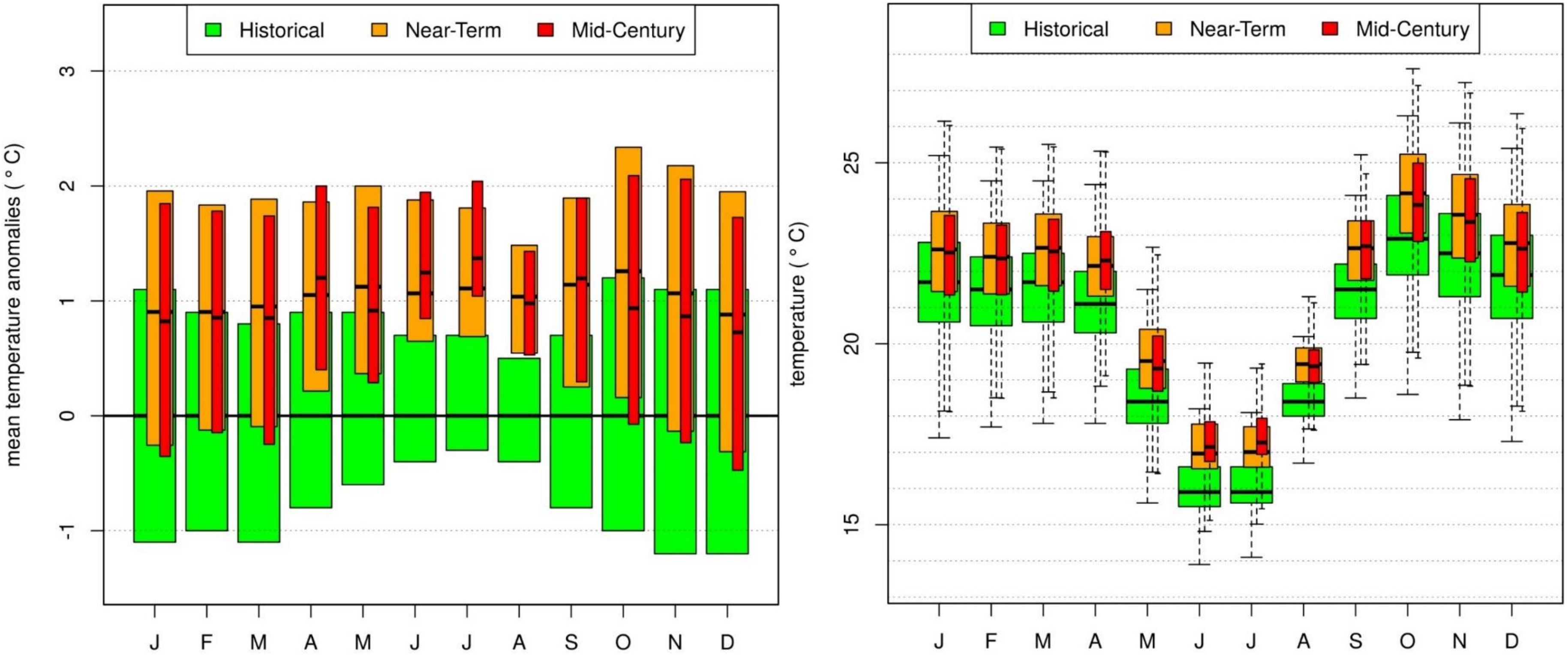


Figure 27. Average monthly anomalies in Mean Temperature (left) and average monthly Mean Temperature (right) in Huíla, at Historical, Near-term and Mid-Century periods.

Predicted change in Mean Precipitation in Huíla

The rainy season in Huíla begins in October and ends in April, peaking in March. Monthly cumulative precipitation projections for rain fall decrease slightly (by ~15 mm) from Historical (885 mm) to NT 2030 (870 mm) timepoints, and then increase to 930 mm by the year 2050.

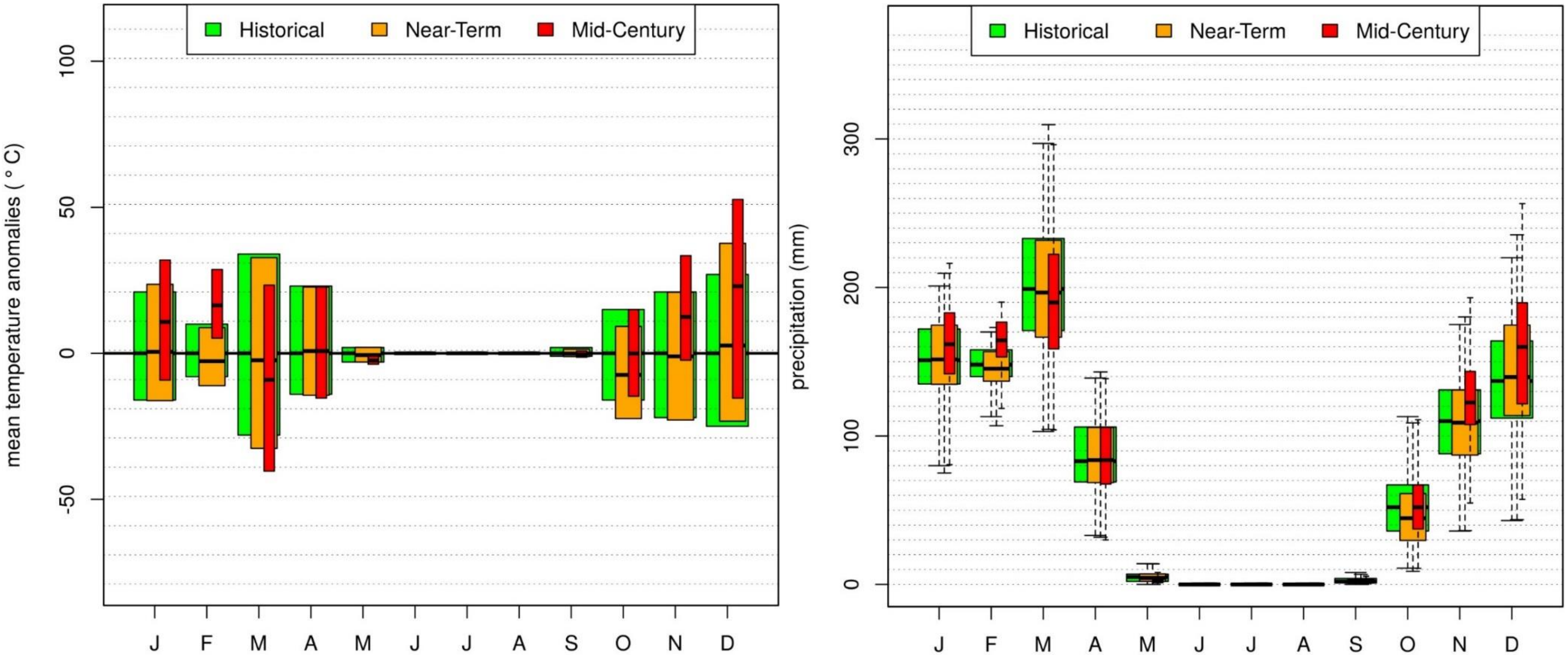


Figure 28. Average monthly anomalies in Mean Monthly Precipitation (left) and average Mean Monthly Precipitation (right) in Huíla, at Historical, Near-term and Mid-Century periods.

3.2.f Predicted monthly changes in precipitation and temperature in Malanje in the period from 'Baseline' to 'Mid-Century 2050' timepoints

The province of Malanje is predicted to experience increased temperatures (measured by Minimum Temperature, **Tmin**, and Mean Temperature, **Tmean**, respectively) as a result of climate change during the period from 'Baseline' to 'NT 2030' and 'MC 2050' timepoint. Projected **Tmin** changes in Malanje indicate an increase of ~1 °C increase during the summer months of December, January, February, and March from ~16.5 to ~17.5 °C. **Tmin** is predicted to increase by a similar margin of ~1 °C during the winter months of June (~10.5 to ~11.5 °C), July (`10.5 to ~11.5 °C), and August (~12.5 to ~13.5 °C) during the period from 'Baseline' 'NT 2030'.

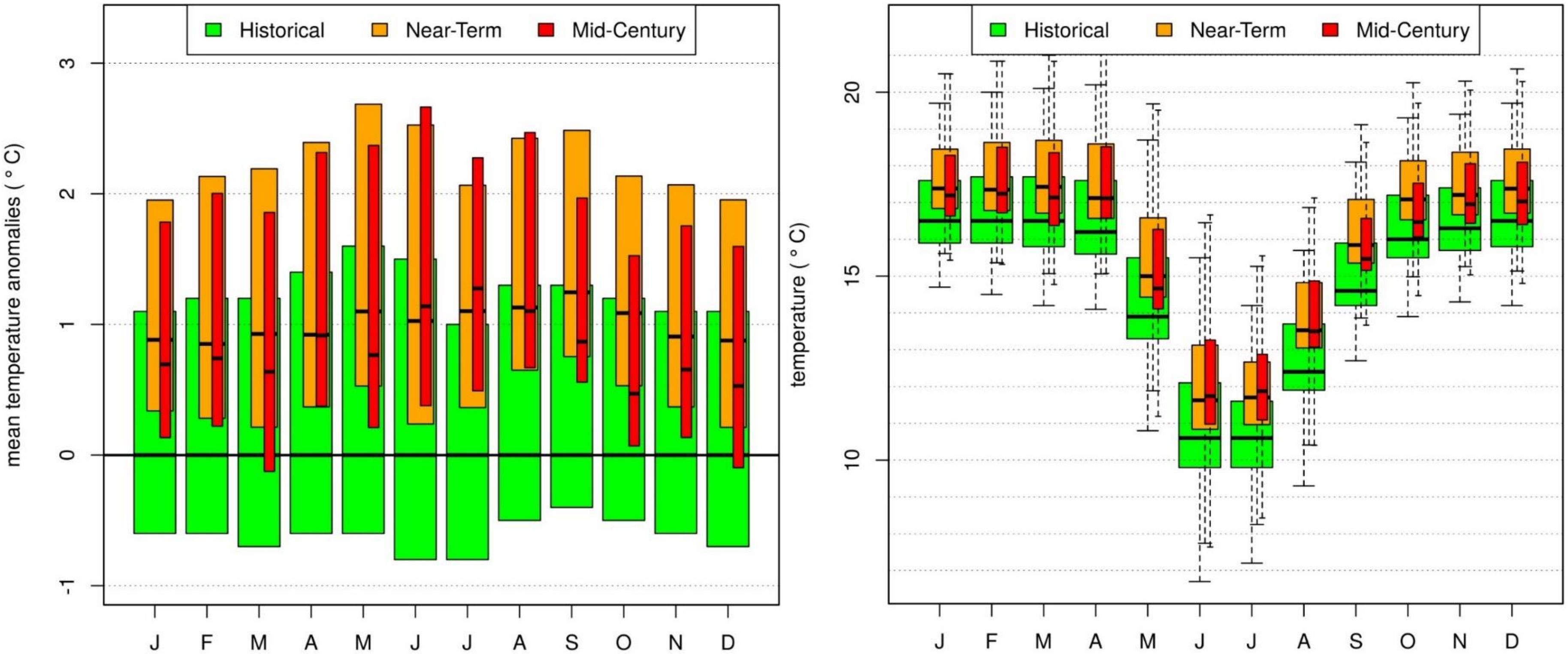


Figure 29. Average monthly anomalies in Minimum Temperature (left) and average monthly Minimum Temperature (right) in Malanje, at Historical, Near-term and Mid-Century periods.

Predicted change in Mean Temperature in Malanje

The increase in mean temperature (**Tmean**) during the period from 'Baseline' to 'NT 2030' is predicted to be ~1 °C for the summer months of December, January, February, March (increasing from ~22 to ~23 °C). Projections for change in **Tmean** for NT 2030 show an increase of ~1 °C for the winter months of June (~19.5 to ~20.5 °C), July (~19.5 to ~20.5 °C), and August (~21 to ~22 °C).

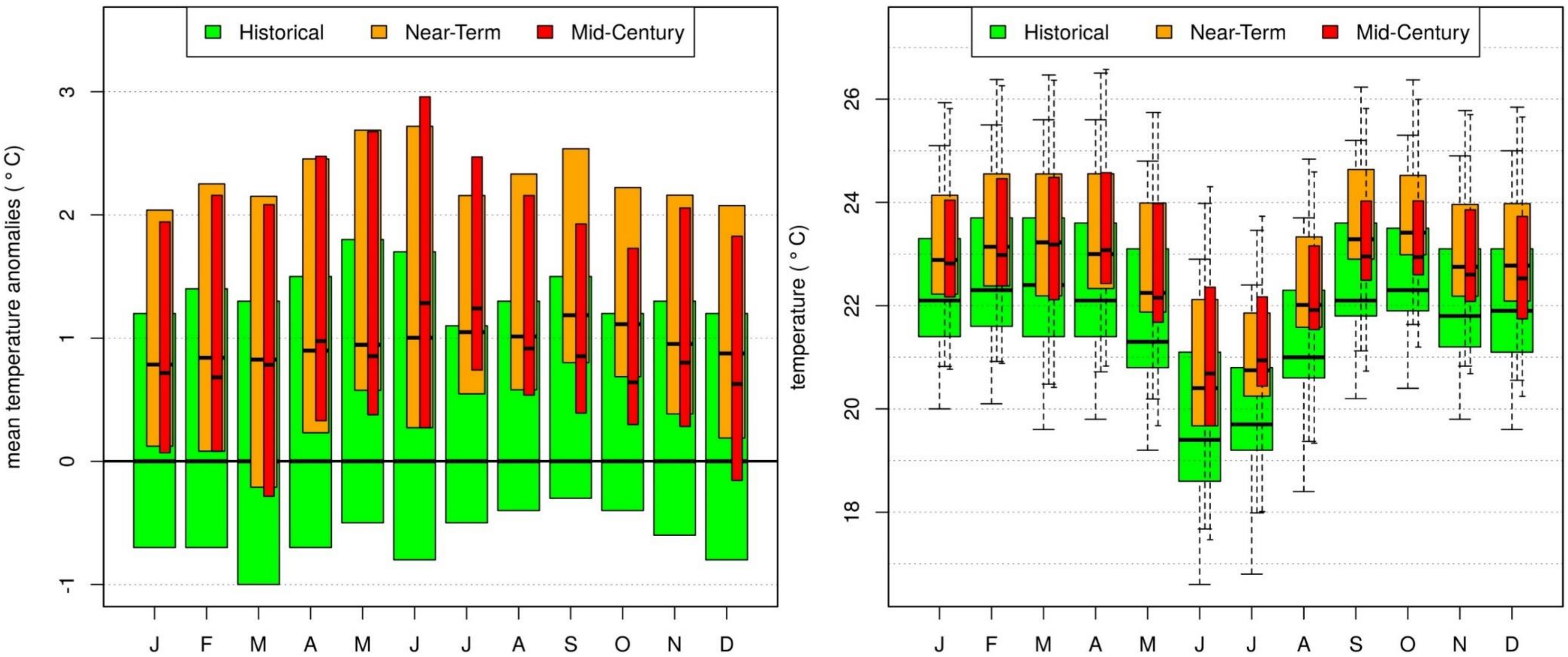


Figure 30. Average monthly anomalies in Mean Temperature (left) and average monthly Mean Temperature (right) in Malanje, at Historical, Near-term and Mid-Century periods.

Predicted change in Mean Precipitation in Malanje

The rainy season in Malanje begins in October and ends in April, peaking in November. Monthly cumulative precipitation projections for precipitation indicate an increase from 1165 mm (Historical) to 1195 (NT 2030), and a decrease to 1175 mm by 2050.

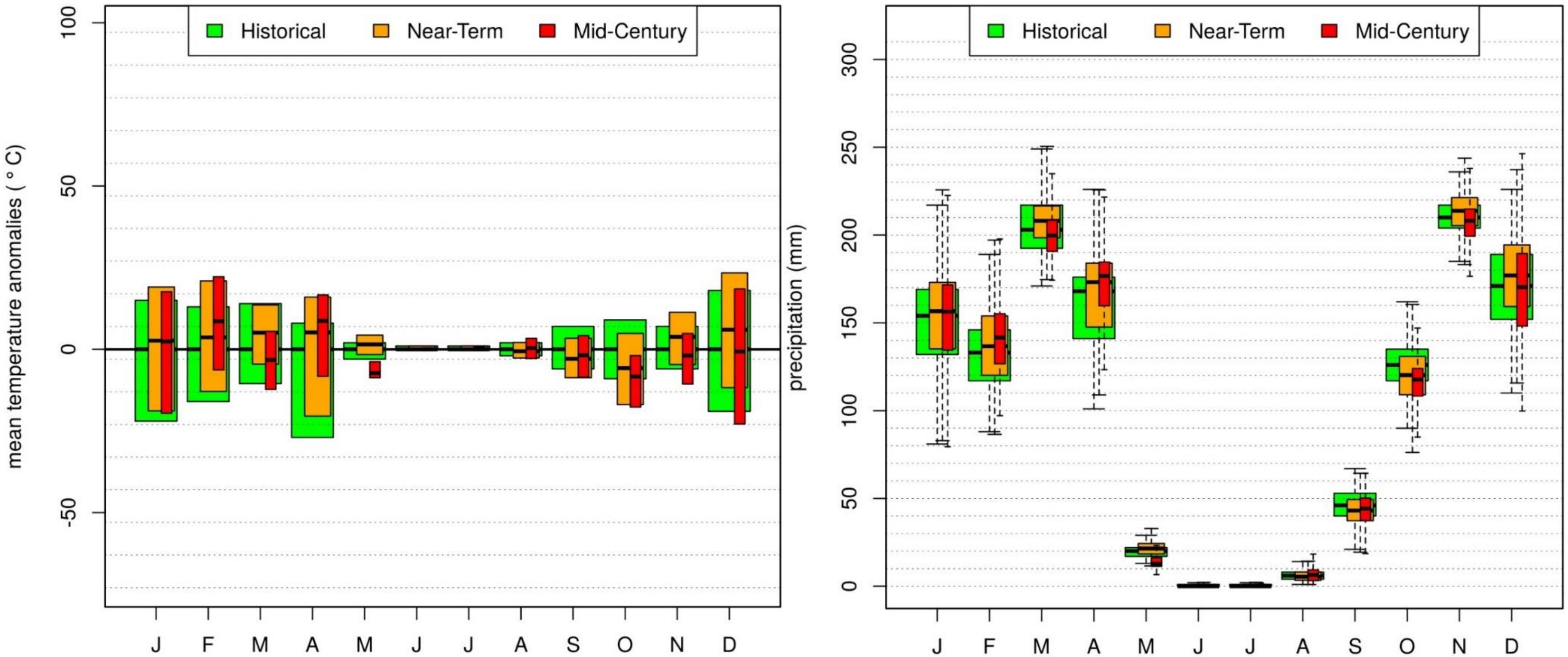


Figure 31. Average monthly anomalies in Mean Monthly Precipitation (left) and average Mean Monthly Precipitation (right) in Malanje, at Historical, Near-term and Mid-Century periods.

4. Modelled crop suitability

Chapter 3, above, summarises the annual climatic variability within and between the studied provinces. The following chapter will summarise the predicted spatial variation of crop suitability within each of the studied provinces during the 'Baseline', 'Near Term 2030' and 'Mid Century 2050' time periods. Analyses were generated using the Food and Agriculture Organisation's EcoCrop Suitability model[3]

Ecocrop allows for the modelling of the potential suitability of over 1,000 crops, based on inputs of environmental information such as mean monthly precipitation and monthly minimum, mean and maximum temperatures. The EcoCrop model is relatively fast and easy to simulate and is therefore preferred for modelling of suitability at high spatial resolutions. The EcoCrop model estimates the suitability of a given crop to the defined environmental conditions based on the known preferences of each crop, such as: i) minimum, optimum and maximum temperature; ii) minimum, optimum and maximum monthly rainfall; and iii) minimum and maximum growing period. Therefore, EcoCrop defines the area of suitability for a given crop based on whether there are adequate climatic conditions (temperature and precipitation) within an adequate growing season, and calculates the climatic suitability of the resulting interaction between rainfall and temperature. Appendix 1 provides a summary of the EcoCrop definitions used for all crops in this analysis.

It should be emphasised that no further calibration or validation of EcoCrop analyses have been carried out in support of this study and that results should be considered as indicative guidelines that require additional groundtruthing. The approach used to describe and visualise the spatial and temporal distribution of crop suitability includes the use of:

i) map-based visualisations of crop suitability zones across the entire study area, and
ii) histogram graph visualisations of the distribution of crop suitability categories within each province.

The use of colour-coded maps to depict the distribution of each category of crop suitability provides a visual demonstration of the distribution of crop suitability categories at each time period. In addition, the comparison of baseline and 'MC2050' maps of crop distribution supports the identification of specific areas which are likely to undergo positive or negative changes in crop suitability.

The histogram graph visualisations are based on the arrangement of 'crop suitability index' scores into discrete categories of suitability, namely "excellent" (Suitability Index score of 0.9–1), "highly suitable" (score of 0.7–0.9), "suitable" (score of 0.5–0.7), "marginally suitable" (score of 0.3–0.5), "very marginally suitable" (score of 0.1–0.3) and "unsuited" (score of 0–0.1). As a result of the assignment of these categories, the proportional and absolute spatial extent of each category of crop suitability can be estimated in each province for each of the time periods ('baseline', 'NT2030' and 'MC2050', respectively). Each of the six categories of crop suitability (ranging from "unsuited" to "excellent" suitability) are depicted visually through the assignment of a colour code, ranging from dark and light green ("excellent" and "high" suitability, respectively), yellow and orange ("suitable" and "marginally suitable", respectively), to pink and grey ("very marginal" and "not suited", respectively).

To assist in the interpretation of crop suitability maps and graphs presented in the sub-chapters below, an example of each is presented and discussed in Figures 32 and 33, below.

[3]http://ecocrop.fao.org/ecocrop/srv/en/home

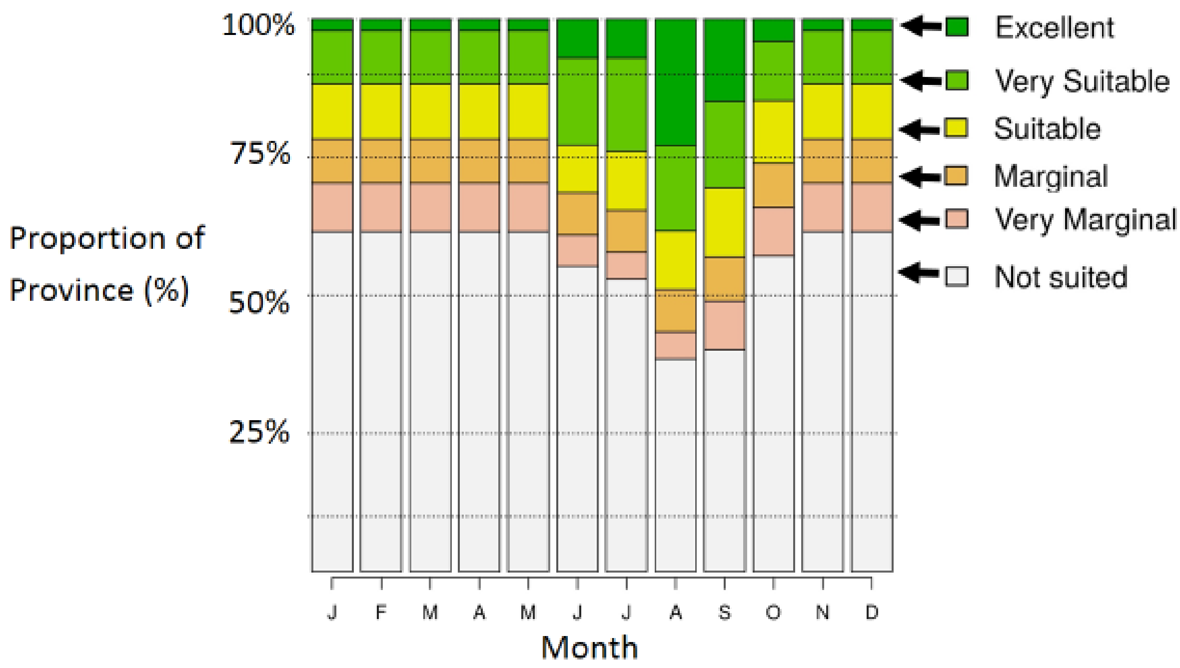


Figure 32. Example demonstration of monthly variability in crop suitability index scores within a single province.

Figure 32, above, can be considered a hypothetical example of seasonal variation in crop suitability index scores within a single province (or study area). The Y-axis indicates the 12 months of the year, from January to December. The X-axis depicts the spatial proportion of the hypothetical province covered by each respective category of crop suitability (i.e. where '100%' indicates the entire spatial extent of the province). The relative size of each coloured bar is proportional to the geographic extent of the corresponding category of crop suitability.

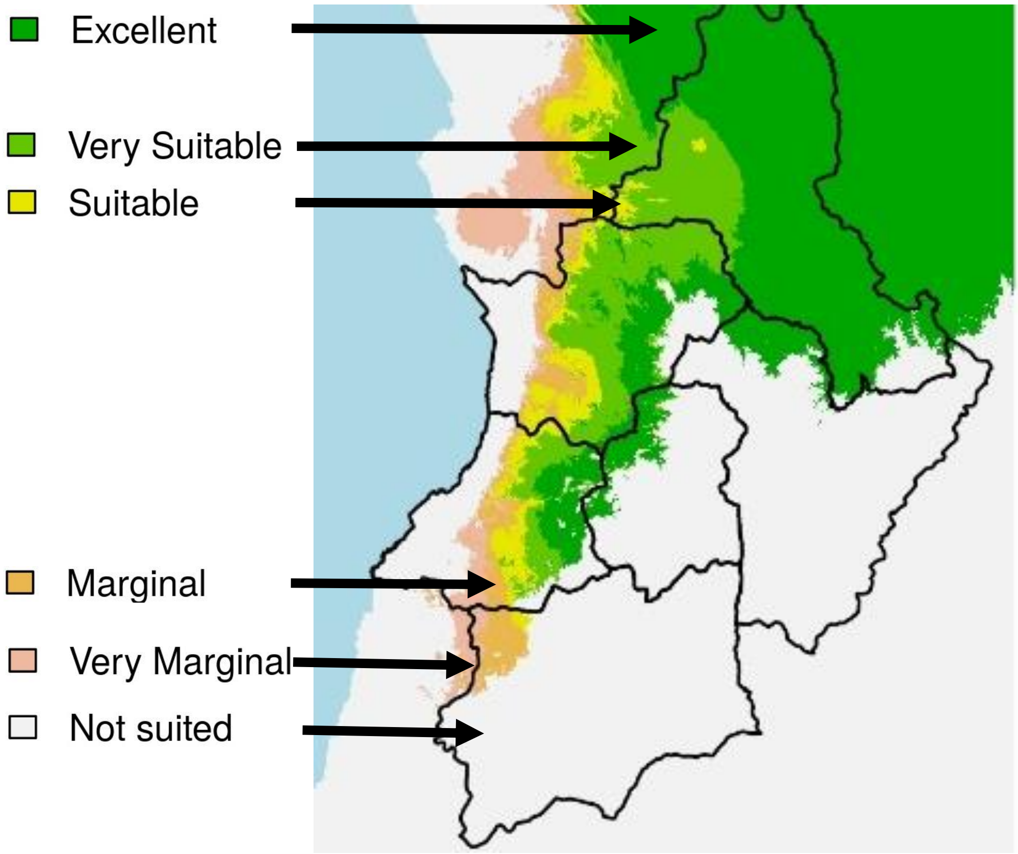


Figure 33. Example demonstration of spatial variability in crop suitability index scores.

Figure 33, above, is an alternative approach to depicting the data presented in Figure 32, where the relative proportion of each colour-shaded area indicates the spatial extent of each corresponding category of crop suitability. The same approach and specific categories of crop suitability scores are adopted in each of the crop-specific analyses described in the following chapters, below.

4.1 Impact of climate change on spatial distribution of areas suitable for production of cassava (*Manihot esculenta*)

Figure 34, below, summarise the historical (baseline) and future (mid-century 2050) suitability of the six pilot provinces (Bié, Benguela, Cuanza Sul, Huambo, Huíla and Malanje) for production of cassava in the months from September to February. In addition to the baseline and future distribution of crop suitability zones, the figures below also illustrate the anomalies (i.e. the absolute changes in suitability at any given location) between the baseline and future time periods.

In the case of cassava, the main effect of climate change is to increase the distribution and spatial extent of crop suitability in the interior of Benguela, Cuanza Sul, Huambo and Malanje. This net positive change in crop suitability primarily occurs in the interior highlands above the coastal escarpment of the latter provinces, stretching northward from the border of Huambo and Benguela, through Cuanza Sul and northwards into Malanje. This trend is generally consistent and unchanged throughout the summer months from October onwards. The exception to this trend is the month of September, for which month EcoCrop analyses predict a significant increase in suitable areas across all provinces. As this result is not consistent during the subsequent months after the onset of the rainy season in October, this result is suggested to be anomalous.

As noted during the Preliminary Climate Risk Analysis (PCRA), the provinces of Huambo, Huíla and Bié are broadly unsuitable for cassava production, even with the effect of climate change. The provincial changes in suitability for cassava production in the period from Baseline to Mid-Century 2050 are discussed further below.

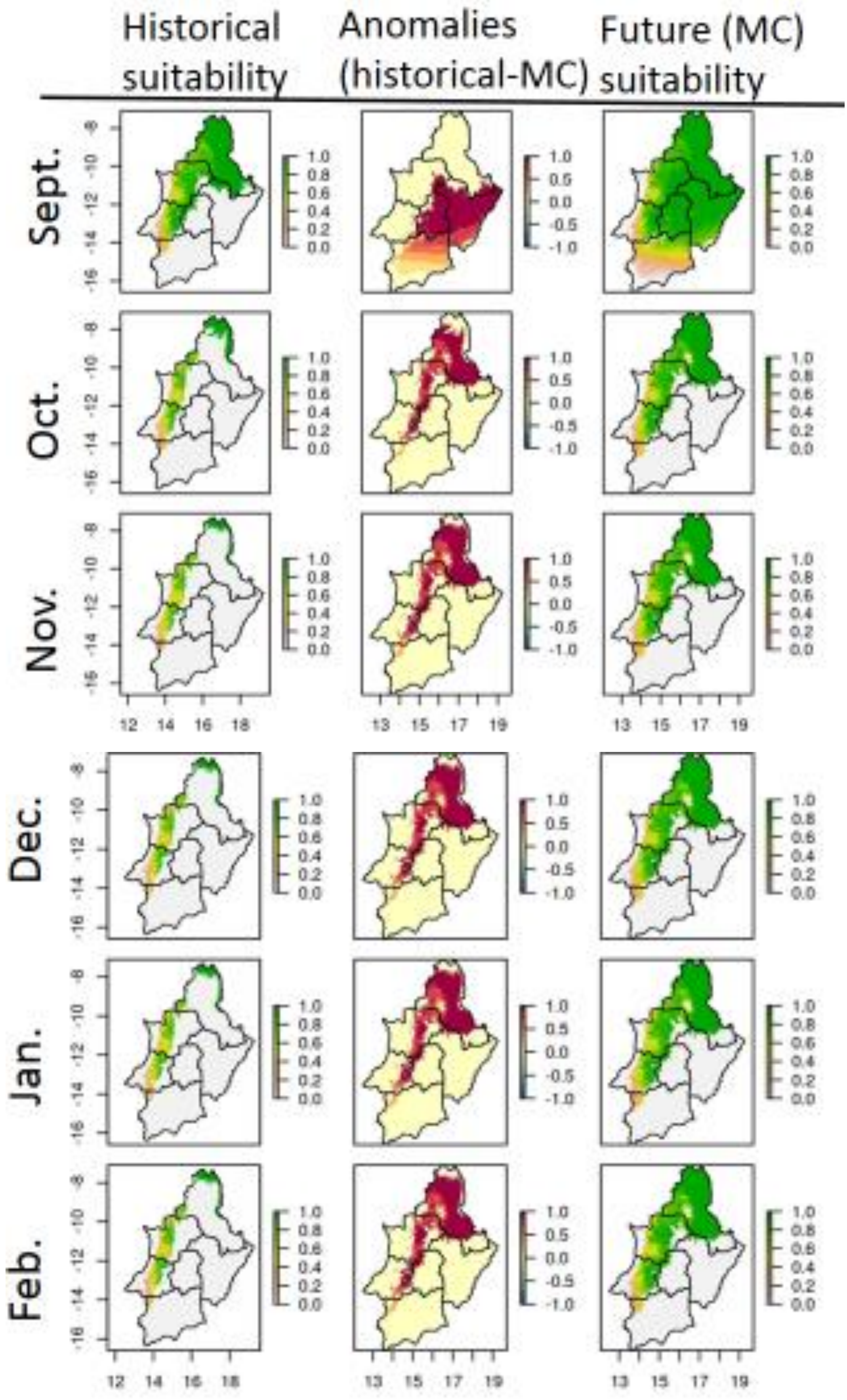


Figure 344. Distribution and changes to suitability for cassava production in the 'baseline' (left) and 'mid-century 2050' (right) scenario in the months of September to February

4.1.a Impact of climate change on production of cassava (*Manihot esculenta*) in Benguela

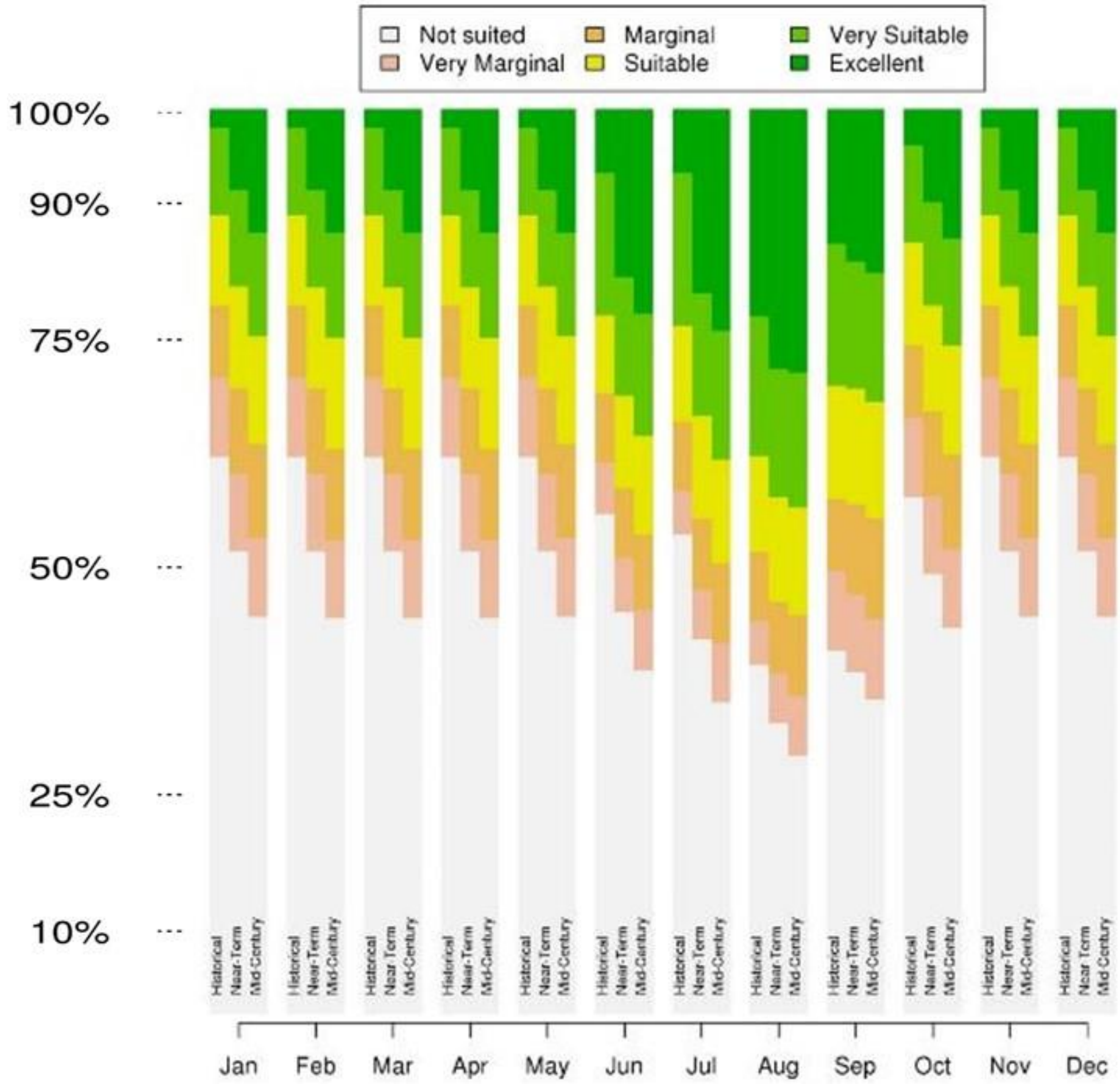


Figure 35. Mean suitability changes of Cassava (*Manihot esculenta*) in Benguela

During the month of October (the onset of the rainy season) the total area suitable for growing Cassava in Benguela is projected to increase from 'Baseline' to 'MC 2050' timepoints. The total provincial increase in suitability for cassava production can be attributed to an increase in the extent of areas considered 'excellent'. The total spatial area of suitability is greatest during the winter months from June to September. The spatial and total area suitability of Benguela for cassava remains generally consistent during the rainy season from October to April. The total extent of cassava-suitable areas is largest during the month of August, during which month there is predicted to be an increase in the extent of areas considered to be 'excellent' between the 'Historical' and 'MC 2050' projections. This projected increase in crop suitability could be a result of the projected increase in Tmean from ~20 ('Baseline') to 21.5 °C ('NT 2030', 'MC 2050'), where cassava has an optimum growth temperature ranging from ~20 to ~29 °C.

As demonstrated in Figure 34, the increase of suitable areas in Benguela for production of cassava primarily occurs in the mid- and high-altitude interior of the province, stretching from the interior of Benguela northwards into Cuanza Sul and Malanje.

4.1.b Impact of climate change on production of cassava (*Manihot esculenta*) in Bié

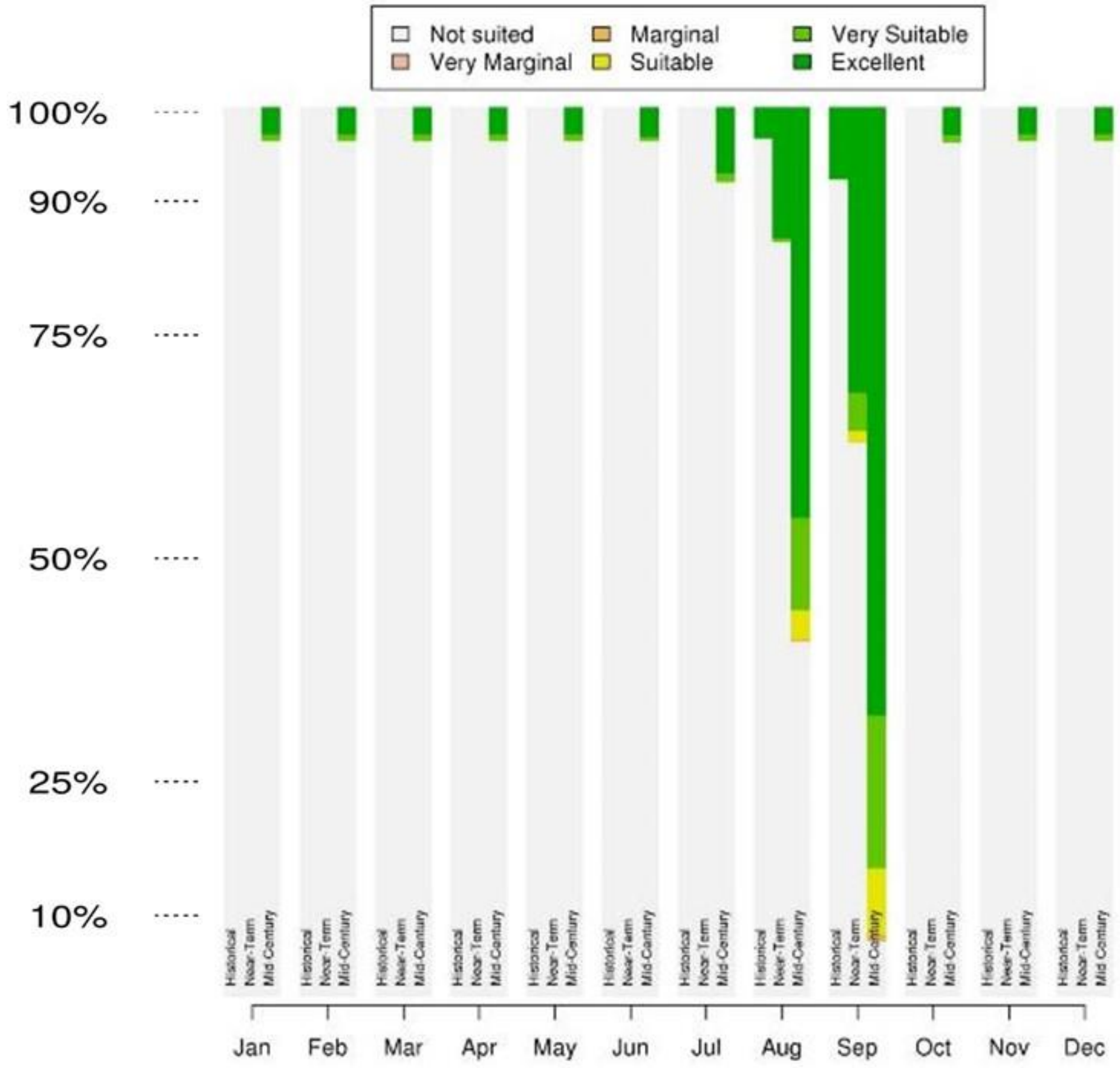


Figure 36. Mean suitability changes of Cassava (*Manihot esculenta*) in Bié

During October, 'Baseline' and 'NT 2030' time points illustrate zero suitability for the growth of cassava in Bié, making the province currently unsuitable for the production of cassava. However, 'MC 2050' projections illustrate that a small area of Bié will become 'excellent' or 'very suitable' for the cultivation of cassava. These areas of increased suitability for cassava primarily occur in the north-east of the province, along the provincial border with Malanje. The projected marginal increases in areas of 'excellent' could be attributed to a ~1 °C increase in Tmean from ~22 ('Baseline') to ~23 °C. The total area suitability of Bié for cassava remains generally consistent throughout the rainy season from October to April. The total extent of cassava-suitable areas is greatest during the month of September, during which month there is predicted to be a considerable increase in the extent of areas considered 'excellent' and 'very suitable' from 'Baseline' to 'MC 2050' time points.

4.1.c Impact of climate change on production of cassava (*Manihot esculenta*) in Cuanza Sul

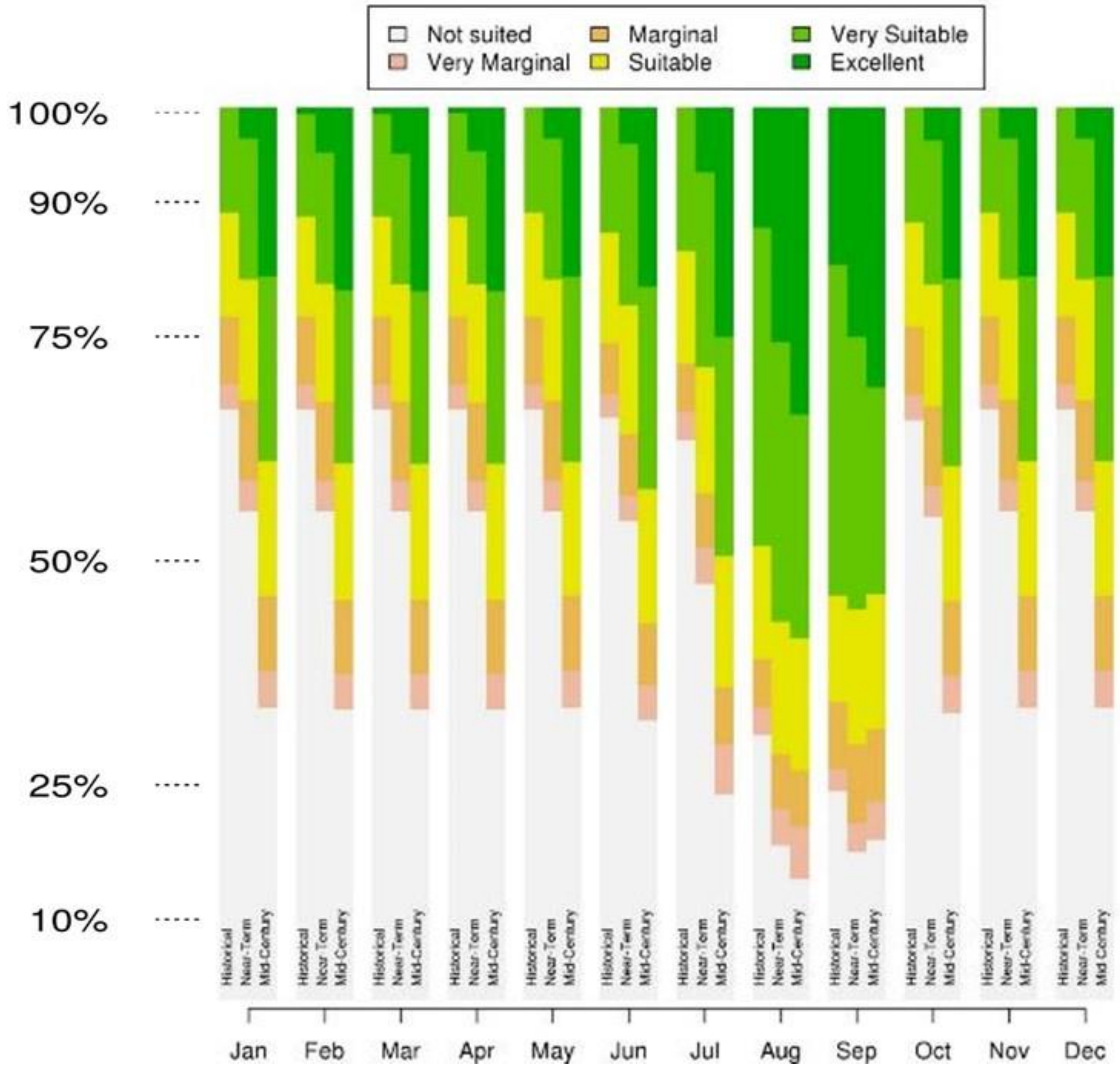


Figure 36. Mean suitability changes of Cassava (*Manihot esculenta*) in Cuanza Sul

During the month of October (considered to be the onset of the rainy season) the total area suitable for growing cassava in Cuanza Sul is predicted to increase considerably from 'Baseline' to 'MC 2050' time points. The total provincial increase in suitability for cassava production can be attributed to an increase in the extent of areas considered 'excellent' and 'very suitable'. The total area suitability for cassava in Cuanza Sul is predicted to remain generally consistent throughout the rainy season from October to April and throughout the dry winter period from May to July. The predicted increases in suitability primarily occur in the central and eastern interior highlands of the province, stretching northwards from Benguela to Malanje. Surprisingly, the total extent of cassava-suitable areas is largest during the months of August and September, during which period there is predicted to be an increase in the extent of areas considered 'excellent' between the 'Baseline' and 'MC 2050' time points. This projected increase in crop suitability could be attributed to the projected increase in Tmean from ~20 ('Baseline') to 21 °C ('NT 2030', 'MC 2050'), where cassava has an optimum growth temperature between ~20 to ~29 °C. However, this unexpected increase in spatial extent of suitability during August and September could be anomalous and is unlikely to reflect real-life crop responses to field conditions as rainfall in the aforementioned months would be inadequate to support crop establishment.

The geospatial distribution of crop suitability index scores for cassava during the baseline and mid-century periods, as well as the relative changes (anomalies) in crop suitability between these time periods, are summarised in Figure 34. As the latter maps illustrate, the overall increase of suitable areas in Cuanza Sul for production of cassava appears to occur in the mid- and high-altitude interior of the province, stretching from the interior of Benguela northwards into Cuanza Sul and Malanje.

4.1.d Impact of climate change on production of cassava (*Manihot esculenta*) in Huambo

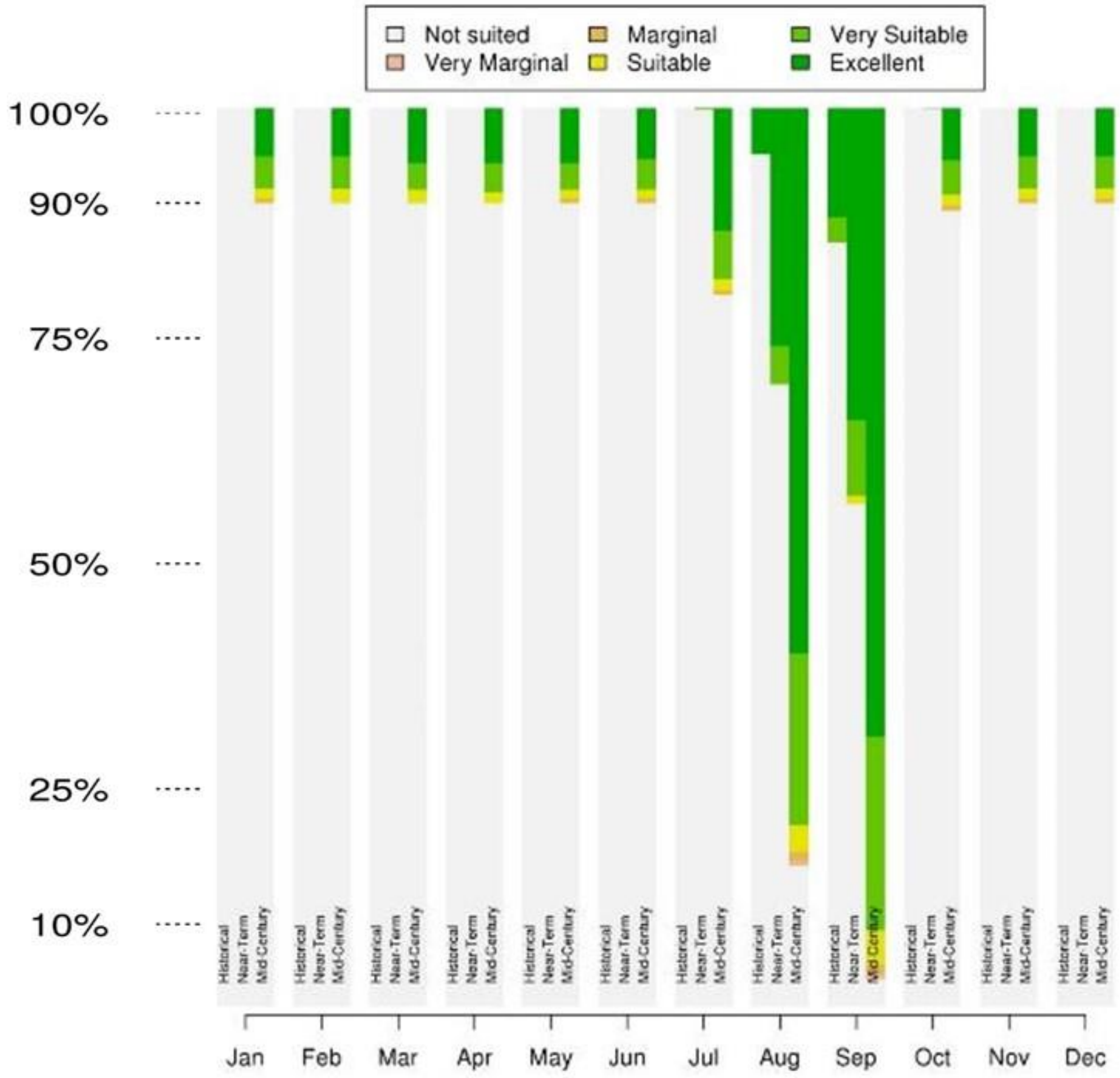


Figure 37. Mean suitability changes of Cassava (*Manihot esculenta*) in Huambo

In the baseline scenario, Huambo is generally considered to be unsuitable for cassava production, except for a very small area that is predicted to have 'excellent' suitability in the months of August and September. At the onset of the rainy season in October, EcoCrop analyses predict that Huambo is totally unsuitable for cassava at 'Baseline' and 'NT 2030' time points, indicating that the province is unsuitable for cultivation of cassava in the present and near-future. However, a predicted increase in the area of suitability for cassava in Huambo is observed during the 'Baseline' to 'MC 2050' period, including during the onset of the rainy season in October. 'MC 2050' projections suggest that a small area of Huambo will become 'very suitable' or even 'excellent' for cultivation of cassava. This predicted increase in suitable area is consistent through all months of the year, with the exception of August and September which indicate considerably larger increases in suitability – the latter two months are suggested to be anomalous and should be disregarded, considering that cultivation is unlikely to be practical in these months as a result of the relatively low monthly rainfall which is unlikely to be adequate for establishment of crops The predicted increase in suitability could be attributed to a warmer climate as an increase of ~0.5 °C in Tmean is predicted for 'MC 2050', particularly during the late winter and early summer months months.

4.1.e Impact of climate change on production of cassava (*Manihot esculenta*) in Huíla

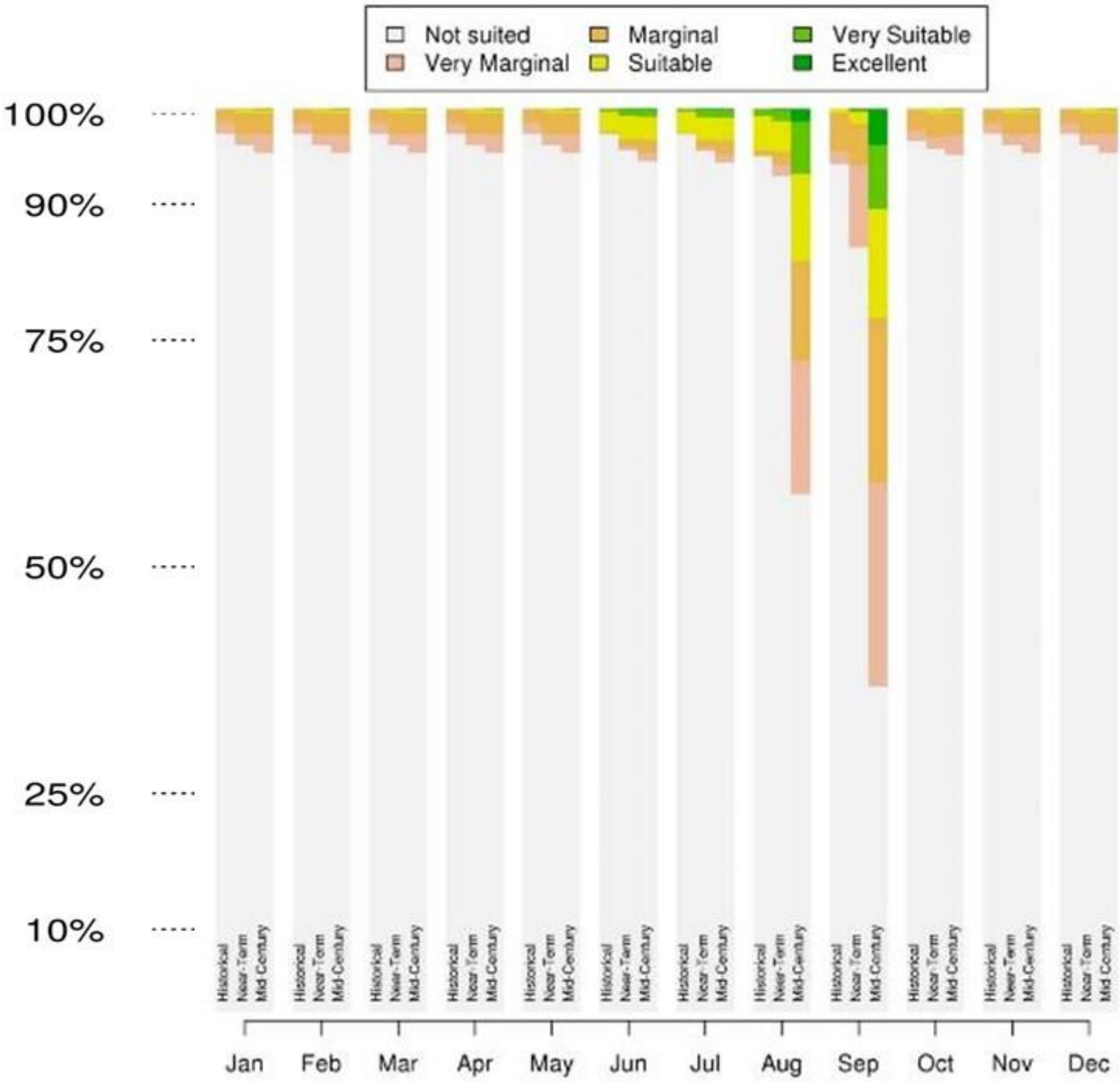


Figure 38. Mean suitability changes of Cassava (*Manihot esculenta*) in Huíla

In general, the majority of Huíla province is unsuitable for cassava production in the baseline and future (mid-century) scenarios. During the month of October (the onset of the rainy season) the total area of suitability for cassava production in Huíla is predicted to increase slightly from 'Baseline' to 'MC 2050' time points. There is a general overall provincial increase in suitability for cassava from 'Baseline' to 'MC 2050' timepoints. The greatest overall increase in suitability for Cassava growth, and the greatest area of suitability overall, is predicted to occur during the months of August and September at 'MC 2050' timepoint. This projected increase in crop suitability could be a result of an increase in Tmean from ~21.5 °C ('Baseline') to ~22.5 °C ('NT 2030', 'MC 2050'), where the predicted increase of Tmean is such that September 2050 is predicted to be as warm as the 'baseline' Tmean for the month of October.

4.1.f Impact of climate change on production of cassava (*Manihot esculenta*) in Malanje

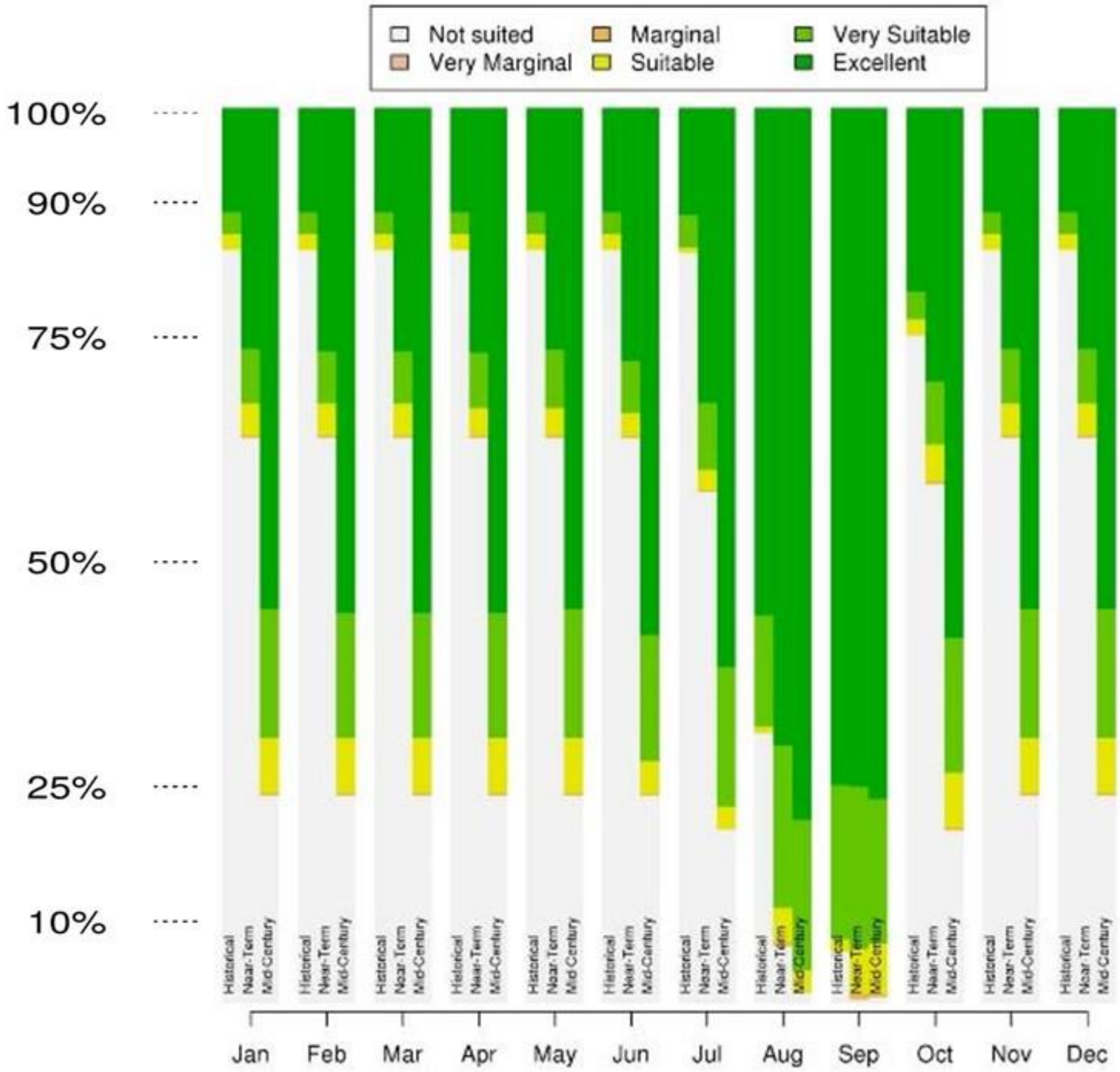


Figure 39. Mean suitability changes of Cassava (*Manihot esculenta*) in Malanje

In general, the overall suitability of Malanje for production of cassava is predicted to increase in total extent during the period from 'Baseline' to 'MC 2050' time points. In the baseline scenario, approximately ¼ of the total provincial area is considered to be suitable for cassava production, while the majority of the province is considered to be unsuited. Ecocrop analyses indicate that the extent of 'excellent', 'very suitable' and 'suitable' areas in Malanje will increase significantly from the baseline scenario to 2050 – in the month of October it is predicted that over ½ of the total provincial area will become 'excellent' for cassava production by 2050. These results suggest that Malanje has the potential to become a major cassava production area in the future and that cassava may be an appropriate crop to promote as a climate-resilient alternative to other climate-vulnerable staple crops. The predicted increases in suitability primarily occur in the central and south-east interior of the province.

4.2 Impact of climate change on spatial distribution of areas suitable for production of coffee Coffee, Arabica (*Coffeea arabica*)

The figures below summarise the historical (baseline) and future (mid-century 2050) suitability of the six pilot provinces (Bié, Benguela, Cuanza Sul, Huambo, Huíla and Malanje) for production of coffee, *C. arabica*, in the months from September to February. In addition to the baseline and future distribution of crop suitability zones, the figures below also illustrate the anomalies (i.e. the absolute changes in suitability at any given location) between the baseline and future time periods.

In the case of C. arabica coffee, the main effect of climate change is to increase the distribution and spatial extent of crop suitability in the interior of Bié, Cuanza Sul, Huambo and Malanje provinces (and to a smaller extent, Benguela province). This net positive change in crop suitability primarily occurs in the interior highlands above the coastal escarpment of the latter provinces, stretching northward from the border of Huambo and Benguela, through Cuanza Sul and northwards into Malanje. This trend is generally consistent and unchanged throughout the summer months from October onwards. The exception to this trend is the month of September, for which month EcoCrop analyses predict a significant increase in suitable areas across all provinces. As this result is not consistent during the subsequent months after the onset of the rainy season in October, this result is suggested to be anomalous. In general, it is predicted that by the 'MC2050' timepoint all provinces with the exception of Huíla will be at least marginally suitable for *C. arabica* production.

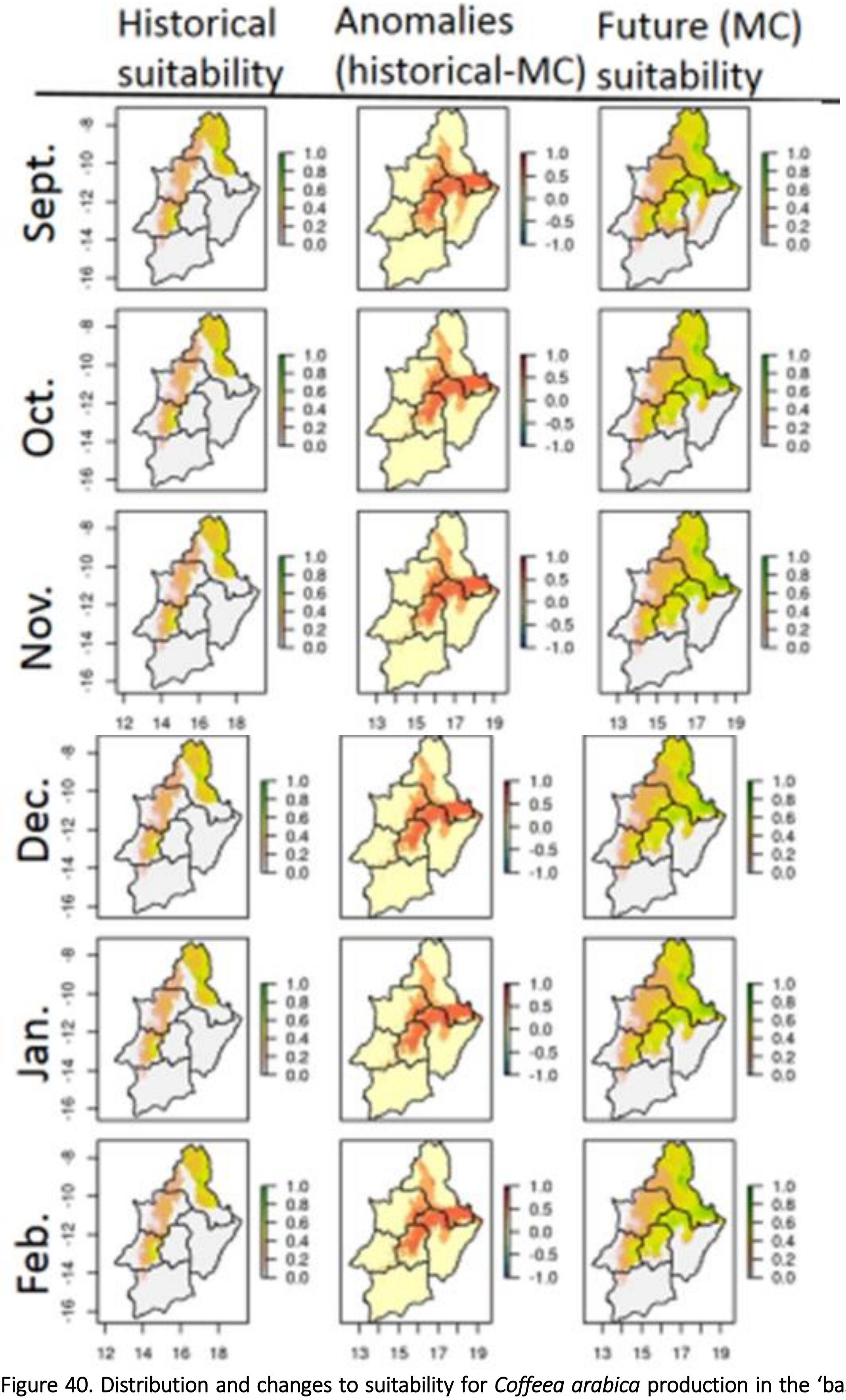


Figure 40. Distribution and changes to suitability for *Coffeea arabica* production in the 'baseline' (left) and 'mid-century 2050' (right) scenario in the months of September to February

4.2a Impact of climate change on production of coffee (*Coffeea arabica*) in Benguela.

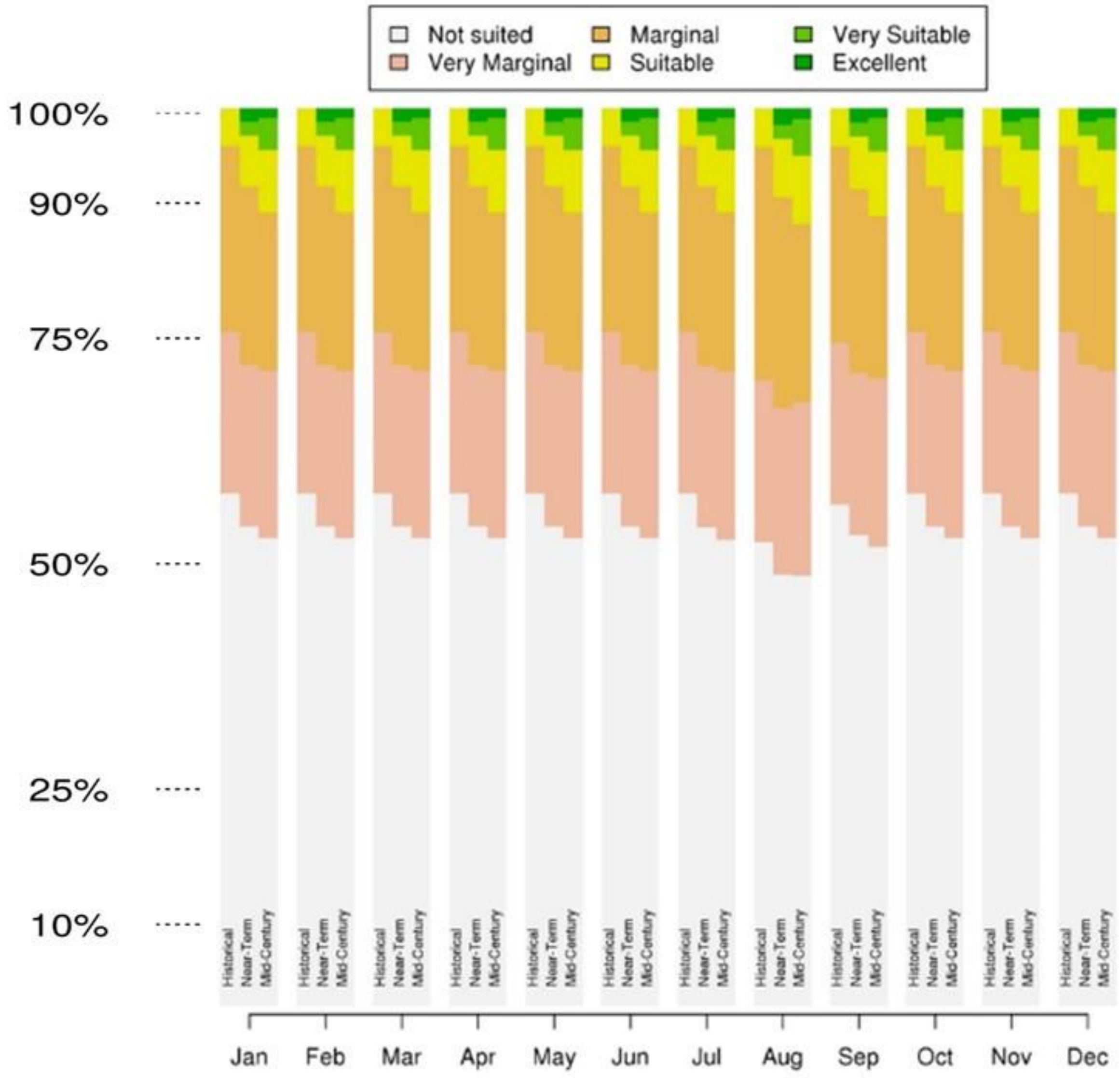


Figure 41 Mean suitability changes of Coffee (*Coffeea arabica*) in Benguela

The total area suitable for growing Coffee (*Coffeea arabica*) in Benguela is projected to increase slightly from 'Baseline' to 'MC 2050' time periods. The total provincial projected increase in suitability for *C. arabica* production is characterised by an increase in the extent of areas categorised as 'excellent' and 'very suitable' in the period from baseline to 'MC 2050'. Maps of baseline and future crop suitability (Figure 40, above) indicate that the changes in suitability for *C. arabica* production primarily occur in the central *planalto* area in a narrow band extending from the eastern interior of Benguela into Huambo province, and northwards through Cuanza Sul and Bié provinces towards Malanje.

The total area of suitability of Benguela for *C.arabica* remains generally consistent during the rainy season from October to April. The highest overall production of *C. arabica* is during the month of August. The increase in suitability could be attributed to an increase in Tmean from ~19 to ~21.5 °C ('Historical' to 'MC 2050') as *C. arabica* has an optimum temperature between ~20 and ~30 °C. However, the overall change in suitability index score is relatively small and as a result is not discernible from mapped plots of changes in suitability.

4.2b Impact of climate change on production of coffee (*Coffeea arabica*) in Bié.

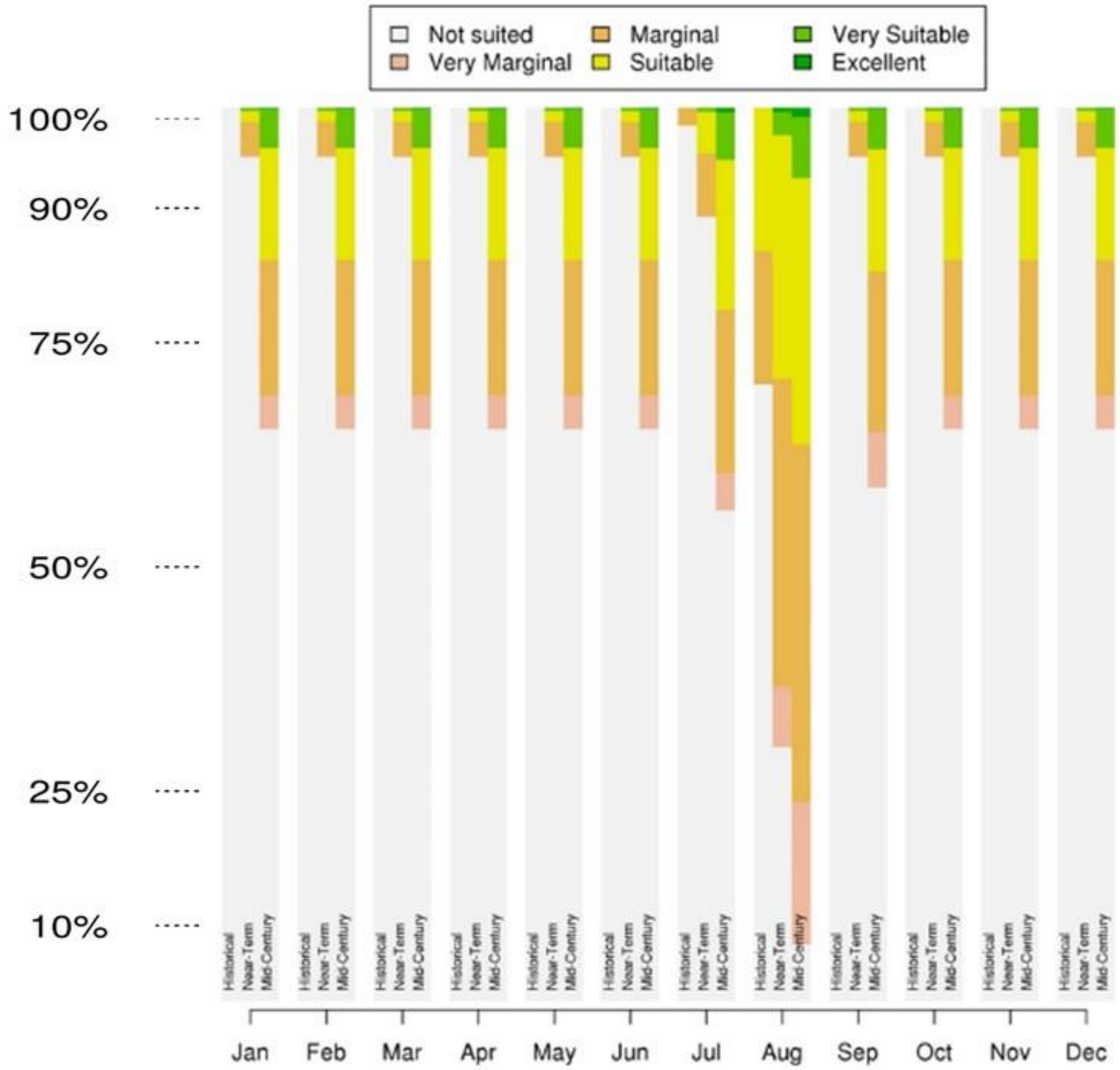


Figure 42. Mean suitability changes of Coffee (*Coffeea arabica*) in Bié

Ecocrop analyses indicate that Bié is entirely unsuitable for the production of Coffee (*Coffeea arabica*) in the 'Baseline' scenario. However, it is predicted that the extent of suitable areas will increase to just over a ⅓ of the total provincial area by 2050, based on the month of October at onset of rainy season. The majority of the areas which are predicted to become suitable are categorised as 'suitable' to 'marginal', while the remaining area of suitability includes some areas of 'marginal' as well as small areas of 'very suitable' land for *C. arabica* production. The increase in the extent of the aforementioned categories could be attributed to a warmer climate, as Tmean in Bié is predicted to increase by ~1 °C (~22 to ~23 °C) from 'Baseline' to 'MC 2050'.

In Bié, the location of the predicted increases in suitability for *arabica* coffee production is restricted to the northwestern extent of the province, adjacent to the borders with Cuanza Sul and Malanje provinces. The eastern interior of Bié is predicted to remain poorly suited to *C. arabica* in the baseline and future scenarios.

4.2c Impact of climate change on production of coffee (*Coffeea arabica*) in Cuanza Sul.

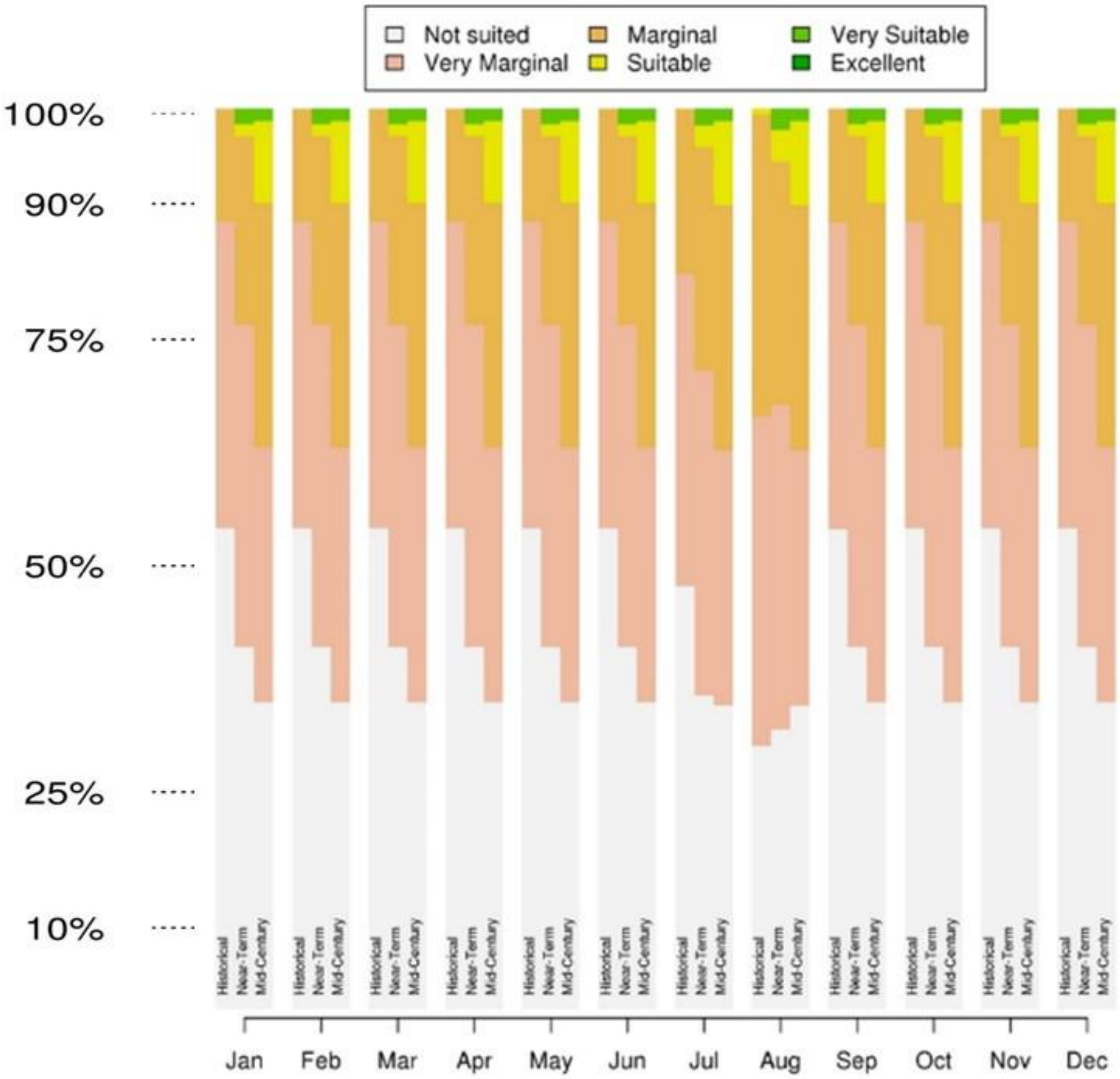


Figure 43. Mean suitability changes of Coffee (*Coffeea arabica*) in Cuanza Sul

The total area suitable for growing Coffee (*Coffeea arabica)* in Cuanza Sul is projected to increase from 'Baseline' to 'MC 2050 timepoints as a result of climate change, which primarily occurs as increases in the proportion of areas considered 'marginal' and 'suitable' between the 'Baseline' and future time periods. Figure 40 indicates that the predicted changes in suitability for *C. arabica* production primarily occur along a narrow band of the *planalto* highlands extending from the borders of Benguela and Huambo provinces northwards through Cuanza Sul and Bié provinces towards Malanje. In Cuanza Sul primarily occur along the northeastern interior of the province, adjacent to the borders shared with Bié and Malanje provinces.

4.2d Impact of climate change on production of coffee (*Coffeea arabica*) in Huambo.

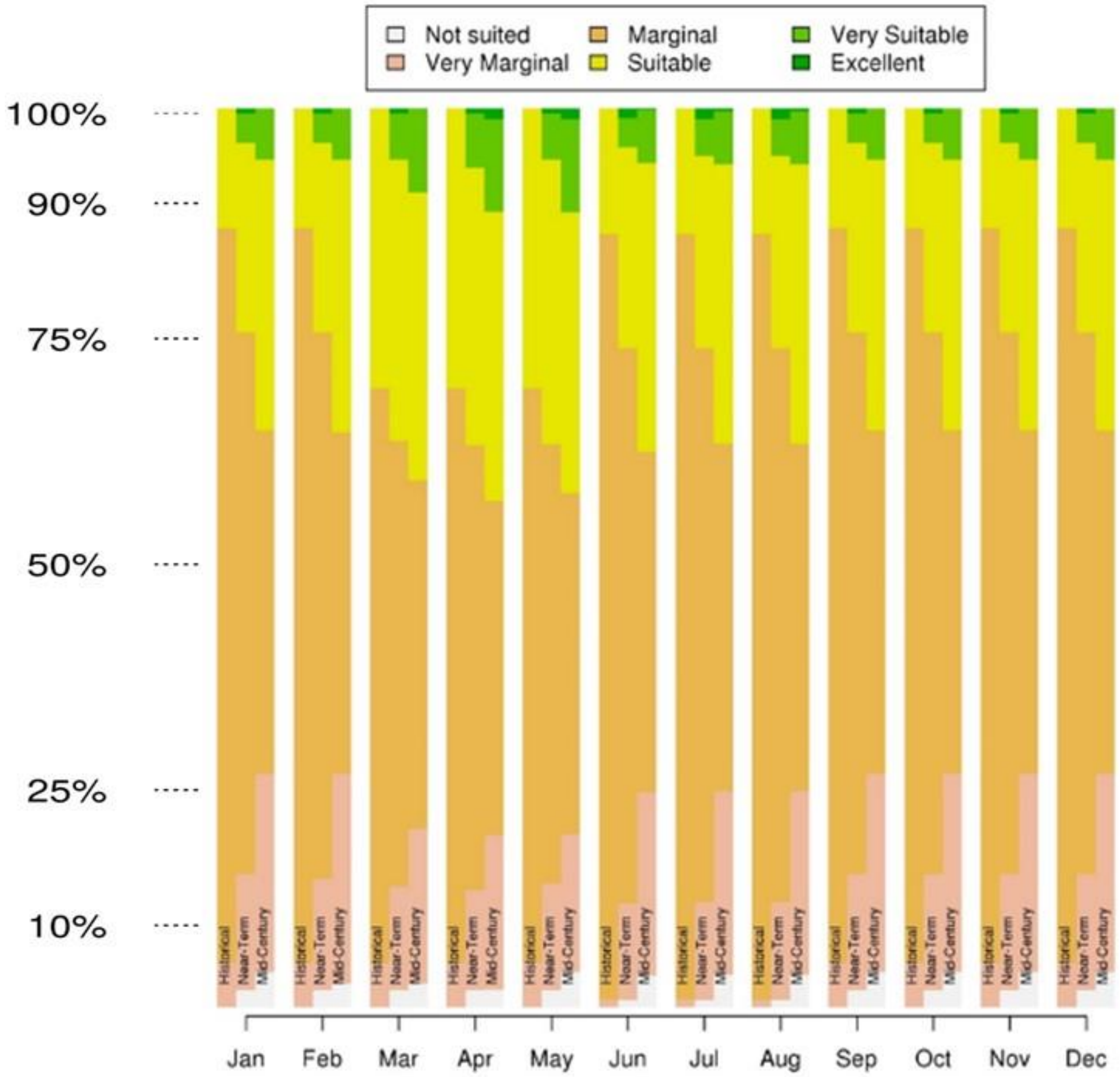


Figure 44. Mean suitability changes of Coffee (*Coffeea arabica*) in Huambo

In general, the overall suitability of Huambo for production of Coffee (*Coffeea arabica)* illustrates a minor or negligible decrease in total area from 'Baseline' to 'MC 2050' time points. However, despite this small overall decrease in projected crop suitability, during the month of October there are predicted to be increases in the extent of areas considered 'very suitable' and 'suitable' from 'Baseline' to 'MC 2050' time points, as well as increases in the extent of 'very marginal' areas. The net increases in the aforementioned categories appear to coincide with net reductions in the predicted extent of 'marginal' areas, suggesting that climate change will increase the suitability of certain 'marginal' areas while decreasing the suitability of other 'marginal' areas.

4.2e Impact of climate change on production of coffee (*Coffeea arabica*) in Huíla.

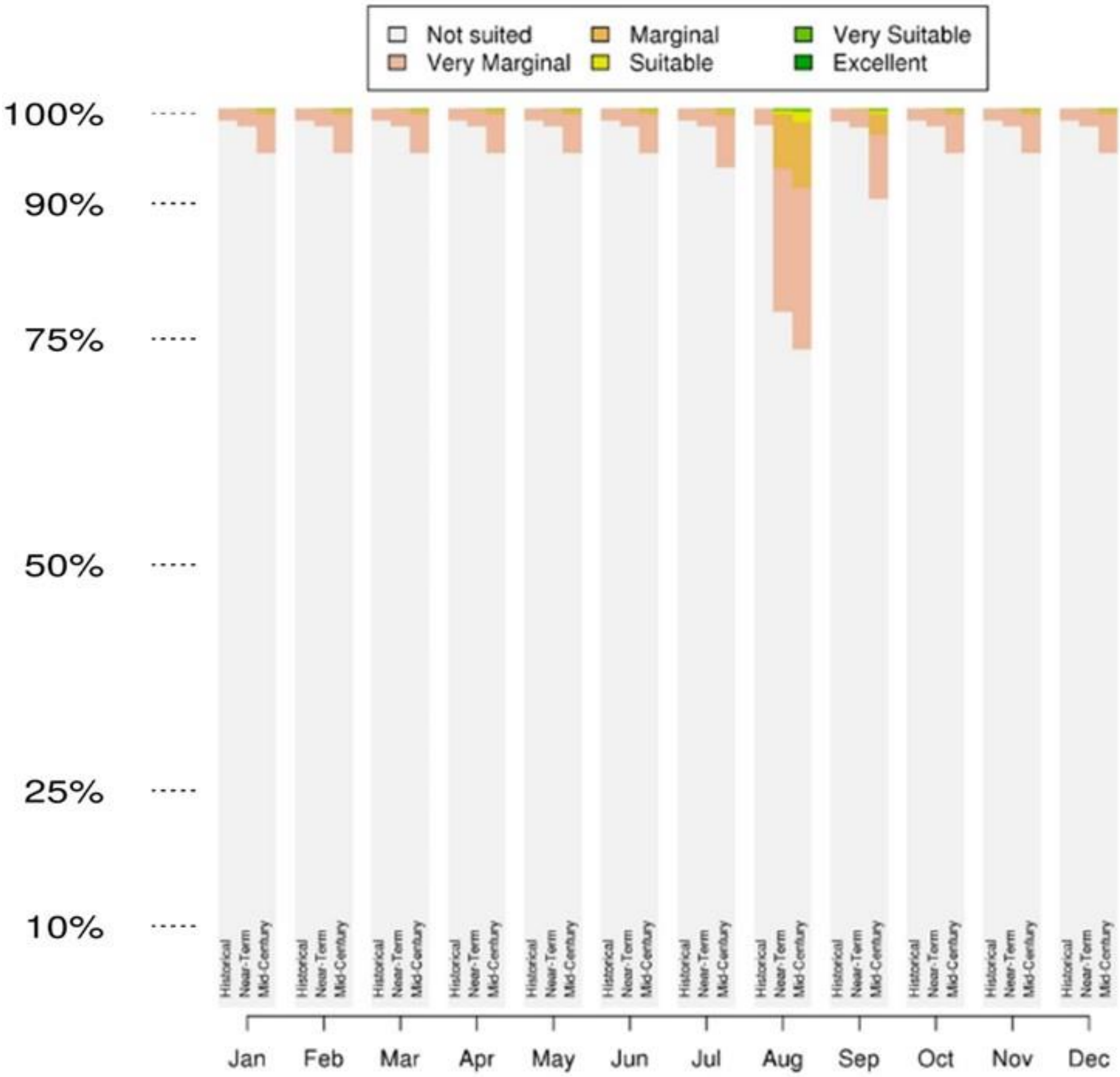


Figure 45. Mean suitability changes of Coffee (*Coffeea arabica*) in Huíla

In the baseline scenario Huíla province is considered to be effectively unsuitable for *C. arabica* production, which is not predicted to change significantly as a result of climate change. The total area suitable for growing Coffee (*Coffeea arabica*) in Huíla illustrates a very small provincial increase between 'Baseline' and 'MC 2050' time points, which is restricted to the northernmost interior of the province.

4.2f Impact of climate change on production of coffee (*Coffeea arabica*) in Malanje.

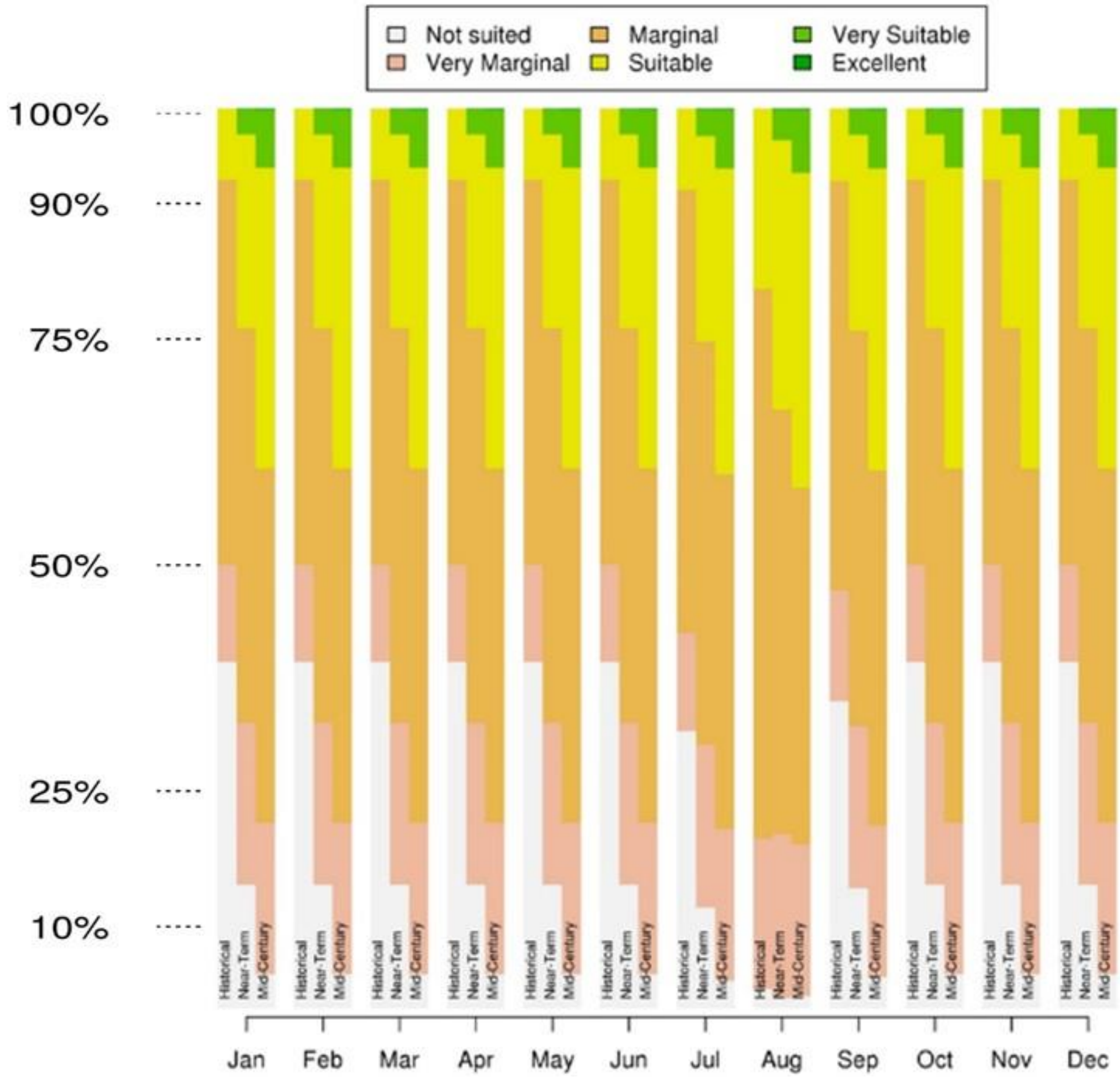


Figure 46. Mean suitability changes of Coffee (*Coffeea arabica*) in Malanje

In general, the total extent of area suitable for the production of Coffee (*Coffeea arabica*) in Malanje is predicted to increase considerably from 'Baseline' to 'MC 2050' time points. Ecocrop analyses indicate that Malanje is moderately suitable for *C. arabica* cultivation in the baseline scenario, where nearly half of Malanje province is 'marginal' and the other half 'not suitable' for coffee production. As a result of climate change, the suitability of Malanje for coffee production is predicted to increase considerably in the period from 'Baseline' to 'MC 2050' so that a large proportion of the province is predicted to be 'suitable' and the remaining area 'very suitable', 'marginal', and 'very marginal'. As a result of climate change, Malanje may have the potential for increased yields and larger production area of *C. arabica.*

4.3 Impact of climate change on spatial distribution of areas suitable for production of Coffee, Robusta (*Coffeea robusta*)

The figures below summarise the historical (baseline) and future (mid-century 2050) suitability of the six pilot provinces (Bié, Benguela, Cuanza Sul, Huambo, Huíla and Malanje) for production of coffee, *C. robusta*, in the months from September to February. In addition to the baseline and future distribution of crop suitability zones, the figures below also illustrate the anomalies (i.e. the absolute changes in suitability at any given location) between the baseline and future time periods.

In the case of *C. robusta* coffee, climate change is not predicted to result in major changes to crop suitability or distribution. As per the baseline situation, the entire provinces of Huambo, Bié and Malanje are considered to be suitable for *robusta* coffee production. Of the remaining provinces – Benguela, Cuanza Sul and Huíla, respectively – the suitable growing range for *C. arabica* is limited by the aridity of the southern and western lowlands below the *planalto* escarpment.

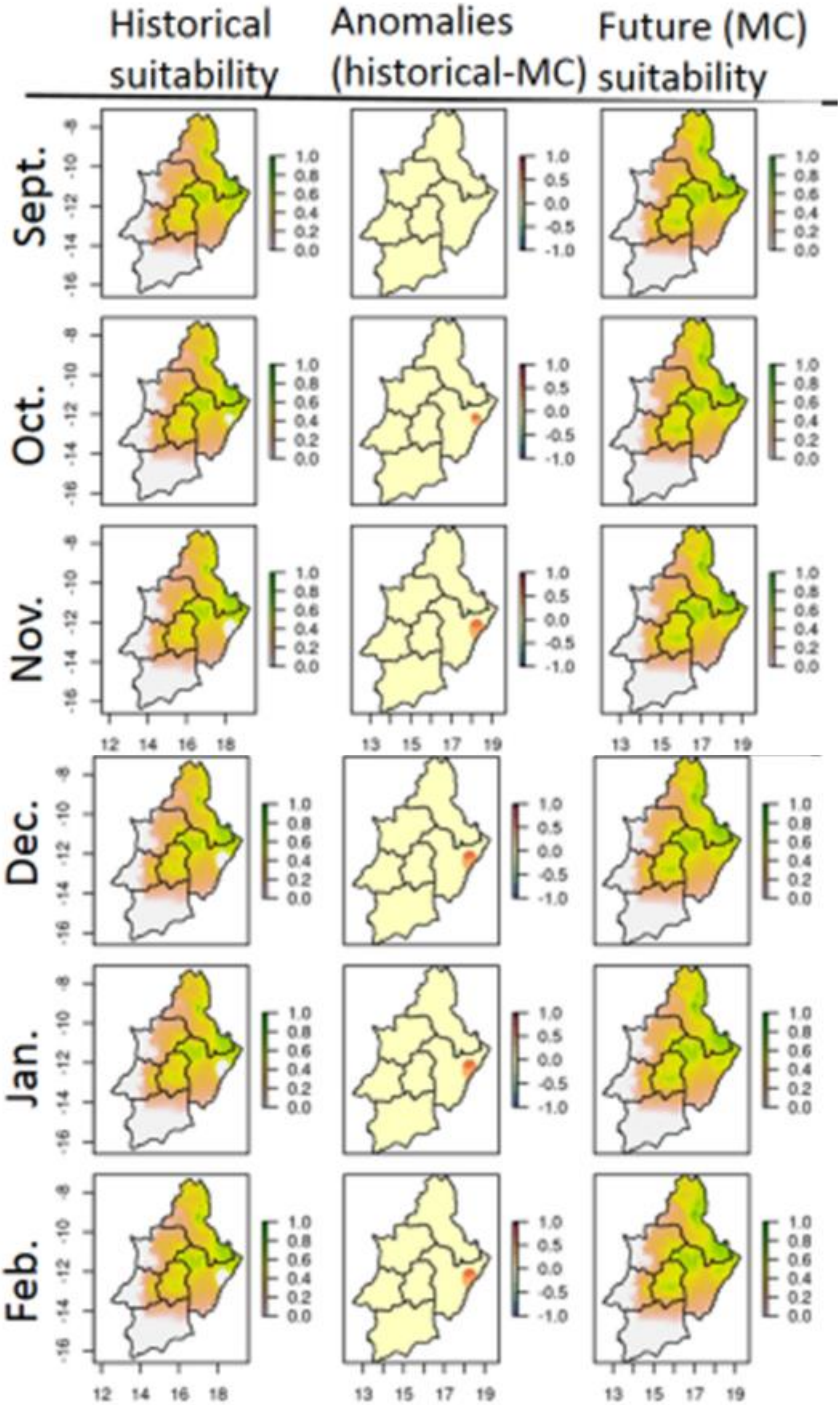


Figure 47. Distribution and changes to suitability for *Coffeea robusta* in the 'baseline' (left) and 'mid-century 2050' (right) scenario in the months of September to February

4.3a Impact of Climate Change on production of coffee (*Coffeea robusta*) in Benguela.

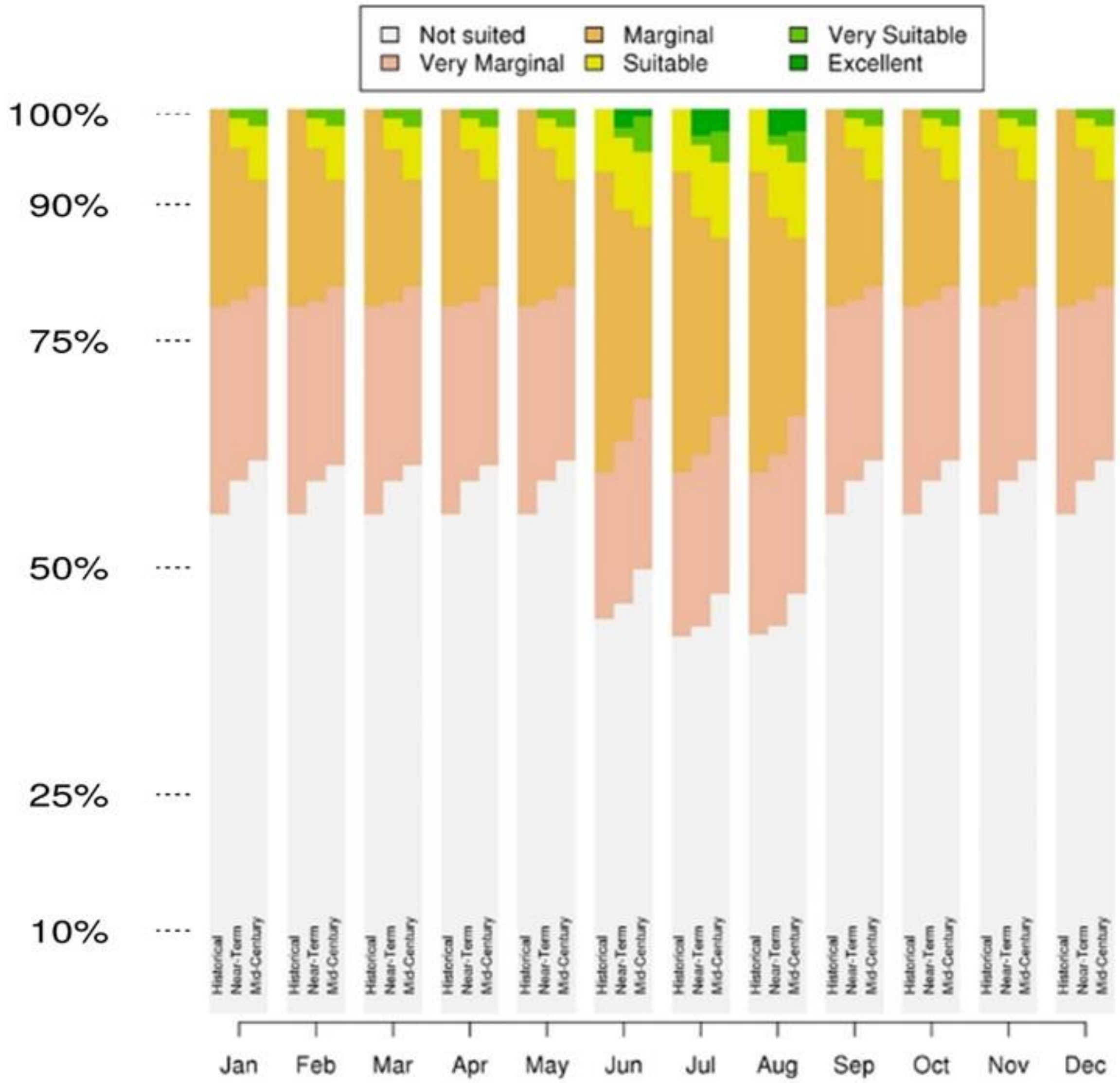


Figure 48. Mean suitability changes of Coffee (*Coffeea robusta*) in Benguela.

In general the overall suitability of Coffee (*Coffea robusta*) illustrates a very minor decreasing trend from 'Baseline' to 'MC 2050' timepoints. However, despite the overall decrease in projected crop suitability, there are predicted to be small simultaneous increases in the proportion of areas considered 'very suitable' and 'suitable', respectively, in the period between 'Baseline', 'Near-Term' (NT 2030) to 'MC 2050' projections. However, comparison with crop anomalies mapped in Figure 47 (above) indicate the total and relative changes in crop suitability are too small to be detected and displayed as anomalies, and can therefore be considered negligible.

4.3b Impact of Climate Change on production of coffee (*Coffeea robusta*) in Bié

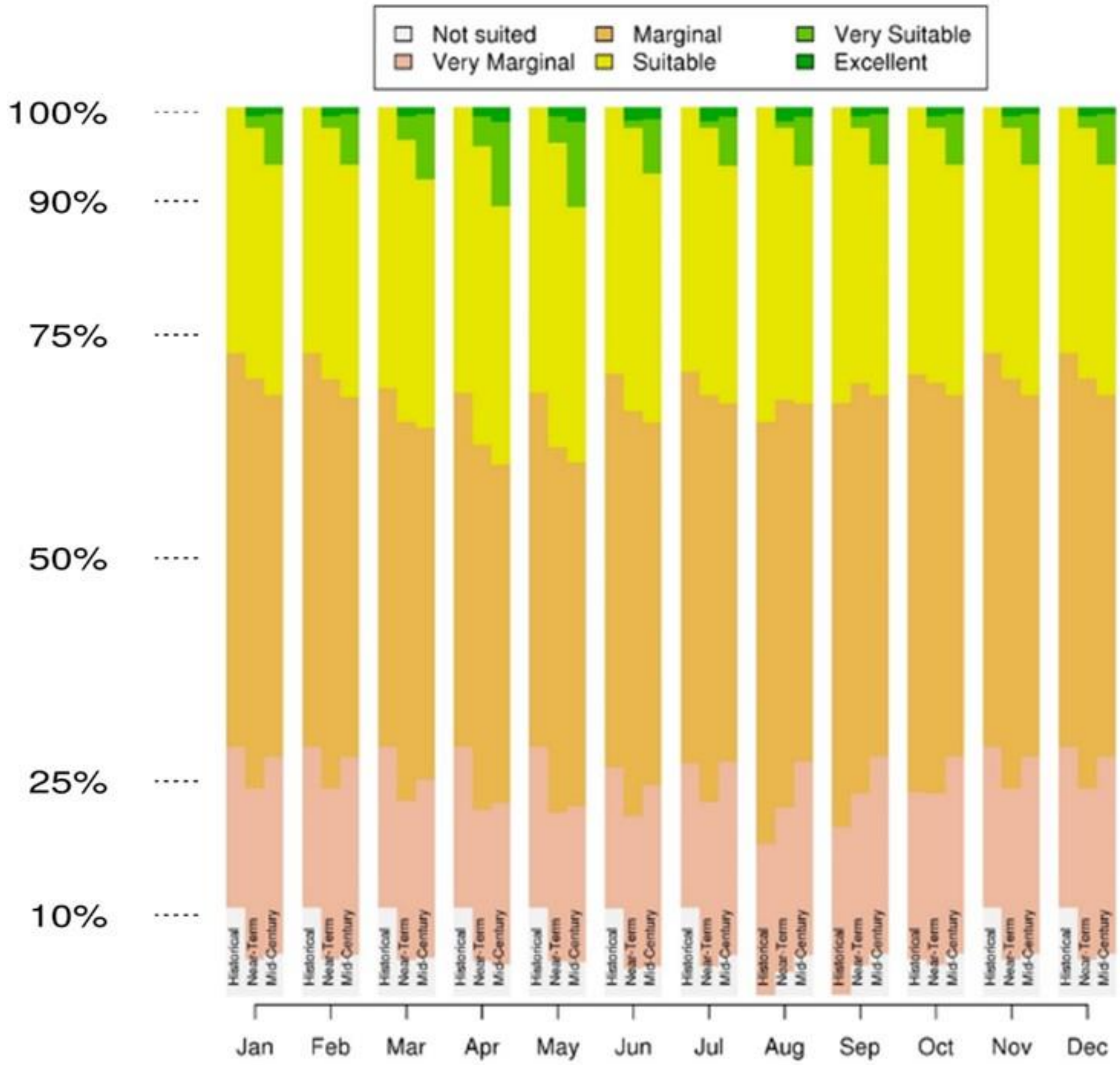


Figure 49. Mean suitability changes of Coffee (*Coffeea robusta*) in Bié

In general there are predicted to be only relatively minor changes as a result of future climate change in the total area of suitability in Bié during the month of October for the production of Coffee (*Coffeea robusta*). During the month of October areas considered 'excellent', and 'very suitable' are predicted to slightly increase from 'Baseline' to 'MC 2050', simultaneous decreases are predicted in the extent of 'suitable' and 'marginal' areas during the 'Baseline' to 'MC 2050' period. Overall, the predicted changes in suitability of Bié province for *C. robusta* production are small enough as to be considered negligible – in both the future and baseline scenarios, the entire extent of the province is at least marginally if not well suited to production of *C. robusta.*

4.3c Impact of Climate Change on production of coffee (*Coffeea robusta*) in Cuanza Sul

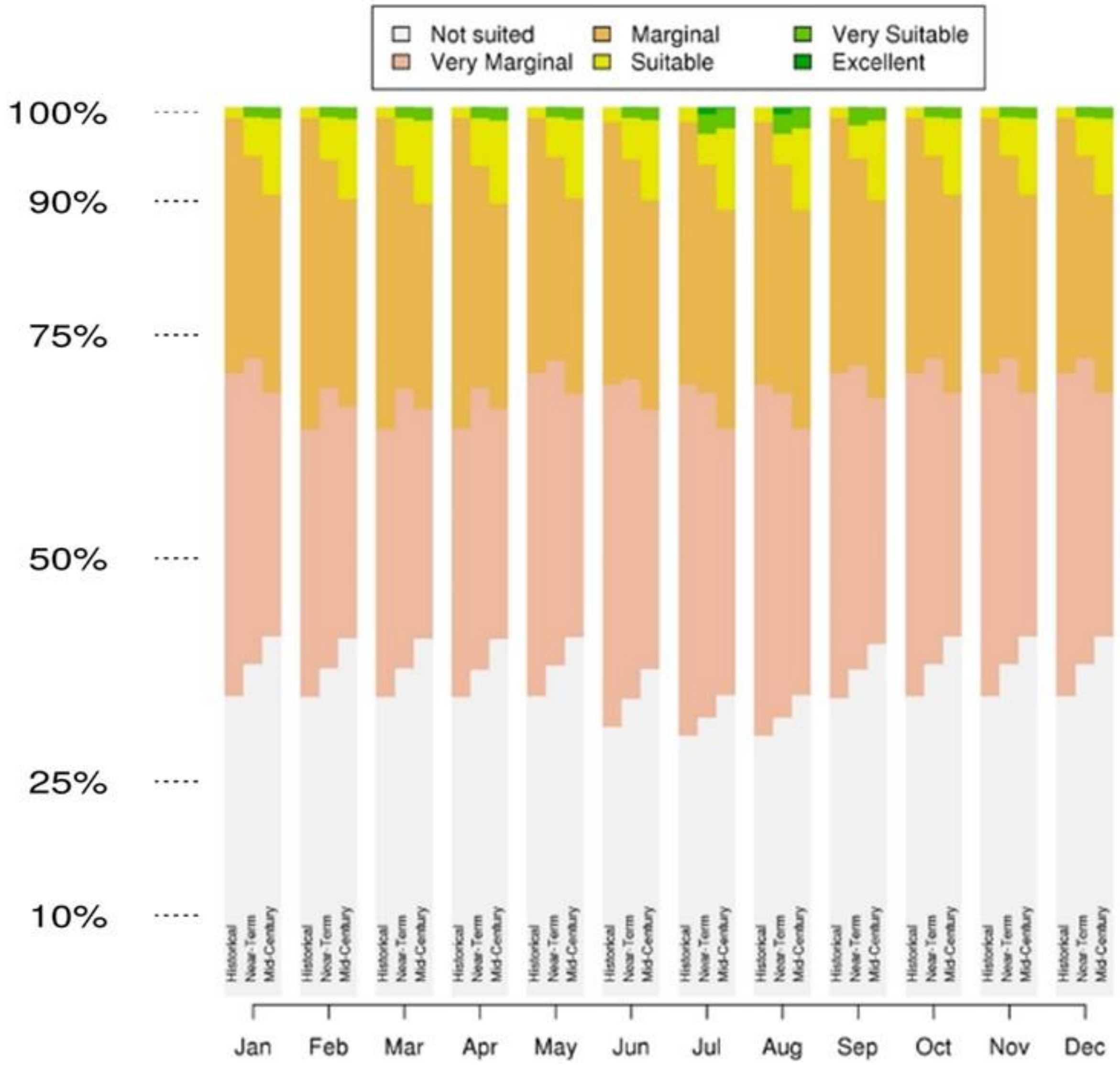


Figure 50. Mean suitability changes of Coffee (*Coffeea robusta*) in Cuanza Sul

Similar to the trend observed for Benguela, in Cuanza Sul province it is predicted that the overall suitability of Coffee (*Coffea robusta*) will decrease slightly in the period from 'Baseline' to 'MC 2050' timepoints. Despite the overall decrease in projected crop suitability, there are predicted to be small simultaneous increases in the proportion of areas considered 'very suitable' and 'suitable', respectively, in the period between 'Baseline', 'Near-Term' (NT 2030) to 'MC 2050' projections. However, comparison with crop anomalies mapped in Figure 47 (above) indicate the total and relative changes in crop suitability are too small to be detected and displayed as anomalies, and can therefore be considered negligible.

4.3d Impact of Climate Change on production of coffee (*Coffeea robusta*) in Huíla

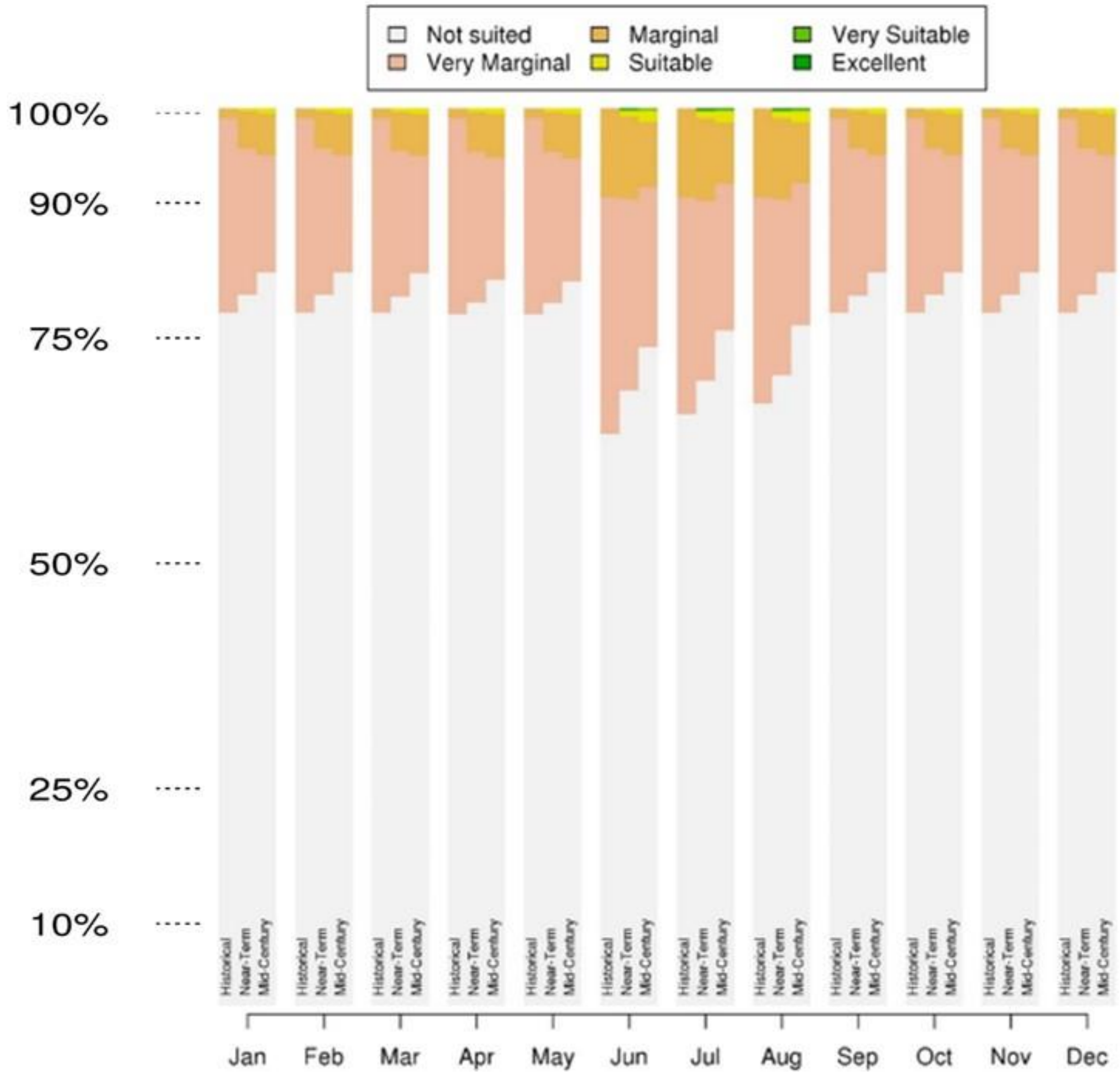


Figure 51. Mean suitability changes of Coffee (*Coffea robusta*) in Huíla

In general the overall provincial suitability of coffee (*Coffea robusta*) in Huíla is predicted to decrease slightly from 'Baseline' to 'MC 2050' time points. However, despite the overall decrease, there are predicted to be increases in the extent of areas considered 'suitable' and 'marginal' during the month of October. The highest overall proportion of suitability for the production of *C. robusta* is predicted to occur during the months from June to August. The small area of Huíla which is suitable for *C. robusta* production is confined to the northern interior of the country, while the southern lowlands of the province are totally unsuitable for any form of coffee production.

4.3e Impact of Climate Change on production of coffee (*Coffeea robusta*) in Huambo

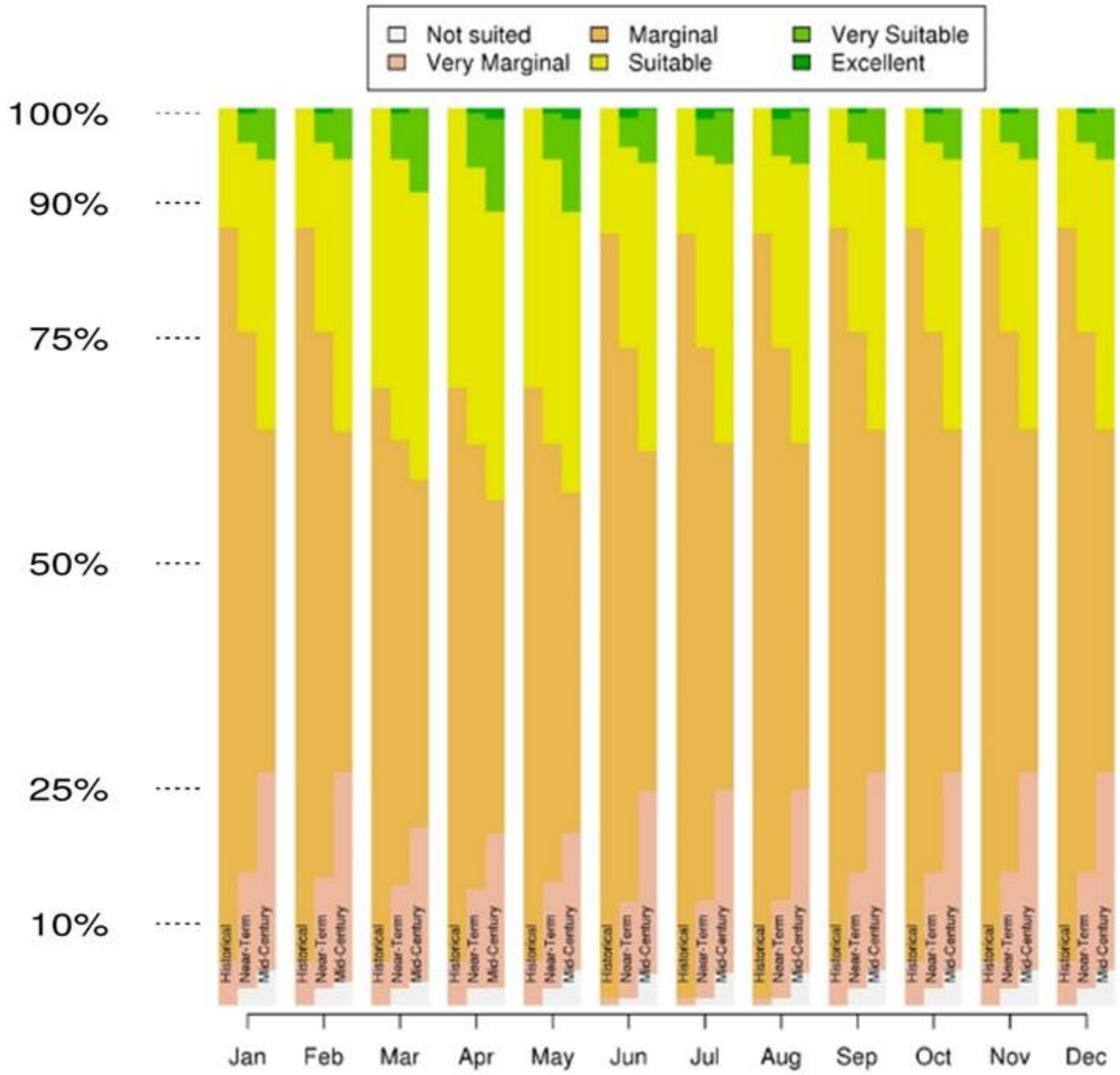


Figure 52. Mean suitability changes of Coffee (*Coffeea robusta*) in Huambo

In both the baseline and future scenarios, the entire Huambo province is considered to be suitable for production of robusta coffee (*C. robusta*). In general, the overall suitability of Huambo for production of *C. robusta* illustrates a minor decrease in total area from 'Baseline' to 'MC 2050' time points. However, despite this small overall decrease in projected crop suitability, during the month of October there are predicted to be increases in the extent of areas considered 'very suitable' and 'suitable' from 'Baseline' to 'MC 2050' time points, as well as increases in the extent of 'very marginal' areas. The net increases in the aforementioned categories appear to coincide with net reductions in the predicted extent of 'marginal' areas, suggesting that climate change will increase the suitability of certain 'marginal' areas while decreasing the suitability of other 'marginal' areas. comparison with crop anomalies mapped in Figure 47 (above) indicate the total and relative changes in crop suitability are too small to be detected and displayed as anomalies, and can therefore be considered negligible.

4.3f Impact of Climate Change on production of coffee (*Coffeea robusta*) in Malanje

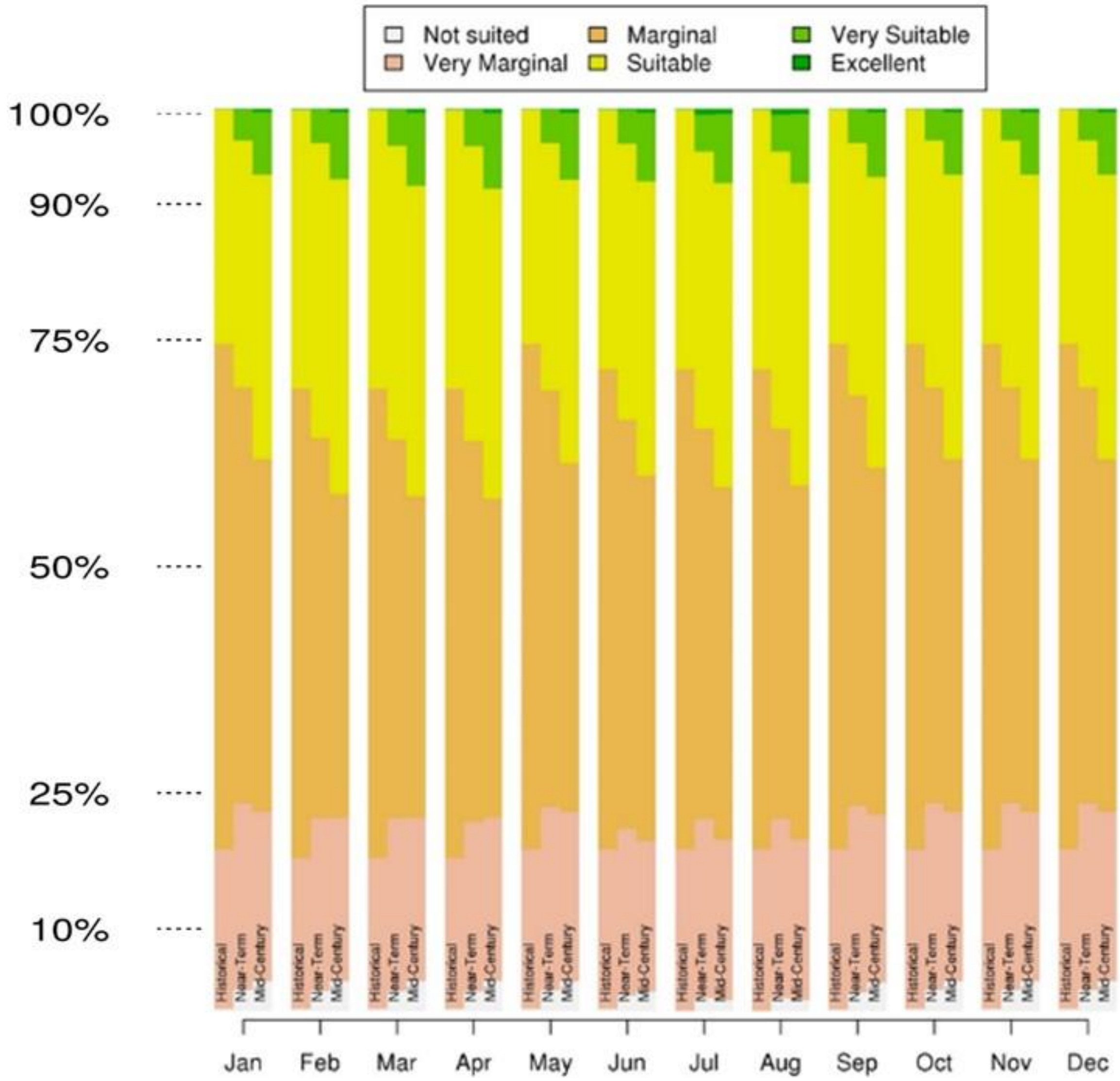


Figure 53. Mean suitability changes of Coffee (*Coffeea robusta*) in Malanje

Overall, there are no predicted major changes in the total area suitable for coffee (*Coffeea robusta*) production in Malanje. However, while the total spatial area remains relatively consistent, there are changes in the relative distribution of several categories of suitability for coffee production. During the month of October there are predicted to be increases in the extent of 'very suitable', and 'suitable' areas for coffee production from 'Baseline' to 'MC 2050' time points. The latter increases in crop suitability appear to coincide with small decreases in the extent of 'marginal' areas – this result suggests that climate change will improve the suitability of certain areas for *C. robusta* production that might be considered 'marginally suited' in the baseline scenario. The total area of Malanje, which is predicted to be suitable for *C. robusta* production remains generally consistent throughout the rainy season from October to April.

4.4 Impact of climate change on spatial distribution of areas suitable for production sugarcane (*Saccharum officinarum*)

The figures below summarise the historical (baseline) and future (mid-century 2050) suitability of the six pilot provinces (Bié, Benguela, Cuanza Sul, Huambo, Huíla and Malanje) for production of sugarcane in the months from September to February. In addition to the baseline and future distribution of crop suitability zones, the figures below also illustrate the anomalies (i.e. the absolute changes in suitability at any given location) between the baseline and future time periods.

In the case of sugarcane, the effects of climate change on crop suitability are predicted to be generally positive. In all provinces, EcoCrop analyses indicates a general increase in suitability index score during the period from Baseline to Mid-Century 2050 timepoints, where provinces such as Cuanza Sul, Benguela, Malanje and Bié are predicted to have increased extent of 'suitable', 'very suitable' and 'excellent' areas. The provinces of Bié, Huíla and Huambo are generally considered poorly suited for sugarcane production in the baseline scenario – however, these three provinces are predicted to benefit from increases in the total area of suitable land, the majority of which is predicted to occur as 'very marginal' or 'marginal' land. In general, monthly distribution and total extent of suitability index scores is predicted to remain consistent throughout the calendar year in all provinces.

The provincial changes in suitability for sugarcane production in the period from Baseline to Mid-Century 2050 are discussed further below.

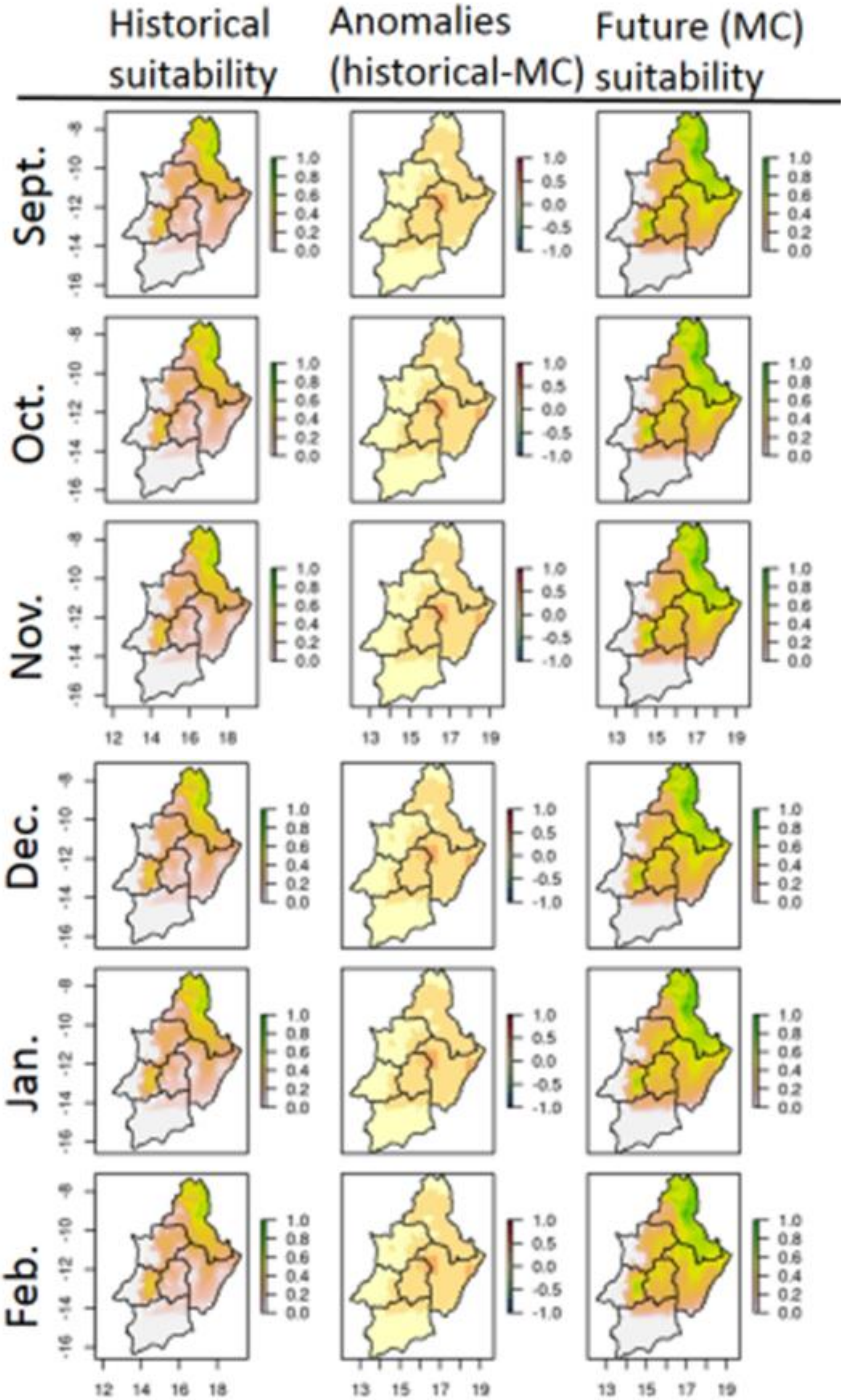


Figure 54. Distribution and changes to suitability for sugarcane production in the 'baseline' (left) and 'mid-century 2050' (right) scenario in the months of September to February

4.4a Impact of climate change on production of sugar cane (*Saccharum officinarum*) in Benguela

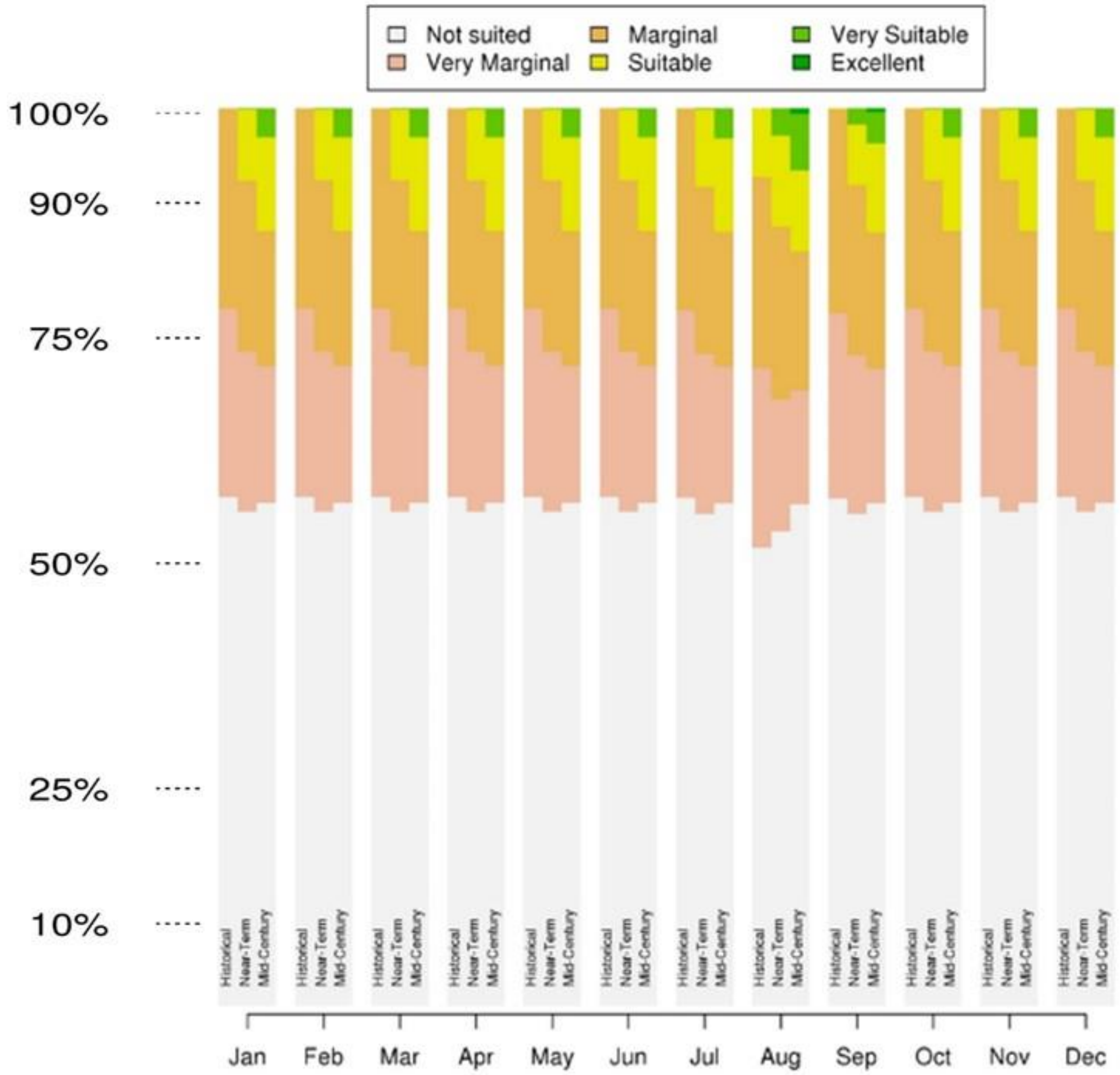


Figure 54 Mean suitability changes of Sugarcane (*Saccharum officinarum*) in Benguela

The proportion of area considered 'suitable' and, 'very suitable' for sugarcane production illustrates a general increase from 'Baseline' to 'MC 2050' time period, although the total spatial extent of suitable areas is not predicted to change. Analysis of mapped anomalies of crop suitability index from Baseline to MC 2050 timepoints indicates that the main improvements in suitability for sugarcane production occurs at the interior planalto highlands of Benguela, stretching northwards towards Cuanza Sul.

The total spatial area suitability of Benguela for sugarcane production during the rainy season months from October to April remains generally consistent.

4.4b Impact of climate change on production of sugar cane (*Saccharum officinarum)* in Bié

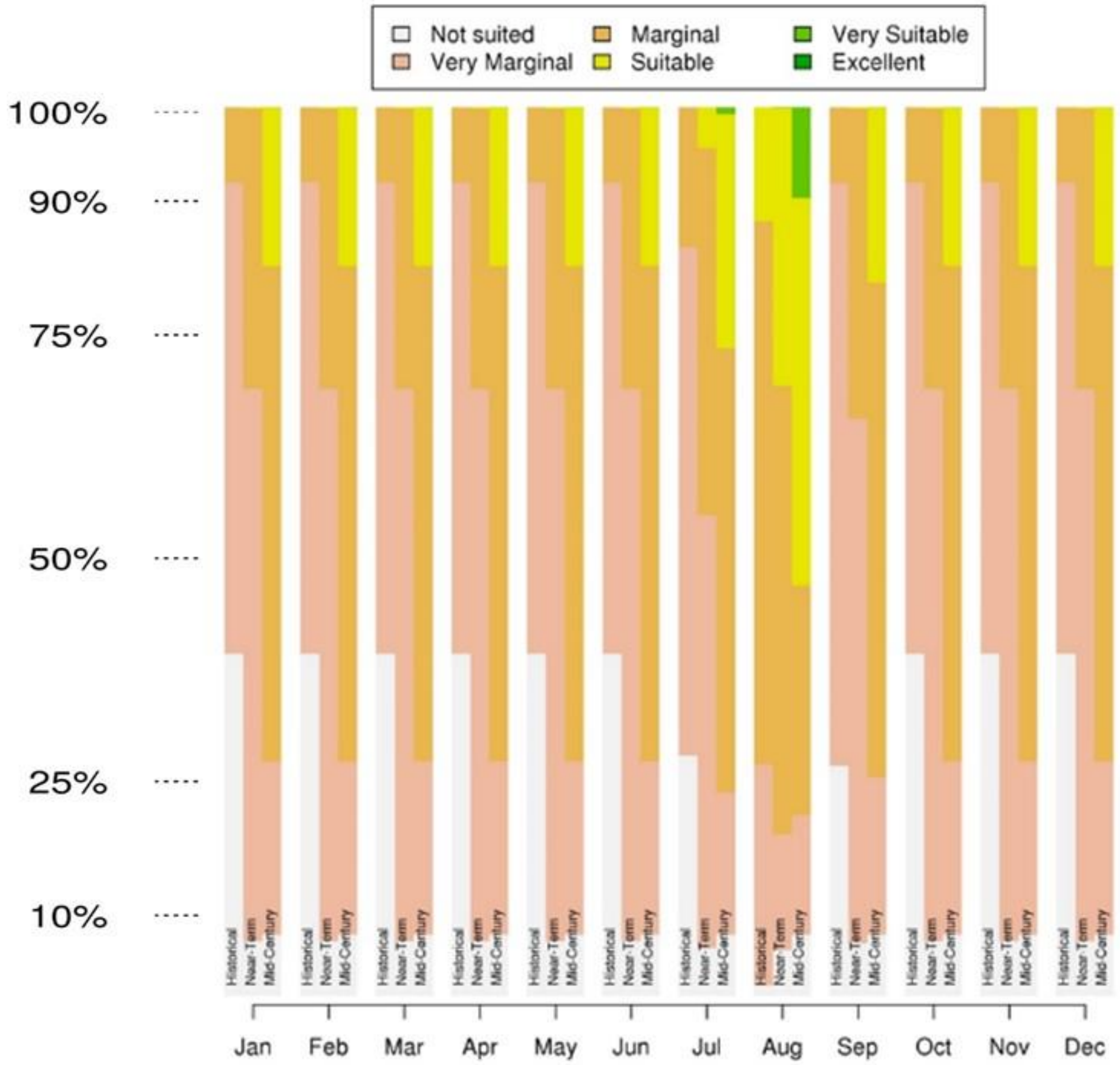


Figure 55. Mean suitability changes of Sugarcane (*Saccharum officinarum*) in Bié

In the baseline scenario, it is predicted that Bié is relatively poorly suited for sugarcane production, where nearly half of the province is 'very marginal' and the remaining areas are not suitable for sugarcane cultivation. As a result of climate change, the suitability of Bié for growing sugarcane is predicted to increase significantly in the period from 'Baseline' to 2050 to the extent that nearly half of the province is predicted to be 'marginal' and the remaining area 'suitable' or 'very marginal'. The total area of Bié which is predicted to be suitable for sugarcane remains generally consistent throughout the rainy season from October to April. The areas of greatest suitability occur in the northern and eastern interiors of the province towards the southern border of Malanje province.

4.4c Impact of climate change on production of sugar cane (*Saccharum officinarum)* in Cuanza Sul

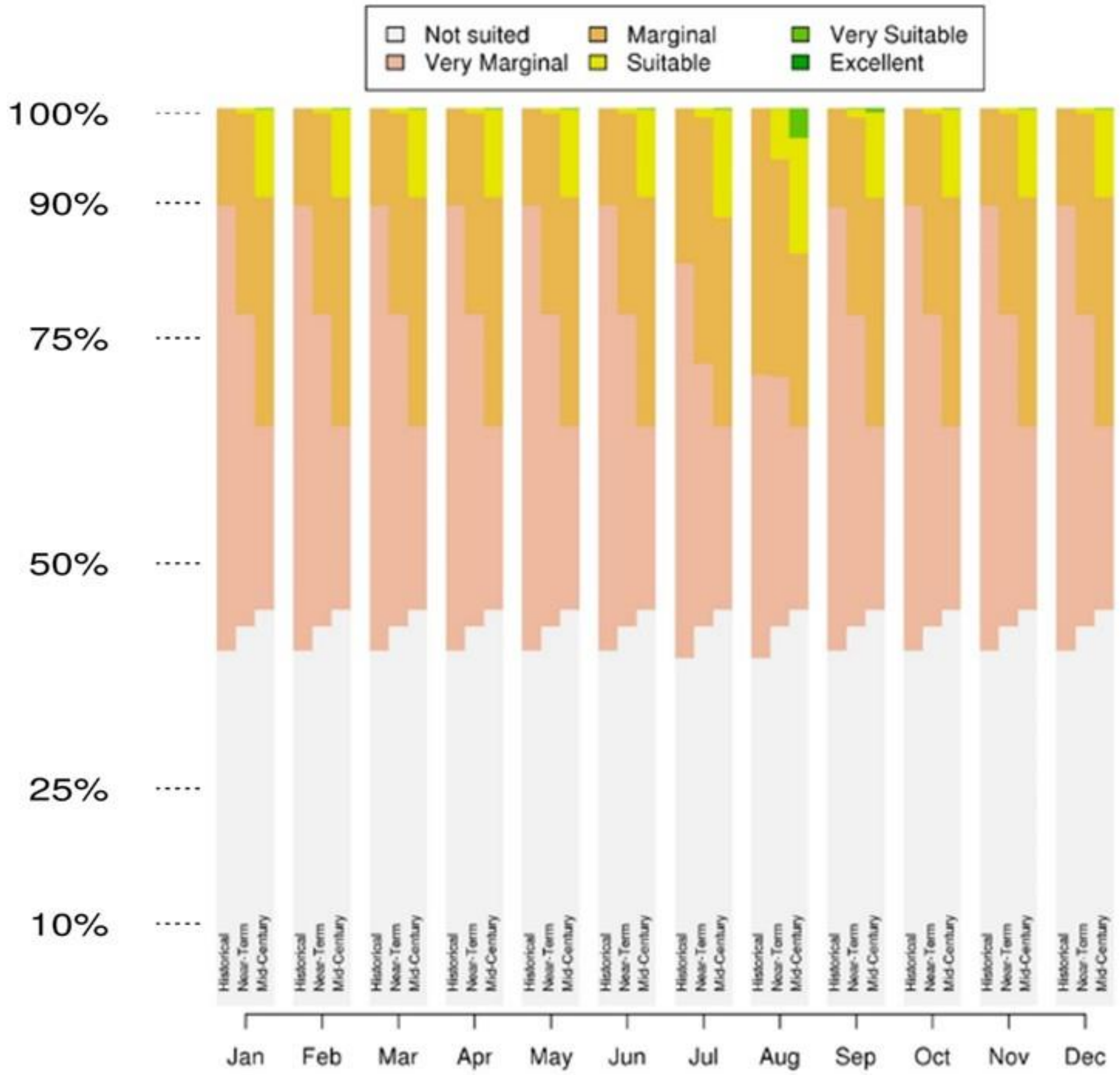


Figure 56. Mean suitability changes of sugarcane (*Saccharum officinarum*) in Cuanza Sul

During the month of October the total area suitable for growing sugarcane is predicted to decrease slightly from 'Baseline' to 'MC 2050' time points. However, despite this small decrease in total area of suitability, simultaneously there are predicted to be increases in the extent of areas considered 'marginal', and 'suitable'. The total area of Cuanza Sul which is predicted to be suitable for sugarcane remains generally consistent throughout the rainy season from October to April. Analysis of mapped anomalies of crop suitability index from Baseline to MC 2050 timepoints indicates that the main improvements in suitability for sugarcane production in Cuanza Sul occurs at the eastern interior of the province along the border with Bié and Malanje provinces.

4.4d Impact of climate change on production of sugar cane (*Saccharum officinarum)* in Huambo

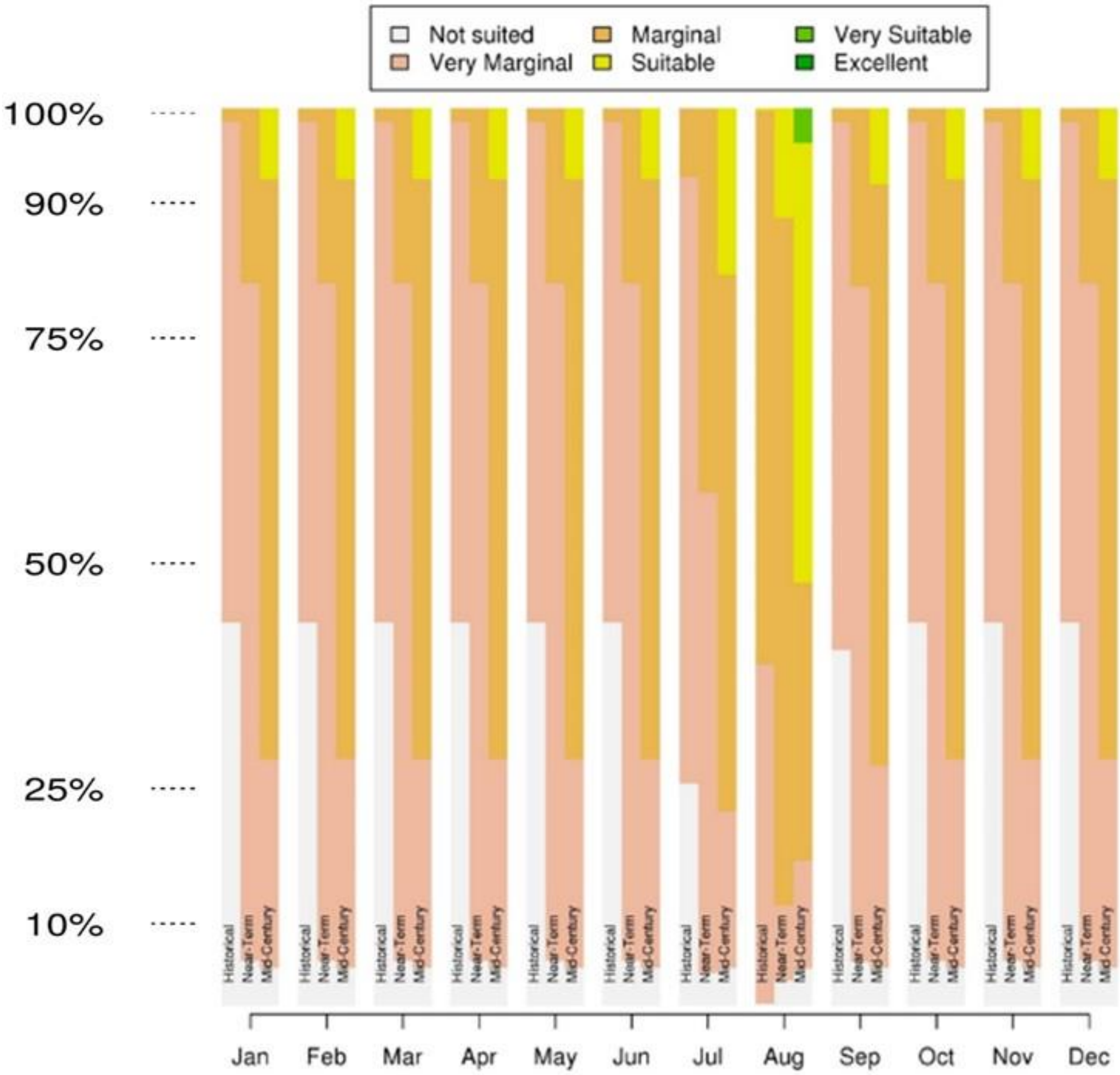


Figure 57. Mean suitability changes of sugarcane (*Saccharum officinarum*) in Huambo

In Huambo province, the total area suitable for production of sugarcane is predicted to increase from 'Baseline' to 'MC 2050' time points. In the baseline scenario, it is predicted that the province is poorly suited to sugarcane, where approximately half of Huambo province is 'very marginal' and the other half unsuitable for sugarcane production. As a result of climate change, the suitability of Huambo for sugarcane production is predicted to increase considerably in the period from 'Baseline' to 2050 to the extent that over half of the province is predicted to be 'marginal' and the remaining area 'suitable' or 'very marginal'. The areas which are predicted to show the greatest increase in suitability for sugarcane production occur at the western interior highlands of the province, adjacent to and overlapping with the borders of Benguela and Cuanza Sul. The total area of Huambo which is predicted to be suitable for sugarcane remains generally consistent throughout the rainy season from October to April.

4.4e Impact of climate change on production of sugar cane (*Saccharum officinarum)* in Huíla

Figure 58. Mean suitability changes of sugarcane (*Saccharum officinarum*) in Huíla

There is predicted to be a large increase in the area of Huíla which can support sugarcane production between the 'baseline' time period and the NT 2030 and MC 2050 time periods, respectively. The baseline scenario suggests that Huíla is virtually entirely unsuitable for sugarcane production, however there is a significant increase in the areas categorised as 'very marginal' and 'marginal' between the 'Baseline' to 'MC 2050' time points. The total area and distribution of suitability is predicted to remain generally consistent between the months of October to April. The month of August has the highest total proportion of suitability for sugarcane productivity. The predicted areas of suitability for sugarcane production in Huíla are restricted to the northern highland interior of the province, whereas the arid southern and western extent of the province are wholly unsuitable.

4.4f Impact of climate change on production of sugar cane (*Saccharum officinarum*) in Malanje

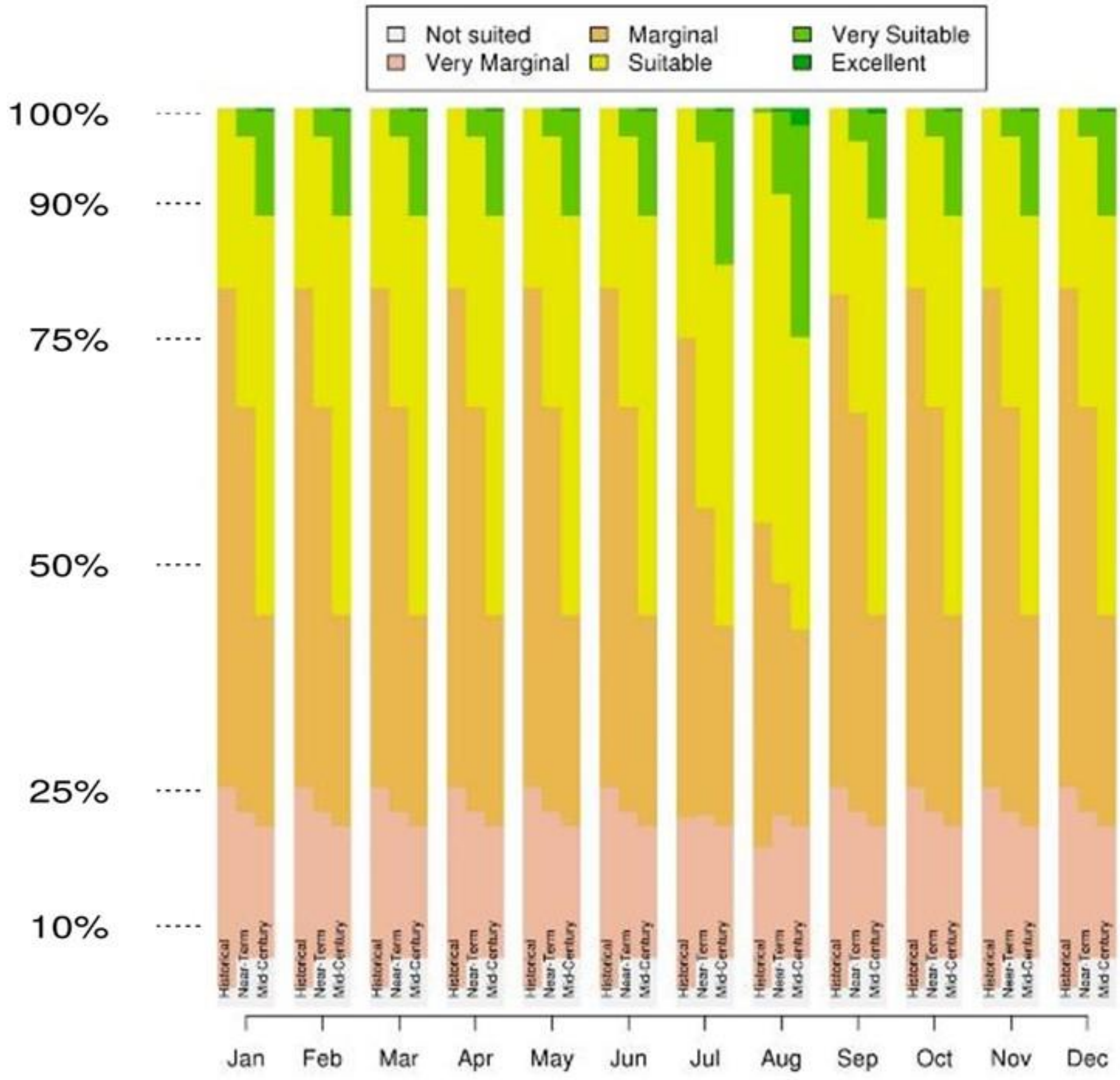


Figure 59. Mean suitability changes of sugarcane (*Saccharum officinarum*) in Malanje

It is predicted that the suitability of Malanje for the cultivation of sugarcane will increase during the period from the baseline scenario to 2050 – in particular, it is predicted that climate change will result in an increase in the extent of areas considered 'excellent', 'very suitable', and 'suitable', respectively. The increased area of the aforementioned categories appears to coincide with a similar reduction in the extent of 'marginal' areas, suggesting that one of the effects of climate change will be to increase the suitability of areas which are considered 'marginal' in the baseline scenario. The aforementioned increases suggest that climate change will increase the suitability of Malanje for sugarcane production. The total area suitable for sugarcane production remains relatively consistent throughout the duration of the rainy season from October to April. It is predicted that the optimal areas for sugarcane production in Malanje will occur in the northern and eastern interior of the country, which is characterised by the highest temperatures and monthly rainfall.

4.5 Impact of climate change on spatial distribution of areas suitable for production of sweet potato (*Ipomoea batatas*)

The figures below summarise the historical (baseline) and future (mid-century 2050) suitability of the six pilot provinces (Bié, Benguela, Cuanza Sul, Huambo, Huíla and Malanje) for production of sweet potato (*Ipomoea batatas*) in the months from September to February. In addition to the baseline and future distribution of crop suitability zones, the figures below also illustrate the anomalies (i.e. the absolute changes in suitability at any given location) between the baseline and future time periods.

In the case of sweet potato, the main effect of climate change is to increase the suitability of the *planalto* area in the six studied provinces. The absolute spatial scale of the changes in suitability for sweet potato production are relatively small, and is not characterised by any marked increases or reductions in spatial extent. Several provinces will benefit from increased suitability for sweet potato production, notably including Malanje, Cuanza Sul and Benguela. In the remaining three provinces, there are small localised changes in crop suitability that are both negative and positive, of which Huíla is the only province which may experience a small reduction in suitable area (in the arid south of the province).

A more subtle change which can be discerned through comparison of mapped anomalies (below) and histogram plots of provincial changes in suitability (described for each province, further below) is an apparent shift in the onset of optimal season for sweet potato production. Comparison of baseline and future (mid-century 2050) projections for the month of October shows very little difference in suitability. However, the later rainfall months of November and December show notable increases in suitability in Benguela, Cuanza Sul, Malanje, and to a lesser extent in Huambo and Bié. This result could be attributable to the predicted increases in monthly precipitation for the latter months of November and December, which may serve to extend the optimal planting/growing season for sweet potato.

The provincial changes in suitability for sweet potato production in the period from Baseline to Mid-Century 2050 are discussed further below.

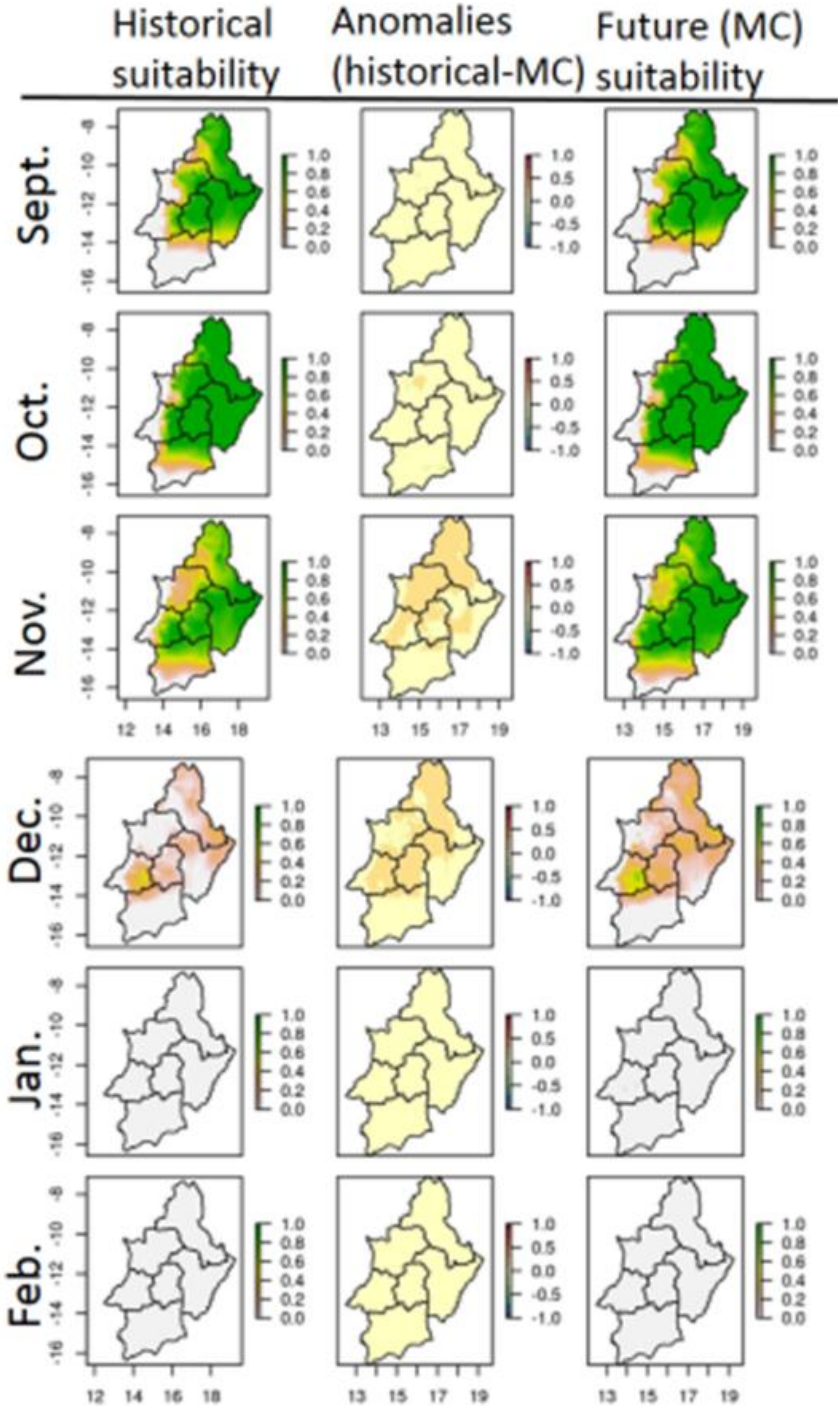


Figure 60. Distribution and changes to suitability for sweet potato production in the 'baseline' (left) and 'mid-century 2050' (right) scenario in the months of September to February

4.5a Impact of climate change on production of sweet potato (*Ipomoea batatas*) in Benguela

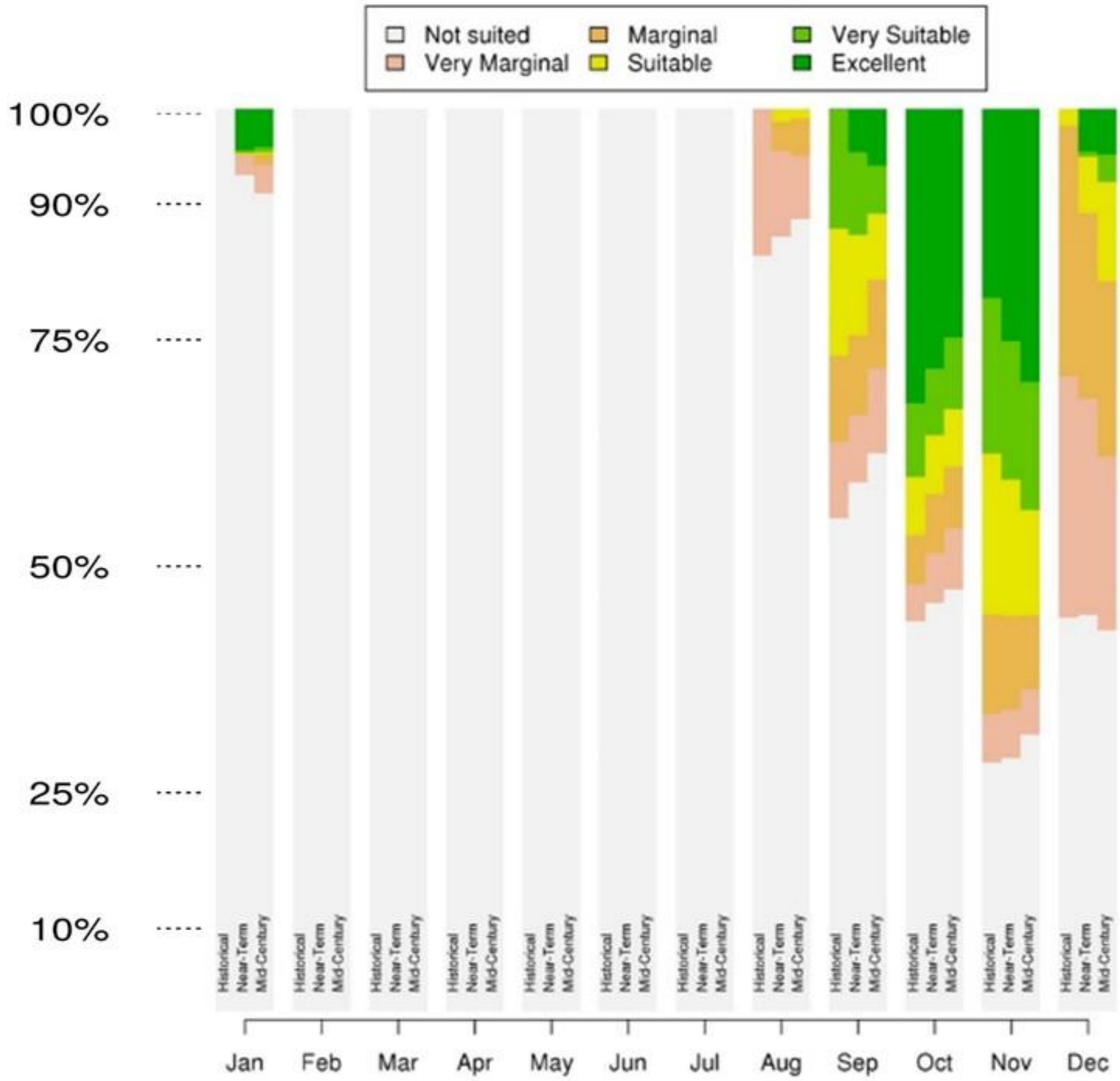


Figure 61. Mean suitability changes of Sweet potato (*Ipomoea batatas*) in Benguela

During the month of October the total area suitable for growing Sweet potato in Benguela is projected to decrease very slightly from 'Baseline' to 'MC 2050' time points in absolute spatial extent, however simultaneously the remaining areas of production are likely to increase in suitability index score. The overall spatial extent of suitability for sweet potato production in Benguela is projected to occur in November, during which month there is projected to be an overall increase in areas considered 'excellent' during the period from Historical to MC 2050 time points. Projected increase in crop suitability for sweet potato could be a result of the projected increase in Tmean from ~22 ('Baseline') to ~25°C ('NT 2030', 'MC 2050'), as sweet potato has an optimum growth temperature ranging from ~18 to ~28 °C. The result could also potentially be attributable to increased monthly rainfall in the months of November and December, which could serve to extend the effective planting date or growing season for sweet potato (where sweet potato has a growing period of 80-170 days). Based on EcoCrop analyses, sweet potato crops can be potentially be established in Benguela at any time between the months of August to January, with the period of greatest suitability occurring in November.

4.5b Impact of climate change on production of sweet potato (*Ipomoea batatas*) in Bié

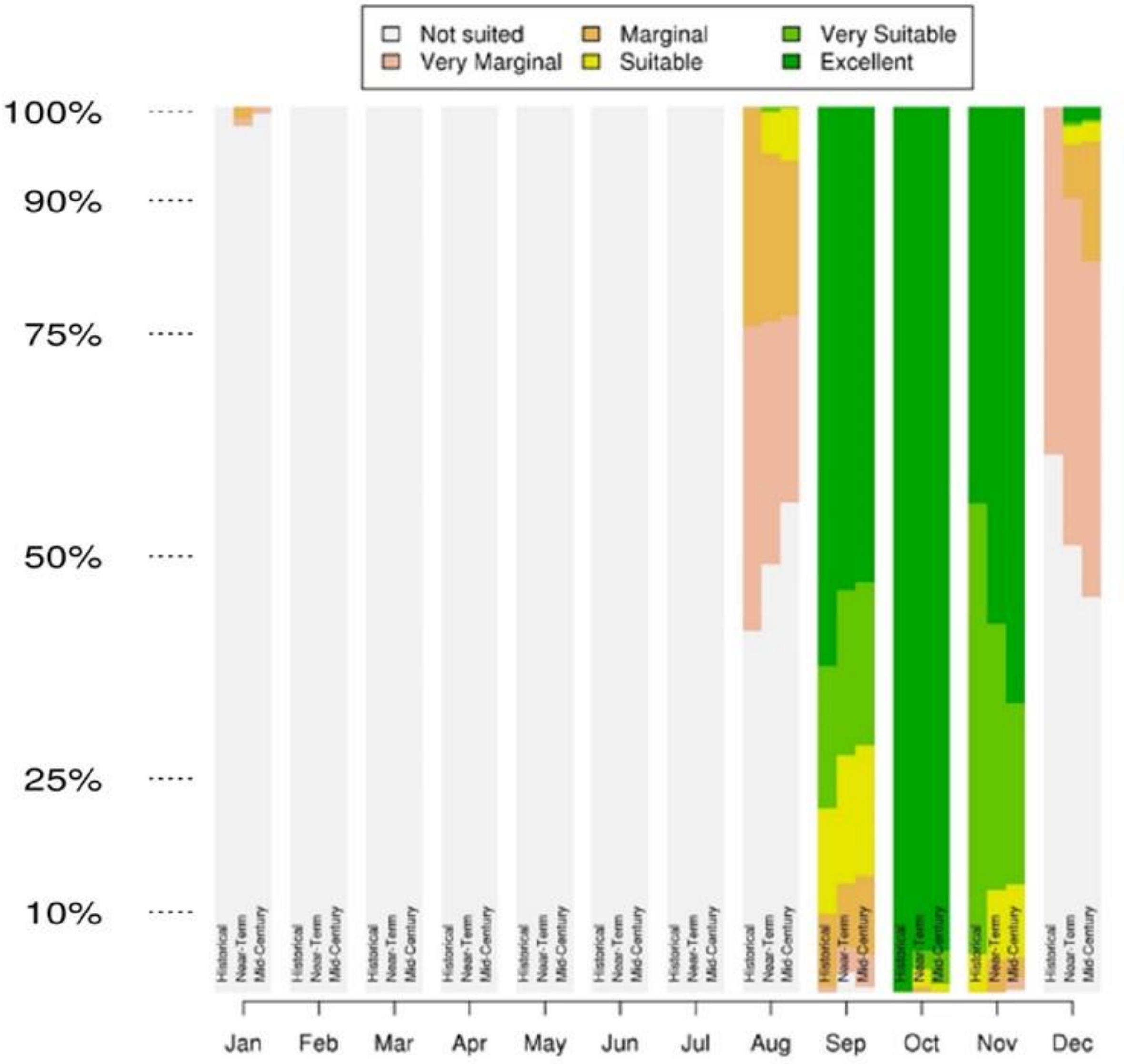


Figure 62. Mean suitability changes of Sweet potato (*Ipomoea batatas*) in Bié

In general, the suitability of Bié for growing sweet potato is predicted to remain relatively consistent during October despite the predicted changes in climate from 'Baseline' to 'MC 2050' time points. During the month of October, the entire province is predicted to remain 'excellent' for sweet potato cultivation consistently throughout the period from 'Baseline' to 2050. The total extent of area suitable for sweet potato production in Bié is greatest during the summer months from September to November. Similar to the effect observed in other provinces, the primary effect of climate change on sweet potato production in Bié is to delay the optimum growing season by approximately a month, where the months of November and December are predicted to become increasingly suitable for sweet potato in the period from 'Baseline' to 'MC 2050' time points.

4.5c Impact of climate change on production of sweet potato (*Ipomoea batatas*) in Cuanza Sul

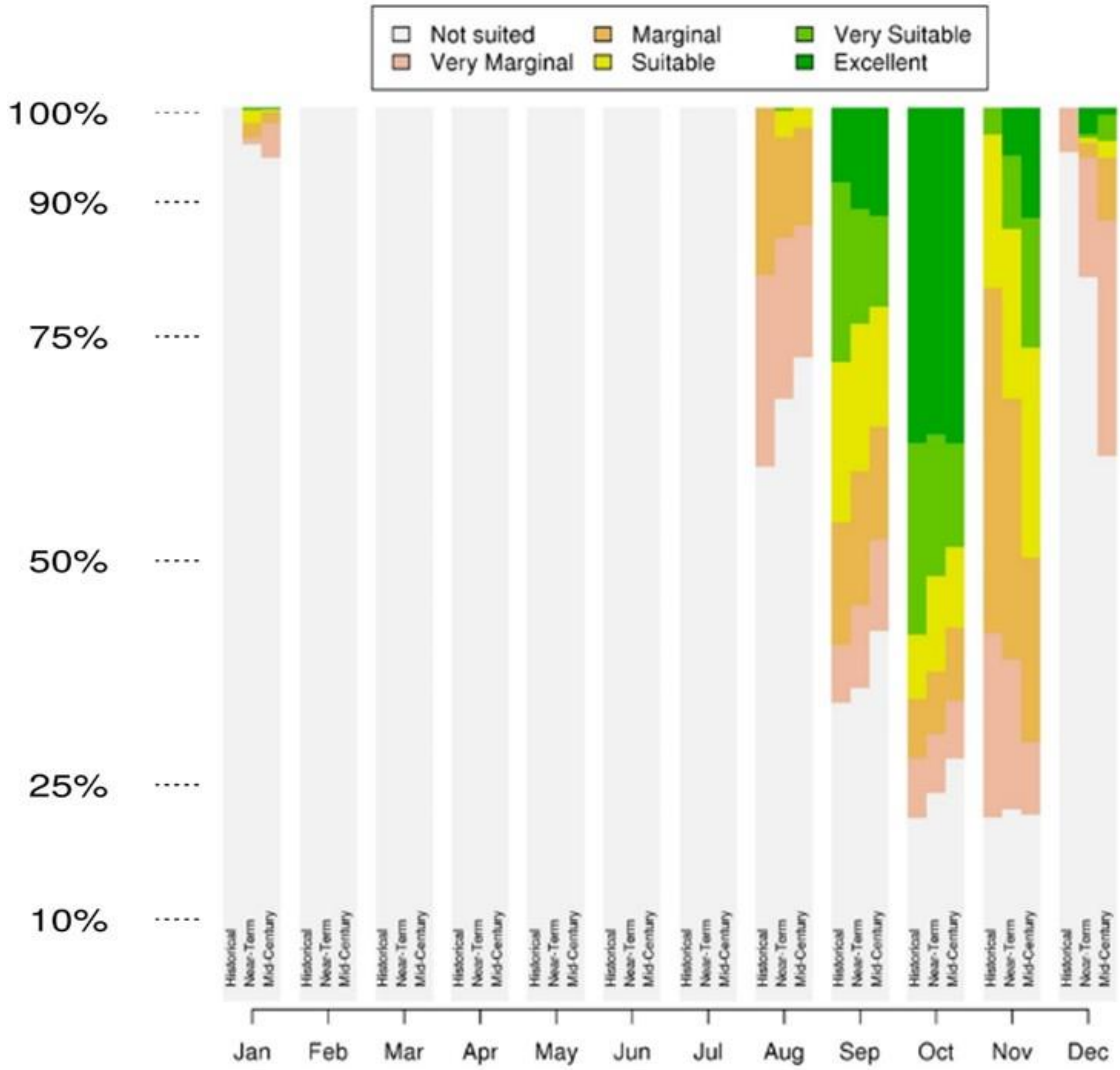


Figure 63. Mean suitability changes of Sweet potato (*Ipomoea batatas*) in Cuanza Sul

In general, the suitability of Cuanza Sul for growing sweet potato is predicted to remain relatively consistent during October despite the predicted changes in climate from 'Baseline' to 'MC 2050' time points, where EcoCrop analyses predict only minor decreases in the total area suitable for growing sweet potato in Cuanza Sul. Similar to Benguela, Bié and Malanje, the months of November and December are predicted to be increasingly suitable sweet potato production and are characterised by a trend towards increased extent of areas considered 'excellent' and 'very suitable' between 'Baseline' and 'MC 2050' projections. The increase in suitability during the month of November could be attributed to an increase in Tmean from ~23 °C ('Baseline') to ~24 °C (NT 2030, MC 2050), as sweet potato has an optimum growth temperature between ~18 to ~28 °C. Similar to the effect observed in other provinces, the primary effect of climate change on sweet potato production in Cuanza Sul is to delay or extend the optimum growing season by approximately a month, where the months of November and December are predicted to become increasingly suitable for sweet potato in the period from 'Baseline' to 'MC 2050' time points.

4.5d Impact of climate change on production of sweet potato (*Ipomoea batatas*) in Huambo

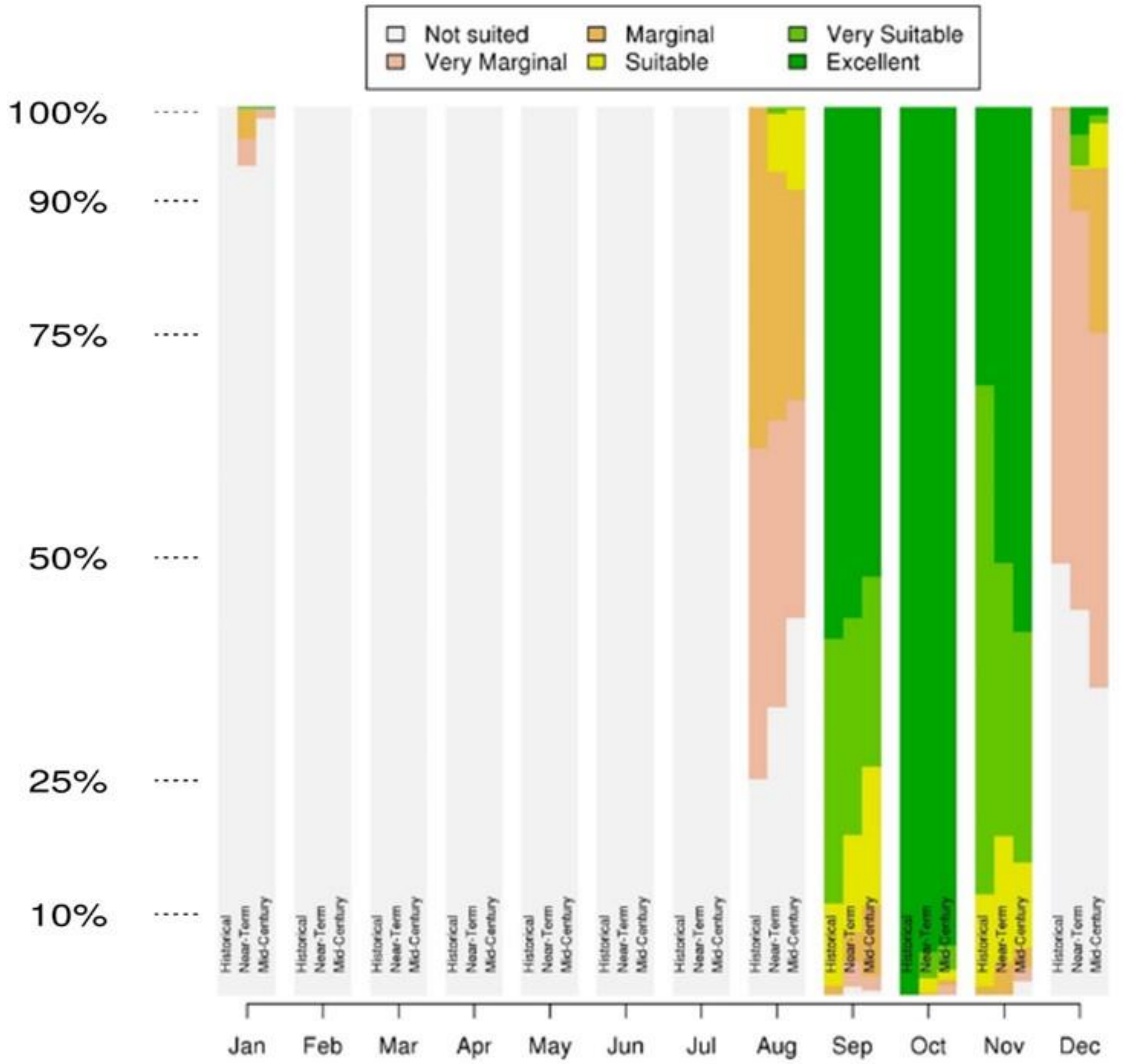


Figure 64. Mean suitability changes of Sweet potato (*Ipomoea batatas*) in Huambo

In general, the suitability of Huambo for sweet potato production is predicted to remain relatively consistent despite the predicted changes in climate from 'Baseline' to 'MC 2050' timepoints. During the month of October, a large proportion of land is considered 'excellent' for 'Baseline', 'NT 2030', and 'MC 2050' predictions. However there is a slight decrease in land area considered 'suitable' from 'Baseline' to 'NT 2030', and 'NT 2030' to 'MC 2050'. The total spatial area of suitability for growing sweet potato in Huambo is greatest during the summer months from September to November, after which suitability declines sharply from December onwards. Similar to the effect observed in other provinces, the primary effect of climate change on sweet potato production in Huambo is to delay or extend the optimum growing season by approximately a month, where the months of November and December are predicted to become increasingly suitable for sweet potato in the period from 'Baseline' to 'MC 2050' time points.

4.5e Impact of climate change on production of sweet potato (*Ipomoea batatas*) in Huíla

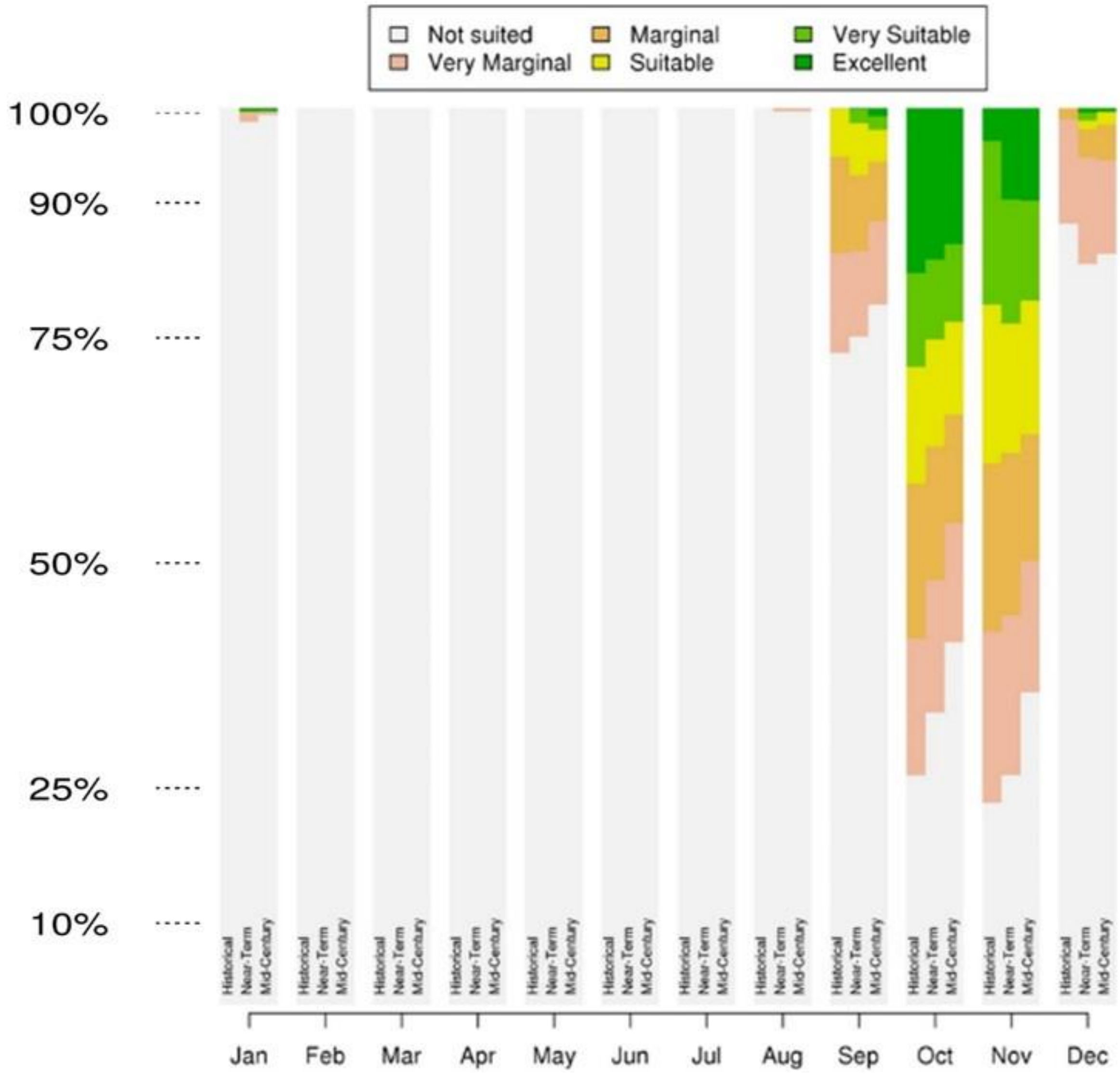


Figure 64. Mean suitability changes of sweet potato (*Ipomoea batatas*) in Huíla

The effect of climate change on production of sweet potato in Huíla is the most negative of the six provinces assessed. Huíla is the only province which is anticipated to under a net reduction in suitability for sweet potato production. The maps presented in Figure 60 indicate that the suitable range for sweet potato production is likely to move northwards in Huíla province, and therefore sweet potato is likely to become increasingly unsuitable for the arid south and interior of Huíla in the period from Baseline to MC 2050 timepoints.

During the month of October the total area suitable for growing sweet potato in Huíla is predicted to decrease from 'Baseline' to 'MC 2050' time points, with small reductions in each category of crop suitability but most particularly a reduction in the total extent of areas categorised as 'excellent'. The month of November has the greatest proportion of area suitable for sweet potato production in Huíla and illustrates an increase in the extent of areas considered to be 'excellent' and 'highly suitable', while simultaneously the overall area of suitability for sweet potato production is predicted to decrease in extent.

4.5f Impact of climate change on production of sweet potato (*Ipomoea batatas*) in Malanje

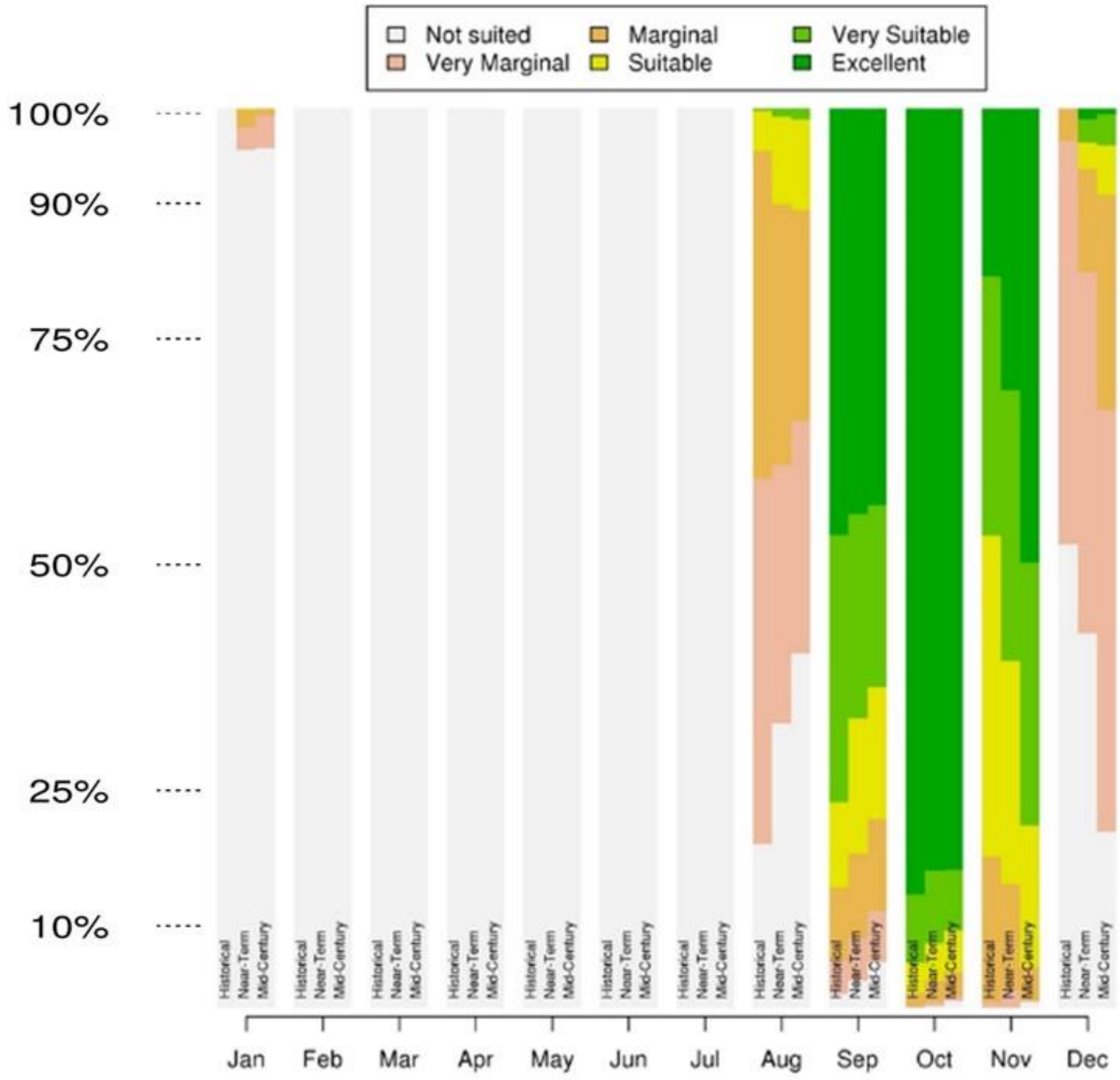


Figure 65. Mean suitability changes of Sweet potato (*Ipomoea batatas*) in Malanje

In general there are predicted to be relatively minor changes in the total area of suitability for Malanje for production of sweet potato in the month of October. Much of the total provincial area is categorized as 'excellent' for sweet potato production irrespective of the effects of climate change - Ecocrop analysis predicts only a minor decrease in the extent of 'excellent' areas from 'Baseline' to 'MC 2050'. While the distribution of crop suitability appears to remain consistent at the onset of the rainy season in October during the period from 'Baseline' to 'MC 2050' timepoints, the month of November indicates a significant increase in the extent of 'excellent' and 'very suitable' areas relative to the baseline scenario. This result suggests that, while the suitability of October for sweet potato production remains relatively unchanged as a result of climate change, farmers may benefit from an extension of the effective planting/growing season in the period from 'Baseline' to 'MC 2050'.

4.6. Impact of climate change on spatial distribution of areas suitable for production of banana (*Musa acuminata*)

The figures below summarise the historical (baseline) and future (mid-century 2050) suitability of the six pilot provinces (Bié, Benguela, Cuanza Sul, Huambo, Huíla and Malanje) for production of Cavendish banana (*M. acuminata,* AAA genome Cavendish variety) in the months from September to February. In addition to the baseline and future distribution of crop suitability zones, the figures below also illustrate the anomalies (i.e. the absolute changes in suitability at any given location) between the baseline and future time periods.

In the case of *M. acuminata* Cavendish banana, climate change is predicted to result in some small localised improvements in crop suitability. In general, the overall spatial extent of suitability is not predicted to increase or decrease notably as a result of climate change in the period up to 'MC 2050' – the only exception to this is Huíla province, which is the least suited to banana cultivation in the baseline scenario and which is predicted to experience a small reduction in total suitable area as a result of climate change. Most notably, the existing areas of suitability in the provinces of Malanje, Bié and Huambo are predicted to increase in suitability index score in the period up to 'MC 2050', which may be attributable to the predicted increases in Tmean and monthly precipitation in those provinces.

The provincial changes in suitability for production of Cavendish banana (*M. acuminata*) in the period from Baseline to Mid-Century 2050 are discussed further below.

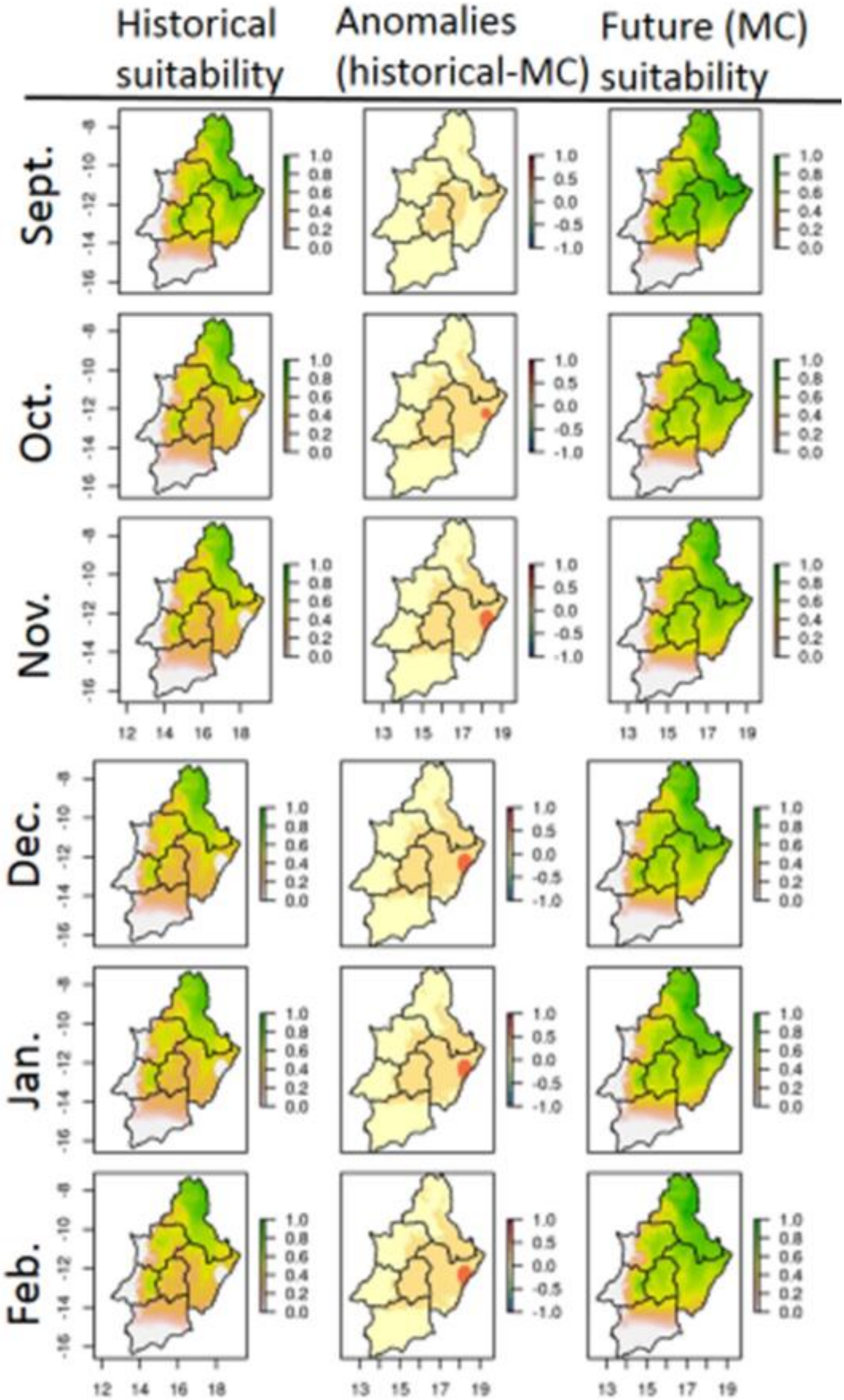


Figure 66. Distribution and changes to suitability for Cavendish banana (*M. acuminata*) production in the 'baseline' (left) and 'mid-century 2050' (right) scenario in the months of September to February

4.6a Impact of climate change on production of Cavendish banana (*M. acuminata*) in Benguela

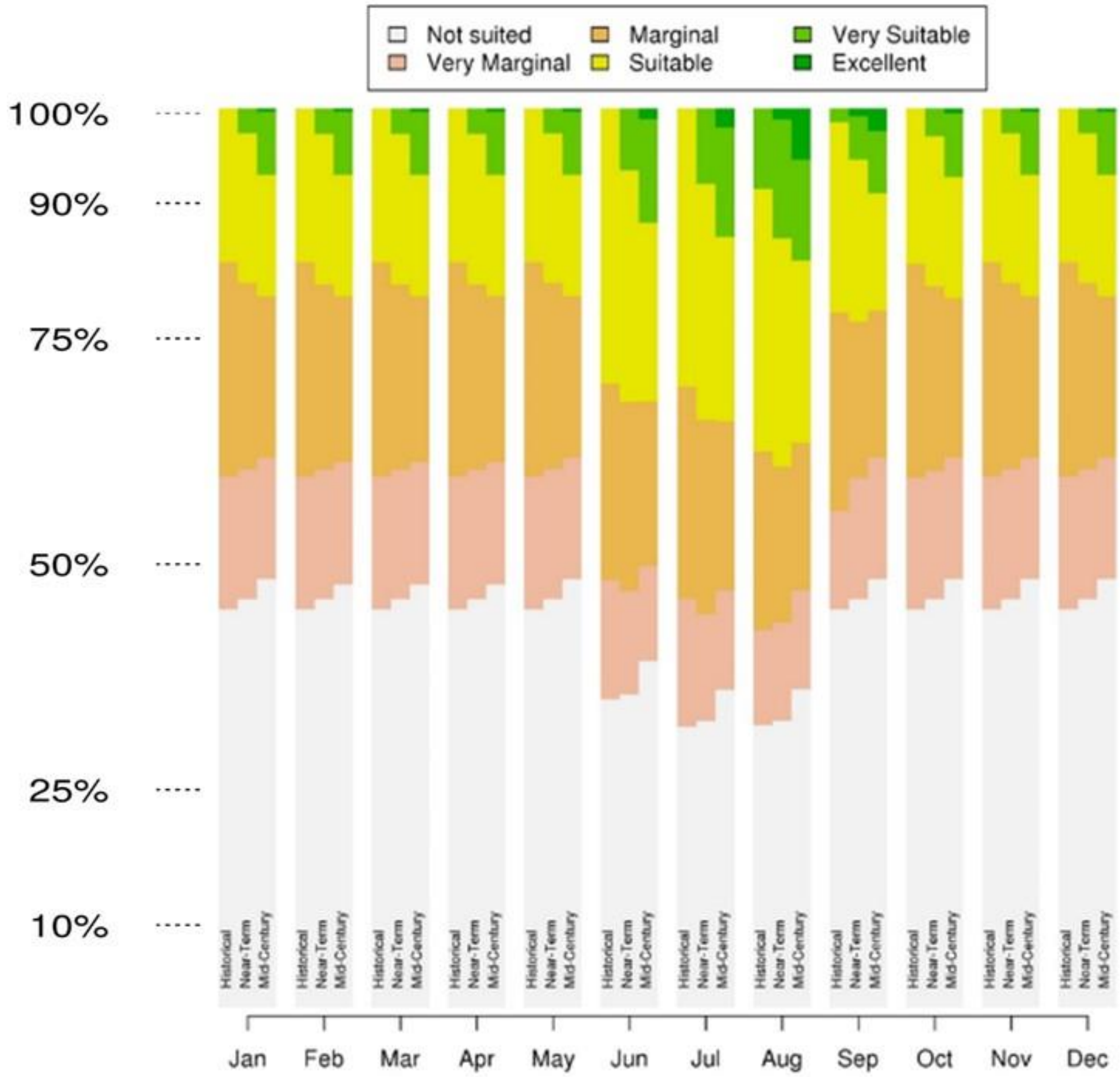


Figure 67. Mean suitability changes of Cavendish banana (*Musa acuminata*, AAA Cavendish variety) in Benguela

There is an overall general decrease in the total area of suitability for production of Banana (*Musa acuminata*, AAA Cavendish variety) in Benguela between 'Baseline' and 'MC 2050' time points. However, despite this very small overall decline in M. acuminata-suitable areas, it is also predicted that there will be small increases in the extent of areas classified as 'excellent', 'very suitable' and 'suitable'. The spatial and total area of suitability for M. acuminata remains relatively consistent throughout the duration of the rainy season from October to April. The total extent of M. acuminata-suitable areas is largest during the month of August, during which month there is predicted to be an increase in the extent of areas considered to be 'excellent' between the 'Historical' and 'MC 2050' projections. The small areas of Benguela which are predicted to undergo changes in suitability index score are confined to the eastern interior highlands of the province, adjacent to the border of Huambo province.

4.6b Impact of climate change on production of Cavendish banana (*M. acuminata*) in Bié

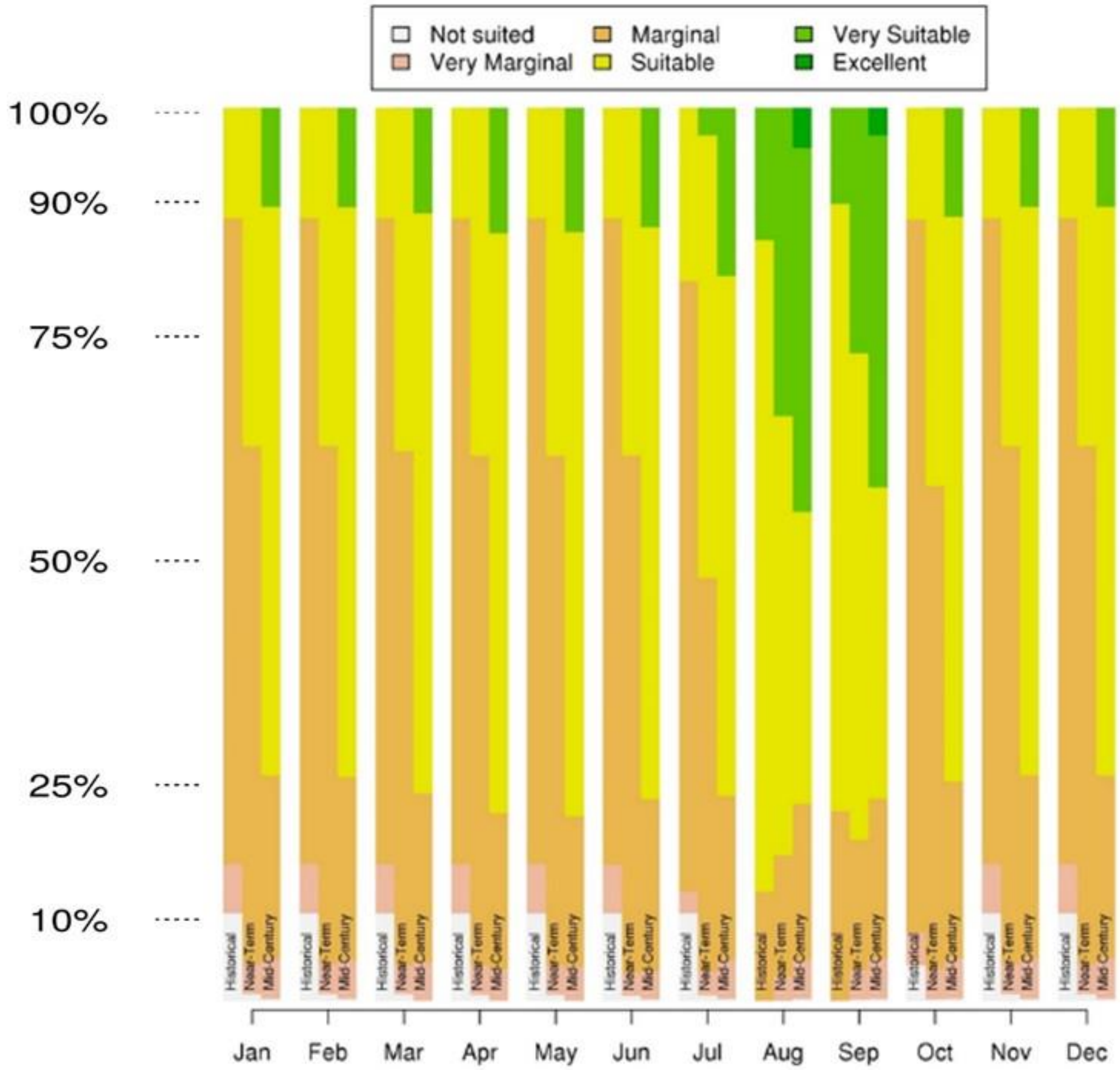


Figure 68. Mean suitability changes of Banana (*Musa acuminata*, AAA Cavendish variety) in Bié

The total spatial area for production of Cavendish banana in Bié predicts a slight increase in the extent of suitable area from 'Baseline' to 'MC 2050' predictions. However while there is little change in total spatial area, there are positive changes in the relative distribution of several categories of suitability for banana production across the entire extent of the province. During the onset of the rainy season in October there is predicted to be increases in the extent of 'very suitable' and 'suitable' areas for the production of Cavendish banana. The net increases in the aforementioned categories appear to coincide with net reductions in the predicted extent of 'marginal' areas, which suggests that climate change will increase the overall suitability of Bié for banana production by improving growing conditions in 'marginal' areas in the baseline scenario.

4.6c Impact of climate change on production of Cavendish banana (*M. acuminata*) in Cuanza Sul

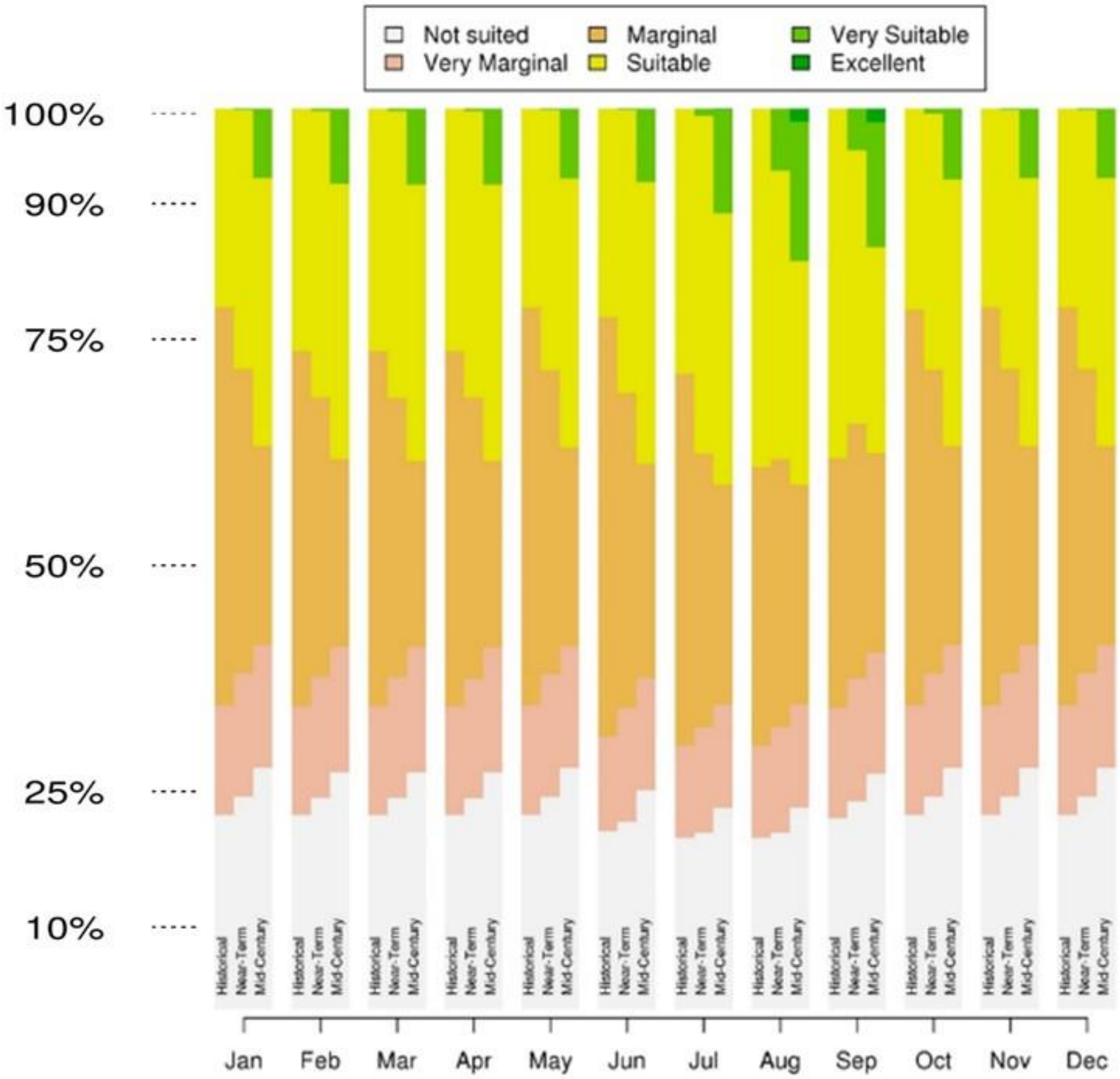


Figure 69. Mean suitability changes of Banana (*Musa acuminata*, AAA Cavendish variety) in Cuanza Sul

There is a general decrease in the total area which is categorised as suitable for production of Banana (*Musa acuminata*, AAA Cavendish variety) in Cuanza Sul between 'Baseline' and 'MC 2050' time points. However, despite the overall decline in banana-suitable areas, it is also predicted that there will be an increase in the extent of areas considered 'excellent', 'very suitable and 'suitable' during the month of October. Similar to Benguela, the total area of suitability for M. acuminate remains relatively consistent throughout the duration of the rainy season from October to April in Cuanza Sul. The total extent of M. acuminata-suitable areas is largest during the month of August, during which month there is predicted to be an increase in the extent of areas considered to be 'excellent' between the 'Historical' and 'MC 2050' projections. The areas of Cuanza Sul which are predicted to benefit from increased suitability for Cavendish banana (*M. acuminata*) suitability are mainly confined to the eastern interior highlands of the province, adjacent to the provincial boundaries of Huambo and Bié provinces.

4.6d Impact of climate change on production of Cavendish banana (*M. acuminata*) in Huambo

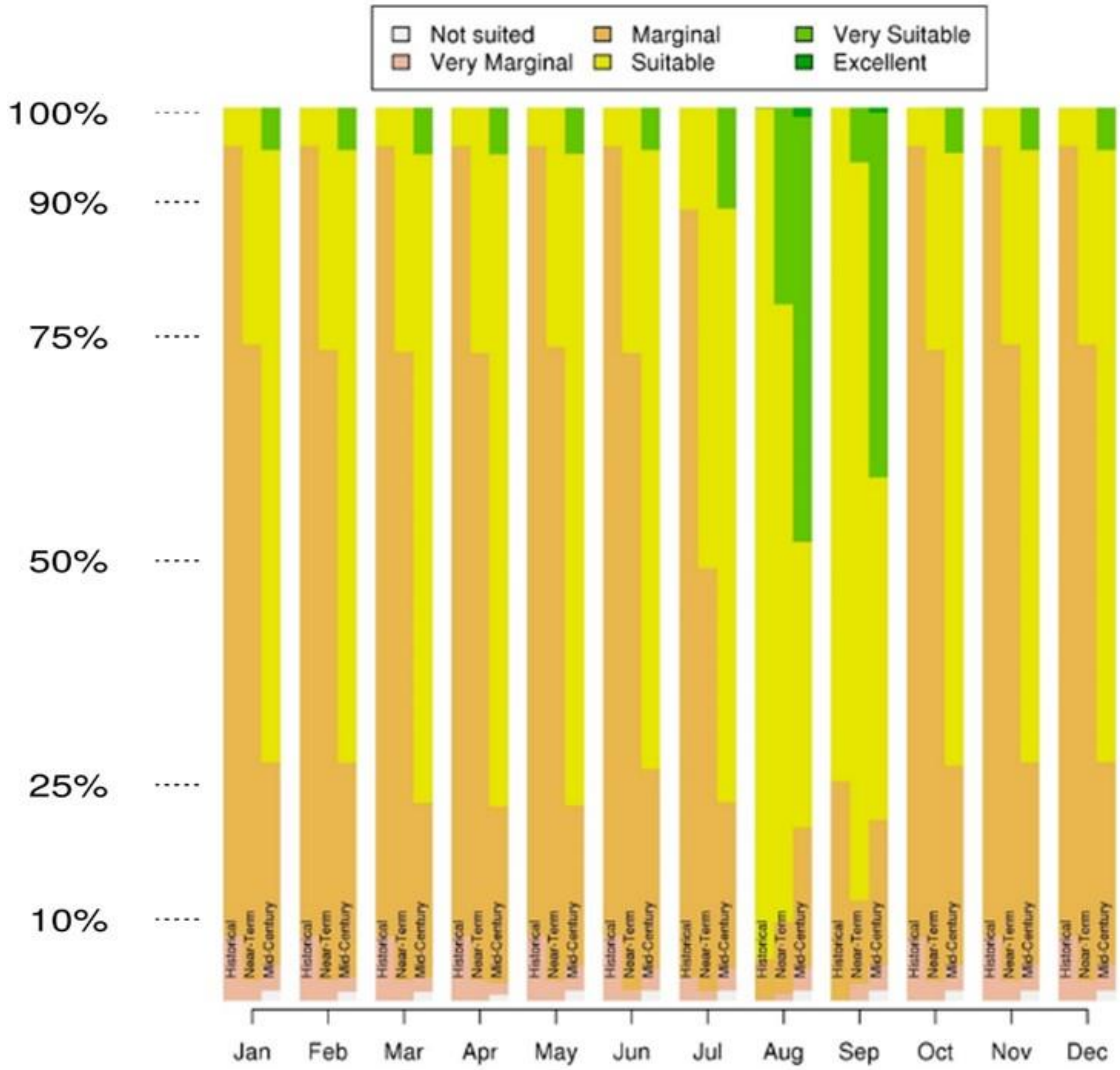


Figure 70. Mean suitability changes of Banana (*Musa acuminata*, AAA Cavendish variety) in Huambo

Overall, there are no major changes in the total spatial area of Huambo which can be considered suitable for Cavendish banana production. However, while the total spatial area remains consistent, there are changes in the relative distribution of several categories of suitability for banana production. During the month of October there is predicted to be an increase in the extent of areas considered 'very suitable' and 'suitable' for *M. acuminata* during the period from 'Baseline' to 'MC 2050' time points. The net increases in the above-mentioned categories appear to coincide with net reductions in the predicted extent of 'marginal' areas, which suggests that climate change will increase the overall suitability of Huambo for production of *M. acuminata* by improving growing conditions in areas which considered to be 'marginal' in the baseline scenario. The total area of Huambo, which is predicted to be suitable for *M. acuminata,* AAA Cavendish remains generally consistent throughout the rainy season from October to April. The month of August illustrates the greatest increase in extent of land area considered 'very suitable'.

4.6e Impact of climate change on production of Cavendish banana (*M. acuminata*) in Huíla

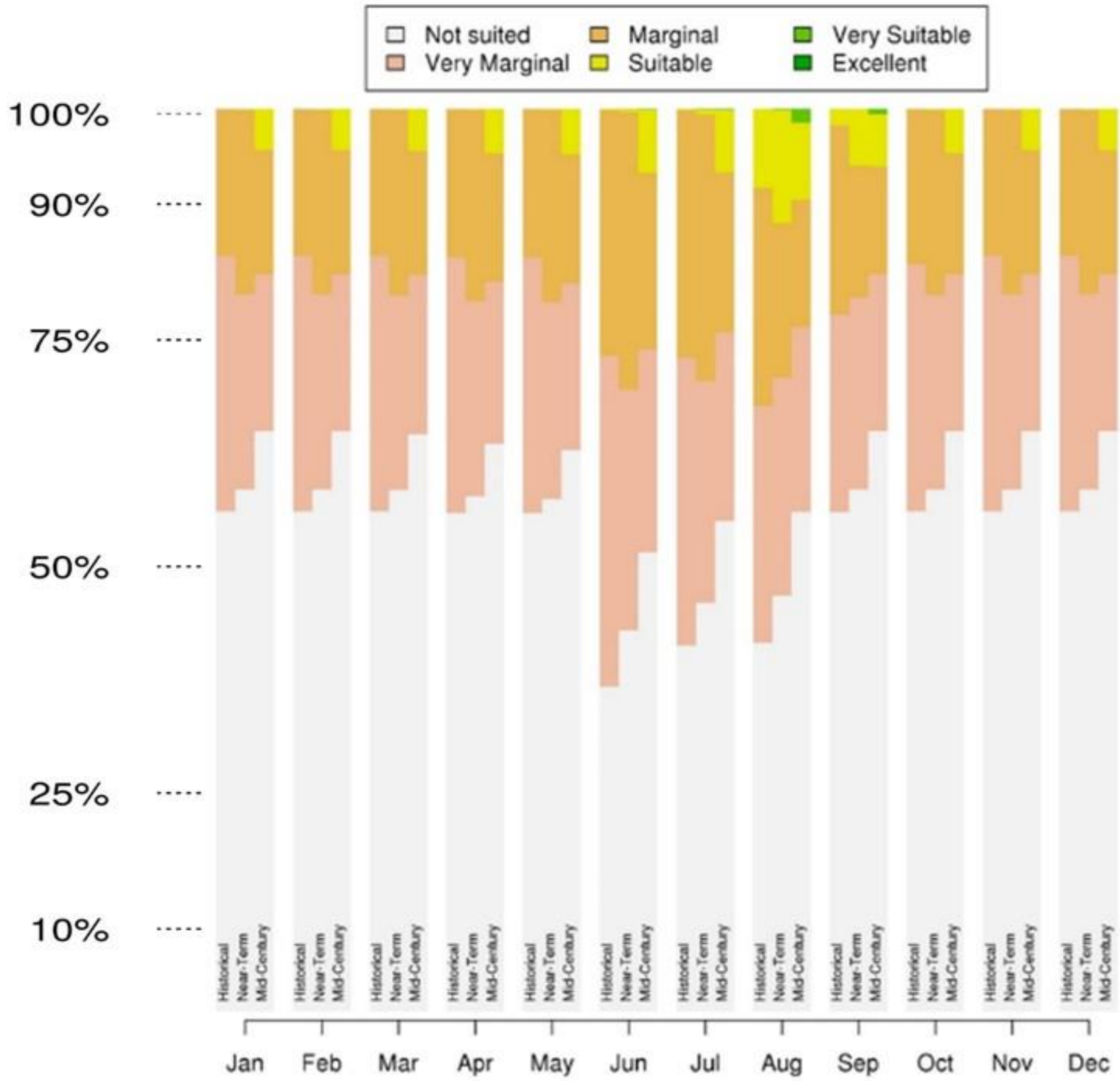


Figure 70. Mean suitability changes of Banana (*Musa acuminata*, AAA Cavendish variety) in Huíla

There is a general decrease in the total area of suitability for production of Banana (*Musa acuminata*, AAA Cavendish variety) in Huíla between the 'Baseline' and 'MC 2050' time points. However, despite the overall decline in *M. acuminata*-suitable areas, it is also predicted that there will be small increases in the extent of areas considered 'suitable'. The spatial and total area of suitability of suitability for *M. acuminata* remains relatively consistent throughout the duration of the growing season from October to April. The total extent of *M. acuminata*-suitable areas is largest during the month of June, during which month there is predicted to be an increase in the extent of areas considered 'very suitable' and 'suitable'. The predicted areas of suitability for Cavendish banana production in Huíla are restricted to the northern highland interior of the province, whereas the arid southern and western extent of the province are wholly unsuitable.

4.6f Impact of climate change on production of Cavendish banana (*M. acuminata*) in Malanje

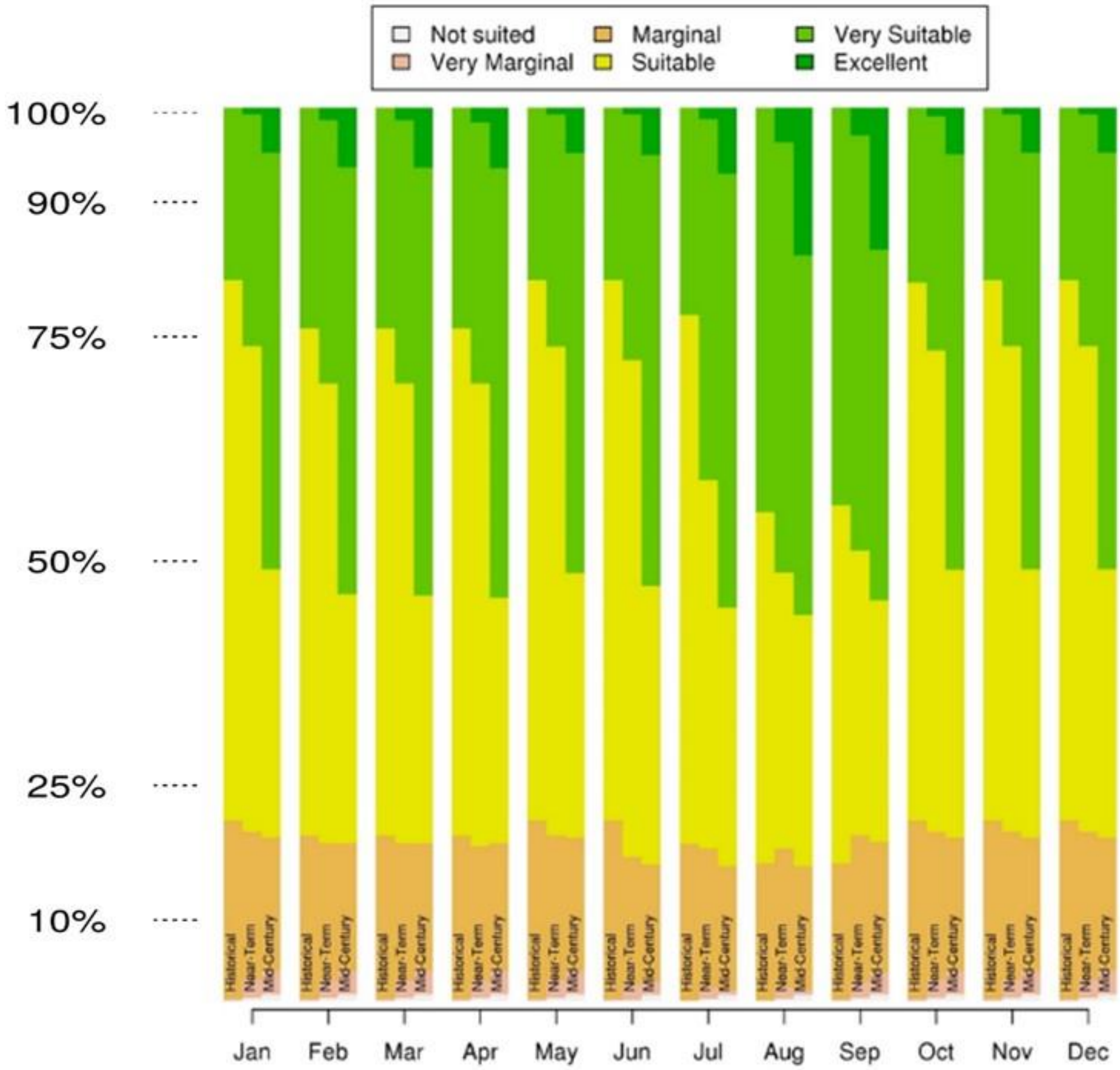


Figure 71. Mean suitability changes of Banana (*Musa acuminata*, AAA Cavendish variety) in Malanje

In, general there are predicted to be very little changes in the total provincial area suitable for Banana (*Musa acuminata*, AAA Cavendish variety) in Malanje from 'Baseline' to 'MC 2050' time points. Ecocrop analyses predict a considerable increase in the extent of 'very suitable' areas for cultivation of Cavendish banana, which occurs simultaneously to a decrease in 'suitable' areas, between 'Baseline' and 'MC 2050' time points for October. The projected increase in 'very suitable' areas and decrease in 'suitable' areas indicate that climate change will increase the overall suitability of Malanje for banana cultivation. It is predicted that the optimal areas for banana in Malanje will occur in the northern and eastern interior of the country, which is characterised by the highest temperatures and monthly rainfall.

4.7. Impact of climate change on spatial distribution of areas suitable for production of plantain banana (M. balbisiana)

The figures below summarise the historical (baseline) and future (mid-century 2050) suitability of the six pilot provinces (Bié, Benguela, Cuanza Sul, Huambo, Huíla and Malanje) for production of plantain banana (*M. balbisiana*) in the months from September to February. In addition to the baseline and future distribution of crop suitability zones, the figures below also illustrate the anomalies (i.e. the absolute changes in suitability at any given location) between the baseline and future time periods.

In the baseline scenario, plantain banana (*M. balbisiana*) is predicted to have a small range of suitability which is confined to a narrow extent of the planalto uplands in Cuanza Sul and Benguela provinces, and another small isolated area in Malanje. The remaining three provinces are considered to be entirely unsuitable for plantain production. The main effect of climate change is to expand the range, and improve the suitability, of the existing areas in Benguela, Cuanza Sul and Malanje provinces, while the remaining provinces are expected to remain unsuitable for production of *M. balbisiana*. The provincial changes in suitability for production of plantain banana (*M. balbisiana*) in the period from 'Baseline' to 'Mid-Century 2050' are discussed further below.

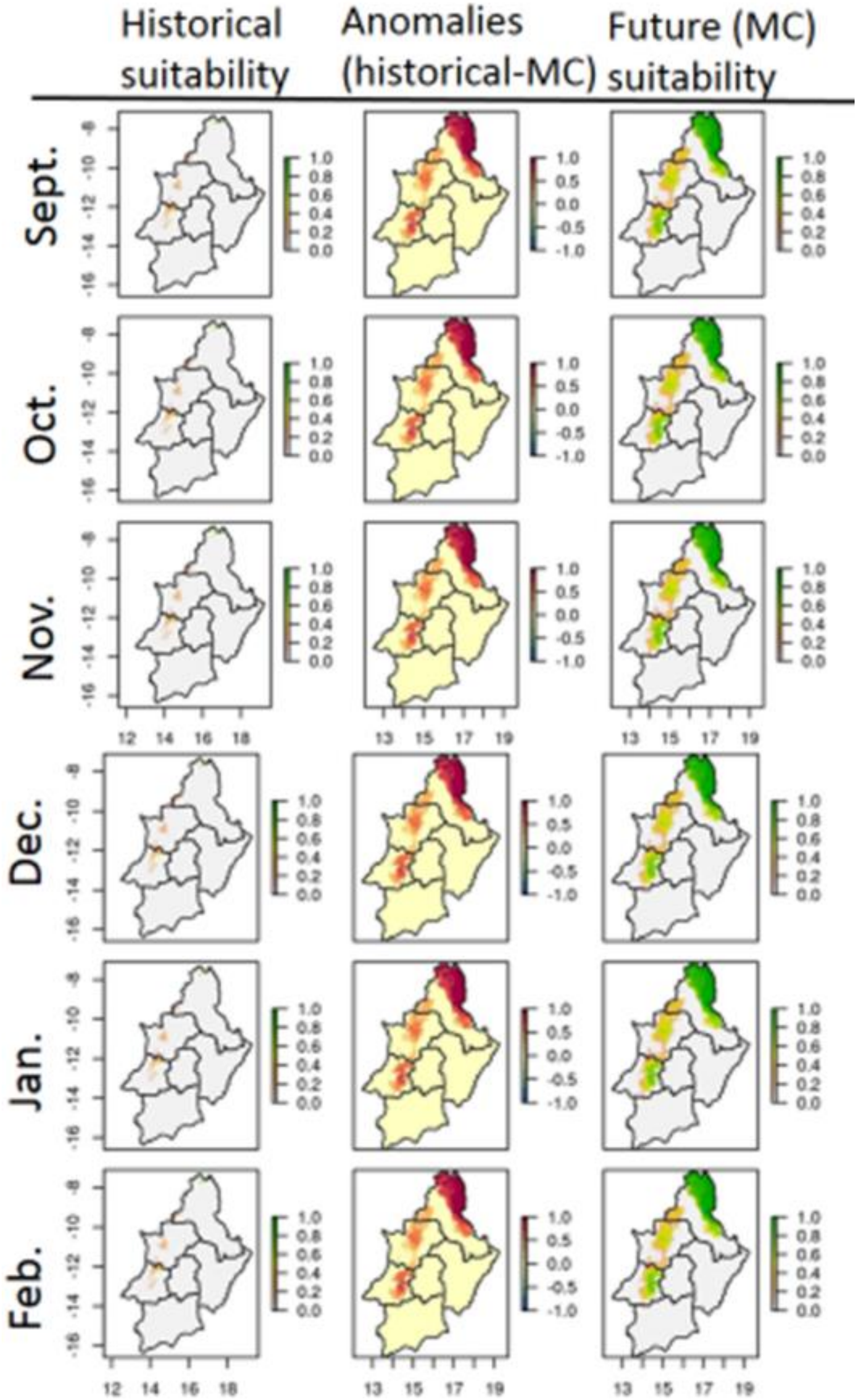


Figure 72. Distribution and changes to suitability for plantain banana (*M. balbisiana*) production in the 'baseline' (left) and 'mid-century 2050' (right) scenario in the months of September to February

4.7a Impact of climate change on production of plantain banana (*M. balbisiana)* in Benguela

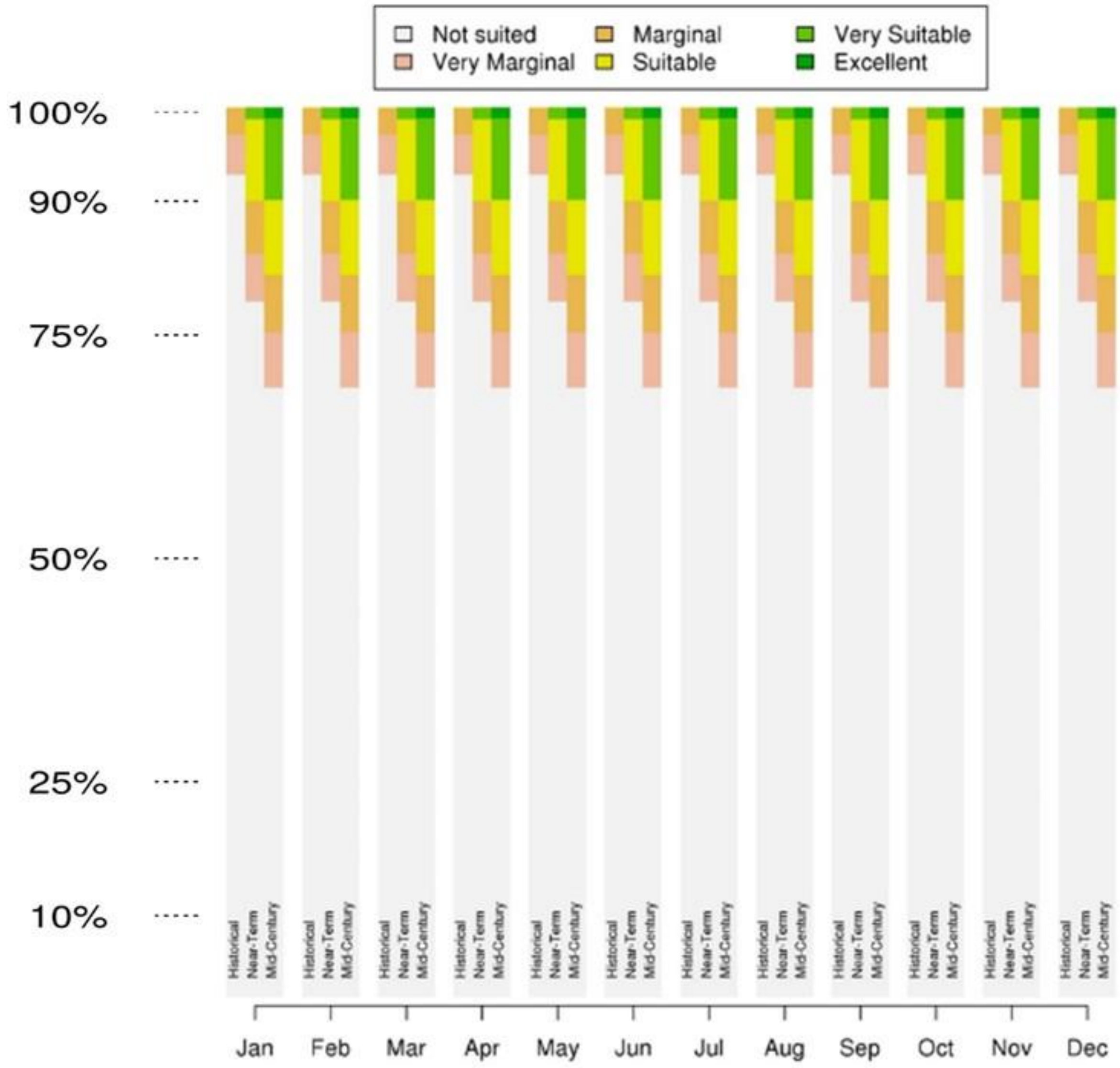


Figure 73. Mean suitability changes of Banana (Musa balbisiana, BB cooking plantain) in Benguela

The total area for Banana (Musa balbisiana, BB cooking plantain) productivity shows an increasing suitability trend from 'Baseline' to 'MC 2050' time points for the month of October. This trend is consistent across all 12 months of the year. The total provincial increase in suitability for M. balbisiana primarily occurs as an increase in the extent of areas categorised as 'excellent'. The increase of total area of suitability of production from the 'Baseline to 'MC 2050' could be a result of an overall increase of ~1 °C in Tmean respectively. The areas which are predicted to increase in suitability occur as a narrow extent of the interior of Benguela, stretching northwards towards and through Cuanza Sul.

4.7b Impact of climate change on production of plantain banana (*M. balbisiana)* in Bié

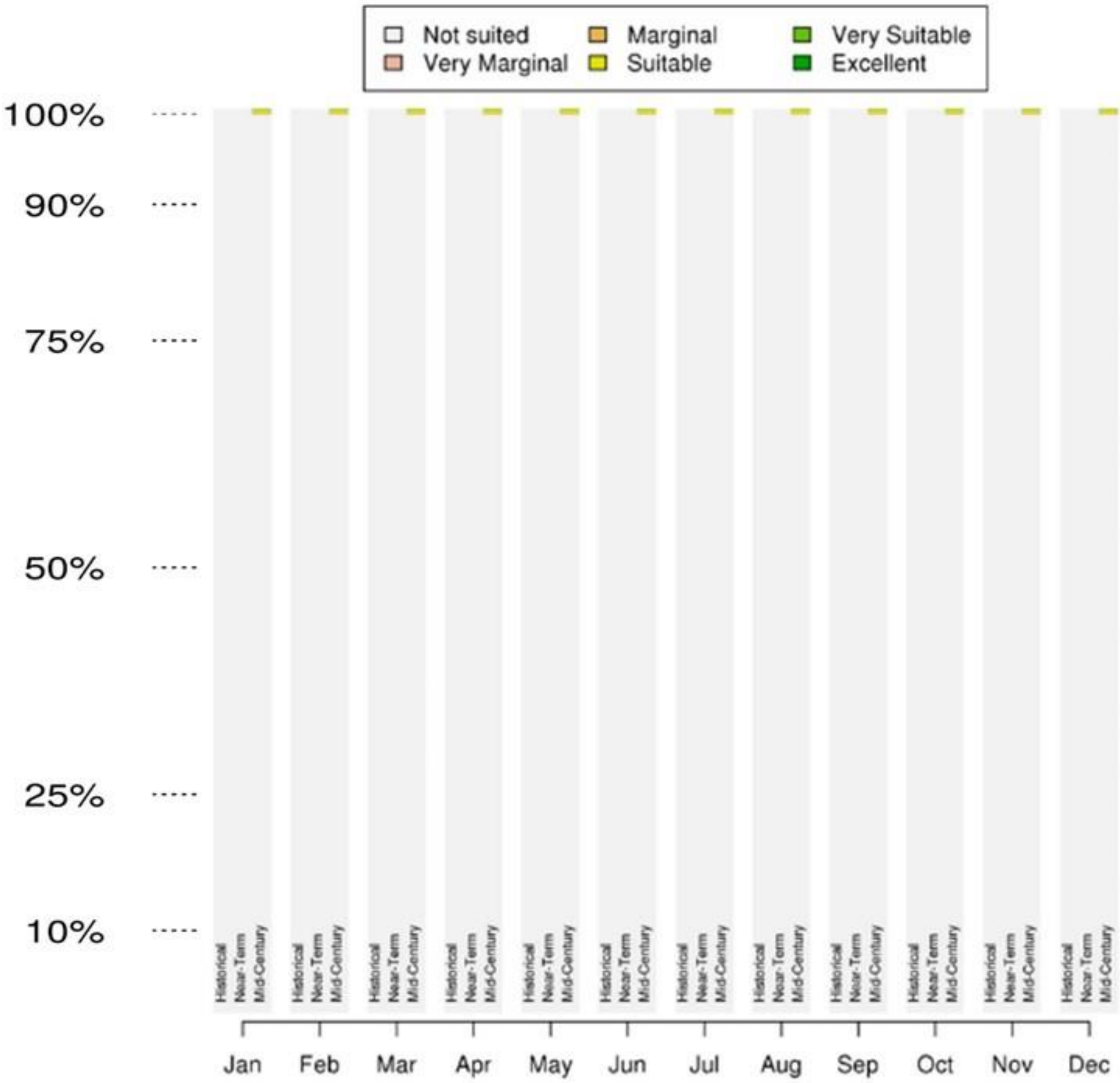


Figure 74. Mean suitability changes of Banana (*Musa balbisiana*, BB cooking plantain) in Bié

Ecocrop analyses indicate that Bié province is virtually entirely unsuitable for production of Banana (*Musa balbisiana*, BB cooking plantain), including baseline and future scenarios irrelevant of the season.

4.7c Impact of climate change on production of plantain banana (*M. balbisiana)* in Cuanza Sul

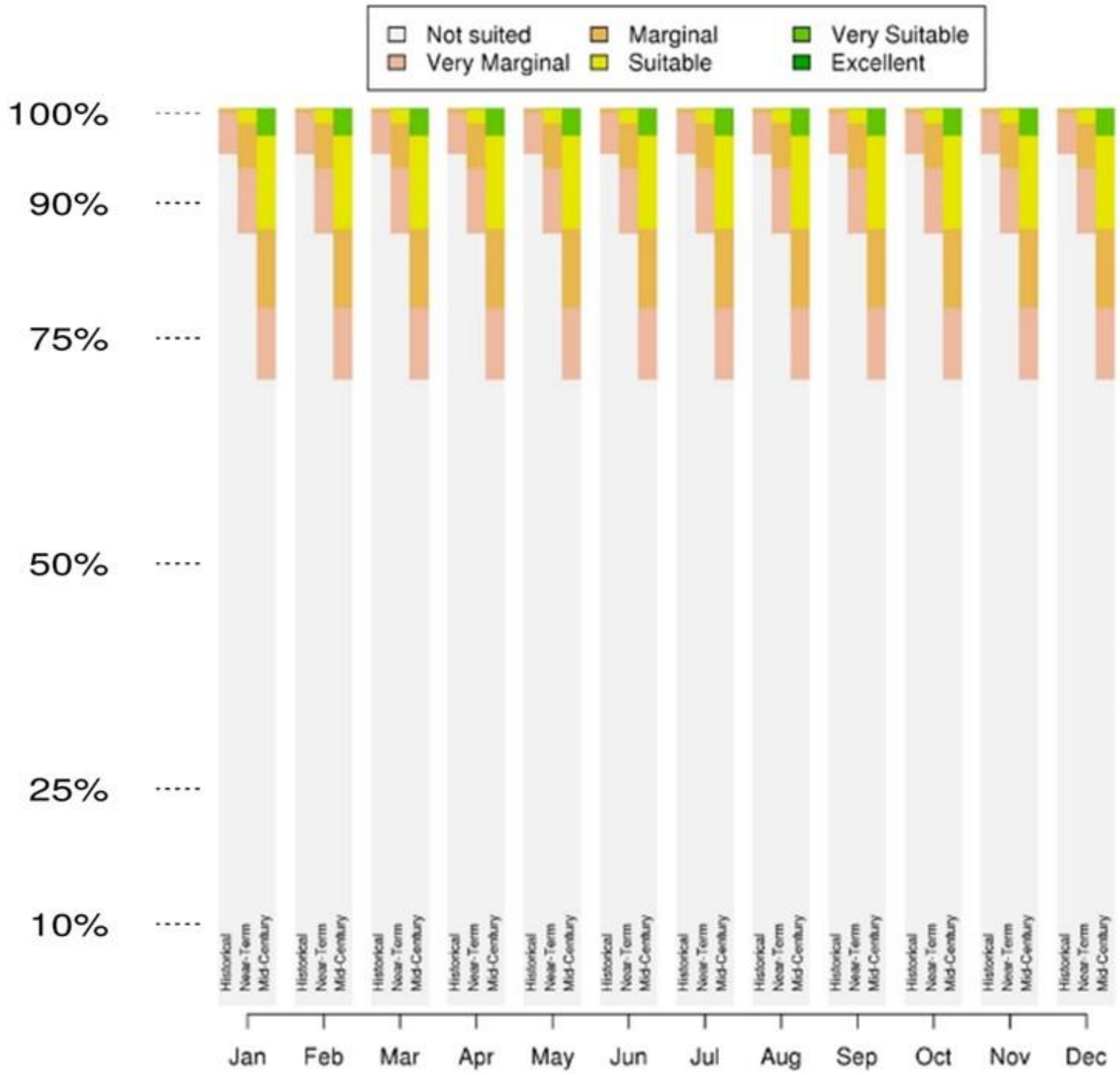


Figure 75. Mean suitability changes of Banana (*Musa balbisiana*, BB cooking plantain) in Cuanza Sul

In the baseline scenario, there is a small area of Cuanza Sul which is predicted to be marginally suitable to production of *M. balbisiana* plantain banana. However, as a result of climate change, it is predicted that the total spatial area of suitability for production of *M. balbisiana* plantain is predicted to increase from 'Baseline' to 'MC 2050' in all months of the year, including at the onset of the rainy season in October. The total provincial increase in suitability of *M. balbisiana* production can mainly be attributed to the extent of areas considered 'very suitable' and 'suitable'. The areas which are predicted to increase in suitability occur as a narrow extent strip extending northwards from the interior highlands of Benguela stretching northwards towards and through Cuanza Sul province. The increase of total suitable area from the 'Baseline' to 'MC 2050' could be a result of an overall increase of ~1 °C, where the aforementioned areas of increased suitability are associated with moderately large positive anomalies in Tmin and Tmean (Section 4).

4.7d Impact of climate change on production of plantain banana (*M. balbisiana)* in Huambo

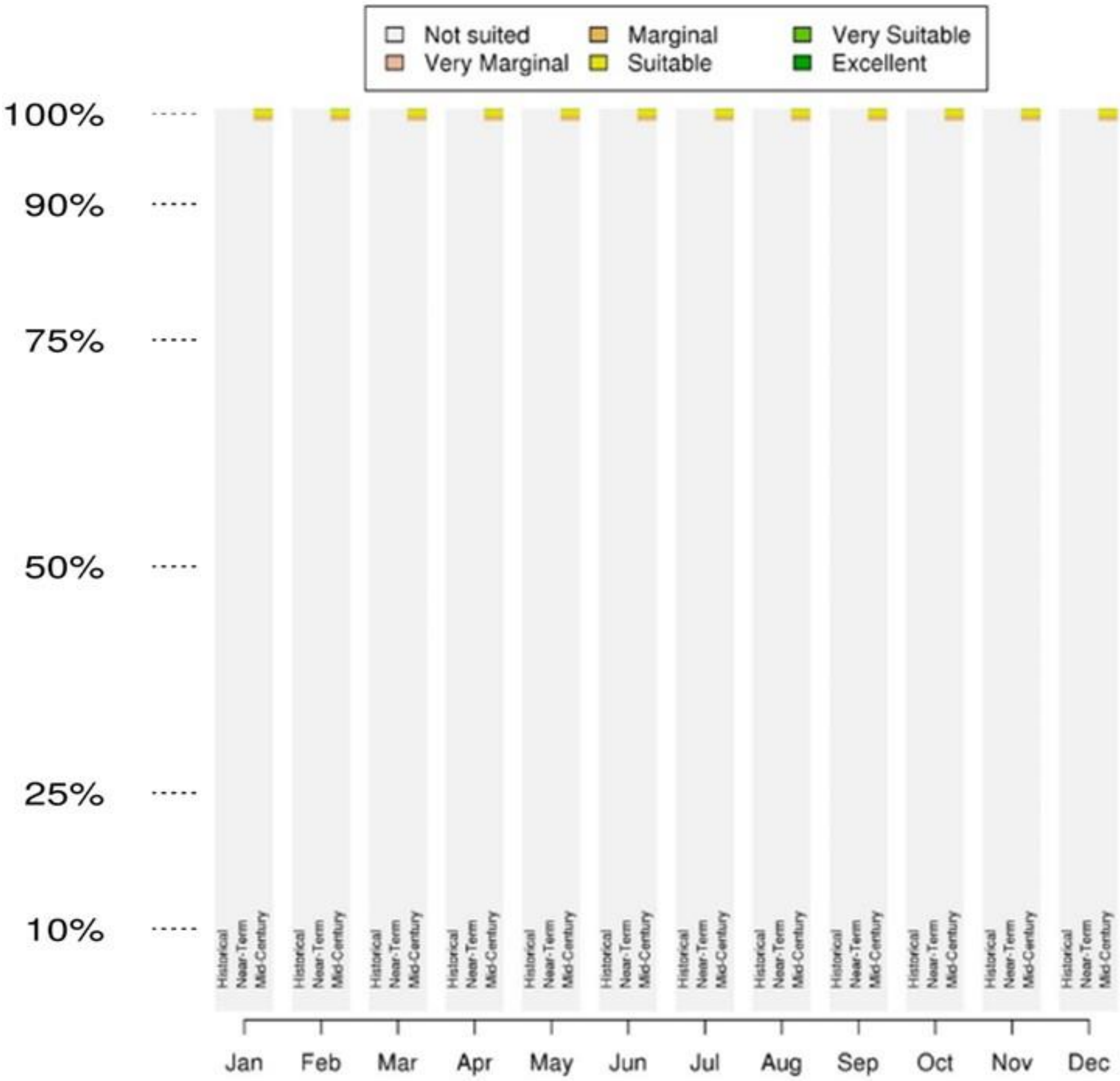


Figure 76. Mean suitability changes of Banana (*Musa balbisiana*, BB cooking plantain) in Huambo

Ecocrop analyses indicate that Huambo is totally unsuitable for the production of banana (*Musa balbisiana*, BB cooking plantain) in both the baseline and future scenarios.

4.7e Impact of climate change on production of plantain banana (*M. balbisiana)* in Huíla

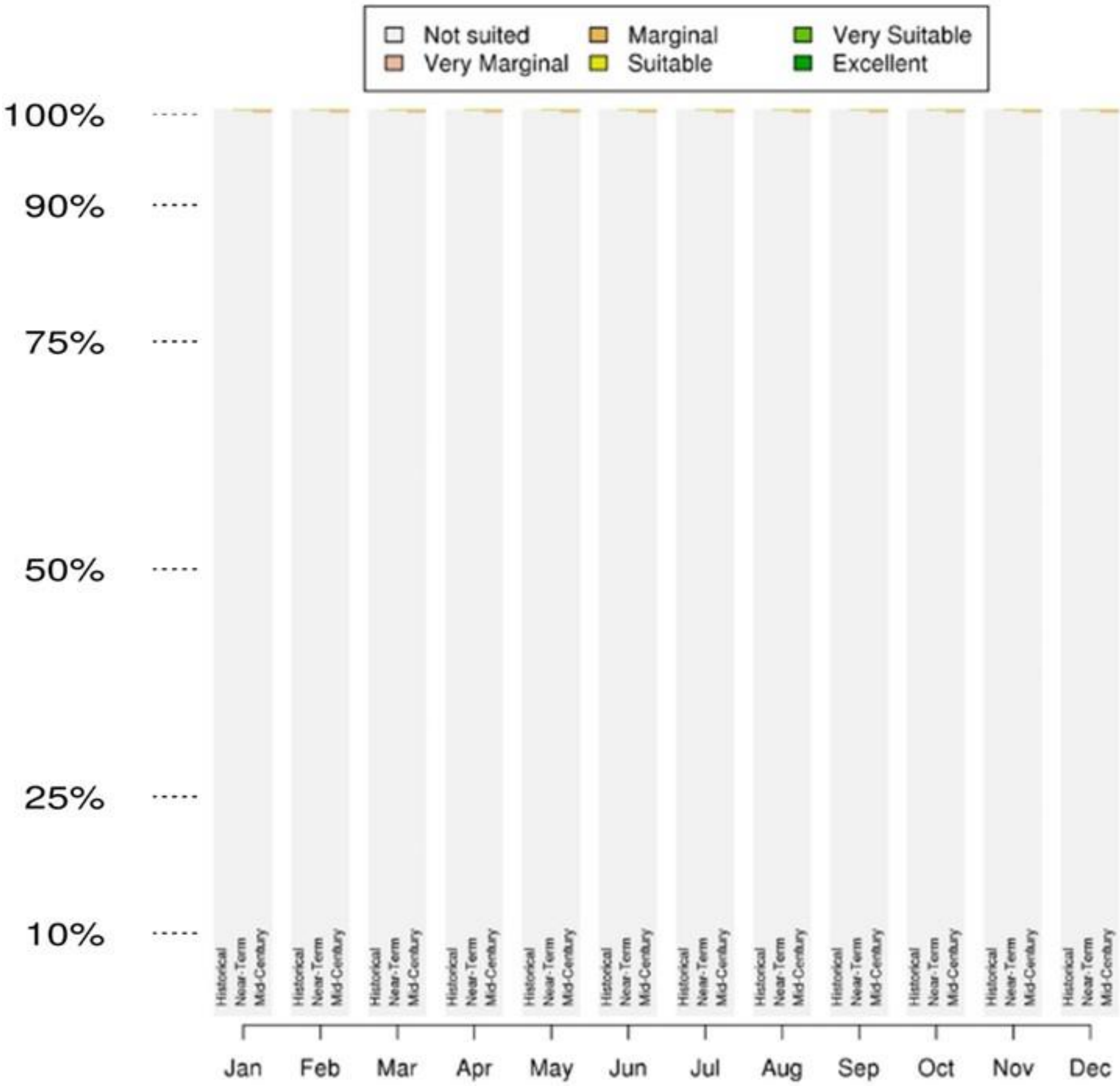


Figure 77. Mean suitability changes of Banana (*Musa balbisiana*, BB cooking plantain) in Huíla

The total area for Banana (*Musa balbisiana*, BB cooking plantain) in Huíla shows very little suitability throughout the year, in both baseline and future scenarios.

4.7f Impact of climate change on production of plantain banana (*M. balbisiana)* in Malanje

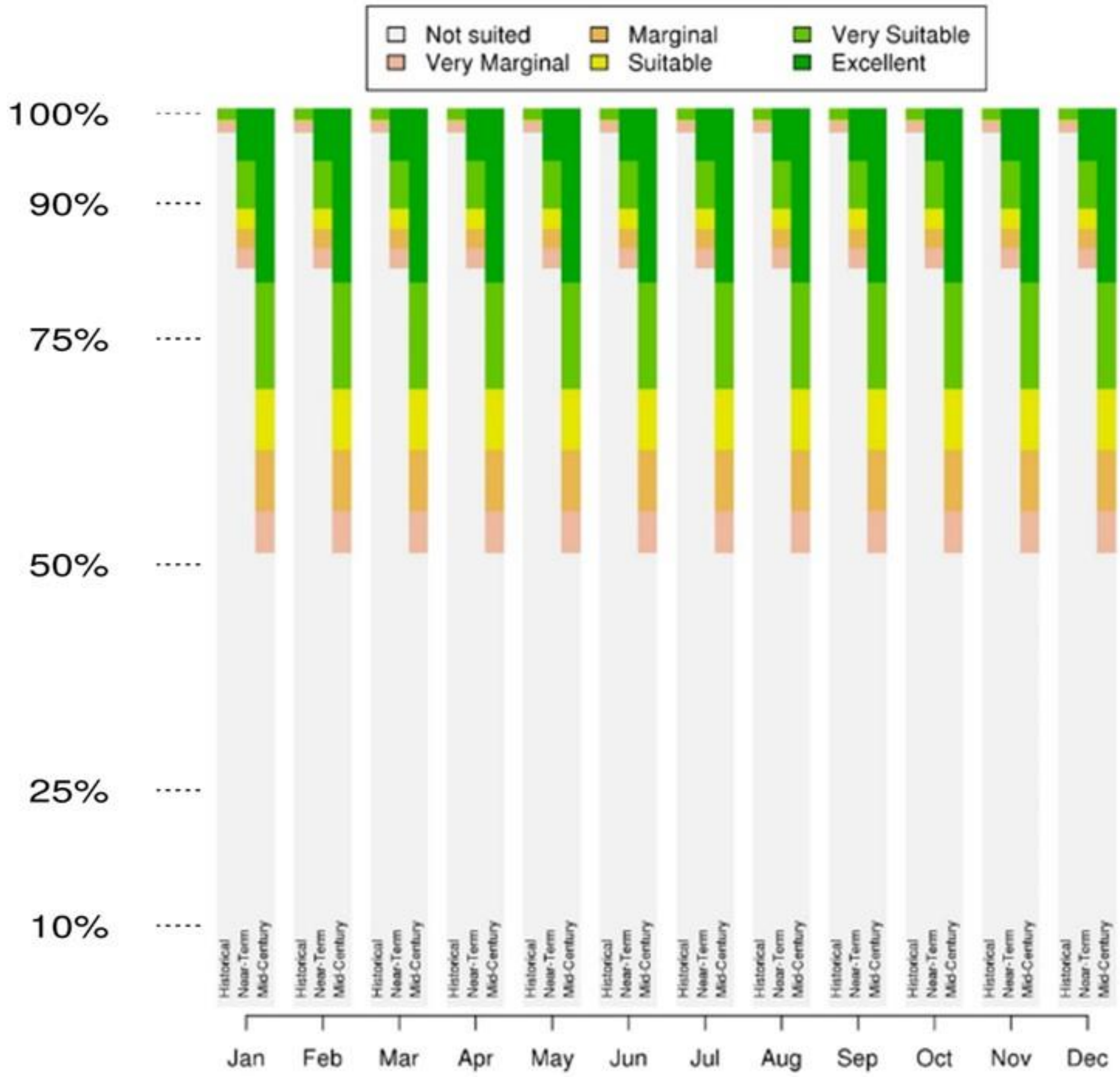


Figure 78. Mean suitability changes of Banana (*Musa balbisiana*, BB cooking plantain) in Malanje

In general, the total extent of area suitable for the growth of Banana (*Musa balbisiana*, BB cooking plantain) in Malanje is predicted to increase considerably from 'Baseline' to 'MC 2050' time points. Ecocrop analyses indicate that Malanje is almost entirely unsuitable for *M. balbisiana* cultivation production in the baseline scenario. However, as a result of climate change it is predicted that the extent of suitable areas will increase to just under ½ of the total provincial area by 2050. The aforementioned increase is categorised by increases in the extent of all categories of crop suitability.
The areas of Malanje provine which are predicted to increase in suitability for production of *M. balbisiana* primarily occur in the northern and eastern interior of the country, which is predicted to coincide with the highest mean monthly temperatures and rainfall in the province.

4.8. Impact of climate change on spatial distribution of areas suitable for production of plantain banana (*M. balbisiana* x *acuminata*)

The figures below summarise the historical (baseline) and future (mid-century 2050) suitability of the six pilot provinces (Bié, Benguela, Cuanza Sul, Huambo, Huíla and Malanje) for production of hybrid cooking plantain banana (*M. balbisiana* x *acuminata*) in the months from September to February. In addition to the baseline and future distribution of crop suitability zones, the figures below also illustrate the anomalies (i.e. the absolute changes in suitability at any given location) between the baseline and future time periods.

In the case of *M. balbisiana* x *acuminata*, EcoCrop analyses indicate that the majority of the study area is poorly suited in the baseline scenario. As a result of climate change, it is predicted that there will be modest increases in suitability in isolated areas of Bié, Huambo and Malanje (and to a smaller degree in Cuanza Sul and Benguela). The provincial changes in suitability for cooking plantain banana (*M. balbisiana* x *acuminata*) in the period from Baseline to Mid-Century 2050 are discussed further below.

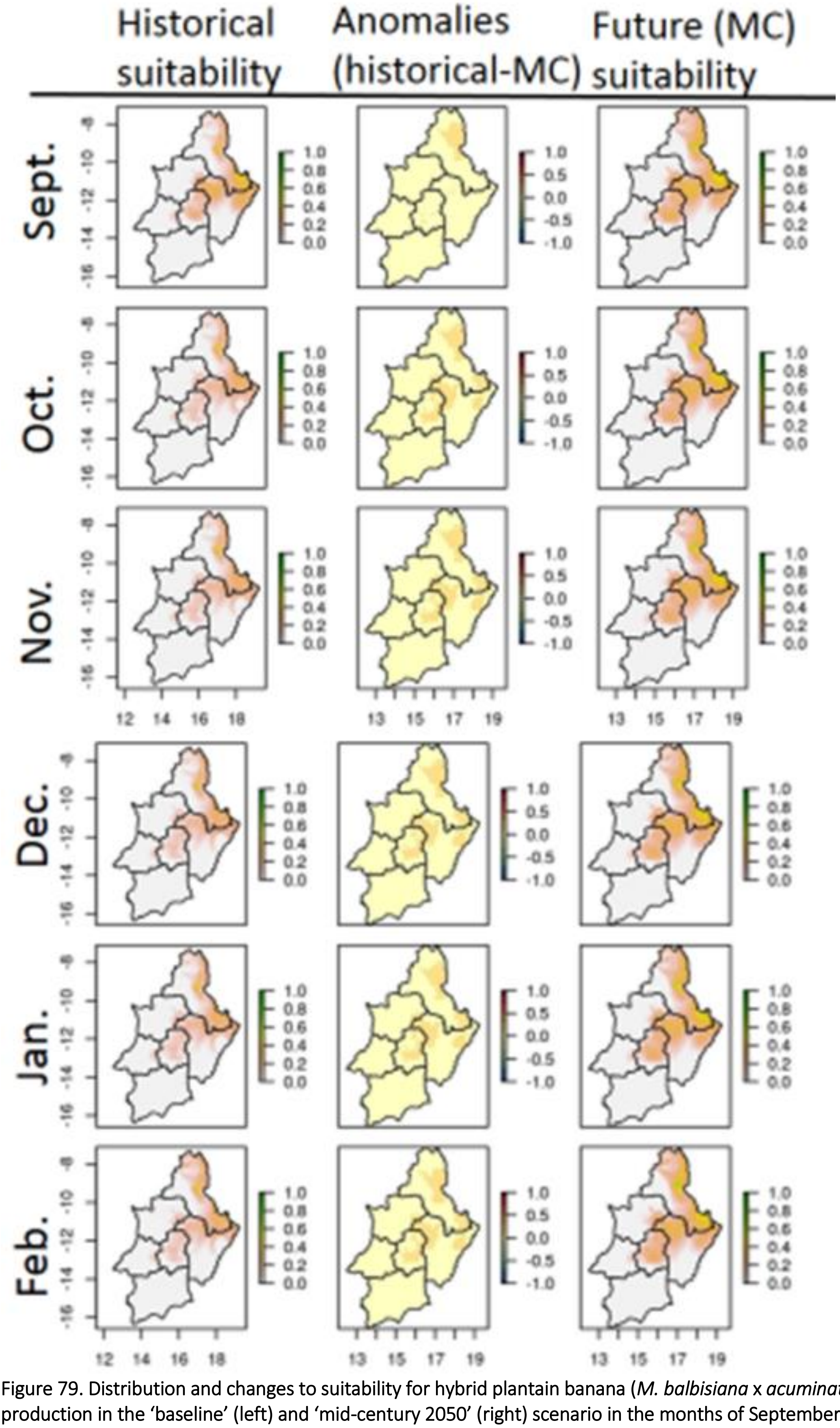


Figure 79. Distribution and changes to suitability for hybrid plantain banana (*M. balbisiana* x *acuminata*) production in the 'baseline' (left) and 'mid-century 2050' (right) scenario in the months of September to February

4.8a Impact of climate change on production of cooking plantain banana (M. balbisiana x acuminata) in Benguela

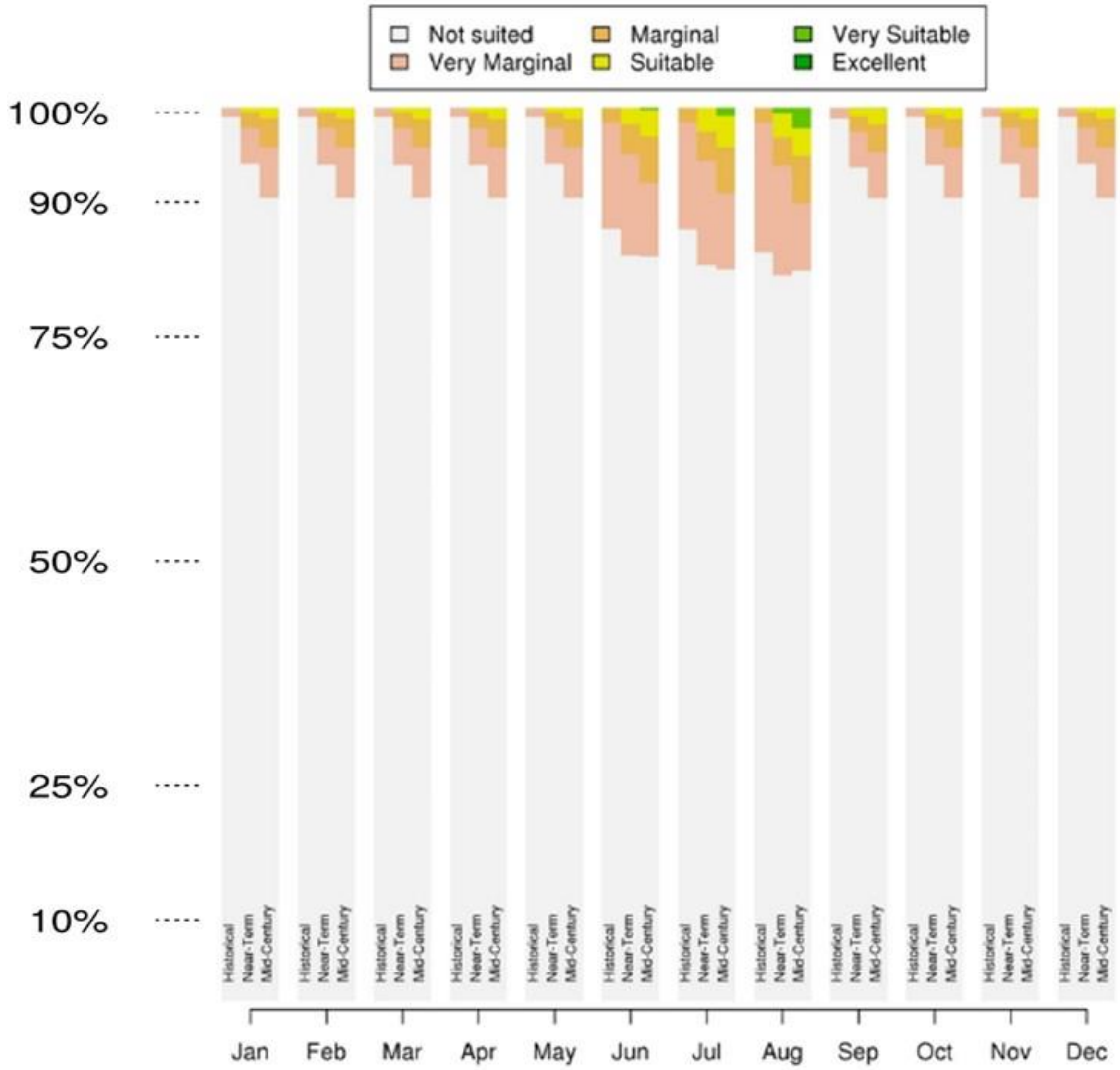


Figure 80. Mean suitability changes of Banana (*Musa acuminata* x *balbisiana*, cooking plantain) in Benguela

The province of Benguela is generally predicted to be poorly suited to *M. acuminata* x *balbisiana*, both in the baseline and future scenarios. The total area of suitability of Banana (*Musa acuminata x balbisiana*, cooking plantain) is predicted to increase slightly from 'Baseline' to 'MC 2050' time periods. Analysis of the distribution of crop suitability categories in the month of October suggests future increases in the spatial extent of land categorised as 'suitable', 'marginal', and 'very marginal' for production of *M. acuminata x balbisiana* in Benguela. The total extent of *M. acuminata x balbisiana*-suitable areas is largest during the winter months between June to August, during which month there is predicted to be an increase in the extent of areas considered to be 'excellent' between the 'Historical' and 'MC 2050' projections. The areas of Benguela which are predicted to increase in suitability for production of cooking plantain are restricted to the eastern interior of the *planalto* region, adjacent to the border with Huambo.

4.8b Impact of climate change on production of cooking plantain banana (M. balbisiana x acuminata) in Bié

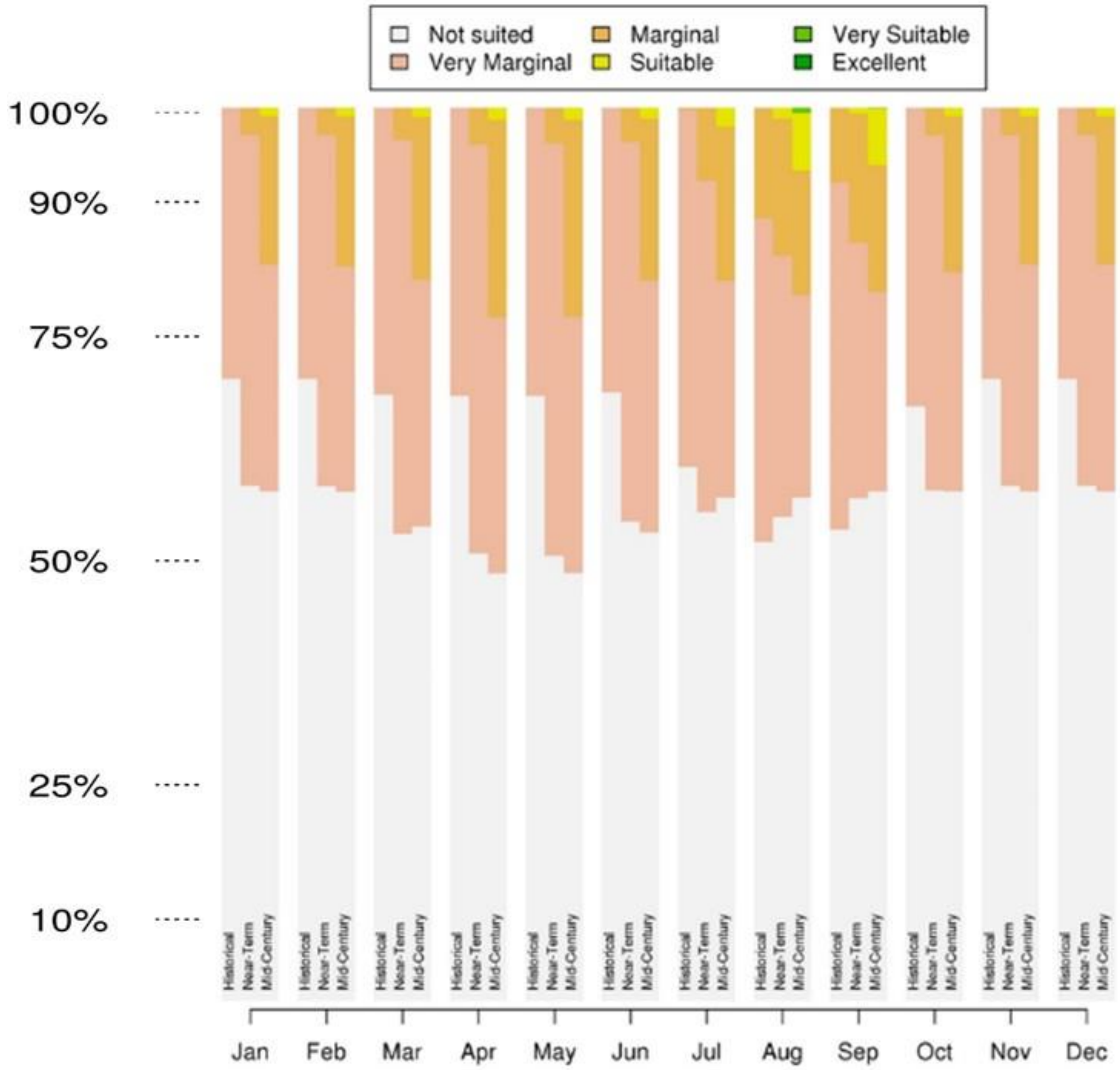


Figure 81. Mean suitability changes of Banana (*Musa acuminata x balbisiana*, cooking plantain) in Bié

The total area of suitability for production of banana (*Musa acuminata x balbisiana*, cooking plantain) in Bié is predicted to increase slightly, based on the month of October, in the period from 'Baseline' to 'MC 2050' time points. Further analysis of the crop suitability categories during the month of October suggests future increases in the extent of 'suitable' and 'marginal' areas. Similar to Benguela and Cuanza Sul provinces, Bié is generally poorly suited to production of cooking plantain in both the baseline and future scenarios. The primary areas which are predicted to increase in suitability are restricted to a narrow extent in the western interior of the province adjacent to the border with Cuanza Sul, and the easternmost extent of the province.

4.8c Impact of climate change on production of cooking plantain banana (*M. balbisiana* x *acuminata*) in Cuanza Sul

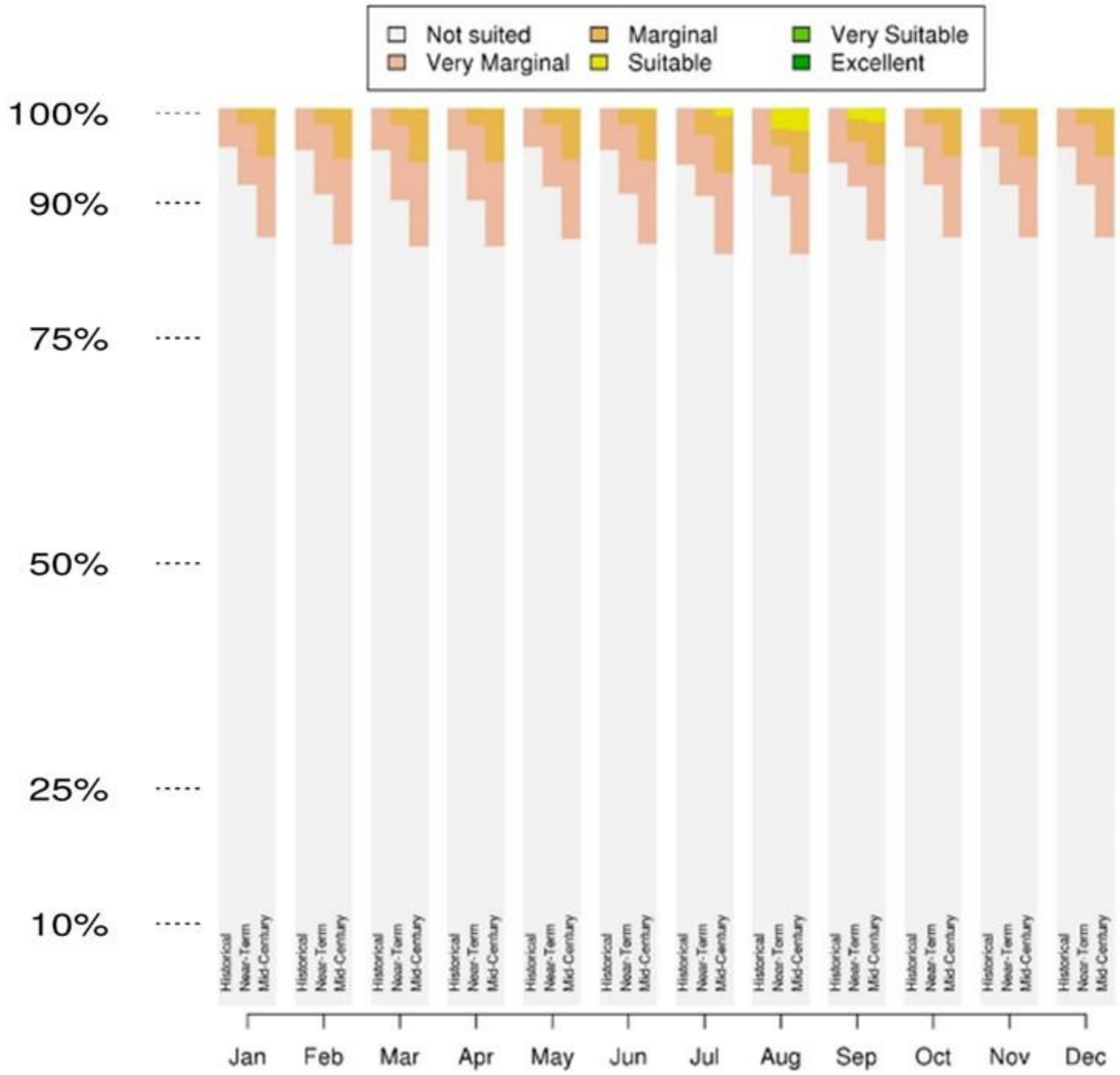


Figure 82. Mean suitability changes of Banana (*Musa acuminata x balbisiana*, cooking plantain) in Cuanza Sul

The province of Cuanza Sul is generally predicted to be poorly suited to *M. acuminata x balbisiana*, both in the baseline and future scenarios. However, it is predicted that climate change will result in small increases in the total area of suitability for production of cooking plantain banana (M. acuminata x balbisiana) in the 'Baseline' to 'MC 2050' time periods. Analysis of the distribution of crop suitability categories in the month of October suggests future increases in the spatial extent of land categorised as 'suitable', 'marginal', and very marginal' for production of *M. acuminta x balbisiana* in Cuanza Sul. The increase in extent of suitable area in October can be attributed to an increase in the extent of land considered 'suitable'. The total extent of *M. acuminta x balbisiana*-suitable areas is largest during the winter months between July to September.

The primary areas of Cuanza Sul which are predicted to be marginally suitable for plantain production are restricted to a narrow extent in the eastern interior of the province adjacent to the border with Bié province.

4.8d Impact of climate change on production of cooking plantain banana (*M. balbisiana x acuminata*) in Huambo

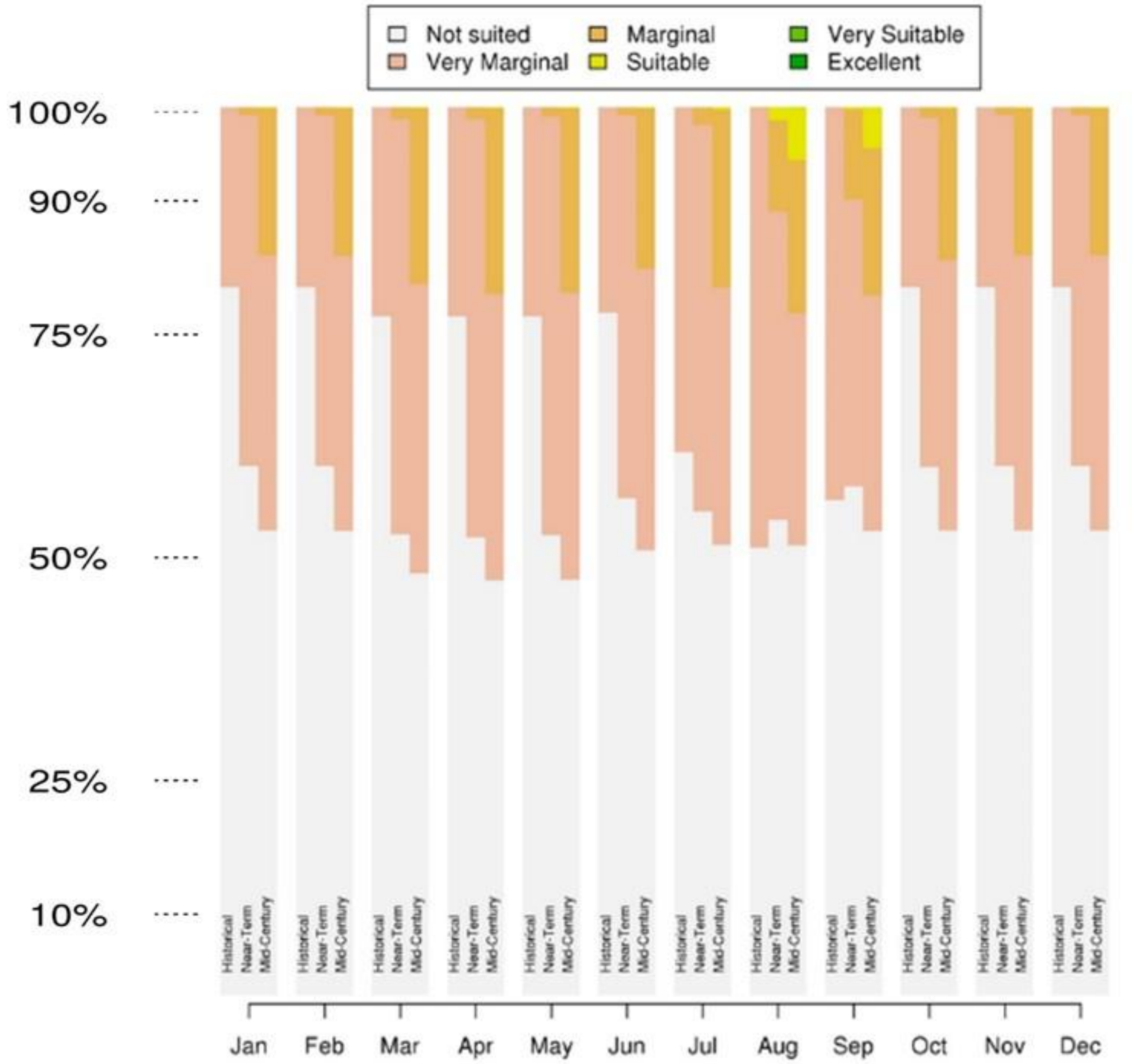


Figure 83. Mean suitability changes of Banana (*Musa acuminata x balbisiana*, cooking plantain) in Huambo

The total area of suitability for production of banana (*Musa acuminata x balbisiana*, cooking plantain) in Huambo is predicted to increase during the month of October from 'Baseline' to 'MC 2050'. Further analysis of the crop suitability categories in the month of October suggests increases in the extent of land area considered 'marginal' and 'very marginal'. Analysis of mapped anomalies in baseline and future crop suitability (Figure 79) indicate that the areas of increased suitability primarily occur in the centre of Huambo province. The total area suitable for *M. acuminata x balbisiana*, cooking plantain remains relatively consistent throughout the duration of the rainy season from October to April in Huambo.

4.8e Impact of climate change on production of cooking plantain banana (*M. balbisiana x acuminata*) in Huíla

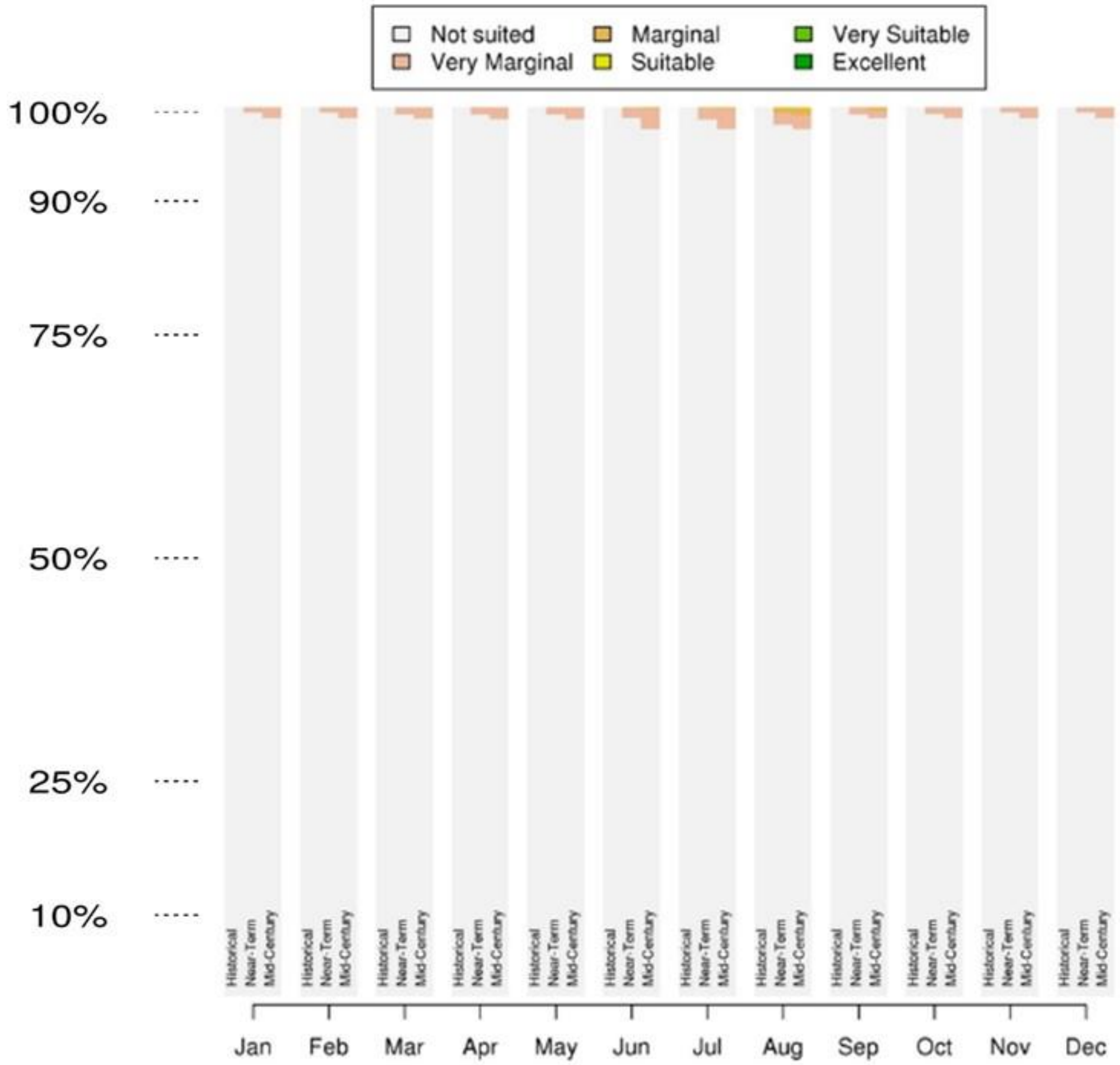


Figure 57c. Mean suitability changes of Banana (*Musa acuminata x balbisiana*, cooking plantain) in Huíla

In both the baseline and future scenarios, Huíla province is broadly predicted to be unsuitable for production of cooking plantain. The total area for production of cooking plantain banana (*Musa acuminata x balbisiana*) in Huíla shows very little suitability throughout the year irrelevant of the season in both the baseline and mid-century 2050 timepoints. During the month of October there is a marginal increase in the extent of areas considered to be 'very marginal' from 'baseline' to 'MC 2050' time points. The month of August has the greatest proportion of suitable area for *M. acuminate x balbisiana*, during which month there is an increase in the extent of areas considered 'marginal' and 'very marginal' from 'Baseline' to 'MC 2050' projections.

4.8f Impact of climate change on production of cooking plantain banana (*M. balbisiana x acuminata*) in Malanje

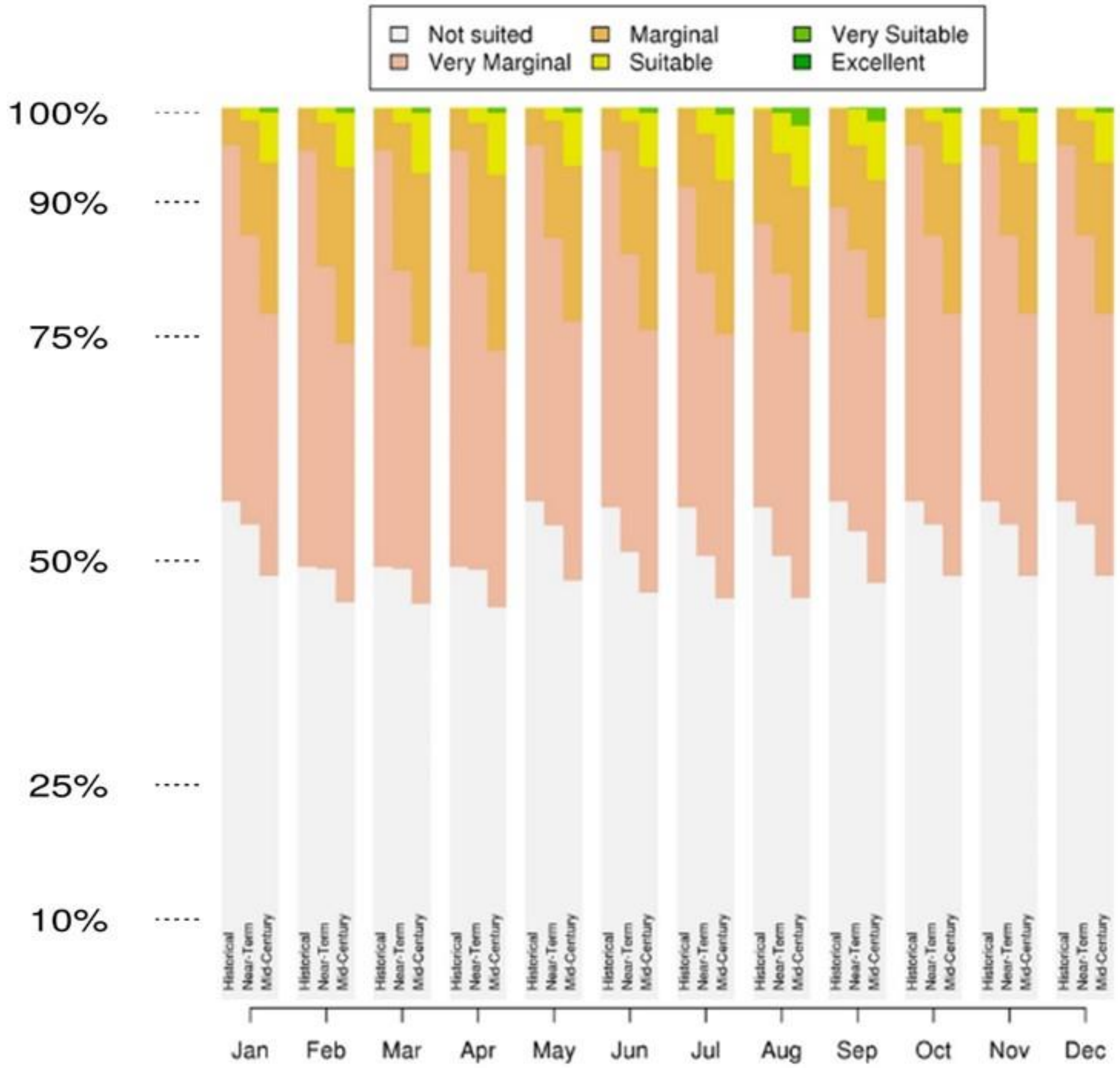


Figure 84. Mean suitability changes of Banana (*Musa acuminata x balbisiana*, cooking plantain) in Malanje

The total area of suitability for production of banana (*Musa acuminata x balbisiana*, cooking plantain) in Malanje is predicted to increase during the period from 'Baseline' to 'MC 2050' timepoints, assuming the month of October and the onset of rainy season as the planting date. Further analysis of the crop suitability categories in the month of October suggests increases in the extent of land area considered 'very suitable', 'suitable', 'marginal' and 'very marginal' from the baseline scenario to 2050, however, half of the province remains unsuitable for *M. acuminata x balbisiana* production. The areas predicted to be most suitable for cooking plantain production in Malanje are primarily in the eastern and northern interior of the province.

4.9. Impact of climate change on spatial distribution of areas suitable for production of maize (*Zea mays* Ls. mays)

The figures below summarise the historical (baseline) and future (mid-century 2050) suitability of the six pilot provinces (Bié, Benguela, Cuanza Sul, Huambo, Huíla and Malanje) for production of maize (*Zea mays* Ls. mays) in the months from September to February. In addition to the baseline and future distribution of crop suitability zones, the figures below also illustrate the anomalies (i.e. the absolute changes in suitability at any given location) between the baseline and future time periods.

In the case of maize (*Z. mays* Ls. mays), climate change is predicted to result in minor but widespread decreases in crop suitability, particularly at the onset of the rainy season in ~October. In Huíla province, the absolute spatial extent of areas which are suitable for maize production are predicted to decrease considerably as a result of climate change, to the extent that the province is likely to become poorly suited to the crop by the mid-century 2050 timepoint. Of the remaining five provinces, the absolute spatial extent of maize-suitable production areas are predicted to remain consistent but are predicted to undergo decreases in crop suitability index score. The reduced suitability for maize production is suggested to be attributable to increased temperatures during the growing season, as well as delayed onset of rainfall in the early growing months of September and October.

A secondary effect of climate change on maize production in the study region may include an effective delay or shortening of growing season, where rainfall anomalies suggest that the onset of rainfall is likely to occur later in the year than in the baseline scenario. The provincial changes in suitability for maize (*Z. mays* Ls. mays) production in the period from Baseline to Mid-Century 2050 are discussed further below.

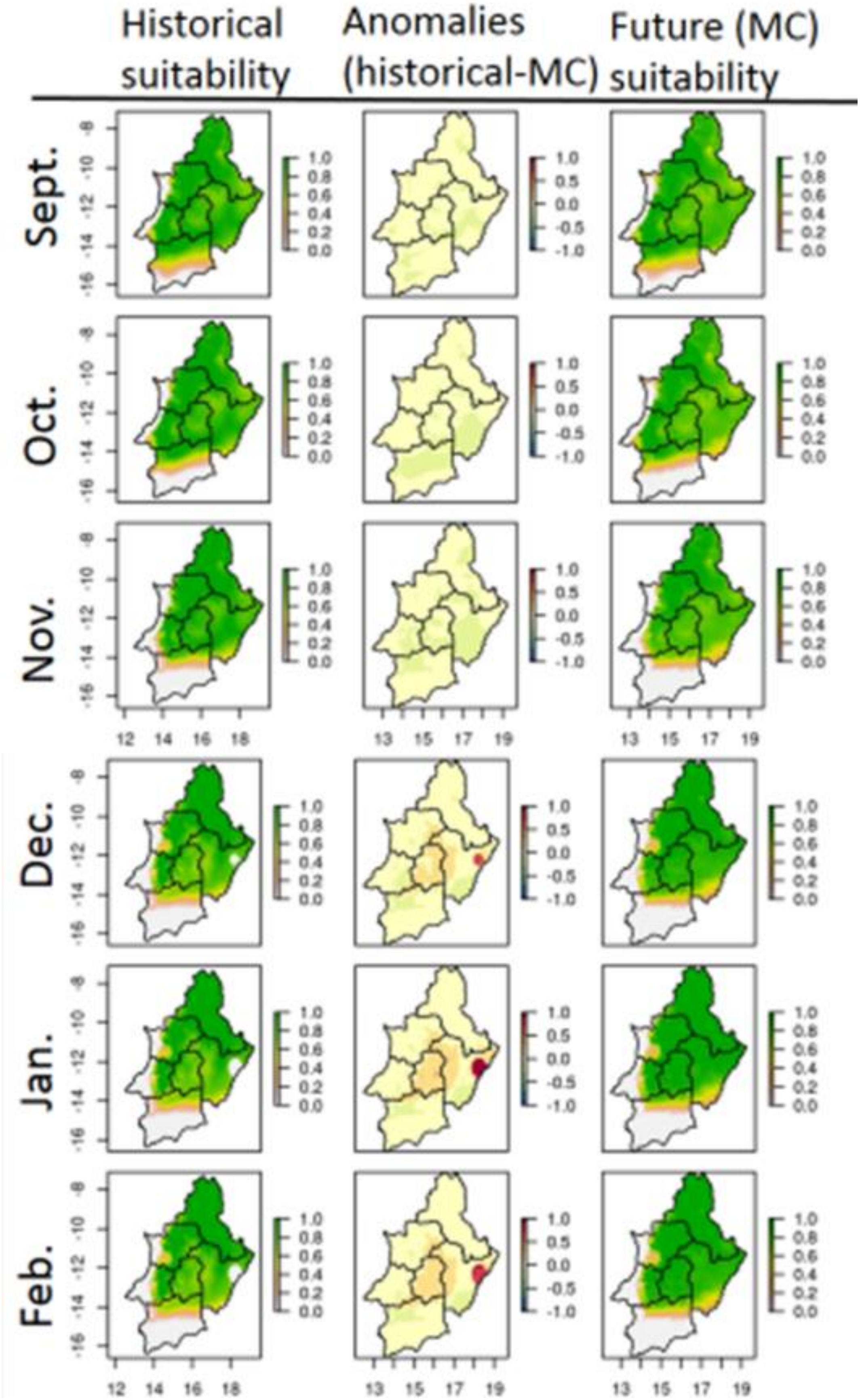


Figure 85. Distribution and changes to suitability for maize (*Zea mays*) production in the 'baseline' (left) and 'mid-century 2050' (right) scenario in the months of September to February

4.9a Impact of climate change on production of *Zea mays* L.s. mays in Benguela

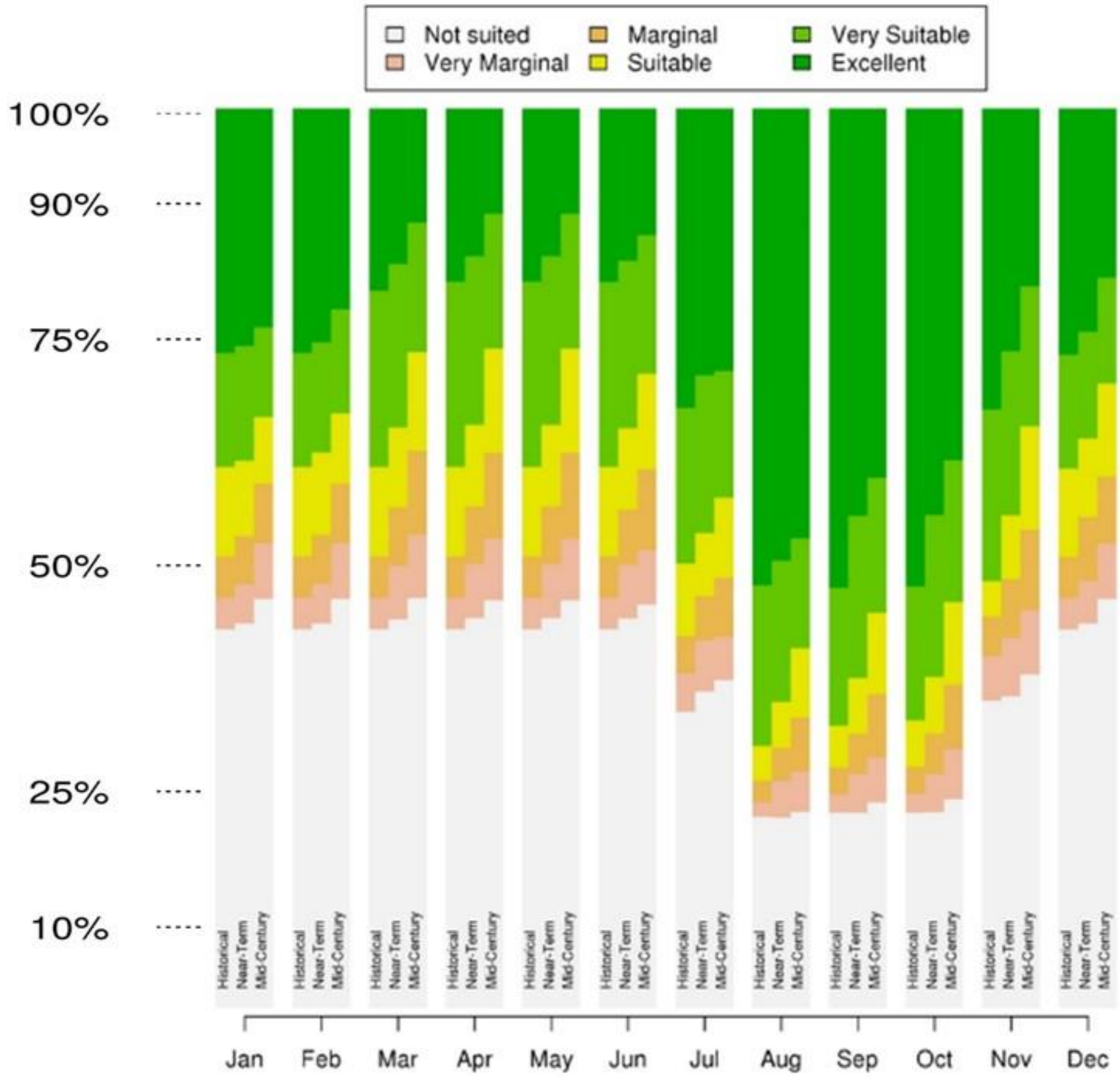


Figure 86. Mean suitability changes of *Zea mays* L.s. *mays* in Benguela

In general the overall area of suitability for production of maize (*Zea mays*, various subspecies) is not predicted to change in total spatial extent in the period from 'Baseline' to 'MC 2050'. However, there is a general trend of decreased suitability index score during the period from 'Baseline' to MC '2050' time periods. The growing seasons months from October onwards are characterised by a decreasing trend in areas considered 'excellent', 'very suitable' and 'suitable, and a concomitant increase in areas considered to be 'marginal', and 'very marginal' relative to the baseline. The total spatial area of suitability is greatest during the months from August to October. During the growing season from October to April there is a decrease in area considered 'excellent' for 'Baseline' to 'MC 2050' projections.

4.9b Impact of climate change on production of *Zea mays* L.s. mays in Bié

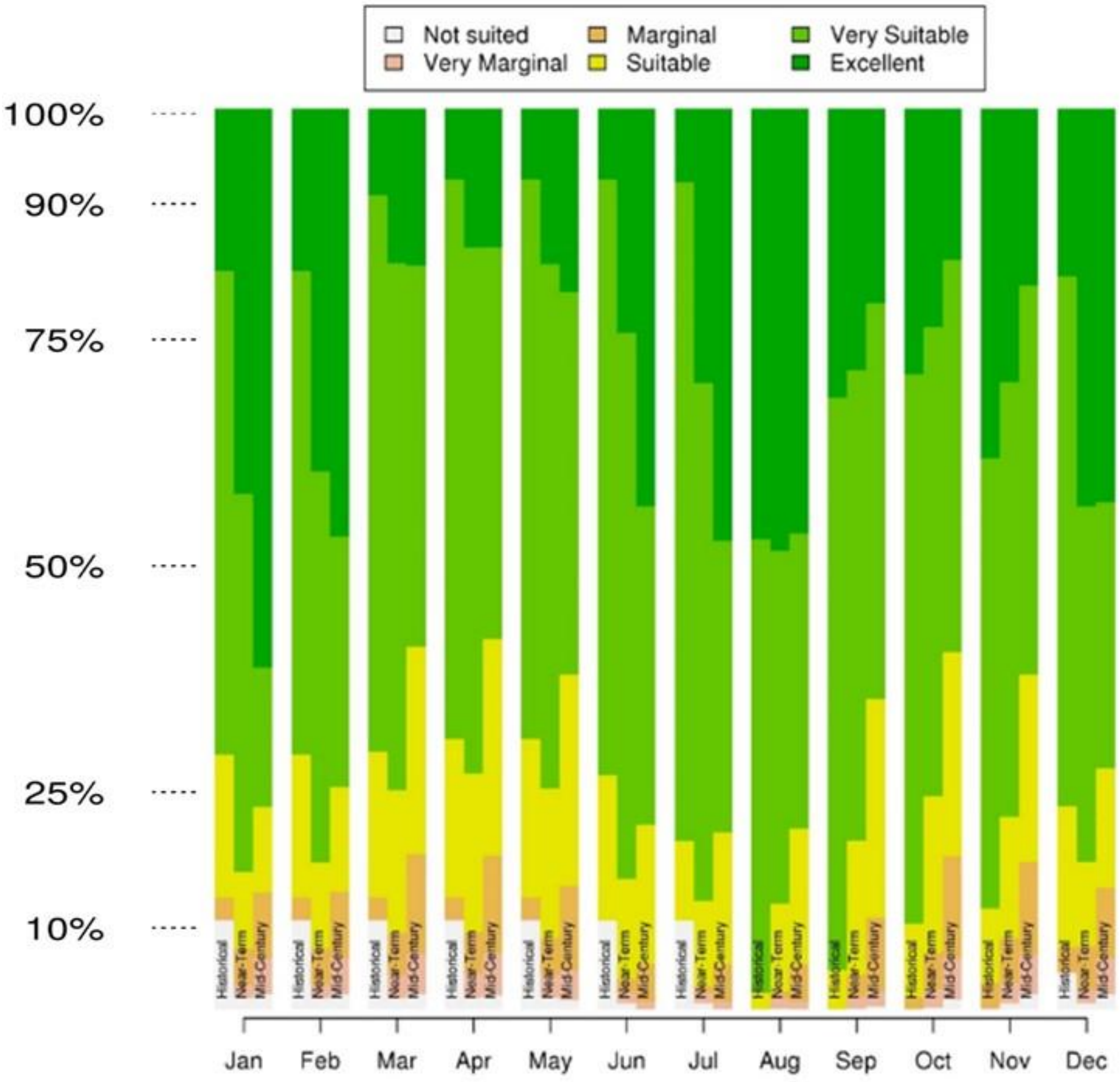


Figure 87. Mean suitability changes of *Zea mays* L.s. mays in Bié

In Bié province, EcoCrop analyse indicate that climate change will result in a decrease in the extent of areas considered to be 'excellent' and 'very suitable' for maize production, during the period from baseline 'MC 2050'. The net reductions in the above-mentioned categories appear to coincide with net increases in the predicted extent of 'suitable', and 'marginal' areas, suggesting that climate change will negatively impact production of *Zea mays* L.s. mays in Bié by reducing crop performance in those areas currently considered to be 'very suitable' in the baseline scenario. The predicted decreases in suitability index score for maize in the months of October and November may be attributable to predicted increases in temperature and decreases in mean monthly rainfall. The areas which coincide with the largest anomalies (i.e. the largest net reduction in crop suitability) are primarily located in the centre and south of Bié province. A secondary effect of climate change in Bié province may be to delay the onset of the growing season, from October/November in the baseline scenario to December/January in the future 'mid-century 2050' scenario. In the future 'Mid Century 2050' scenario, EcoCrop analyses predict that the months of December to February will characterised by surprising increases in crop suitability at a time of year which is traditionally associated with maturation, rather than establishment, of maize. This result may potentially be attributable to predicted increases in rainfall during the months of December – February.

4.9c Impact of climate change on production of *Zea mays* L.s. mays in Cuanza Sul

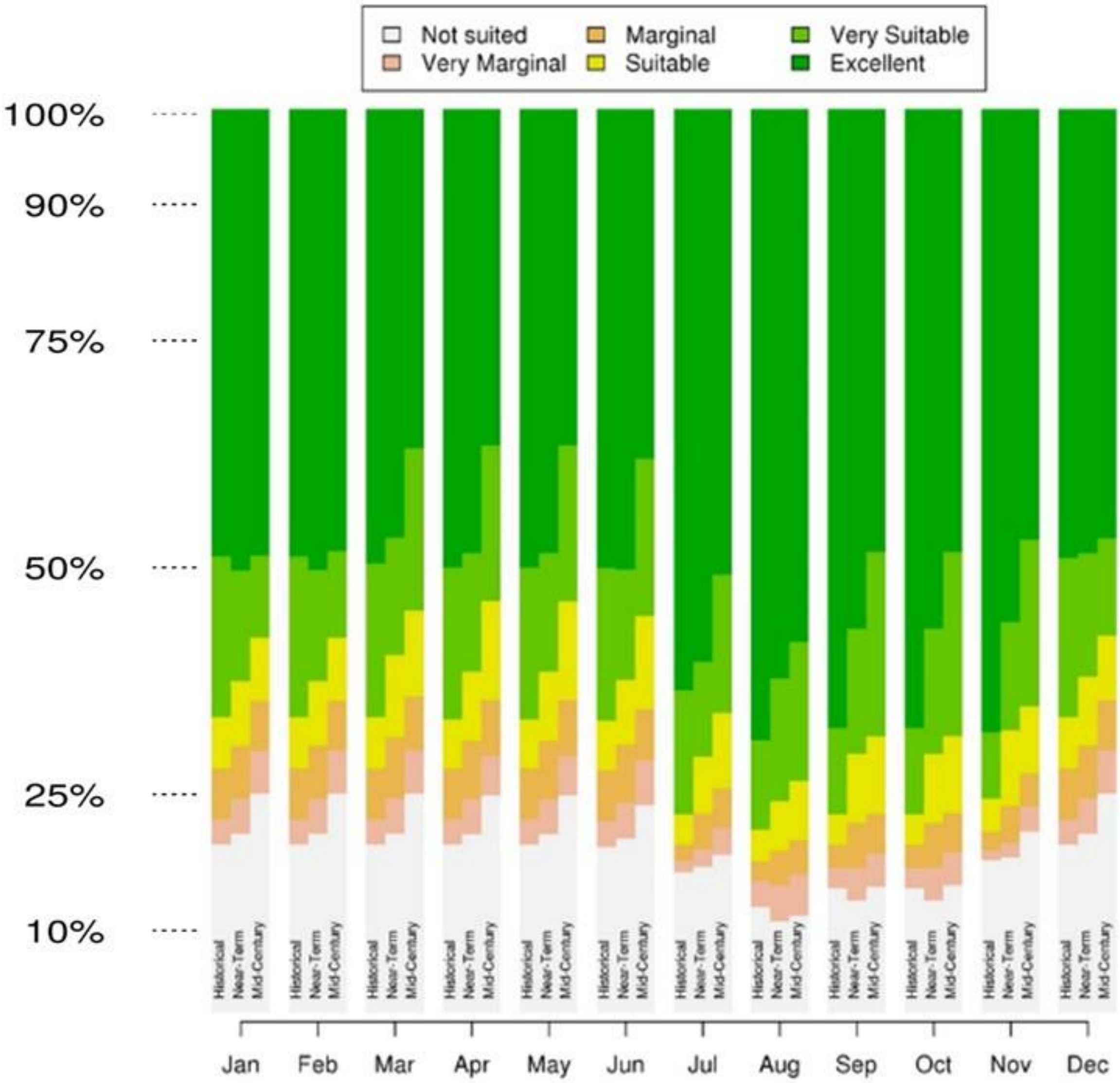


Figure 88. Mean suitability changes of *Zea mays* L.s. *mays* in Cuanza Sul

During the month of October the total area suitable for growing *Zea mays* L.s. *mays* in Cuanza Sul is predicted to increase from 'Baseline' to 'NT 2030', and decrease from 'NT 2030' to 'MC 2050' time points. The most significant change to the distribution of maize suitability occurs as a reduction in the extent of areas considered 'excellent'. The decrease in 'excellent' areas is partly offset by a smaller increase in areas considered 'very suitable' from 'Baseline' and 'MC 2050' time points. Mapped anomalies of changes in crop suitability (Figure 85) indicate that those areas characterised by the largest decreases in crop suitability are primarily concentrated around the eastern interior highlands of the province.

The increase in total suitable area during the month of October could be attributed to a ~1 °C increase in Tmean from 'Baseline' to 'NT 2030', respectively, the decrease from 'NT 2030' could be attributed to a ~0.5 °C decrease in Tmean, where *Zea mays* L.s. *mays* has an optimum growth temperature range between 18 to 33 °C. The total spatial area of suitability for growth of *Zea mays* L.s. *mays* in Cuanza Sul is greatest during the months from July to November.

4.9d Impact of climate change on production of *Zea mays* L.s. mays in Huambo

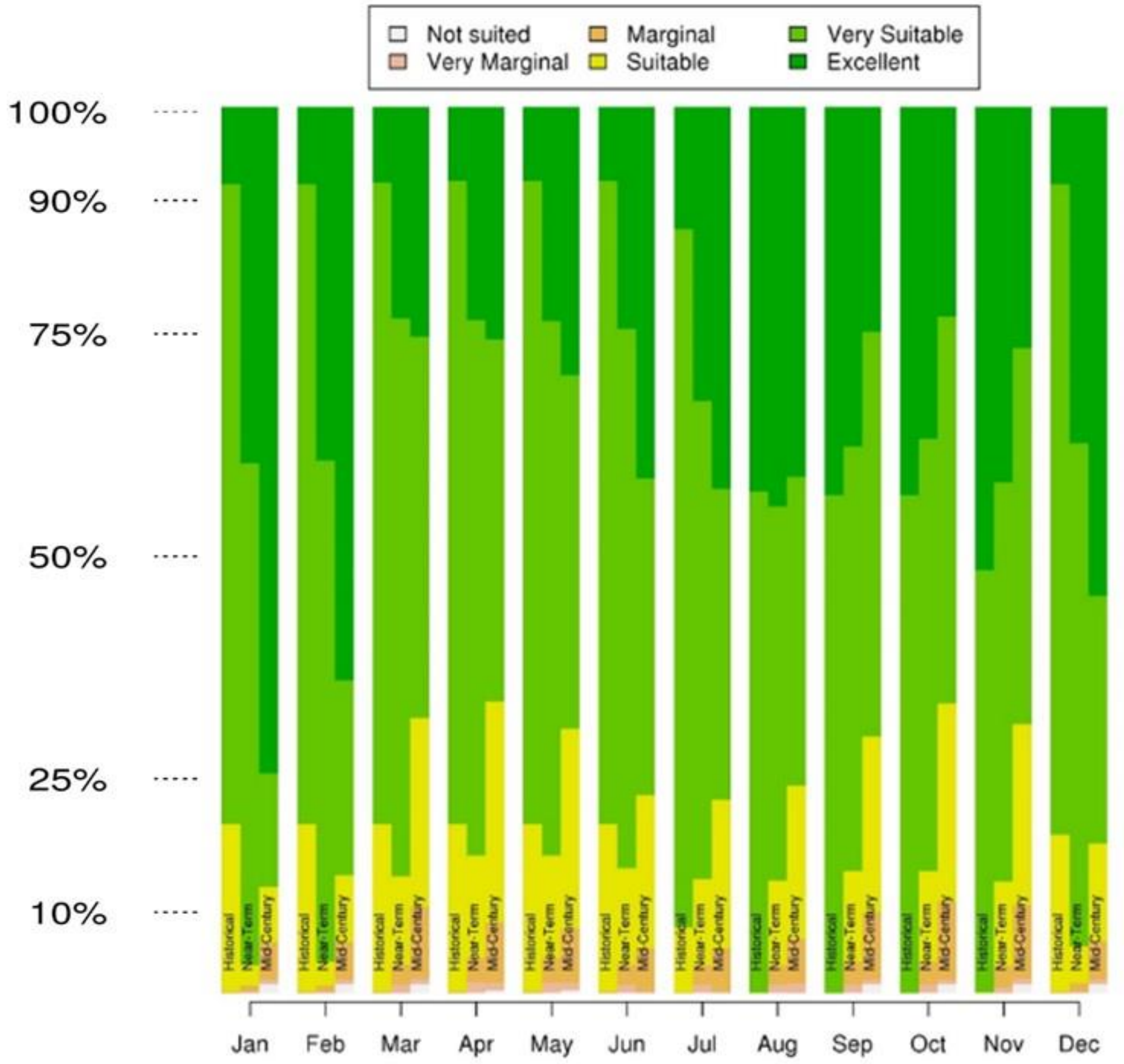


Figure 89. Mean suitability changes of *Zea mays* L.s. *mays* in Huambo

In general, the overall suitability of Huambo for production of *Zea mays* L.s. illustrates a minor decrease in total area from 'Baseline' to 'MC 2050' time points. During October there is predicted to be a decrease in the extent of land area considered 'excellent' and 'very suitable', and a simultaneous increase in areas considered 'suitable' and 'marginal' from 'Baseline' to 'MC 2050' time points. The most significant change to the distribution of *Z. mays* L.s *mays* occurs during the month of January where a large increase in the extent of land considered 'excellent' for maize production is predicted for the period from 'Baseline' to 'MC 2050' predictions.

The predicted decreases in suitability index score for maize in the months of October and November may be attributable to predicted increases in temperature and decreases in mean monthly rainfall in Huambo province. However, although the months of September to November are predicted to reduced rainfall, it is further predicted that the months of December – March will be characterised by relatively higher amounts of rain than the baseline scenario. Therefore, a potential secondary effect of climate change in Huambo province may be to delay the onset of the growing season, from October/November in the baseline scenario to December/January in the future 'mid-century 2050' scenario.

4.9e Impact of climate change on production of *Zea mays* L.s. mays in Huíla

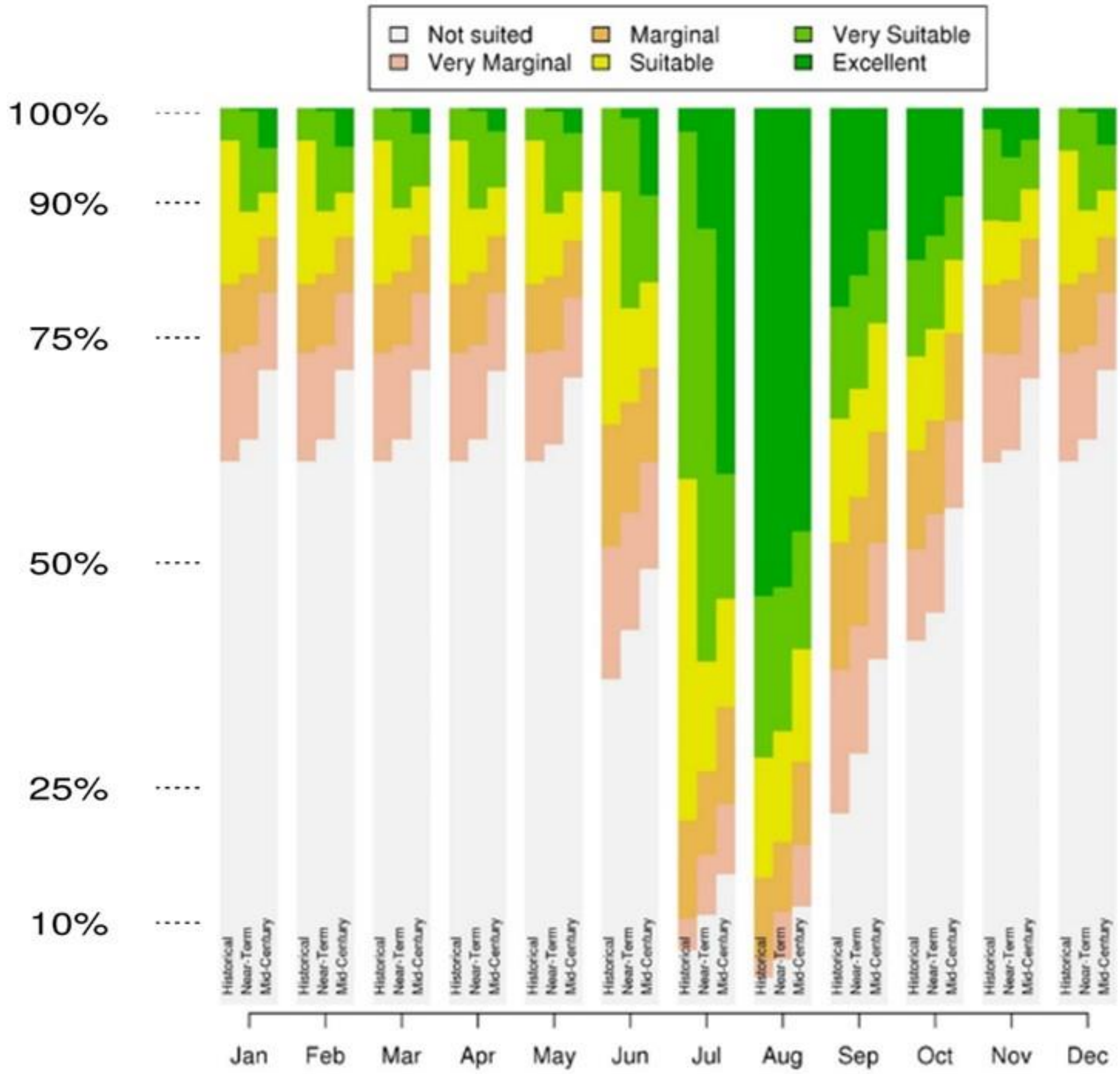


Figure 90. Mean suitability changes of *Zea mays* L.s. *mays* in Huíla

In general the overall suitability of *Zea mays* L.s. is predicted to decrease for each month of the year from 'Baseline' to 'MC 2050' time points. During the month of October (and onward throughout successive months of the growing season), it is predicted that the total area of Huíla which is suitable for *Zea mays* L.s.*mays* production will decrease considerably during the period from 'Baseline' to 'MC 2050' time points. The decrease in total area of suitability is characterised by reductions in areas categorised as 'excellent', 'highly suitable' and 'suitable'. Mapped anomalies of crop suitability changes indicate that the existing and predicted future range of *Z. mays* production in Huíla is confined to the northern interior highlands of the province. The western and southern extents of Huíla province remain wholly unsuitable for *Z. mays*.

4.9f Impact of climate change on production of *Zea mays* L.s. mays in Malanje

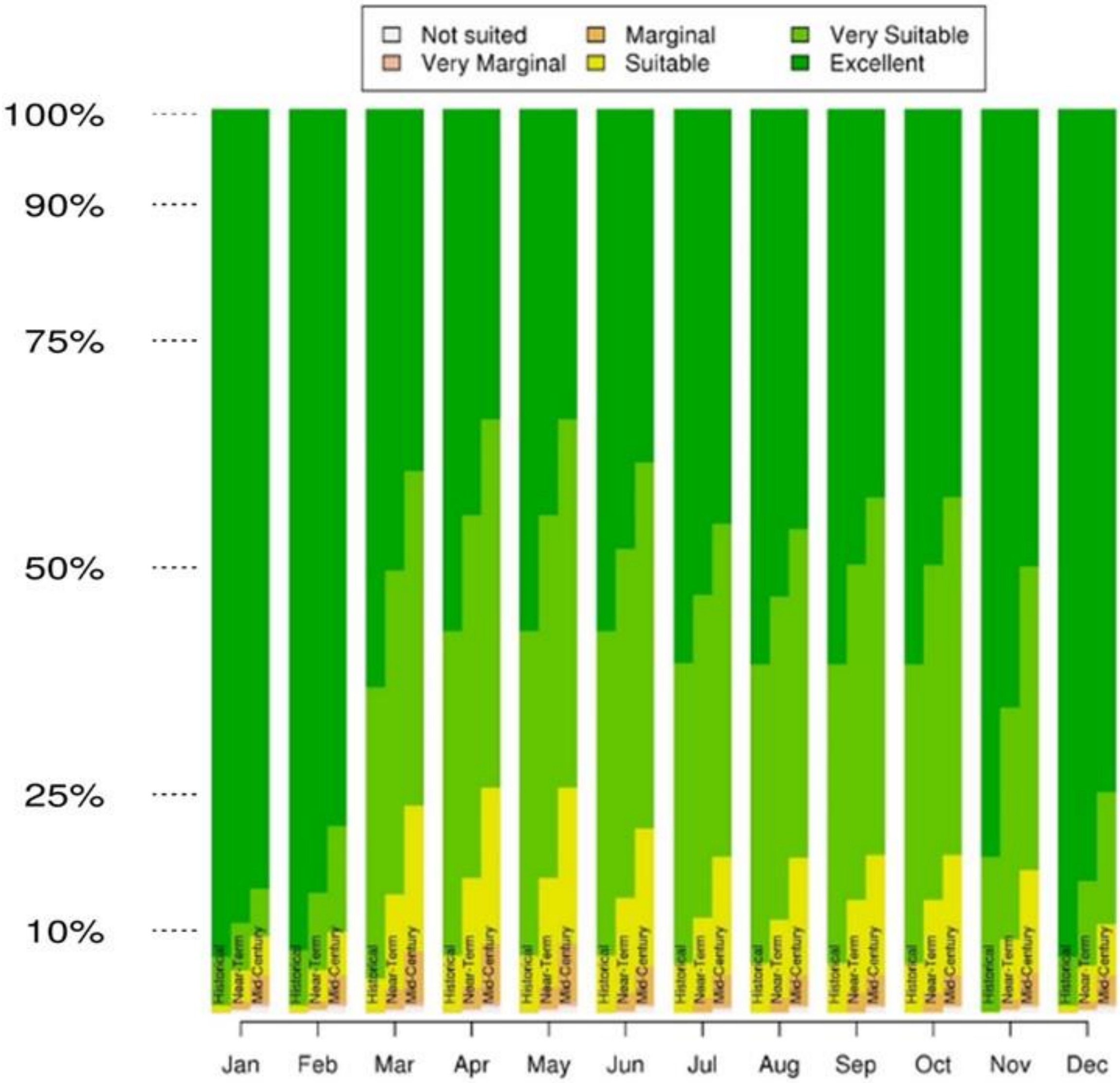


Figure 91. Mean suitability changes of *Zea mays* L.s. *mays* in Malanje

Ecocrop analyses of *Zea mays* L.s. *mays* in Malanje indicate a decrease in the extent of 'excellent' areas during the month of October from 'Baseline' to 'MC 2050', and a concomitant increase in the extent of areas considered 'very suitable' and 'suitable'. This suggests that climate change will decrease the overall suitability of Malanje for *Zea mays* L.s. *mays* in Malanje by reducing growing conditions in 'excellent' areas during the baseline scenario. However, in general it is predicted that in general Malanje will remain an area of strong suitability for maize production, where over 90% of the province is predicted to remain 'very suitable' or 'excellent' by 2050.

4.10. Impact of climate change on spatial distribution of areas suitable for production of Maize, flint or dent (*Z. mays* v. *indurata* or *indentata*)

The figures below summarise the historical (baseline) and future (mid-century 2050) suitability of the six pilot provinces (Bié, Benguela, Cuanza Sul, Huambo, Huíla and Malanje) for production of flint and/or dent maize, *Z. mays v. indurata* or *indentata*, in the months from September to February. In addition to the baseline and future distribution of crop suitability zones, the figures below also illustrate the anomalies (i.e. the absolute changes in suitability at any given location) between the baseline and future time periods.

In the case of flint and dent maize, the main effect of climate change is similar to that described for *Zea mays* Ls. *mays* (previously described above). Climate change is predicted to result in minor but widespread decreases in crop suitability, particularly at the onset of the rainy season in ~October. In Huíla province, the absolute spatial extent of areas which are suitable for maize production are predicted to decrease considerably as a result of climate change, to the extent that the province is likely to become poorly suited to the crop by the mid-century 2050 timepoint. Of the remaining five provinces, the absolute spatial extent of maize-suitable production areas are predicted to remain consistent but are predicted to undergo decreases in crop suitability index score. The reduced suitability for maize production is suggested to be attributable to increased temperatures during the growing season, as well as delayed onset of rainfall in the early growing months of September and October.

As described previously for *Z. mays* Ls. *mays*, a secondary effect of climate change may be to shorten or delay the onset of the growing season. In the case of dent/flint maize types, small areas of all provinces except Huíla are predicted to benefit from minor increase in crop suitability in November and December. The latter results may potentially be attributable to anomalous increases in mean monthly rainfall in the aforementioned months.

The provincial changes in suitability for flint and dent maize production in the period from Baseline to Mid-Century 2050 are discussed further below.

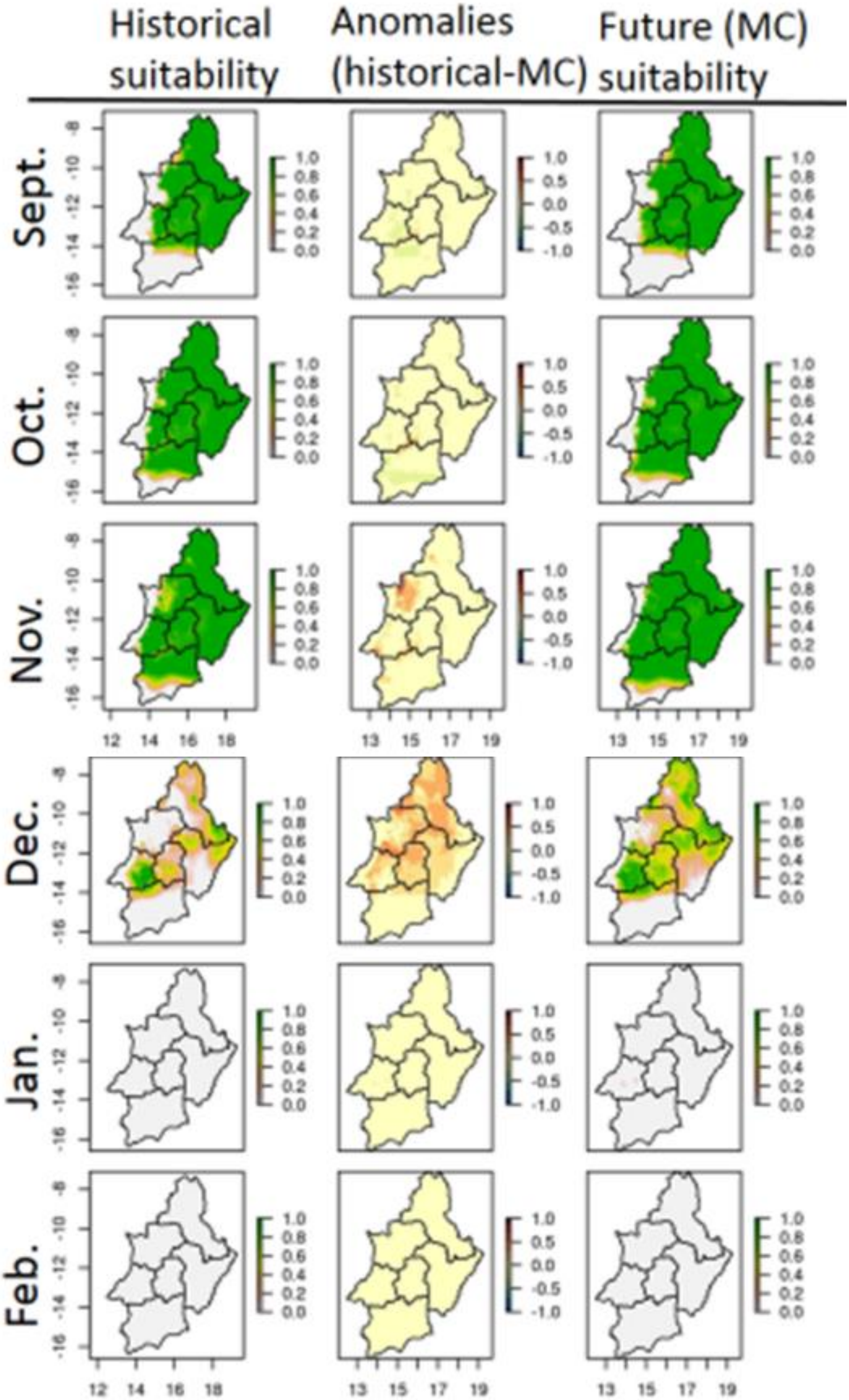


Figure 92. Distribution and changes to suitability for flint/dent maize (*Z. mays indurata*/*indentata*) production in the 'baseline' (left) and 'mid-century 2050' (right) scenario in the months of September to February

4.10a Impact of climate change on production of flint or dent maize (*Z. mays indurata* or *indentata*) in Benguela

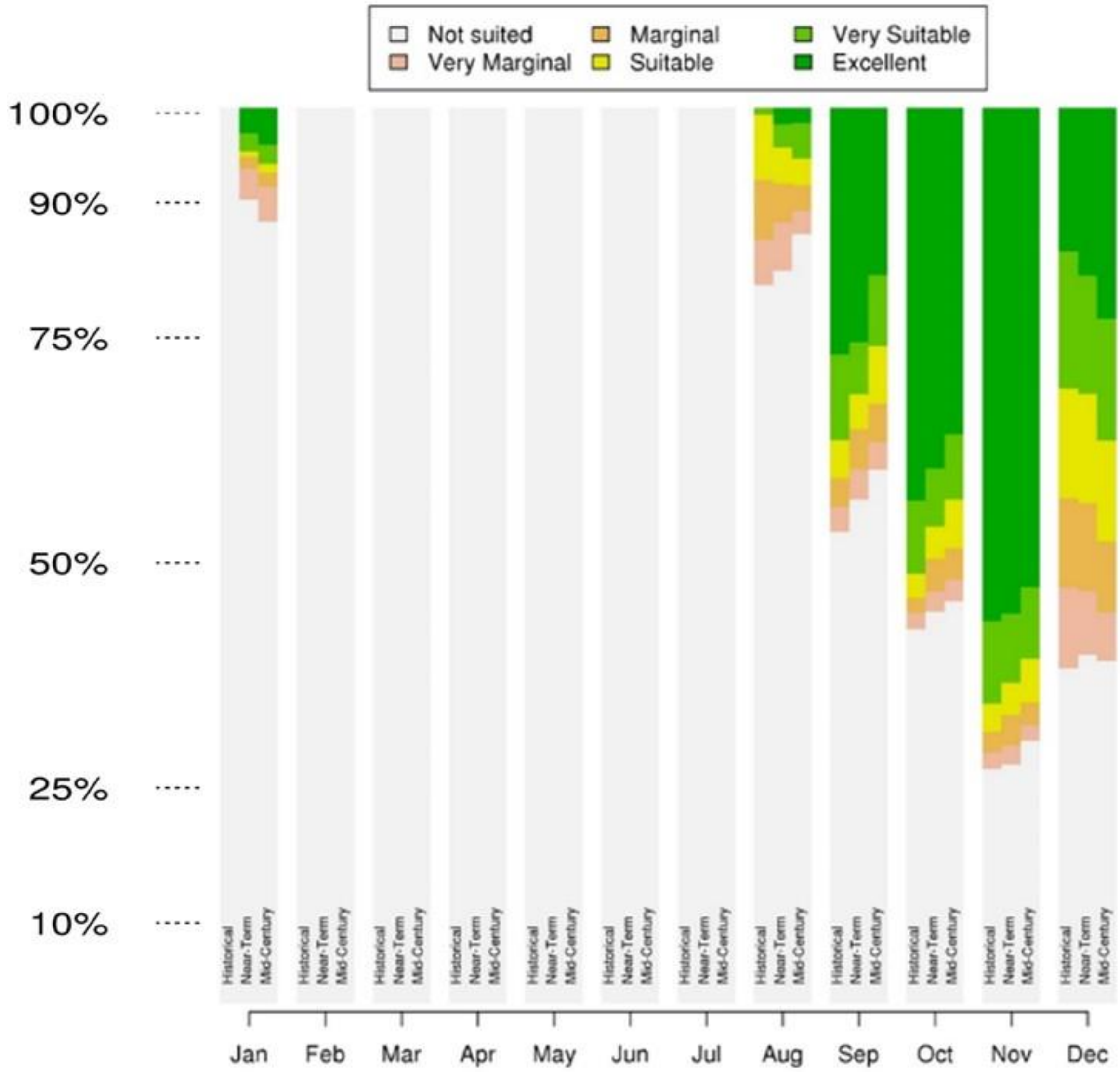


Figure 93. Mean suitability changes of Maize, flint or dent (*Z. mays v. indurata* or *indentata* Sturtmays) in Benguela

The total area suitable for growing flint or dent maize (*Z. mays* v. *indurata* or *indentata* Sturtmays) in Benguela during the month of October is predicted to decrease from 'Baseline' to 'MC 2050'. The total spatial area of suitability is greatest during the month of November, however, those areas considered 'excellent' are predicted to decrease from 'Baseline' to 'MC 2050'. The total area suitable for crop growth decreases greatly from December to January.

4.10b Impact of climate change on production of flint or dent maize (*Z. mays indurata* or *indentata*) in Bié

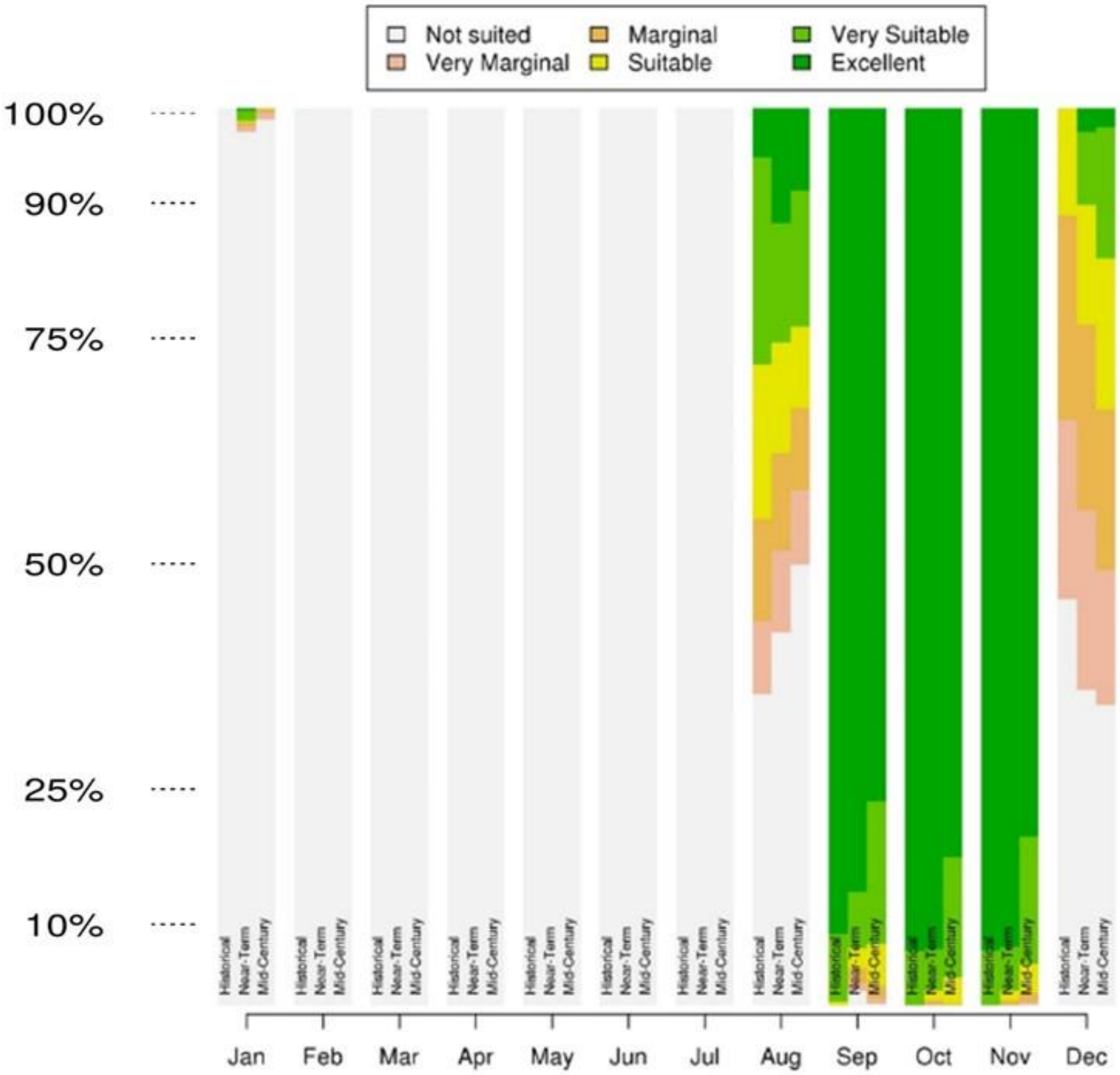


Figure 94. Mean suitability changes of Maize, flint or dent (*Z. mays v. indurata* or *indentata* Sturtmays) in Bié

The total area suitable for growing Maize, flint or dent (*Z. mays* v. *indurata* or *indentata* Sturtmays) in Bié is predicted to remain relatively constant during the month of October from 'Baseline' to 'MC 2050' time points. The most significant change to the distribution of *Z. mays* v. *indurata* or *indentata* Sturtmays in Bié during October is the slight decrease in the extent of areas considered 'excellent' and 'very suitable' from 'Baseline' to 'MC 2050' time points. The total spatial area of suitability for growing *Z. mays* v. *indurata* or *indentata* Sturtmays in Bié is greatest during the summer months from September to November.

4.10c Impact of climate change on production of flint or dent maize (*Z. mays indurata* or *indentata*) in Cuanza Sul

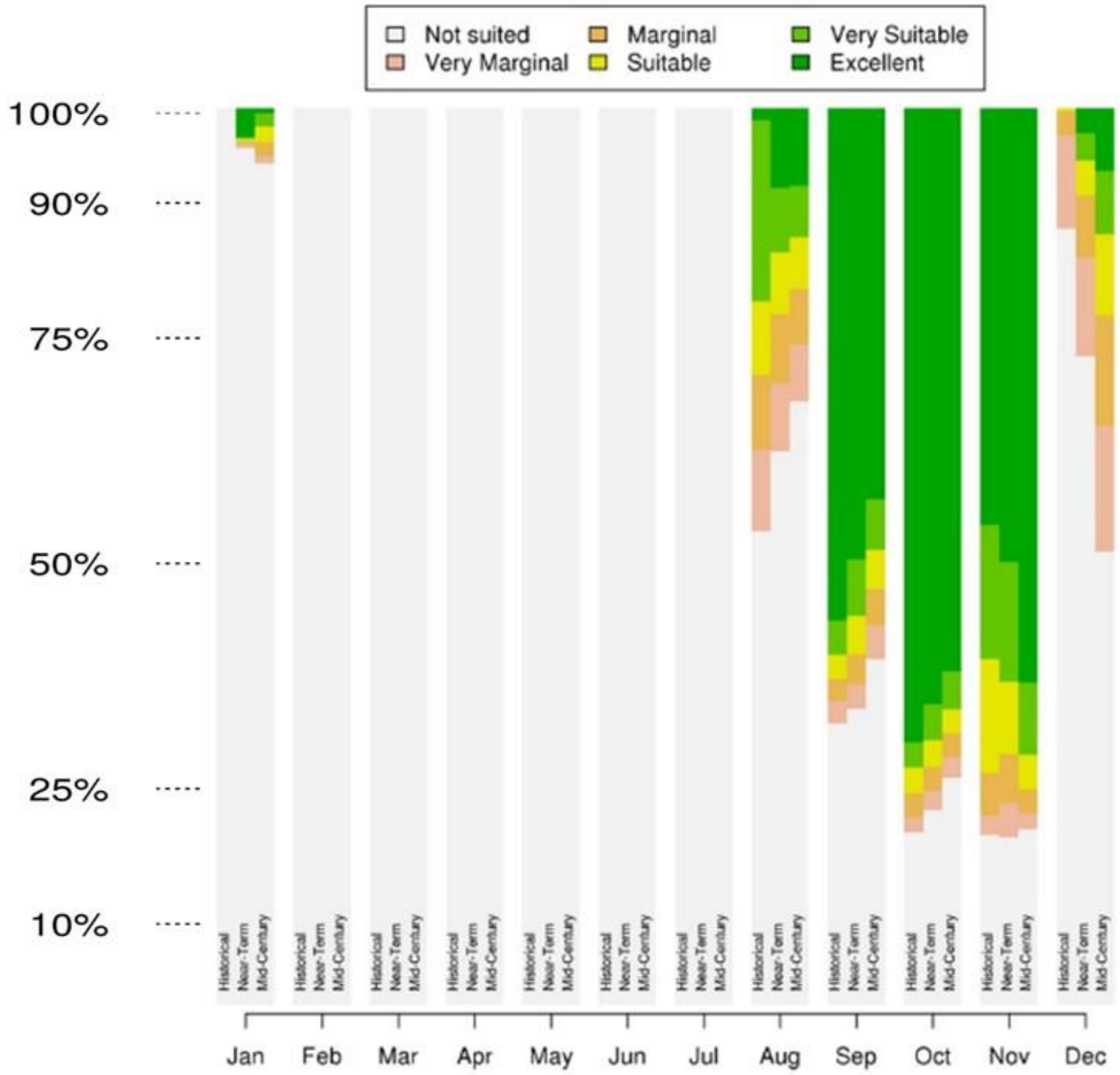


Figure 94. Mean suitability changes of Maize, flint or dent (*Z. mays v. indurata* or *indentata* Sturtmays) in Cuanza Sul

The total area of suitability of Maize, flint or dent (*Z. mays v. indurata* or *indentata* Sturtmays) is predicted to increase from 'Baseline' to 'MC 2050'. The overall decrease in the extent of suitable growing area is a result of a decrease in the extent of area considered 'excellent'. The total spatial area of suitability is greatest during the month of November, during which area considered 'excellent' is projected to increase from 'Baseline' to 'MC 2050' time points. The total area suitable for growth decreases greatly from December to January, and zero suitability is predicted from February to July. Similar to the effect observed in Huambo and Malanje provinces (and to a lesser degree in Benguela), climate change may result in a delayed onset or shortening of the growing season for flint and dent maize, where the months of November and December are predicted to be comparatively more suitable in the future 'MC 2050' scenario relative to the baseline.

4.10d Impact of climate change on production of flint or dent maize (*Z. mays indurata* or *indentata*) in Huambo

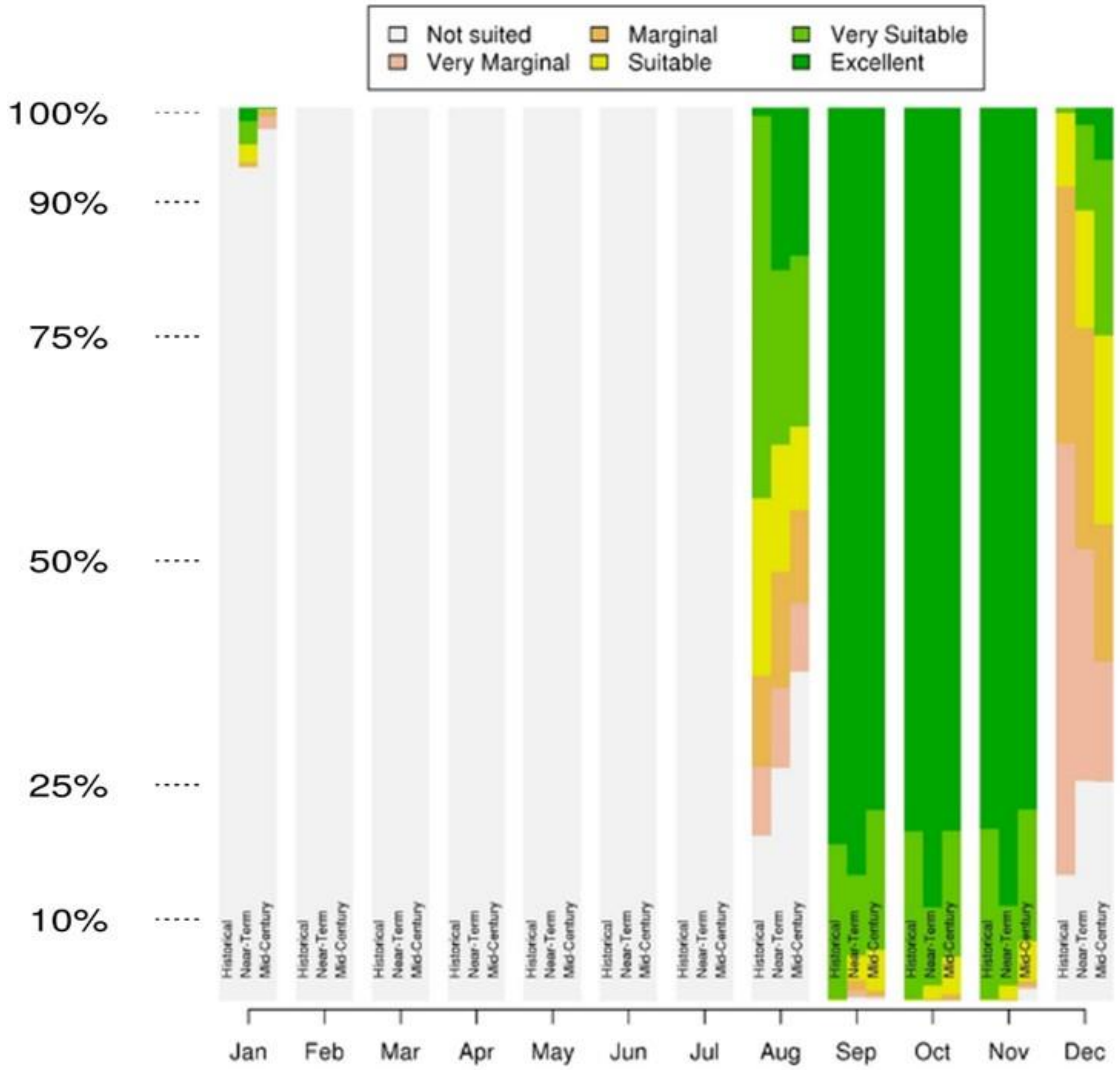


Figure 95. Mean suitability changes of Maize, flint or dent (*Z. mays v. indurata* or *indentata* Sturtmays) in Huambo

During the month of October the extent of land considered to be 'excellent' for growing Maize, flint or dent (*Z. mays v. indurata* or *indentata* Sturtmays) in Huambo is predicted to increase between 'Baseline' and 'NT 2030', and decrease from 'NT 2030' to 'MC 2050' time points. The total spatial area of suitability for growing *Z. mays v. indurata* or *indentata* Sturtmays in Huambo is greatest during the months of September to November, and remains quite consistent and comparable between these three months. In general, the overall extent of land suitable for production of flint or dent maize is predicted to remain relatively constant in Huambo despite the effects of climate change.

4.10e Impact of climate change on production of flint or dent maize (*Z. mays indurata or indentata*) in Huíla

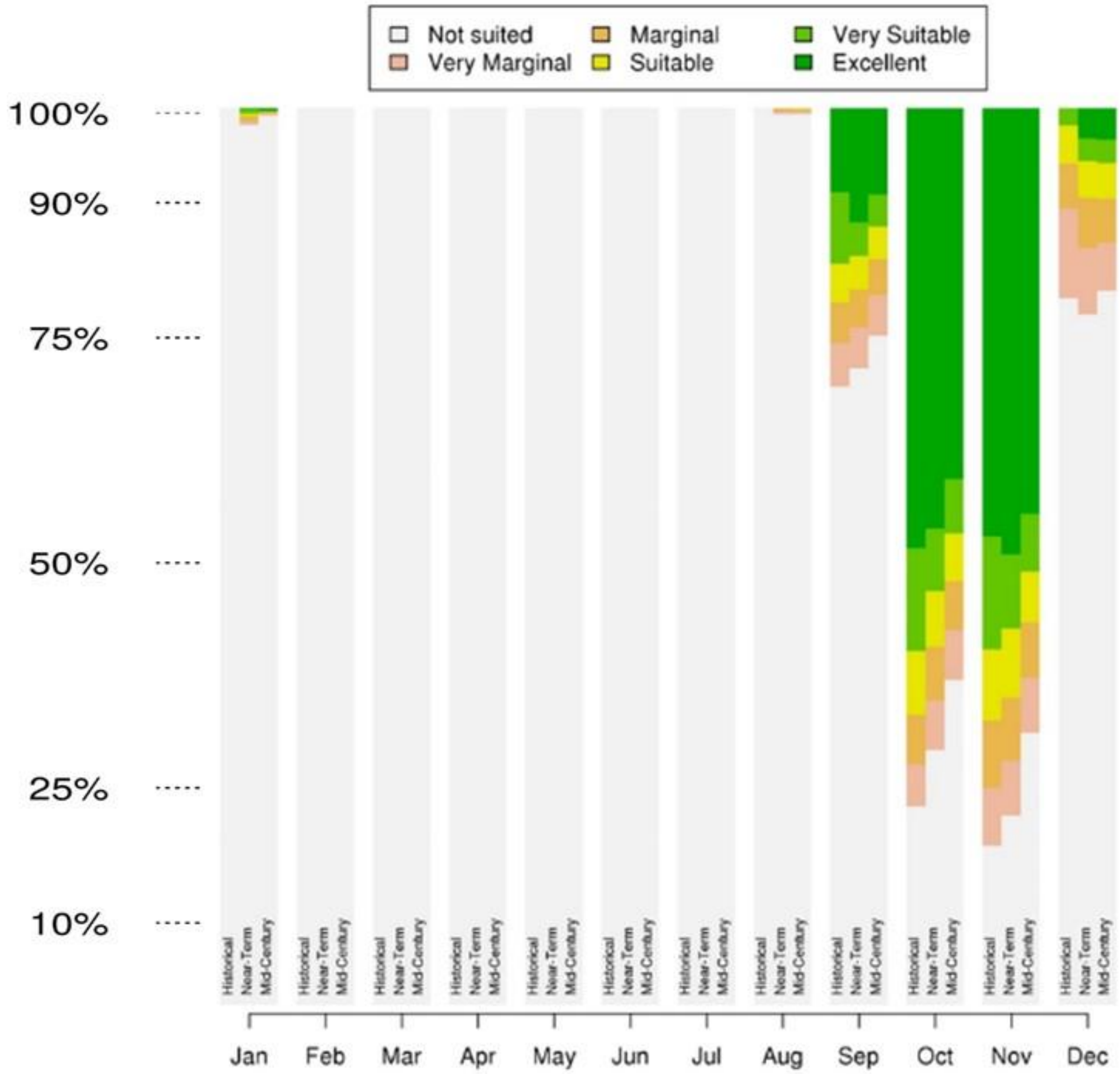


Figure 96. Mean suitability changes of Maize, flint or dent (*Z. mays v. indurata* or *indentata* Sturtmays) in Huíla

The total area suitable for growing Maize, flint or dent (*Z. mays v. indurata* or *indentata* Sturtmays) in Huíla during the month of October is predicted to decrease from 'Baseline' to 'MC 2050', primarily as a result of a reduction in the area categorised as 'excellent'. The total spatial area of suitability is greatest during the month of November. The total area suitable for crop growth decreases greatly from December to January, whilst zero suitability is predicted from February to July.

During the month of October (and onward throughout successive months of the growing season), it is predicted that the total area of Huíla which is suitable for production of flint or dent maize (*Z. mays v. indurata* or *indentata* Sturtmays) will decrease considerably during the period from 'Baseline' to 'MC 2050' time points. The decrease in total area of suitability is characterised by reductions in areas categorised as 'excellent', 'highly suitable' and 'suitable'. Mapped anomalies of crop suitability changes indicate that the existing and predicted future range of *Z. mays* production in Huíla is confined to the northern interior highlands of the province. The western and southern extents of Huíla province remain wholly unsuitable for production of flint and dent maize.

4.10f Impact of climate change on production of flint or dent maize (*Z. mays indurata* or *indentata*) in Malanje

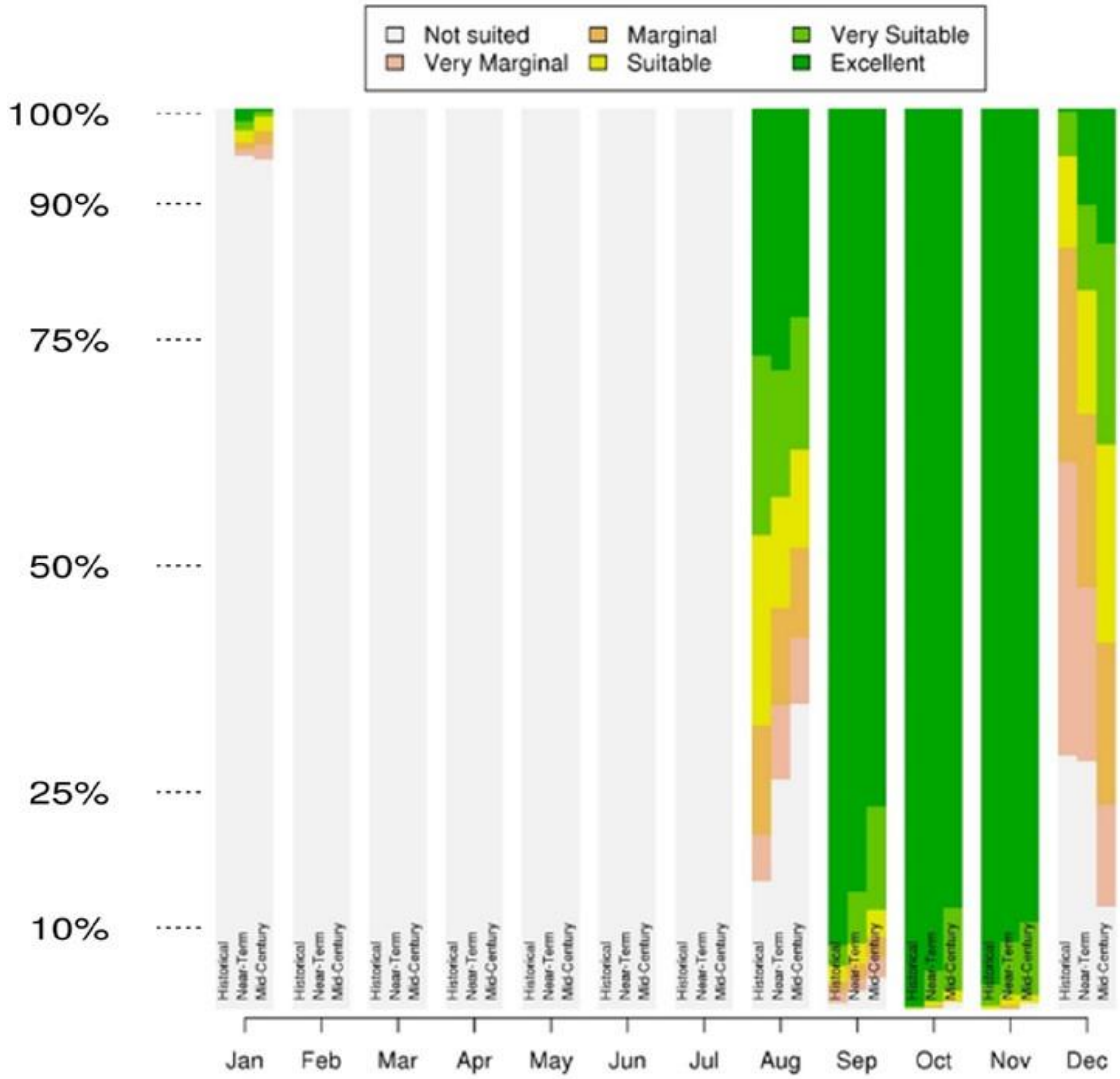


Figure 97. Mean suitability changes of Maize, flint or dent (*Z. mays v. indurata* or *indentata* Sturtmays) in Malanje

The impact of climate change on the total spatial area of suitability for Maize, flint or dent (*Z. mays v. indurata* or *indentata* Sturtmays) in Malanje is similar to the analyses undertaken for *Z. mays* Ls. mays (described above). EcoCrop analyses predict that the distribution of crop suitability across Malanje for production of *Z. mays* v. *indurata* or *indentata* is predicted to remain relatively consistent during 'Baseline' to 'MC 2050' during the rainy season months, primarily the period from September – November. Ecocrop analyses indicate that, in the baseline scenario for the month of October, the entire province of Malanje is considered to be 'excellent' for production of *Z. mays v. indurata* or *indentata* Sturtmays. The only notable effect of climate change during the months of September to November is that the area of 'excellent' suitability is predicted to decrease by ~5% by 2050, with a concomitant increase in the extent of 'very suitable' and 'suitable' areas during the period from 'Baseline' to 'MC 2050' time points. Similar to the effect observed in Huambo and Cuanza Sul (and to a lesser degree in Benguela), climate change may result in a delayed onset or shortening of the growing season for flint and dent maize in Malanje, where the months of November and December are predicted to be comparatively more suitable in the future 'MC 2050' scenario relative to the baseline.

4.11. Impact of climate change on spatial distribution of areas suitable for production of soft, pop and pod maize, soft, pop and pod (*Z. mays* v. *amylacea*, *everta*, *tunicata*)

The figures below summarise the historical (baseline) and future (mid-century 2050) suitability of the six pilot provinces (Bié, Benguela, Cuanza Sul, Huambo, Huíla and Malanje) for production of soft, pod and pop maize in the months from September to February. In addition to the baseline and future distribution of crop suitability zones, the figures below also illustrate the anomalies (i.e. the absolute changes in suitability at any given location) between the baseline and future time periods.

In the case of *Z. mays v. amylacea, everta* and *tunicata*, the main effect of climate change is similar to that described previously for i) *Z. mays* v. *indurata* or *indentata*; and ii) *Z. mays* Ls. *mays*. Climate change is predicted to result in minor but widespread decreases in crop suitability, particularly at the onset of the rainy season in ~October. In Huíla province, the absolute spatial extent of areas which are suitable for maize production are predicted to decrease considerably as a result of climate change, to the extent that the province is likely to become poorly suited to the crop by the mid-century 2050 timepoint. Of the remaining five provinces, the absolute spatial extent of maize-suitable production areas are predicted to remain consistent but are predicted to undergo decreases in crop suitability index score. The reduced suitability for maize production is suggested to be attributable to increased temperatures during the growing season, as well as delayed onset of rainfall in the early growing months of September and October.

As described previously for other varieties of maize, a secondary effect of climate change may be to shorten or delay the onset of the growing season. In the case of soft, pop and pod maize types, small areas of all provinces except Huíla are predicted to benefit from minor increase in crop suitability in November and December. The latter results may potentially be attributable to anomalous increases in mean monthly rainfall in the aforementioned months.

The provincial changes in suitability for production of *Z. mays v. amylacea, everta* and *tunicata* in the period from Baseline to Mid-Century 2050 are discussed further below.

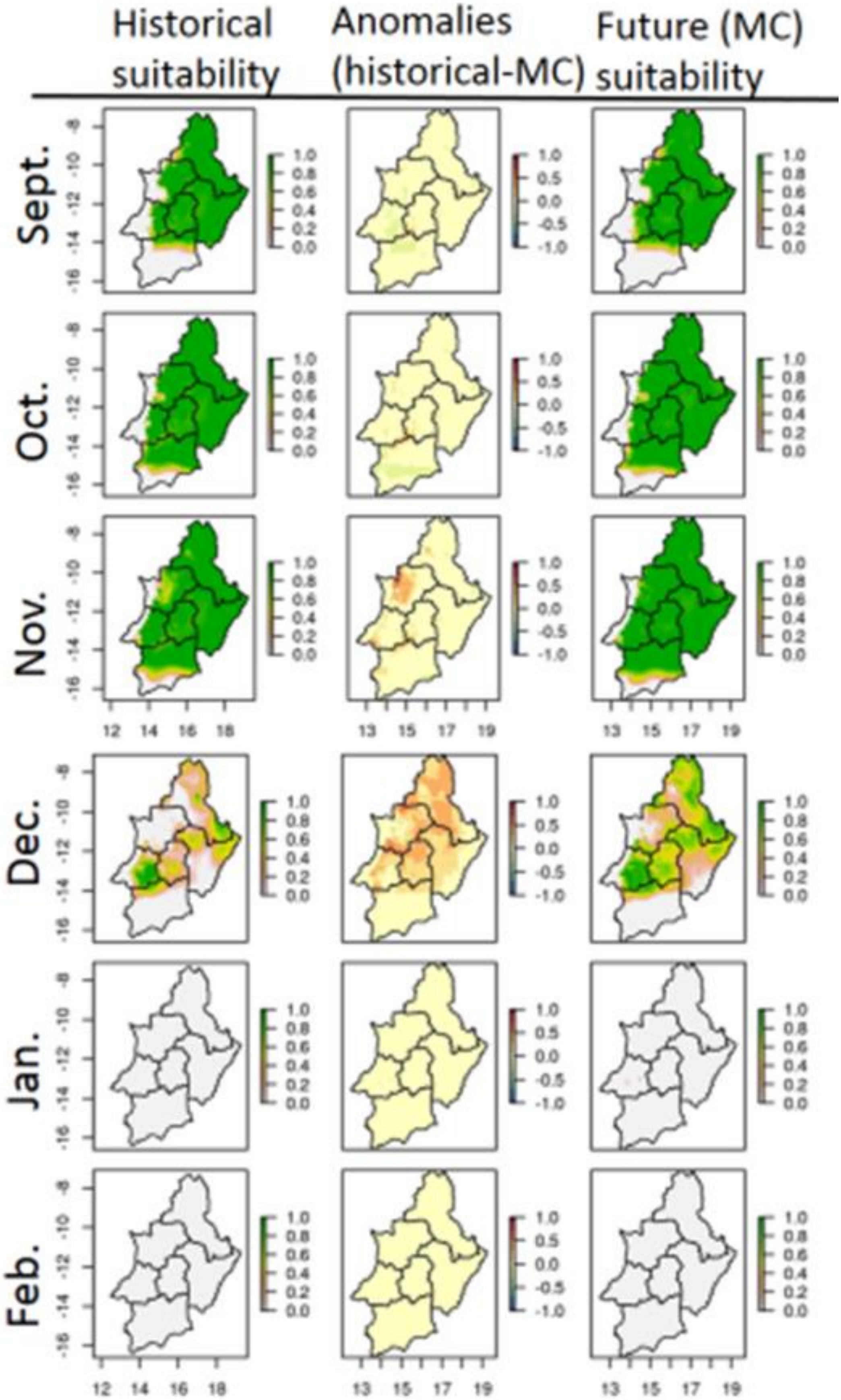


Figure 98. Distribution and changes to suitability for pop, pod or soft maize (*Z. mays v. amylacea, everta* and *tunicata*) production in the 'baseline' (left) and 'mid-century 2050' (right) scenario in the months of September to February

4.11a Impact of climate change on production of soft, pop and pod maize *(Z. mays v. amylacea, everta*, *tunicata*) in Benguela

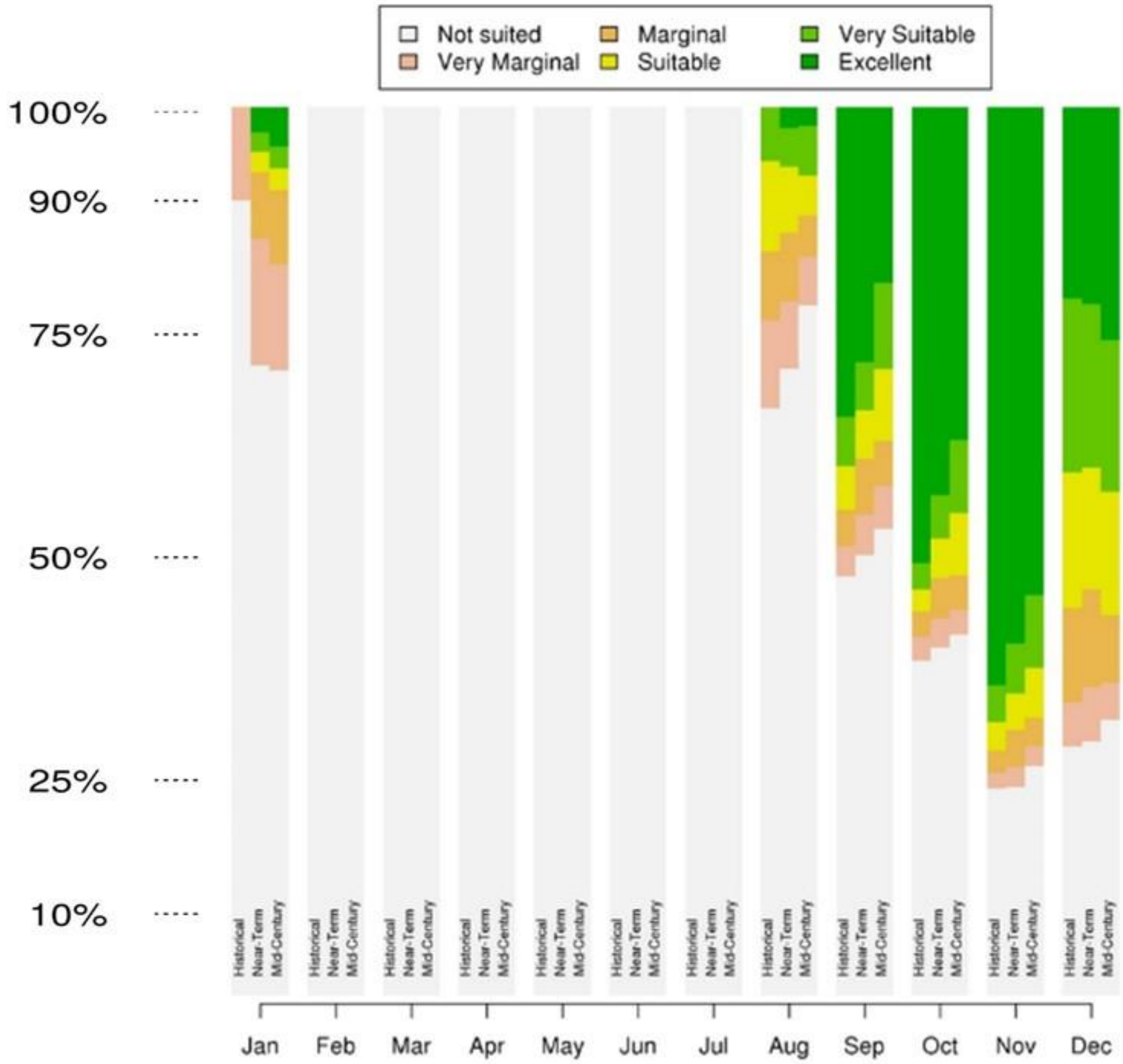


Figure 99. Mean suitability changes of Maize, soft, pop and pod (*Z. mays v. amylacea, everta, tunicata*) in Benguela

During the month of October the total area suitable for growing Maize, soft, pop and pod (*Z. mays v. amylacea, everta, tunicata*) in Benguela is predicted to decrease from 'Baseline' to 'MC 2050', however areas considered 'very suitable' and 'suitable' are predicted to increase from 'Baseline' to 'MC 2050'. The total provincial decrease in suitability for *Z. mays v. amylacea, everta, tunicata* in Benguela can be attributed to a decrease in in the extent of areas considered 'excellent'. The total spatial area of suitability is greatest during August to December, whilst the months between and including February to July illustrate zero suitability for crop growth.

4.11b Impact of climate change on production of soft, pop and pod maize (*Z. mays v. amylacea, everta, tunicata*) in Bié

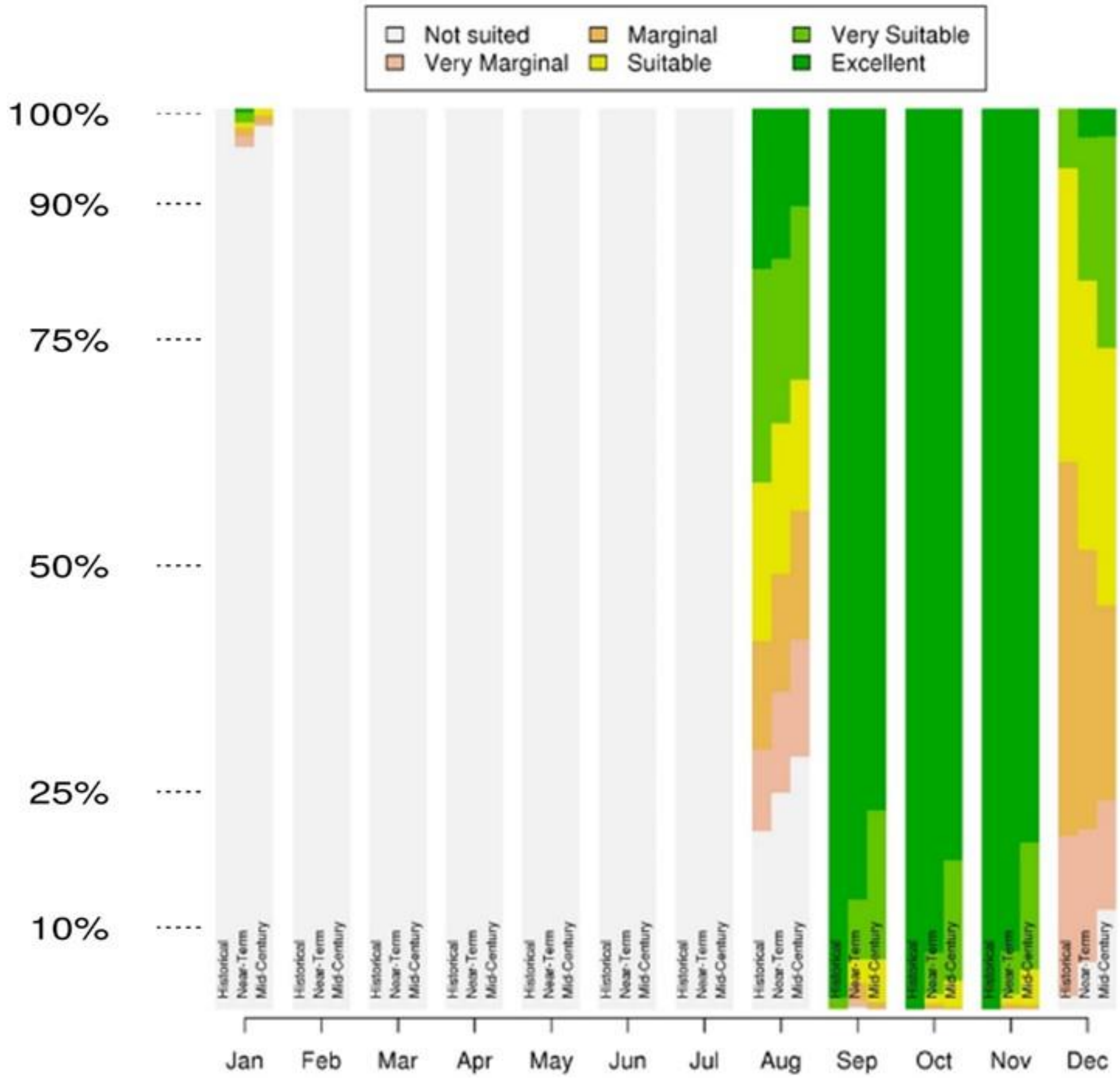


Figure 100. Mean suitability changes Maize, soft, pop and pod (*Z. mays v. amylacea, everta, tunicata*) in Bié

The total area suitable for growing Maize, soft, pop and pod (*Z. mays v. amylacea, everta, tunicata*) in Bié is predicted to remain relatively constant during the month of October from 'Baseline' to 'MC 2050' time points during October. Ecocrop analyses indicate that Bié is almost entirely suitable for *Z. mays v. amylacea, everta* and *tunicata* production for baseline scenario, it is predicted that areas considered 'excellent' will decrease by nearly a ¼ in extent of area from 'Baseline' to 'MC 2050'. The decrease in the extent of 'excellent' areas is partly offset by a smaller increase in areas considered 'suitable' from 'Baseline' and 'MC 2050' time points.

4.11c Impact of climate change on production of soft, pop and pod maize (*Z. mays v. amylacea, everta, tunicata*) in Cuanza Sul

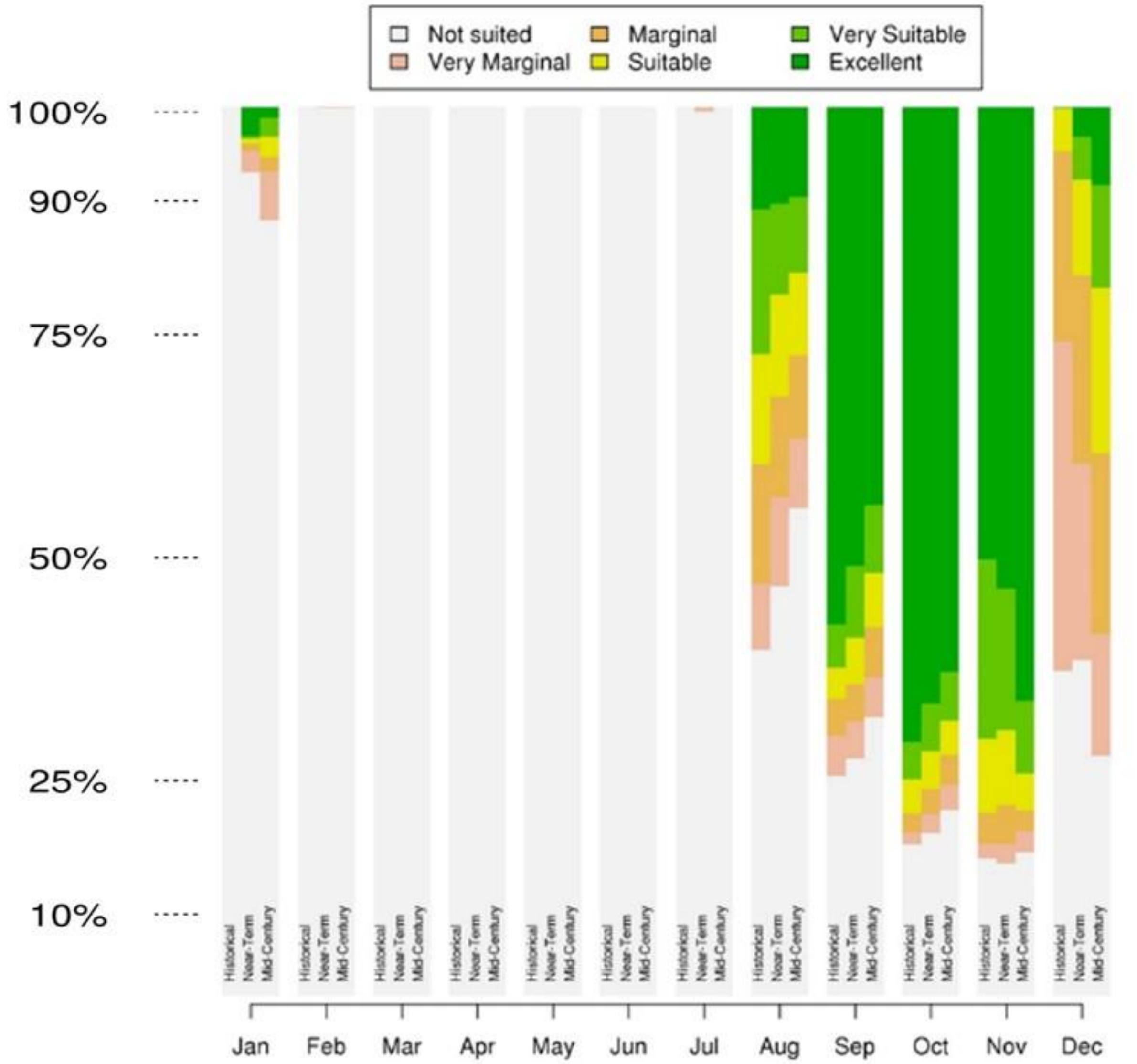


Figure 101. Mean suitability changes of Maize, soft, pop and pod (*Z. mays v. amylacea, everta, tunicata*) in Cuanza Sul

During the month of October the total area suitable for growing Maize, soft, pop and pod (*Z. mays v. amylacea, everta* and *tunicata*) in Cuanza Sul is predicted to decrease slightly from 'Baseline' to 'MC 2050'. However, despite this overall decrease in suitability there is also predicted to be an increase in the extent of those areas categorised as 'very suitable' between the 'Baseline' and 'MC 2050' time points in October. The total spatial area of suitability is greatest during the months of September to December.

4.11d Impact of climate change on production of soft, pop and pod maize (*Z. mays v. amylacea, everta, tunicata*) in Huambo

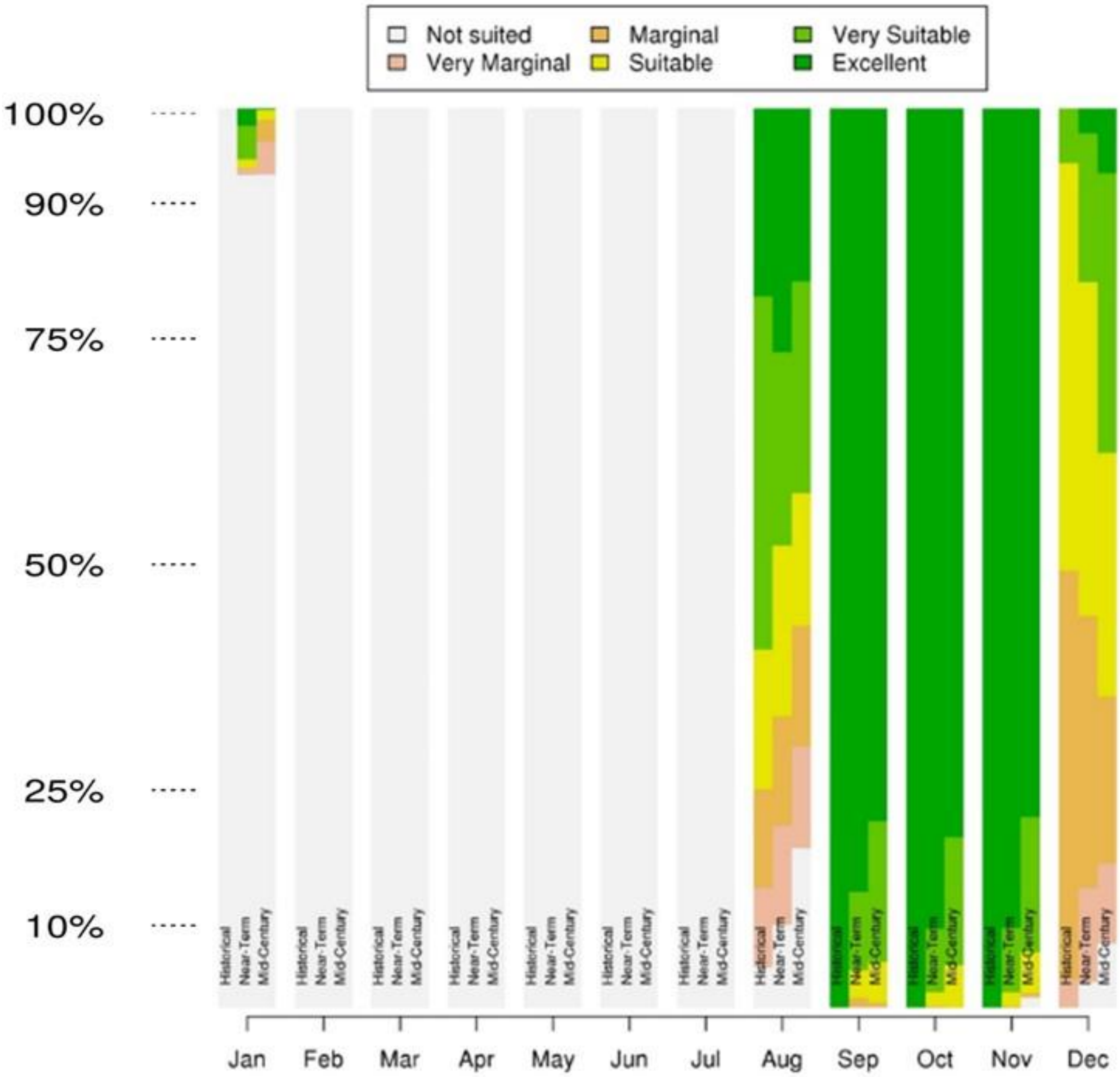


Figure 102. Mean suitability changes of Maize, soft, pop and pod (*Z. mays v. amylacea, everta, tunicata*) in Huambo

The total spatial area of suitability for Maize, soft, pop and pod (*Z. mays v. amylacea, everta, tunicata*) is predicted to remain constant during the 'Baseline' to 'MC 2050' during the month of October. Ecocrop analyses indicate that Huambo is almost entirely suitable for *Z. mays v. amylacea, everta, tunicate* production, it is predicted that areas considered 'excellent' will decrease by nearly a ¼ in extent of area from 'Baseline' to 'MC 2050'. The decrease in the extent of 'excellent' areas is partly offset by a smaller increase in areas considered 'very suitable' from 'Baseline' and 'MC 2050' time points.

4.11e Impact of climate change on production of soft, pop and pod maize (*Z. mays v. amylacea, everta, tunicata*) in Huíla

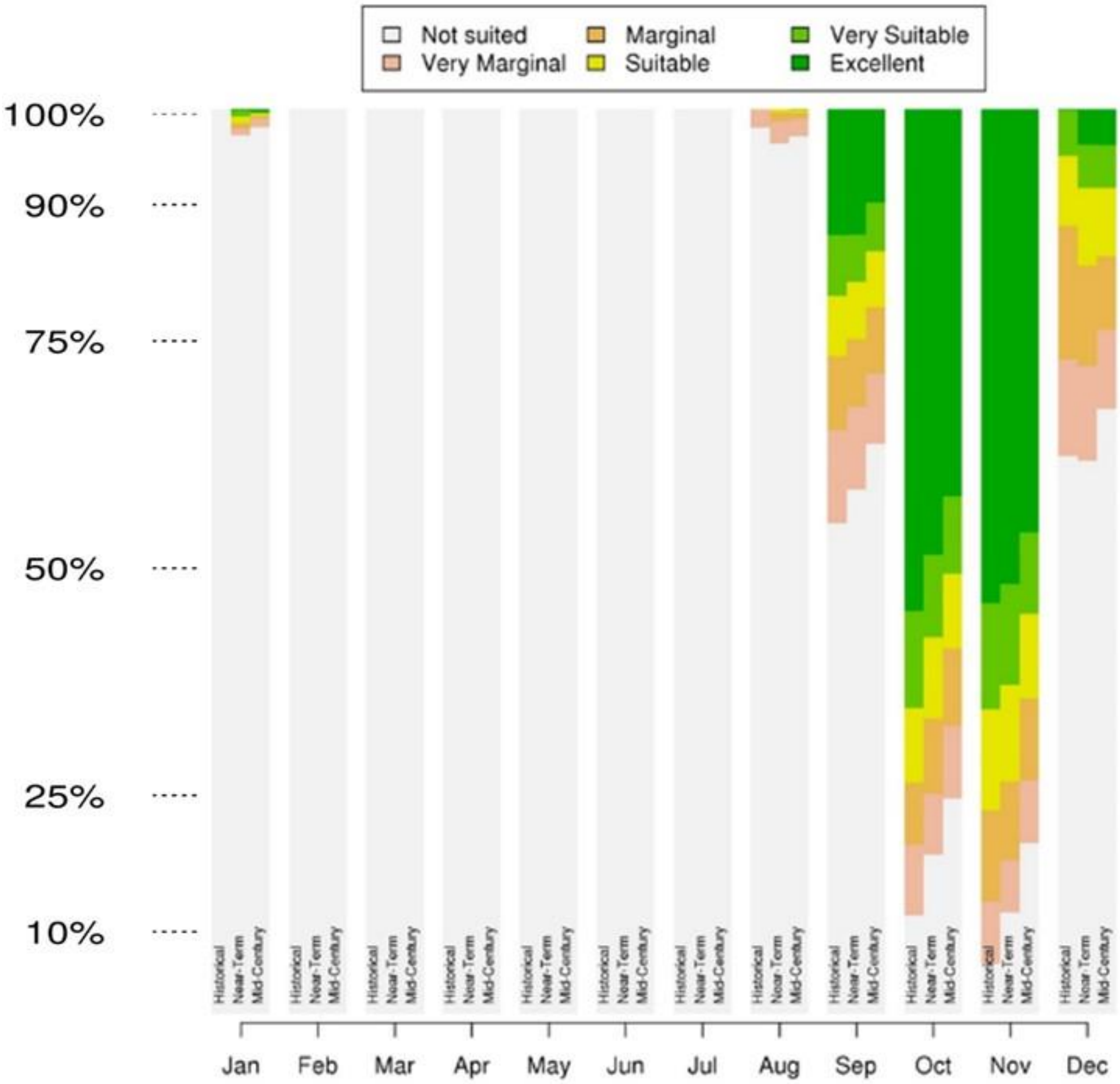


Figure 103. Mean suitability changes of Maize, soft, pop and pod (*Z. mays v. amylacea, everta, tunicata*) in Huíla

During the month of October, the total area suitable for growing Maize, soft, pop and pod (*Z. mays v. amylacea, everta, tunicata*) in Huíla is predicted to decrease from 'Baseline' to 'MC 2050' time points. The decrease in total area suitable during October can be attributed to a decrease in the extent of areas considered 'excellent'. The total spatial area of suitability is greatest during the months of September to November, whilst the months from February to July illustrate zero suitability for the growth of *Z. mays v. amylacea, everta, tunicata* in the province of Huíla.

4.11f Impact of climate change on production of soft, pop and pod maize (*Z. mays v. amylacea, everta, tunicata*) in Malanje

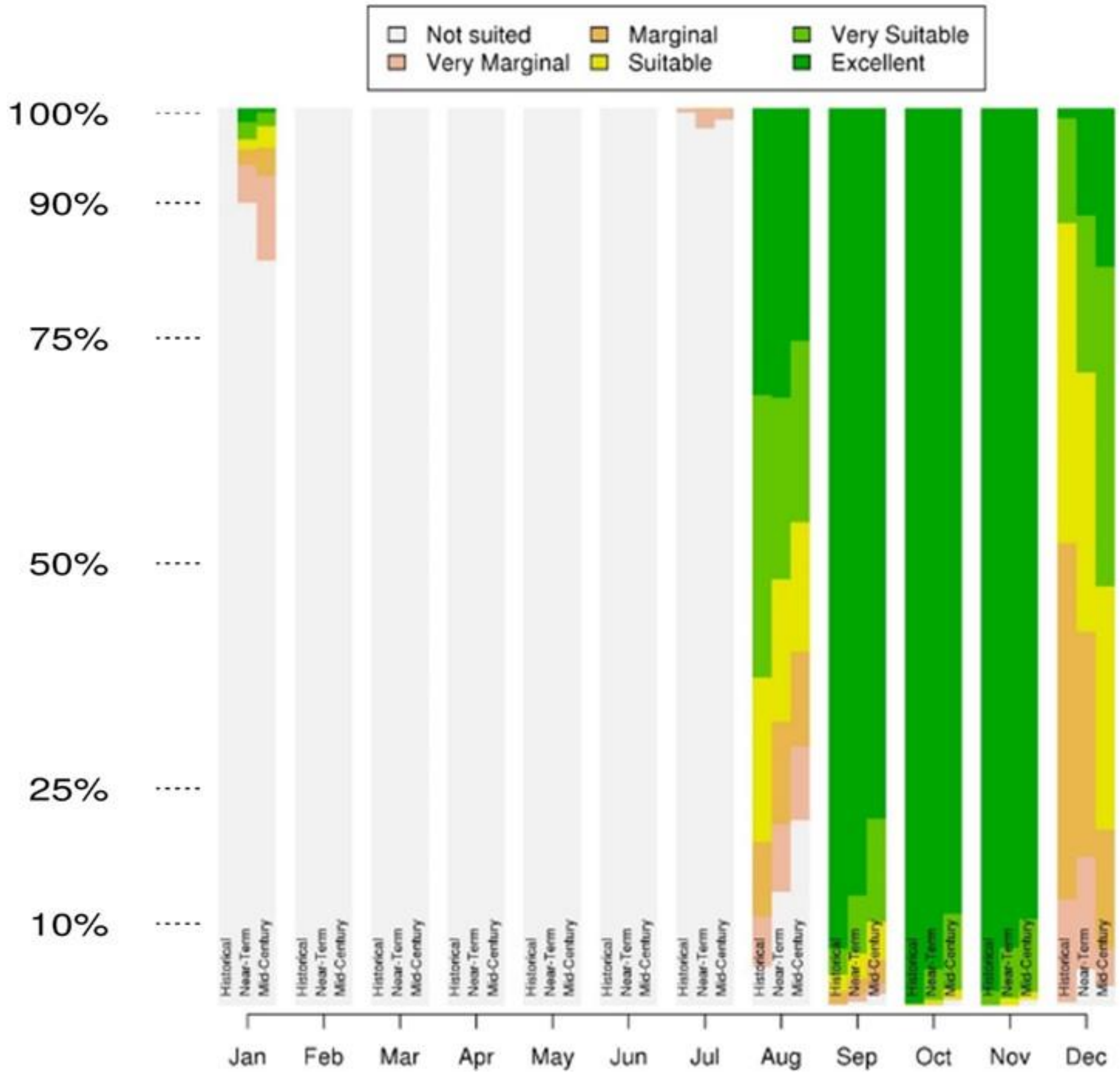


Figure 104. Mean suitability changes of Maize, soft, pop and pod (*Z. mays v. amylacea, everta, tunicata*) in Malanje

The general trend observed in the predicted changes to suitability in Malanje for production of maize, soft, pop and pod (*Z. mays v. amylacea, everta, tunicata*) is comparable to the trend predicted for maize, flint or dent (see above). In the month of October, nearly the entire province is of 'excellent' suitability for *Z. mays v. amylacea, everta, tunicata* production during the baseline scenario. EcoCrop analyses predict that climate change will result in a small decrease (<5%) in the extent of 'excellent' areas during the period from 'Baseline' to 'MC 2050' , with concomitant increases in the extent of land considered 'very suitable' for *Z. mays v. amylacea, everta, tunicata* production.

4.12. Impact of climate change on spatial distribution of areas suitable for production of millet (*Pennisetum glaucum*)

The figures below summarise the historical (baseline) and future (mid-century 2050) suitability of the six pilot provinces (Bié, Benguela, Cuanza Sul, Huambo, Huíla and Malanje) for production of millet (*P. glaucum*) in the months from September to February. In addition to the baseline and future distribution of crop suitability zones, the figures below also illustrate the anomalies (i.e. the absolute changes in suitability at any given location) between the baseline and future time periods.

In the case of millet, the main effect of climate change is to increase the spatial range as well as the average crop suitability index score in all provinces. In all provinces, the months of September to January are characterised by increases in the crop suitability index scores during the period from 'baseline' to 'mid-century 2050' time periods. This increase in suitability is suggested to be attributable to increased average Tmean and Tmin during the months of the active growing season relative to the 'baseline' scenario. In addition, the increased suitability index scores for millet in the mid-to-late summer months of December to February may also be partially attributable to predicted increases in rainfall during the aforementioned months, which could have the effect of extending the growing season for millet in the studied provinces of the planalto region. Therefore, millet may be an appropriate cereal crop to be promoted as a climate-resilient alternative or complement to other staple rainfed crops grown by subsistence and commercial farmers in the planalto.

The provincial changes in suitability for production of millet in the period from Baseline to Mid-Century 2050 are discussed further below.

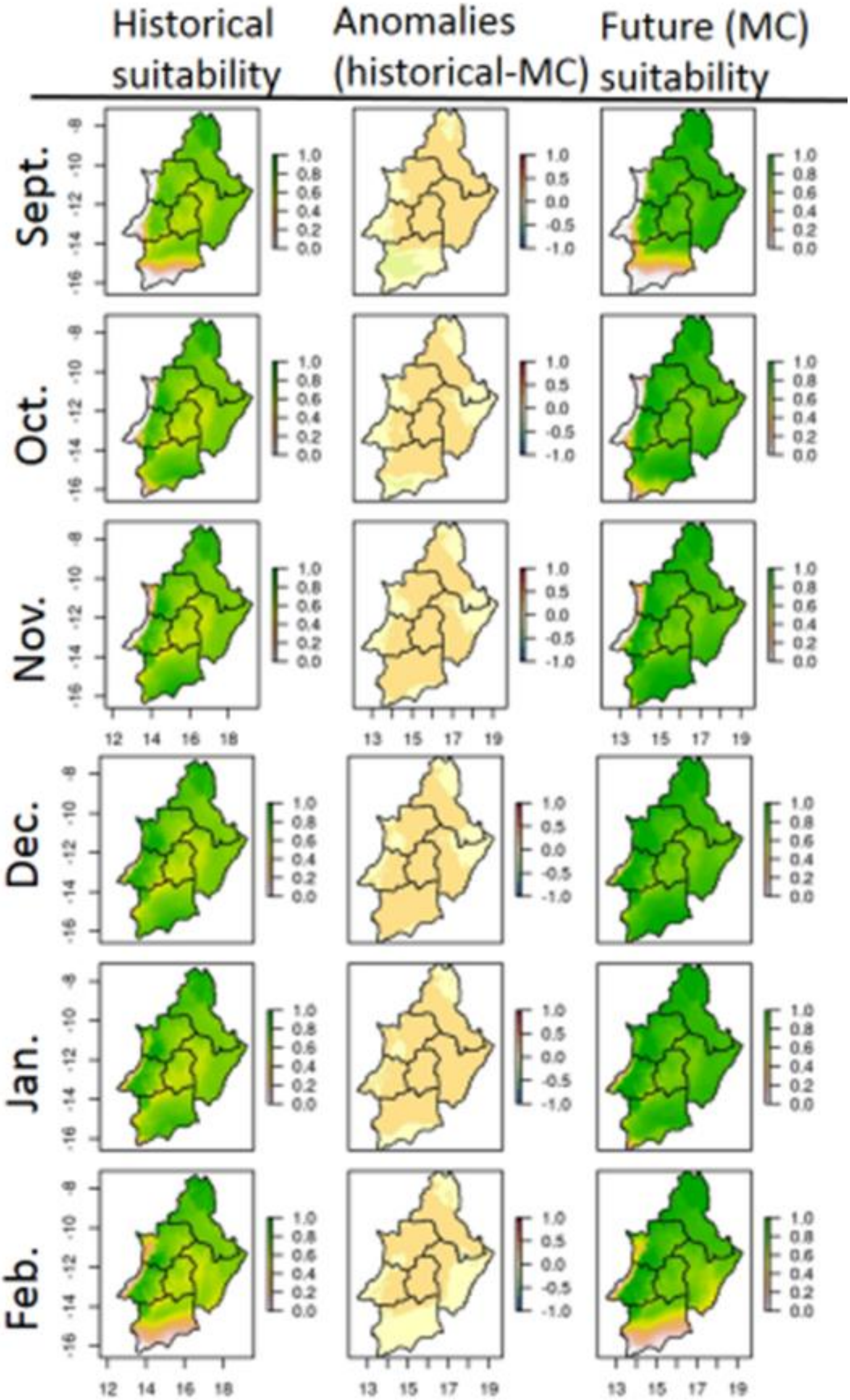


Figure 105. Distribution and changes to suitability for millet (*Pennisetum glaucum*) production in the 'baseline' (left) and 'mid-century 2050' (right) scenario in the months of September to February

4.12a Impact of climate change on production of millet (*Pennisetum glaucum*) in Benguela

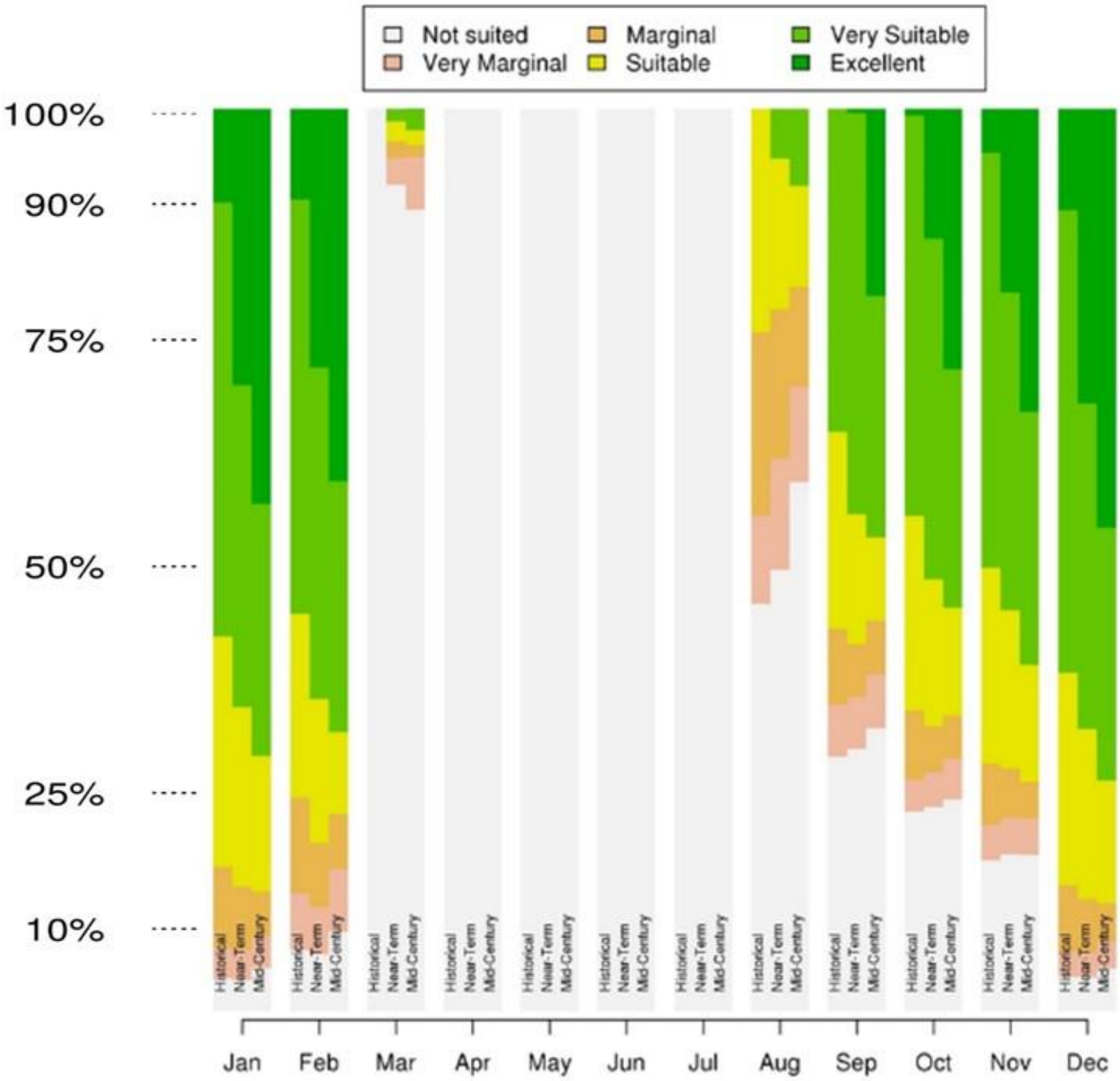


Figure 106. Mean suitability changes of Millet (*Pennisetum glaucum* (L)R.Br.) in Benguela

During the month of October there is an increase in areas considered 'excellent' and 'very suitable' from 'Baseline' to 'MC 2050' projections The total area suitable for Millet (*Pennisetum glaucum* (L)R.Br.) growth in the Benguela province is predicted to show an overall slight decrease between 'Baseline' and 'MC 2050' time points during the month of October. The total spatial area of suitability for growing *P. glaucum* in Benguela is greatest during the summer months between October to February, after which there is a great decrease of suitable growing area during March, and zero suitability from April to July. The projected increase in areas considered 'excellent' and 'very suitable' during October could be a result of an increase in Tmean from ~23 °C (Baseline) to ~24 °C, where *P. glaucum* has an optimum growth temperature ranging between ~25 to 35 °C.

4.12b Impact of climate change on production of millet (*Pennisetum glaucum*) in Bié

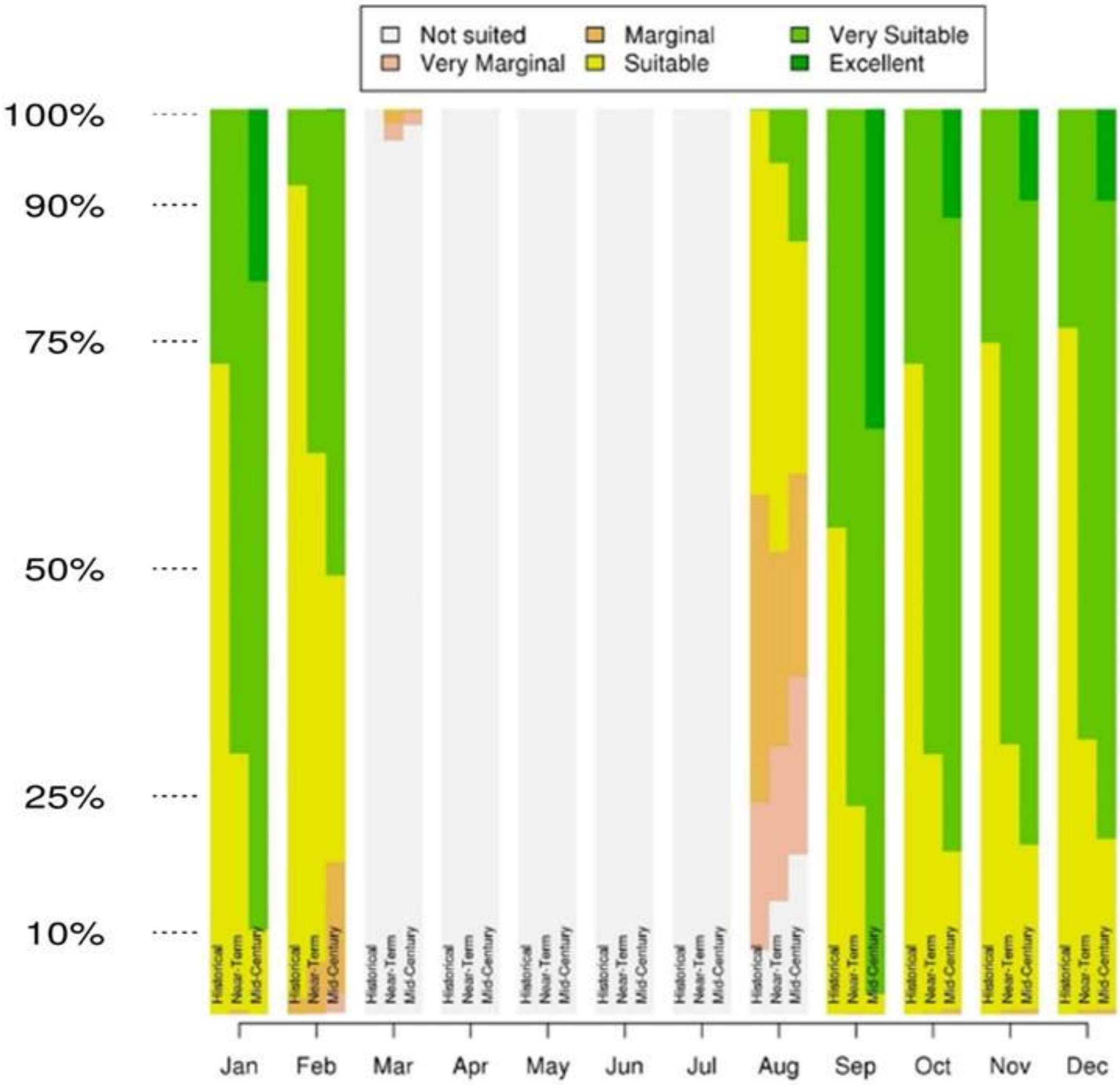


Figure 107. Mean suitability changes Millet (*Pennisetum glaucum* (L)R.Br.) in Bié

During the month of October there is a predicted increase in the spatial extent of areas considered ‘excellent’ and, ‘very suitable’ for growing of millet, while the extent of ‘suitable’ areas is predicted to decrease from the baseline scenario to 2050. This predicted decrease in ‘suitable’ areas, and increase in ‘excellent’ and ‘very suitable’ areas suggest that climate change will increase the future provincial suitability of millet production in Bié. The total spatial area suitable for millet production in the Bié province is greatest during the summer months of September to February. The projected increase in the extent of areas considered ‘excellent’ and ‘very suitable’ during October could be attributed to an increase in Tmean from ~21.5 °C (‘Baseline’) to ~23 °C (NT 2030, MC 2050), where millet has an optimum temperature between ~25 to 35 °C.

4.12c Impact of climate change on production of millet (*Pennisetum glaucum*) in Cuanza Sul

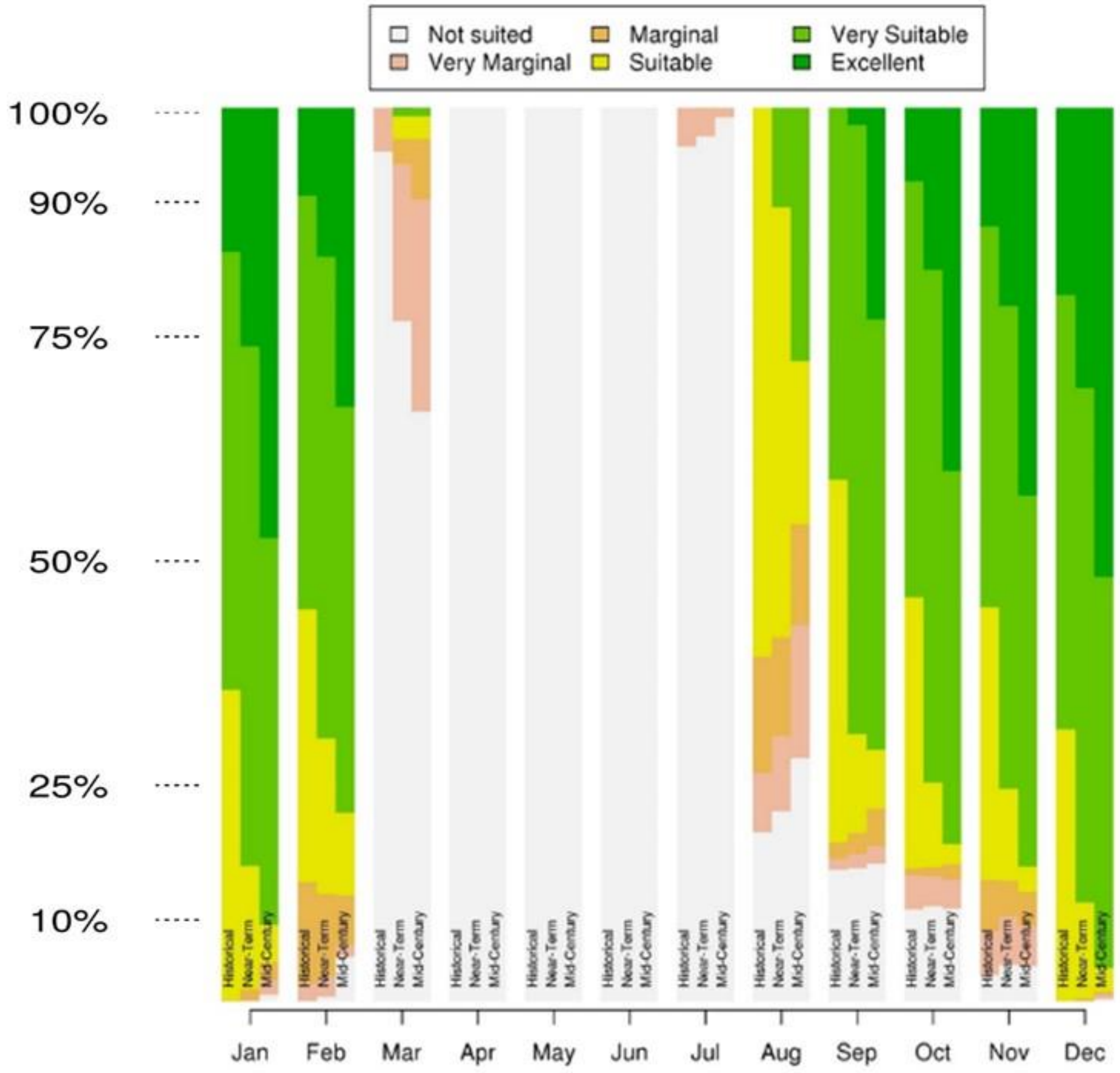


Figure 108. Mean suitability changes of Millet (*Pennisetum glaucum* (L)R.Br.) in Cuanza Sul

During the month of October there is an increase in areas considered 'excellent' and 'very suitable' for growth of millet, however, areas considered 'suitable' are predicted to decrease respectively. The total area suitable for millet growth in the Cuanza Sul province is predicted to slightly decrease from 'Baseline' to 'MC 2050' time points during the month of October. The total spatial area of suitability for growing millet in Cuanza Sul is greatest during the summer months from October to February, after which suitability declines sharply from March onwards. The projected increase in extent of areas considered 'excellent' and 'very suitable' during October could be attributed to an increase in Tmean from ~22 °C ('Baseline') to ~23 °C (NT 2030), and ~22.5 °C (MC 2050), respectively, where millet has an optimum growth temperature between ~25 to 35 °C.

4.12d Impact of climate change on production of millet (*Pennisetum glaucum*) in Huambo

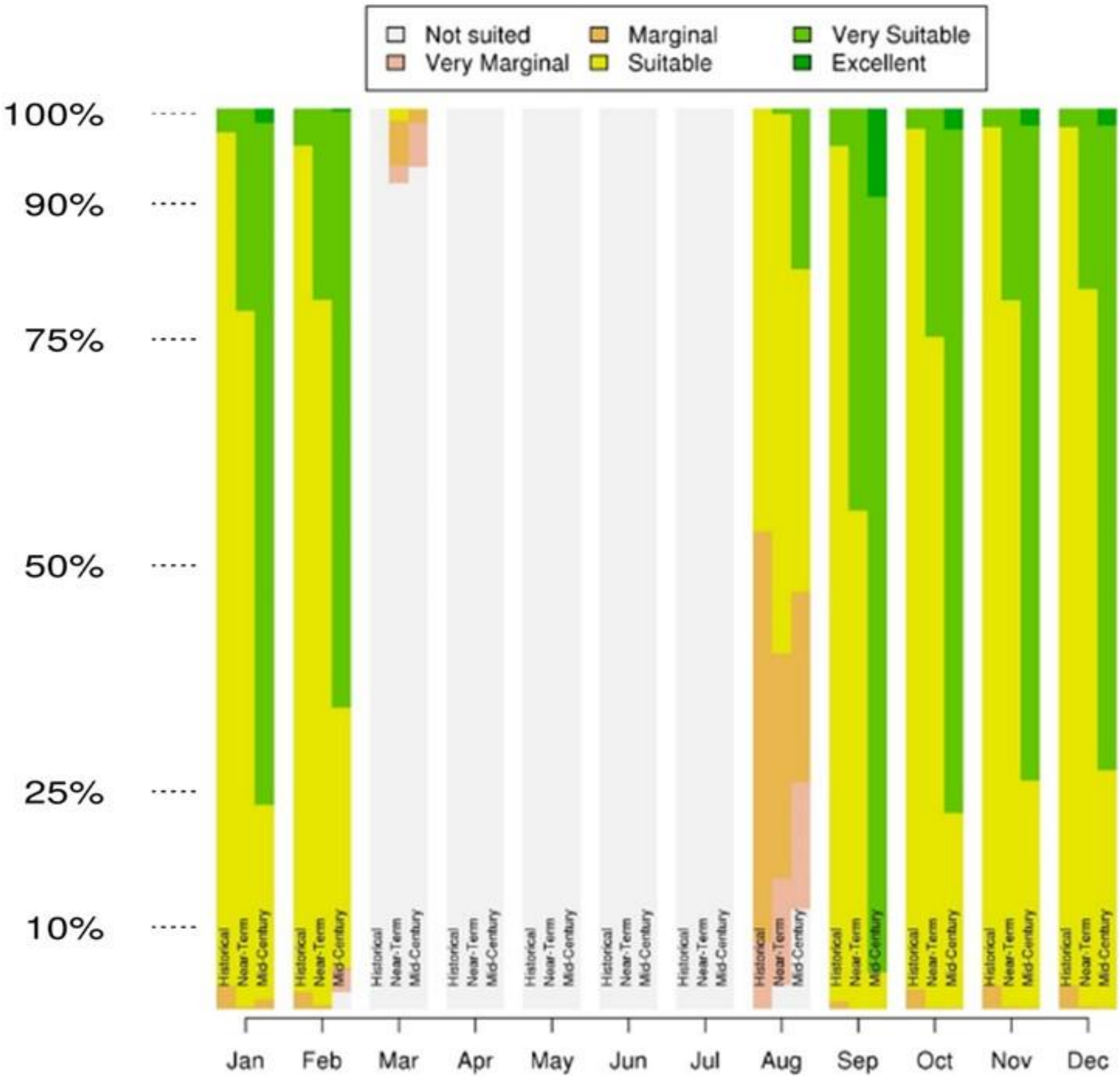


Figure 109. Mean suitability changes of Millet (*Pennisetum glaucum* (L)R.Br.) in Huambo

During the month of October the total spatial area suitable for production of millet is predicted to remain consistent from 'Baseline' to 'MC 2050' time points. However, further analysis of the spatial distribution of crop suitability categories in the month of October suggests future increases in the extent of land areas considered 'excellent', 'very suitable', and a simultaneous decrease in the extent of areas considered 'suitable' from 'Baseline' to 'MC 2050' time points. The projected increase in areas considered 'excellent' and 'very suitable' during the month of October could be attributed to an increase in Tmean from ~22 °C ('Baseline') to ~23 °C (NT 2030, MC 2050), where millet has an optimum temperature between ~25 to 35 °C.

4.12e Impact of climate change on production of millet (*Pennisetum glaucum*) in Huíla

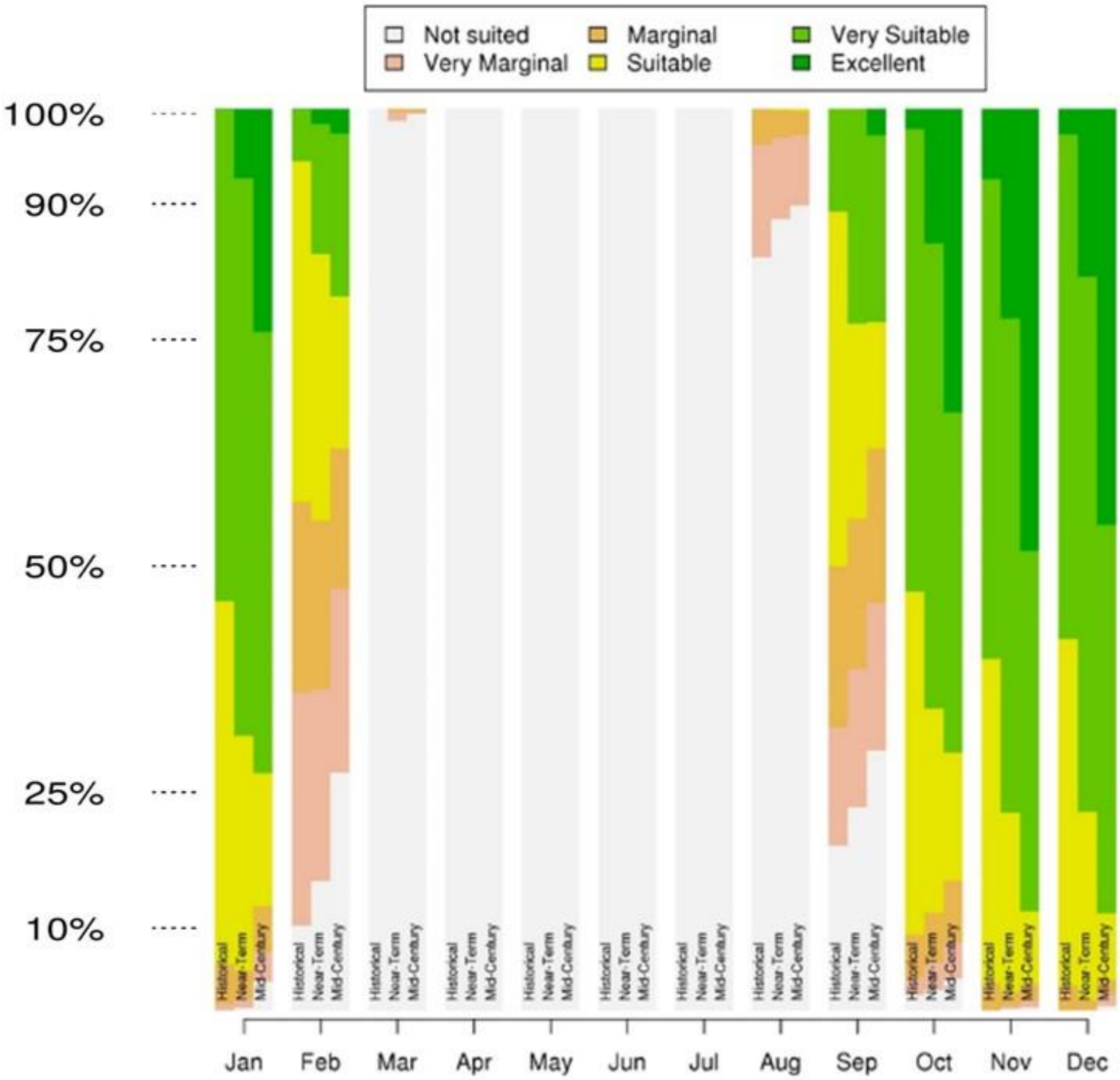


Figure 110. Mean suitability changes of Millet (*Pennisetum glaucum* (L)R.Br.) in Huíla

During the month of October there is an increase in the suitability of areas considered 'excellent' for the growth of Millet in the province of Huíla between 'Baseline' and 'MC 2050' time points. The total area suitable for the growth of Millet in Huíla is predicted to show a slight decrease from 'baseline' to 'MC 2050'. The total spatial area of suitability for growing Millet is in Huíla is greatest during the summer months of October to February, after which nearly zero suitability is predicted from the months of March to July. The projected increase in areas considered 'excellent' during the month of October could be attributed to an increase in Tmean from ~23 °C ('Baseline') to 24 °C (NT 2030, MC 2050), where millet has an optimum temperature between ~25 to 35 °C.

4.12f Impact of climate change on production of millet (*Pennisetum glaucum*) in Malanje

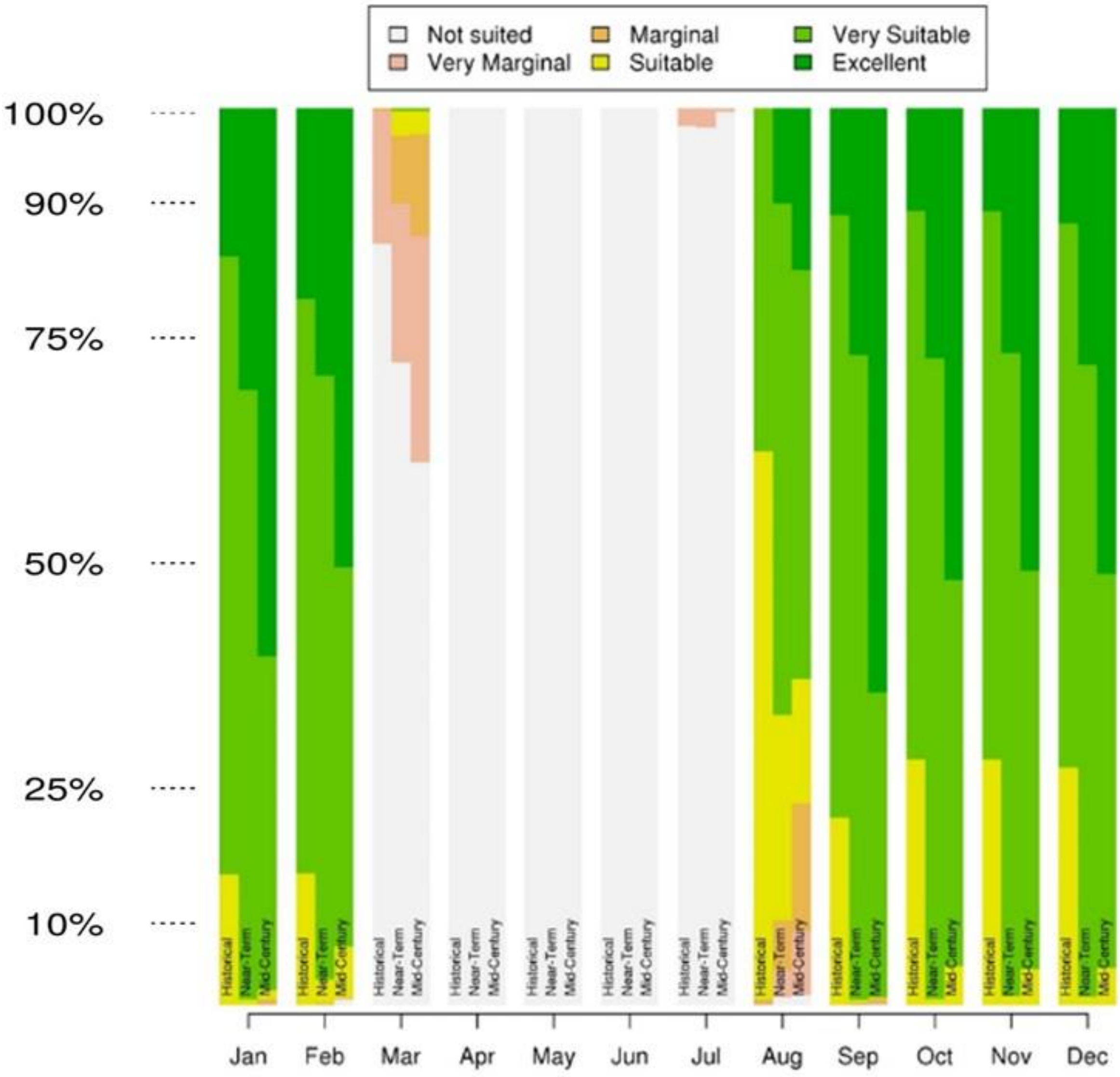


Figure 111. Mean suitability changes of Millet (*Pennisetum glaucum* (L)R.Br.) in Malanje

In the baseline scenario, the entire province of Malanje is considered to be suitable for production of millet (*P. glaucum*) to some degree. It is predicted that climate change could result in some beneficial effects on the suitability of Malanje for production of millet, where EcoCrop analyses suggest a significant increase in the extent of areas of 'excellent' suitability during the period from 'Baseline' to 'MC 2050' time points. The increase in 'excellent' areas is observed to occur simultaneously with a decrease in the extent of 'highly suitable' and 'suitable' areas in the period from the baseline scenario to 2050. As a result of climate change, it is predicted that ~95% of Malanje province will become 'excellent' or 'highly suitable' for production of millet by 2050. Therefore, millet may be an appropriate crop to promote as a climate-resilient alternative or complement to other staple rainfed crops grown by subsistence and commercial farmers in Malanje.

4.13. Impact of climate change on spatial distribution of areas suitable for production of sorgum, low-altitude variety (*Sorghum bicolor*)

The figures below summarise the historical (baseline) and future (mid-century 2050) suitability of the six pilot provinces (Bié, Benguela, Cuanza Sul, Huambo, Huíla and Malanje) for production of sorgum, low-altitude variety (*Sorghum bicolor*) in the months from September to February. In addition to the baseline and future distribution of crop suitability zones, the figures below also illustrate the anomalies (i.e. the absolute changes in suitability at any given location) between the baseline and future time periods.

In the case of low-altitude sorghum (*Sorghum bicolor*) varieties, the main effect of climate change is to increase the spatial range as well as the average crop suitability index score in all provinces, with the exception of Huíla. Of the five provinces which experience positive climate change effects on sorghum production, the months of September to December are characterised by increases in the crop suitability index scores during the period from 'baseline' to 'mid-century 2050' time periods. This increase in suitability is suggested to be attributable to increased average Tmean and Tmin during the months of the active growing season relative to the 'baseline' scenario. In addition, the increased suitability index scores for sorghum in the mid-to-late summer months up to December/January may also be partially attributable to predicted increases in rainfall during the aforementioned months, which could have the effect of extending the growing season for *S. bicolor* in the studied provinces of the *planalto* region. In the case of Huíla province, analyses suggest that climate change may result in positive increases to crop suitability in certain areas, while simultaneously reducing the overall spatial extent of suitable areas, during the period from 'baseline' to 'MC 2050' timepoints. However, this effect is only observed in the month of November, while the months of September and October are predicted to increase in relative and total area of suitability for S. bicolor production.

Therefore, similar to the results described previously for millet (*Pennisetum glaucum*), results suggest that *S. bicolor* may be an appropriate cereal crop to be promoted as a climate-resilient alternative or complement to other staple rainfed crops grown by subsistence and commercial farmers in the *planalto*. The provincial changes in suitability for production of sorghum in the period from Baseline to Mid-Century 2050 are discussed further below.

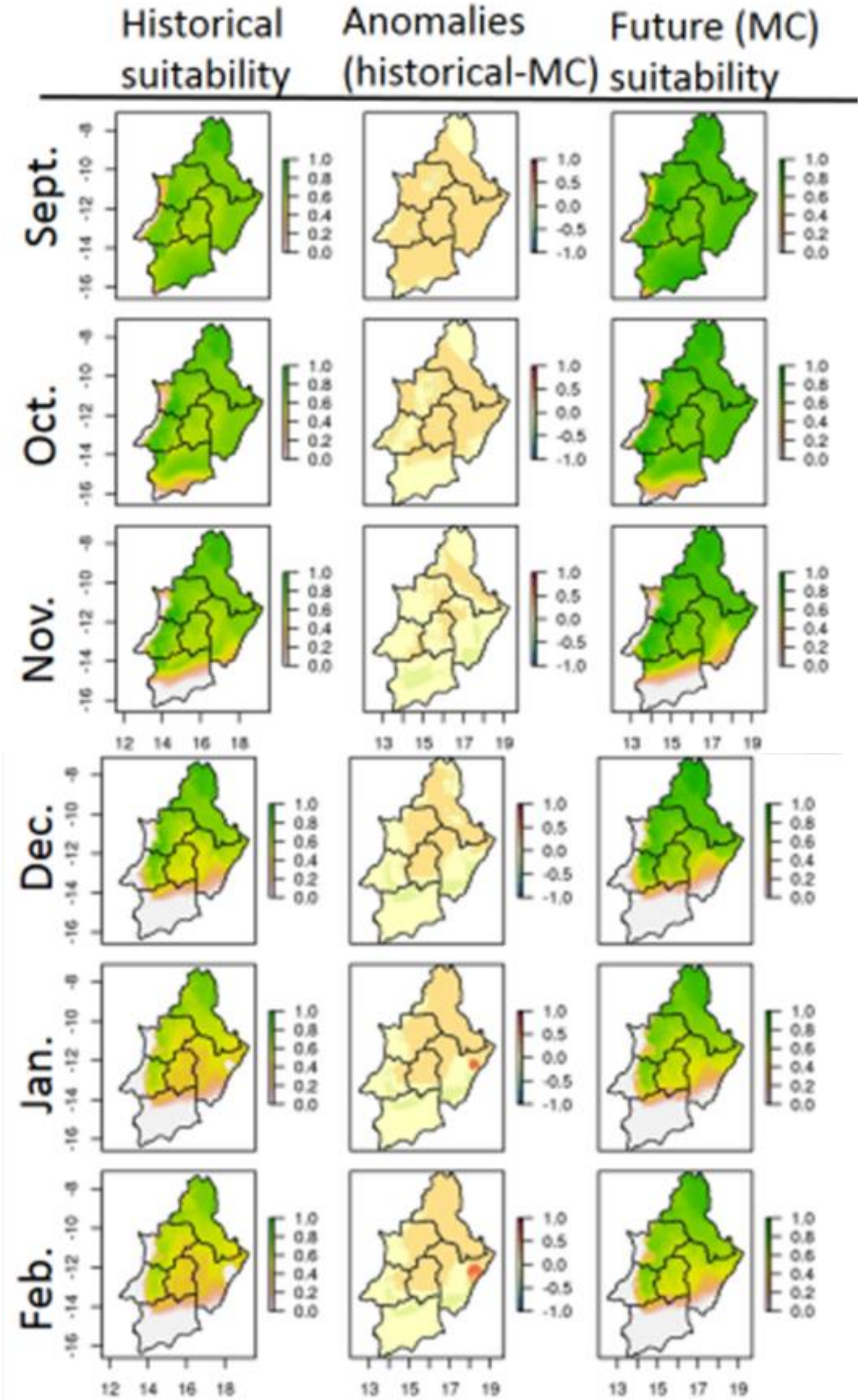


Figure 112. Distribution and changes to suitability for sorghum (*Sorghum bicolor*, low altitude variety) production in the 'baseline' (left) and 'mid-century 2050' (right) scenario in the months of September to February

4.13a Impact of climate change on production of sorgum, low-altitude variety (*Sorghum bicolor*) in Benguela

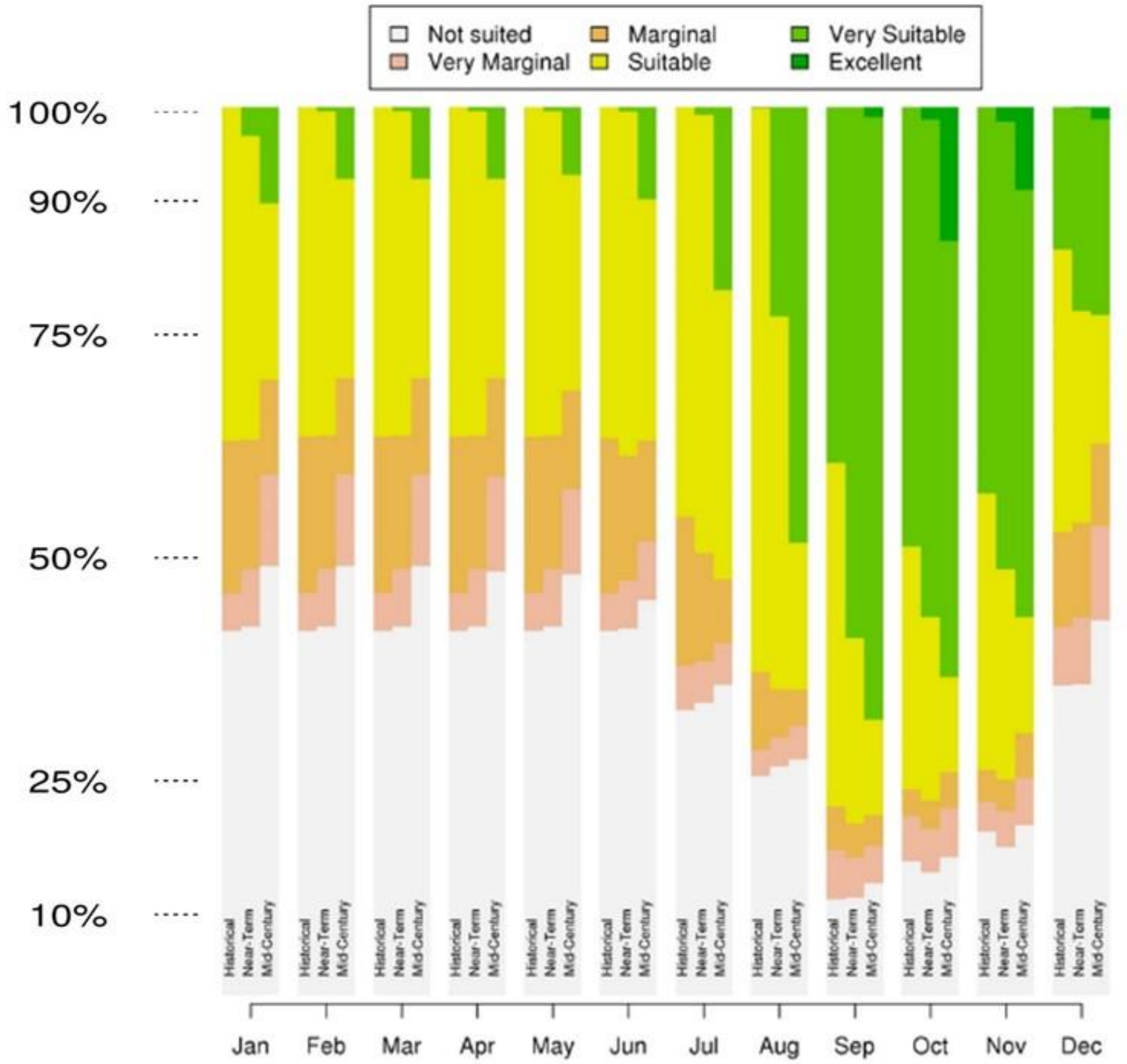


Figure 113. Mean suitability changes of Sorghum, low altitude variety (*Sorghum bicolor* (L) Moench) in Benguela

During the months of September – November, the total area suitable for growing low-altitude sorghum varieties is predicted to remain relatively constant during the period from 'Baseline' to 'MC 2050' timepoints. The decrease in overall suitability for crop growth from 'NT 2030' to 'MC 2050' can be attributed to a decrease in the extent of areas considered to be 'suitable'. However despite the overall decrease in crop suitability from 'NT 2030' to 'MC 2050', there is an increase in areas considered 'excellent' and 'very suitable' in the period from 'Baseline' to 'MC 2050' timepoints. The projected increase in areas considered 'excellent' and 'very suitable' during October could be a result of a predicted increase in Tmean from ~23 °C (Baseline) to ~24 °C, where sorghum, low altitude variety has an optimum growth temperature ranging between ~25 to 35 °C. The total spatial area of suitability for sorghum, low altitude variety is greatest during the months of September to November. In general, the suitability index scores for *S. bicolor* are greatest in the midlands and uplands of the provincial interior, and decrease westwards towards the coastal escarpment.

4.13b Impact of climate change on production of sorgum, low-altitude variety (*Sorghum bicolor*) in Bié

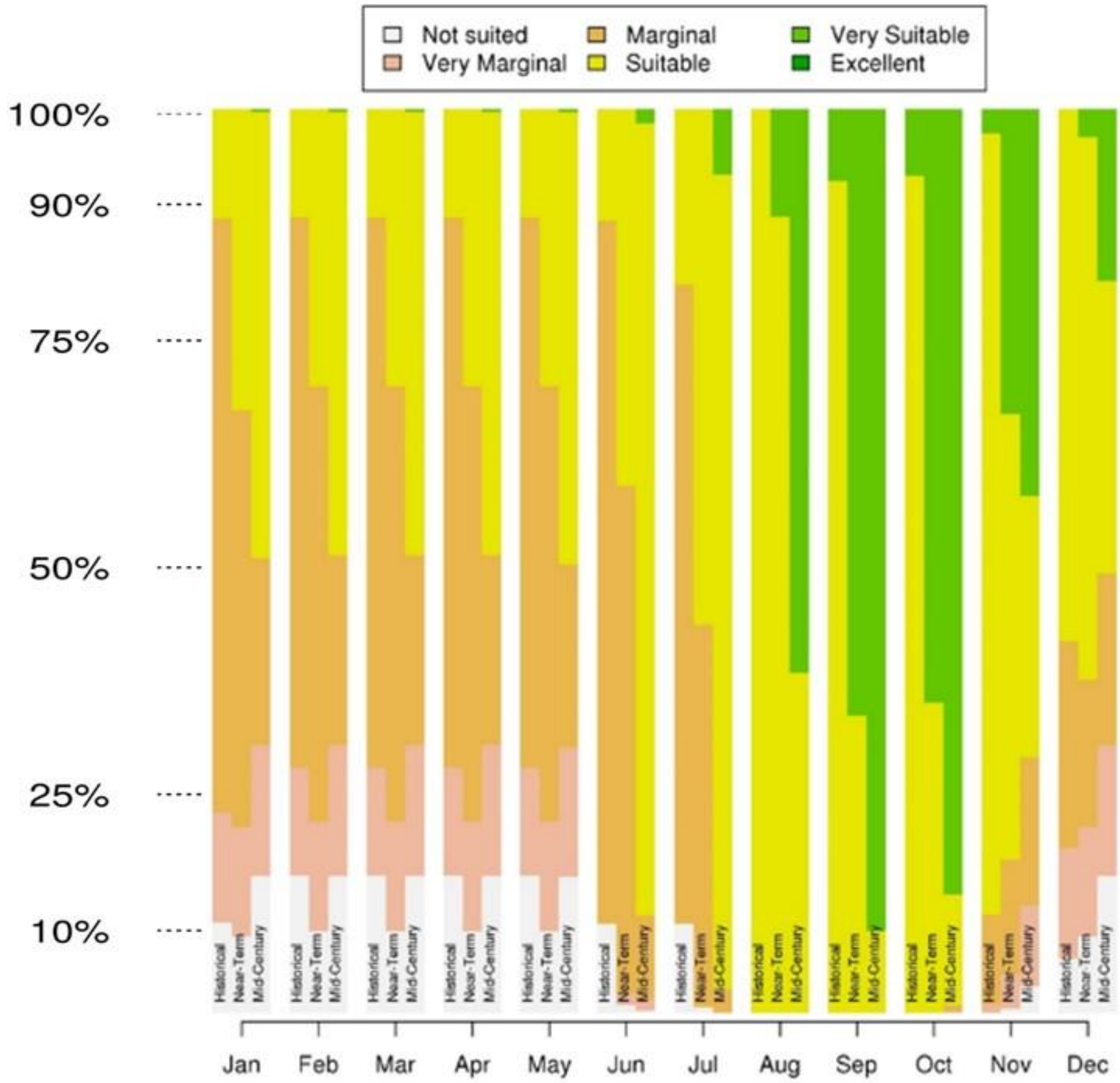


Figure 114. Mean suitability changes of Sorghum, low altitude variety (*Sorghum bicolor* (L) Moench) in Bié

The general trend observed in the predicted changes to suitability in Bié for production of sorghum (low-altitude variety) is a significant increase in the extent of areas considered 'very suitable' for cultivation of low-altitude sorghum, which occurs simultaneously to a decrease in 'suitable' areas. The predicted increases in the extent of areas considered 'very suitable' in the month of October could be attributed to an increase in Tmean from ~22 (Baseline) to ~23 °C (NT 2030, MC 2050), where low-altitude sorghum has an optimum temperature between ~25 to ~35 °C. The month of September illustrates the largest increase in the extent of areas considered 'very suitable' during the period from 'Baseline' to 'MC 2050' time points. Virtually the entire province of Bié is considered to have some degree of suitability for sorghum production.

4.13c Impact of climate change on production of sorgum, low-altitude variety (*Sorghum bicolor*) in Cuanza Sul

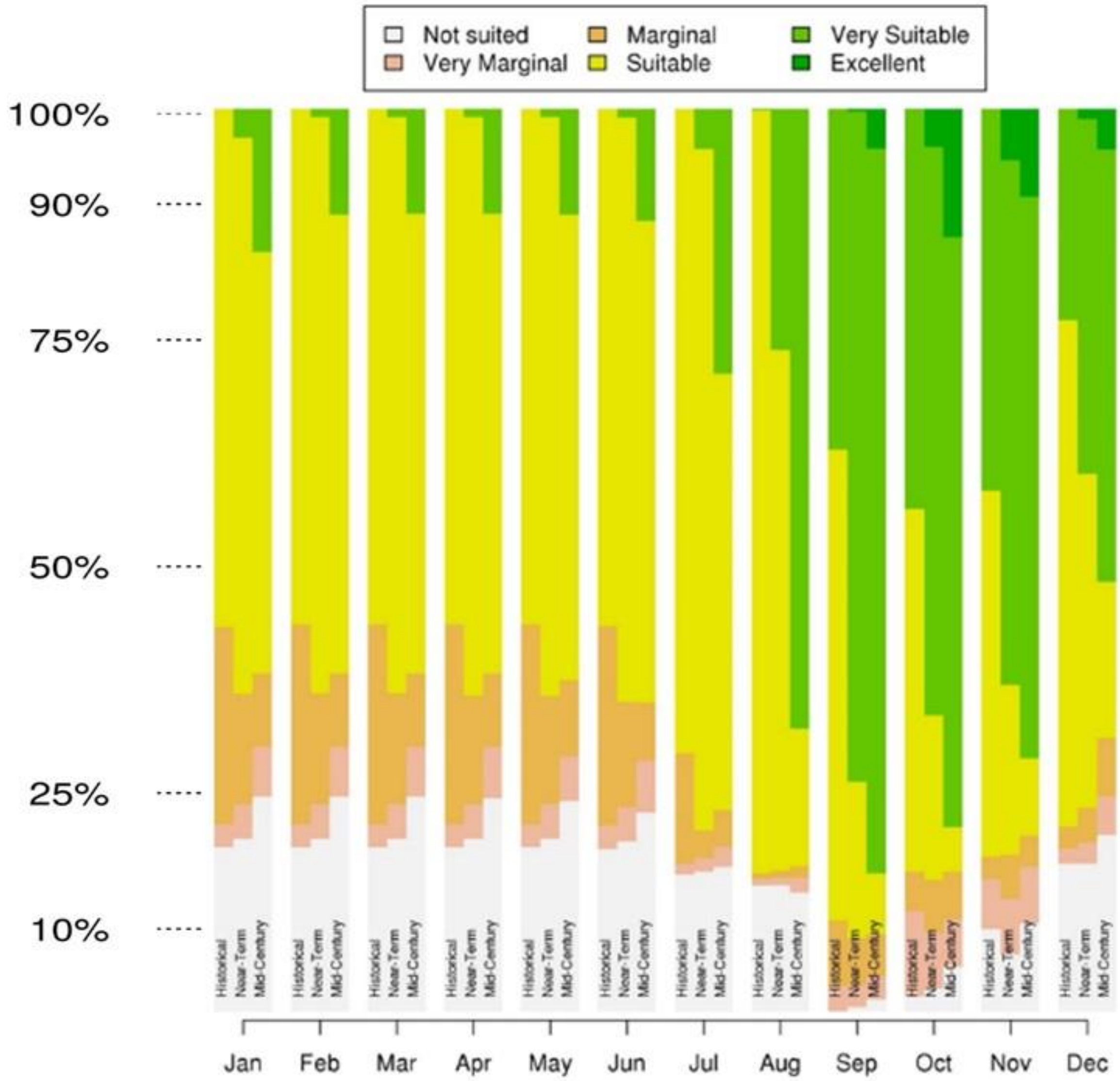


Figure 115. Mean suitability changes of Sorghum, low altitude variety (*Sorghum bicolor* (L) Moench) in Cuanza Sul

The general trend observed in the predicted changes to suitability of Cuanza Sul for production of sorghum (low-altitude variety) is an increase in the extent of areas considered 'excellent' and 'very suitable', and a concomitant decrease in the area considered to be 'suitable'. The projected increase in areas considered 'excellent' and 'very suitable' could be attributed to a predicted increase of Tmean in Cuanza Sul from ~22 °C ('Baseline') to ~23 °C (NT 2030), and ~22.5 °C (MC 2050), respectively, where Sorghum, low altitude has an optimum temperature range from 27 to 35 °C. The total spatial area of suitability for Sorghum, low-altitude variety is greatest during the months of September to November. The total extent of Sorghum, low-altitude variety is largest during the month of September, during which month predictions indicate an increase in areas considered 'excellent' between 'Baseline' and 'MC 2050' timepoints. Virtually the entire extent of Cuanza Sul is suitable for sorghum cultivation to a certain extent, with the exception of the hot and arid coastal zone.

4.13d Impact of climate change on production of sorghum, low-altitude variety (*Sorghum bicolor*) in Huambo

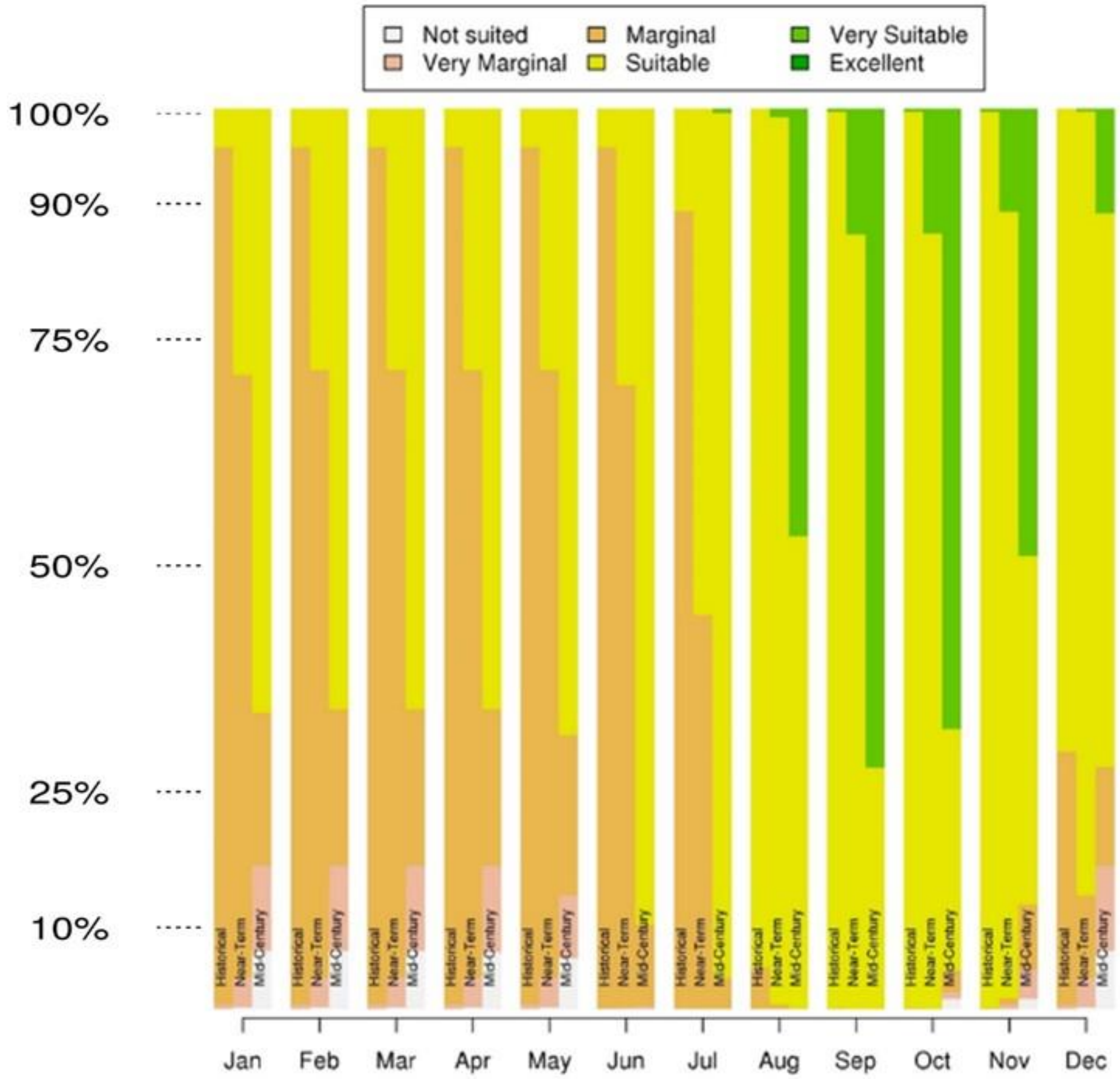


Figure 116. Mean suitability changes of Sorghum, low altitude variety (*Sorghum bicolor* (L) Moench) in Huambo

The general trend observed in the predicted changes to suitability in Huambo for production of sorghum (low-altitude variety) is comparable to the trends predicted for millet (see above). EcoCrop analyses predict a significant increase in the extent of areas considered 'very suitable' for cultivation of low-altitude sorghum, which occurs simultaneously to a decrease in 'suitable' areas, between 'Baseline' and 'MC 2050' time points for October. The projected increases in the extent of areas considered 'very suitable' can be attributed to an increase in Tmean from ~22 °C ('Baseline') to ~23 °C (NT 2030, MC 2050), where sorghum (low-altitude variety) has an optimum temperature between ~27 to 35 °C. The most significant change to the distribution of sorghum (low-altitude variety) occurs as an increase of areas considered 'very suitable' from 'Baseline' to 'MC 2050' time point during the months of August to November.

4.13e Impact of climate change on production of sorgum, low-altitude variety (*Sorghum bicolor*) in Huíla

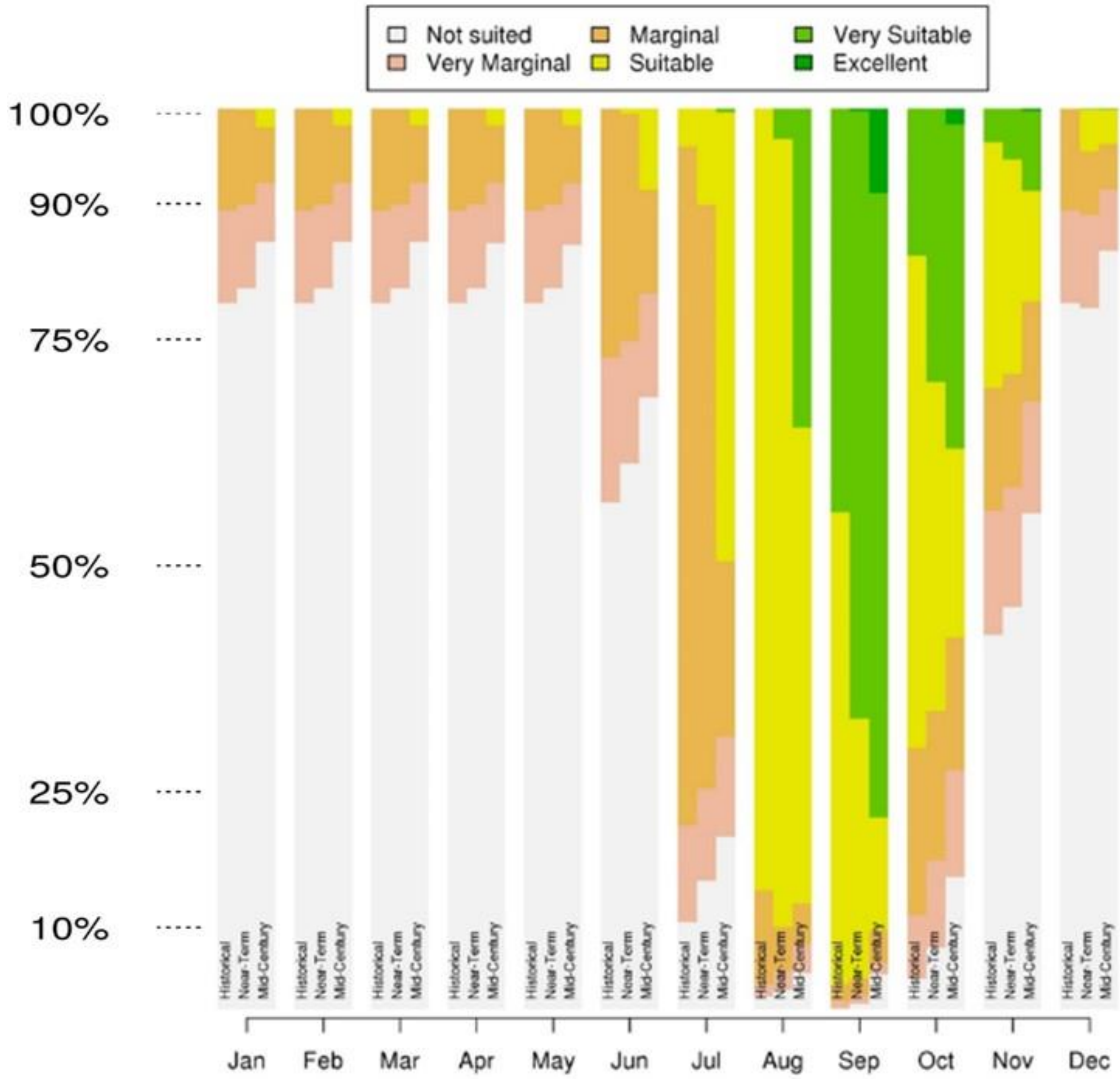


Figure 117. Mean suitability changes of Sorghum, low altitude variety (*Sorghum bicolor* (L) Moench) in Huíla

Of the six provinces assessed, Huíla is the only province which is predicted to undergo a slight decrease in the extent of areas considered to be suitable for production of low-altitude sorghum varieties. The total area suitable for growing sorghum (low altitude variety) is predicted to decrease slightly in Huíla from 'Baseline' to 'MC 2050' time points during the months of October and November (where, in contrast, other provinces have generally benefited from positive climate change effects on sorghum production potential). However, more significant than the overall change in area of suitability is the large decrease in the extent of areas considered to be 'suitable' concomitant with an increase in the extent of areas considered 'very suitable'. The predicted increases in the extent of areas considered 'very suitable' and 'excellent' in the months of September and October could be attributed to an increase in Tmean from ~23 (Baseline) to ~24 °C (NT 2030, MC 2050), where low-altitude sorghum has an optimum temperature between ~25 to ~35 °C. The total spatial area of suitability for sorghum (low-altitude variety) is greatest during the months of August to October. The total extent of areas suitable for production of sorghum (low-altitude variety) is largest during the month of September, during which there is an increase in the extent of areas considered 'excellent' and 'very suitable' between the 'Baseline' and 'MC 2050' time points. The suitable area for production of sorghum in Huíla is limited by the arid southern and western lowlands of the province.

4.13f Impact of climate change on production of sorghum, low-altitude variety (*Sorghum bicolor*) in Malanje

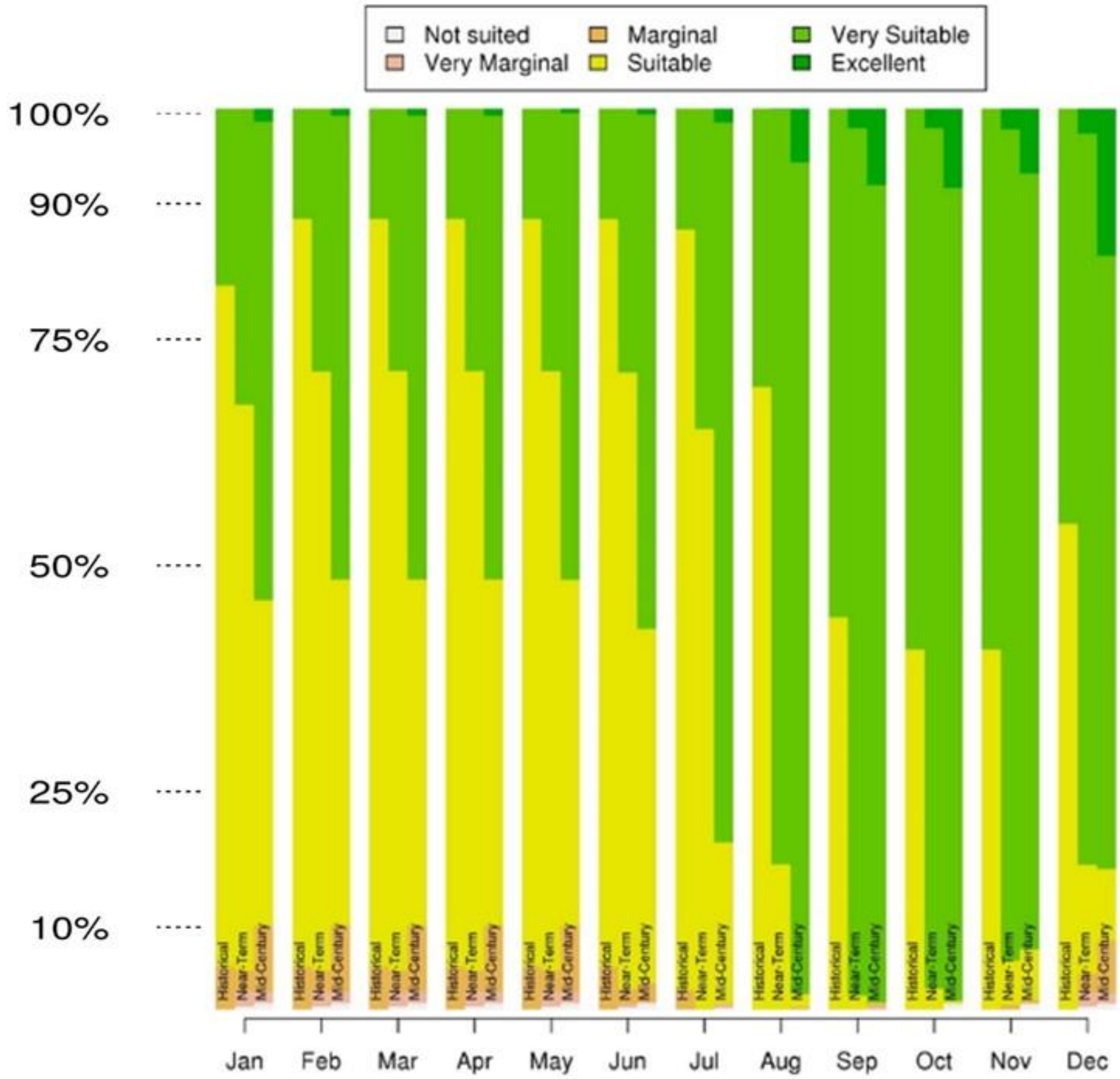


Figure 118. Mean suitability changes of Sorghum, low altitude variety (*Sorghum bicolor* (L) Moench) in Malanje

Overall there are no major changes in the total spatial area of Malanje which can be considered suitable for sorghum (low-altitude variety) production. However, while the total spatial area remains consistent, there are predicted to be changes in the distribution of several categories of suitability for sorghum production. During the month of October there is predicted to be an increase in the extent of areas considered 'excellent' and 'very suitable' for sorghum production. The net increases in 'excellent' and 'very suitable' areas appears to coincide with net reductions in 'suitable' area, which suggests that climate change will increase the overall suitability of Malanje for sorghum production by improving growing conditions in areas considered to be 'suitable' in the baseline scenario during October and throughout the rainy season into January/February. Sorghum (low-altitude variety) may be an appropriate crop to promote as a climate-resilient alternative or complement to other staple rainfed crops grown by subsistence and commercial farmers in Malanje.

4.14. Impact of climate change on spatial distribution of areas suitable for production of sorghum, high-altitude variety (*Sorghum bicolor*)

The figures below summarise the historical (baseline) and future (mid-century 2050) suitability of the six pilot provinces (Bié, Benguela, Cuanza Sul, Huambo, Huíla and Malanje) for production of sorghum, high-altitude variety (*Sorghum bicolor*) in the months from September to February. In addition to the baseline and future distribution of crop suitability zones, the figures below also illustrate the anomalies (i.e. the absolute changes in suitability at any given location) between the baseline and future time periods.

In the case of high-altitude sorghum (*Sorghum bicolor*) varieties, the main effect of climate change is similar to that described previously for low-altitude varieties of sorghum. It is predicted that climate change will increase the spatial range as well as the average crop suitability index score in all provinces, with the exception of Huíla. Of the five provinces which experience positive climate change effects on sorghum production, the months of September to December are characterised by increases in the crop suitability index scores during the period from 'baseline' to 'mid-century 2050' time periods. This increase in suitability is suggested to be attributable to increased average Tmean and Tmin during the months of the active growing season relative to the 'baseline' scenario. In addition, the increased suitability index scores for sorghum in the mid-to-late summer months up to December/January may also be partially attributable to predicted increases in rainfall during the aforementioned months, which could have the effect of extending the growing season for *S. bicolor* in the studied provinces of the *planalto* region. In the case of Huíla province, analyses suggest that climate change may result in positive increases to crop suitability in certain areas, while simultaneously reducing the overall spatial extent of suitable areas, during the period from 'baseline' to 'MC 2050' timepoints. However, this effect is only observed in the month of November, while the months of September and October are predicted to increase in relative and total area of suitability for *S. bicolor* production.

Therefore, similar to the results described previously for millet (*Pennisetum glaucum*) and low-altitude varieties of *S. bicolor*, high-altitude varieties of sorghum may be an appropriate cereal crop to be promoted as a climate-resilient alternative or complement to other staple rainfed crops grown by subsistence and commercial farmers in the *planalto*. The provincial changes in suitability for production of sorghum in the period from Baseline to Mid-Century 2050 are discussed further below.

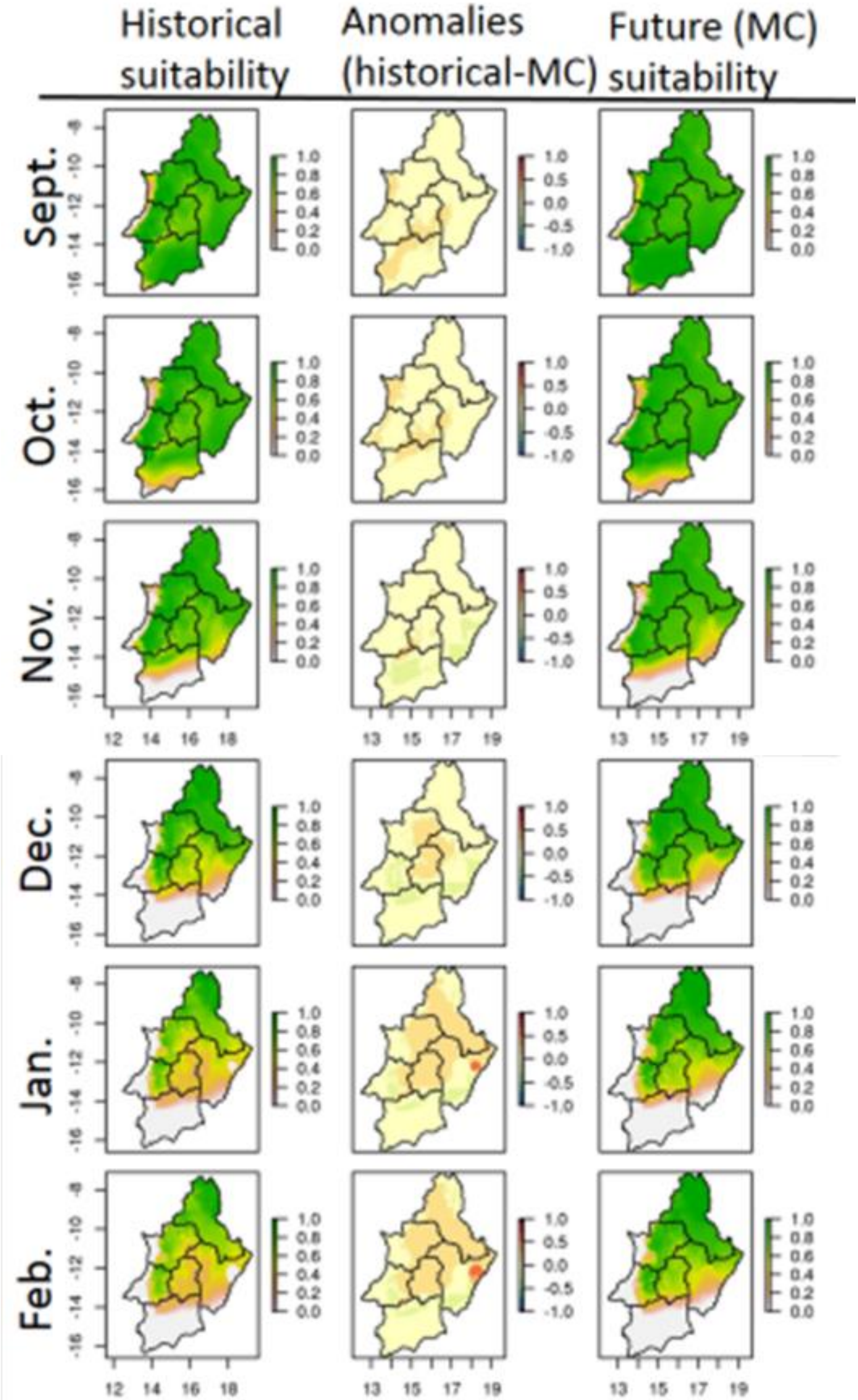


Figure 119. Distribution and changes to suitability for sorghum (*Sorghum bicolor*, high altitude variety) production in the ‘baseline’ (left) and ‘mid-century 2050’ (right) scenario in the months of September to February

4.14a Impact of climate change on production of sorgum, high-altitude variety (*Sorghum bicolor*) in Benguela

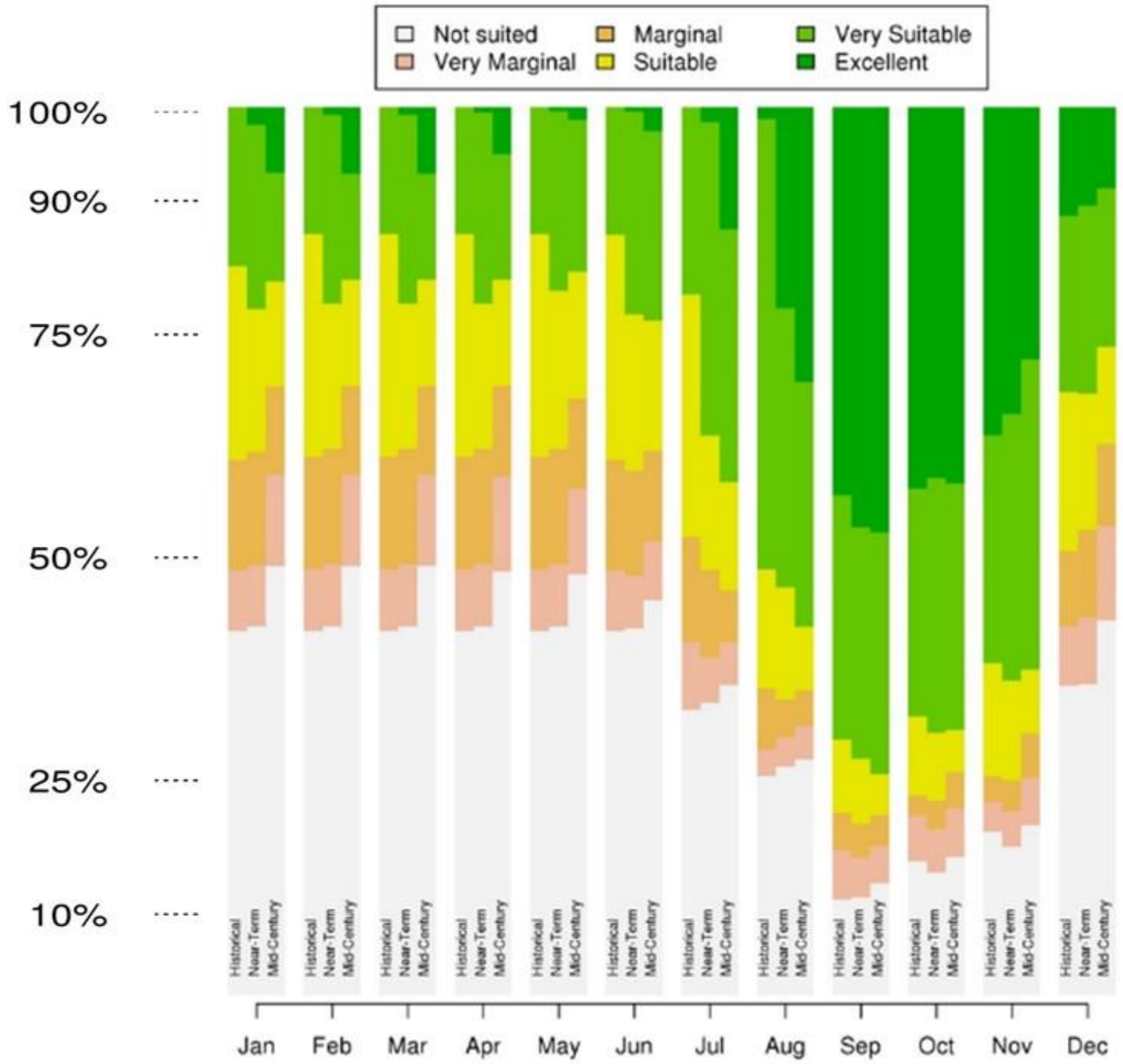


Figure 120. Mean suitability changes of Sorghum, high altitude (*Sorghum bicolor* (L) Moench) in Benguela

The total area suitable for growing high-altitude sorghum varieties in Benguela is not predicted to increase or decrease significantly in the period from 'Baseline' to 'MC 2050' time points. Similarly to Sorghum, low altitude, the total spatial area of suitability for Sorghum, high altitude variety is greatest during the months from September to November.

4.14b Impact of climate change on production of sorghum, high-altitude variety (*Sorghum bicolor*) in Bié

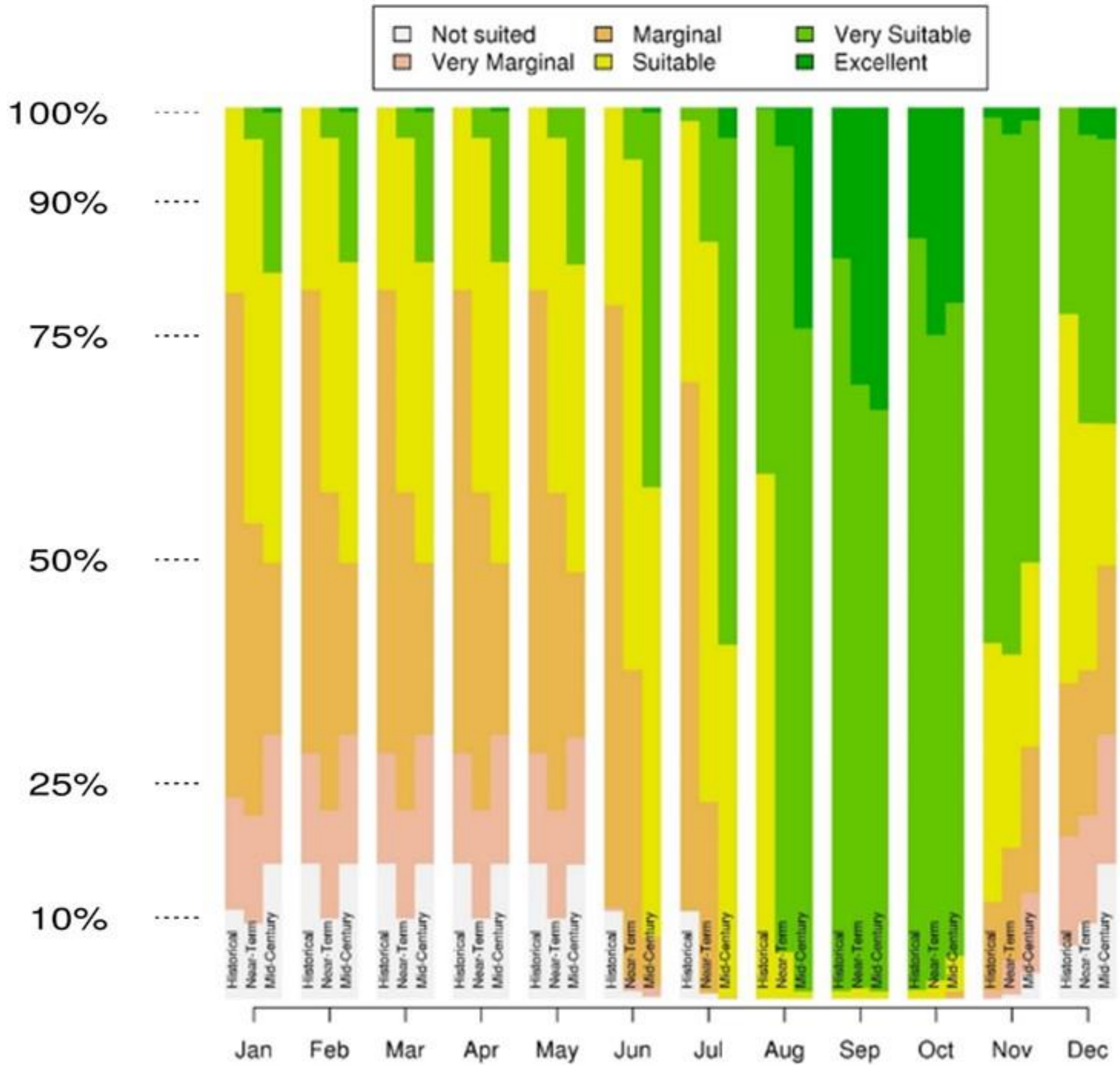


Figure 121. Mean suitability changes of Sorghum, high altitude (*Sorghum bicolor* (L) Moench) in Bié

The total area suitable for growing high-altitude sorghum varieties in Bié is not predicted to increase or decrease significantly in the period from 'Baseline' to 'MC 2050' time points during the early summer rainfall months from September to November. Analysis of the months of August to September suggests a future increase in the extent of area considered excellent for 'Baseline' to 'NT 2030' time points, and a decrease in the extent of areas considered 'excellent' for 'NT 2030' to 'MC 2050' time points for production of sorghum (high-altitude variety).

4.14c Impact of climate change on production of sorghum, high-altitude variety (*Sorghum bicolor*) in Cuanza Sul

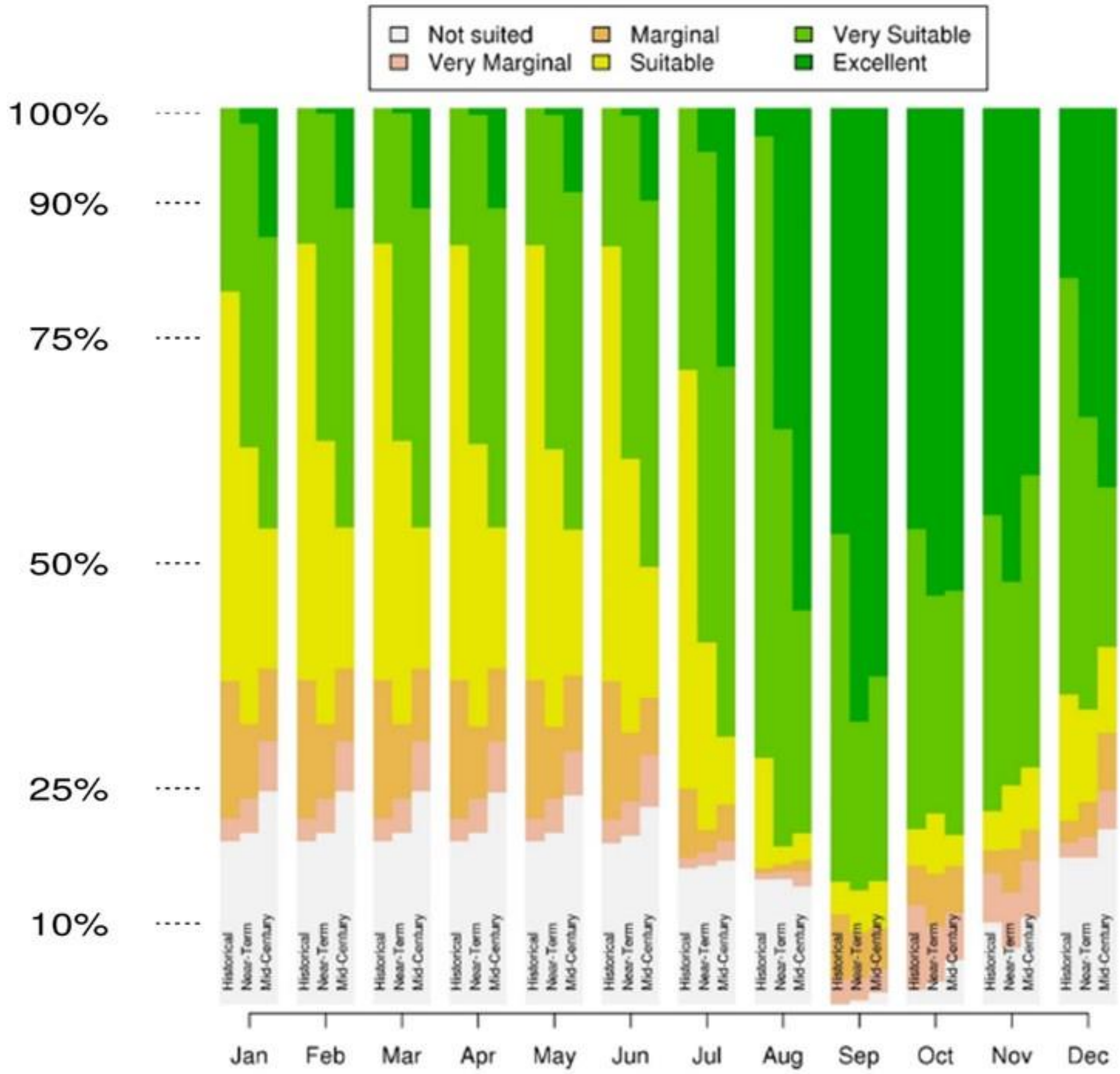


Figure 122. Mean suitability changes of Sorghum, high altitude (*Sorghum bicolor* (L) Moench) in Cuanza Sul

In general, there are predicted to be only relatively minor changes in the suitability of Cuanza Sul for production of sorghum (high-altitude variety). During the primary growing season months of September to November, there is a very small overall decrease in suitable area. However, the most significant changes predicted are the increased extent of areas categorised as 'excellent' and a concomitant decrease in the extent of areas categorised as 'very suitable' from 'Baseline' to 'MC 2050' time points. The highest overall proportion of suitability for the growth of sorghum (high-altitude variety) is during the month of September, during which there is an increase in areas considered 'excellent' from 'Baseline' to 'NT 2030' and a decrease from 'NT 2030' to 'MC 2050'.

4.14d Impact of climate change on production of sorgum, high-altitude variety (*Sorghum bicolor*) in Huambo

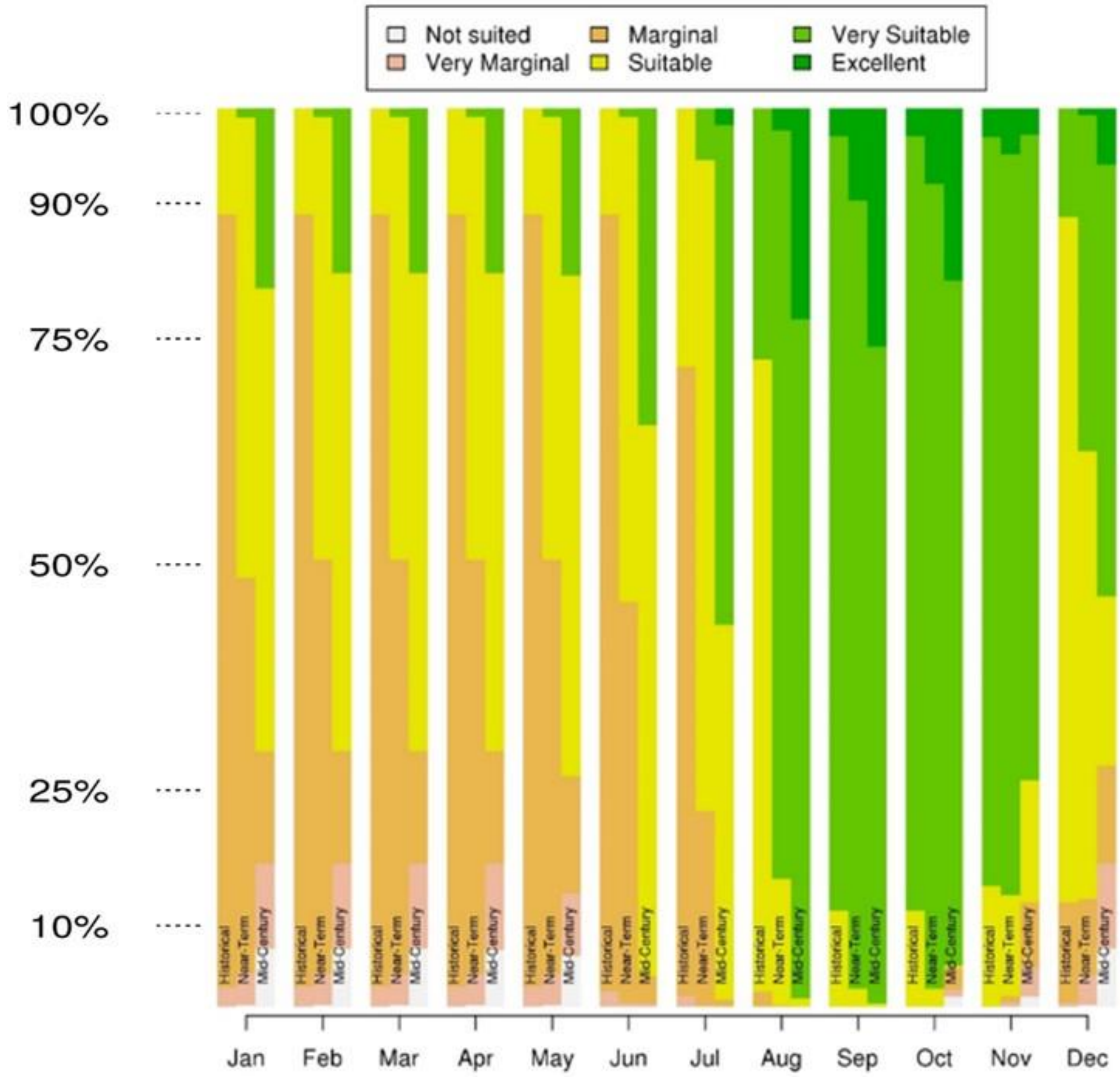


Figure 123. Mean suitability changes of Sorghum, high altitude variety (*Sorghum bicolor* (L) Moench) in Huambo

In general there are predicted to be only relatively minor changes in the total area of suitability for Huambo for production of sorghum (high-altitude variety) in the month of October. However, the most significant changes predicted are the increased extent of areas considered 'excellent' and 'very suitable' from 'Baseline' to 'MC 2050' time points. The most significant increase in the extent of areas considered 'excellent' and 'very suitable' are predicted during the month of September from 'Baseline' to 'MC 2050' time points.

4.14e Impact of climate change on production of sorgum, high-altitude variety (*Sorghum bicolor*) in Huíla

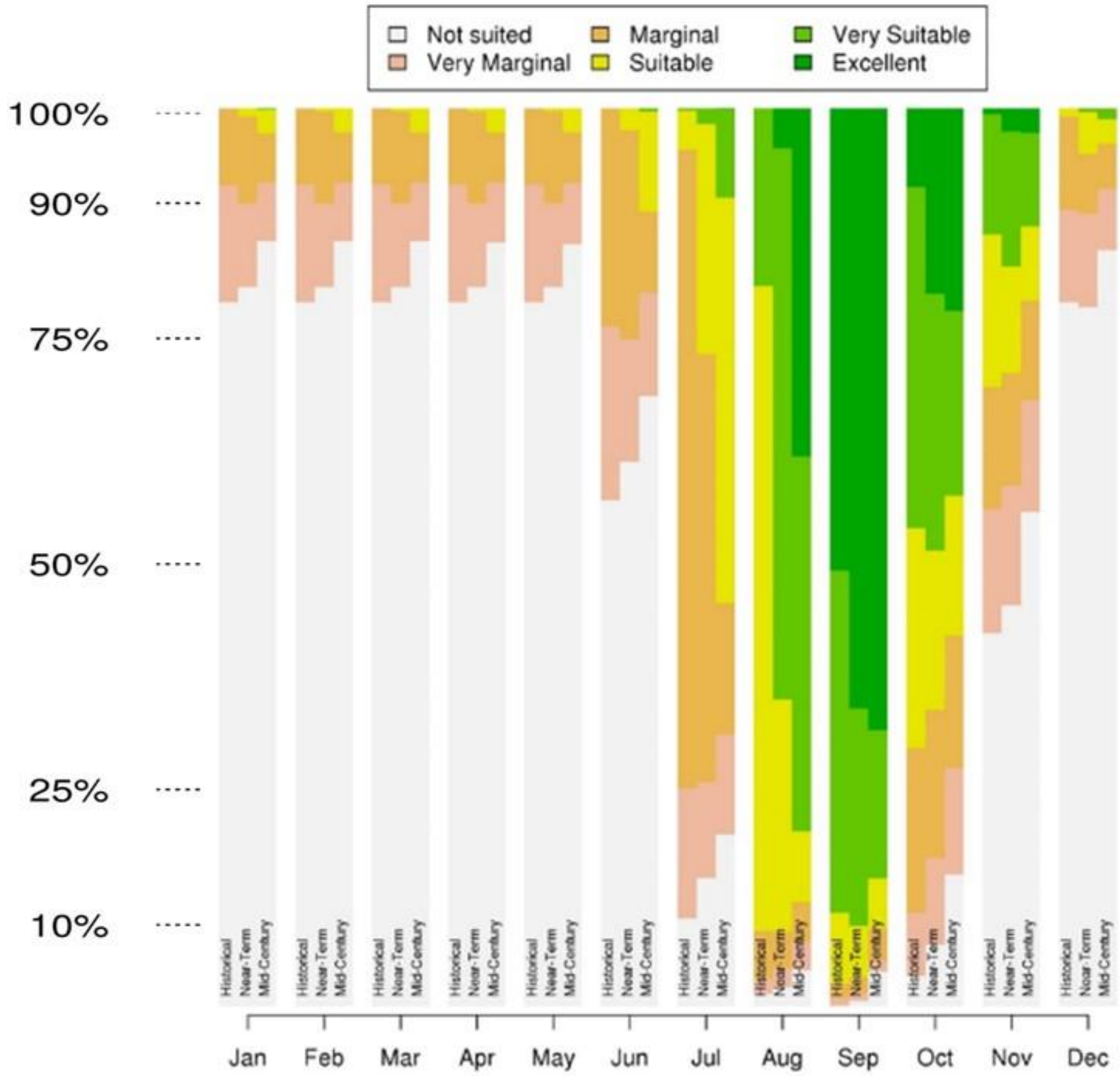


Figure 124. Mean suitability changes of Sorghum, high altitude variety (*Sorghum bicolor* (L) Moench) in Huíla

The total area suitable for growing sorghum (high altitude variety) in Huíla is predicted to decrease between the 'Baseline' to 'MC 2050' time points during the month of October. However, the extent of areas considered 'excellent' illustrate an increase between 'Baseline' and 'MC 2050' time points, respectively. The highest overall proportion of suitability for the growth of sorghum (high altitude variety) is during the month of September, during which there is an increase in extent of area considered 'excellent' from 'Baseline' to 'MC 2050'. This increase in areas considered 'excellent' during September could be attributed to an increase in Tmean from ~21.5 (Baseline) to 22.5 °C (NT 2030, MC 2050), where sorghum (high altitude variety) has an optimum temperature between ~22 and ~32 °C.

4.14f Impact of climate change on production of sorgum, high-altitude variety (*Sorghum bicolor*) in Malanje

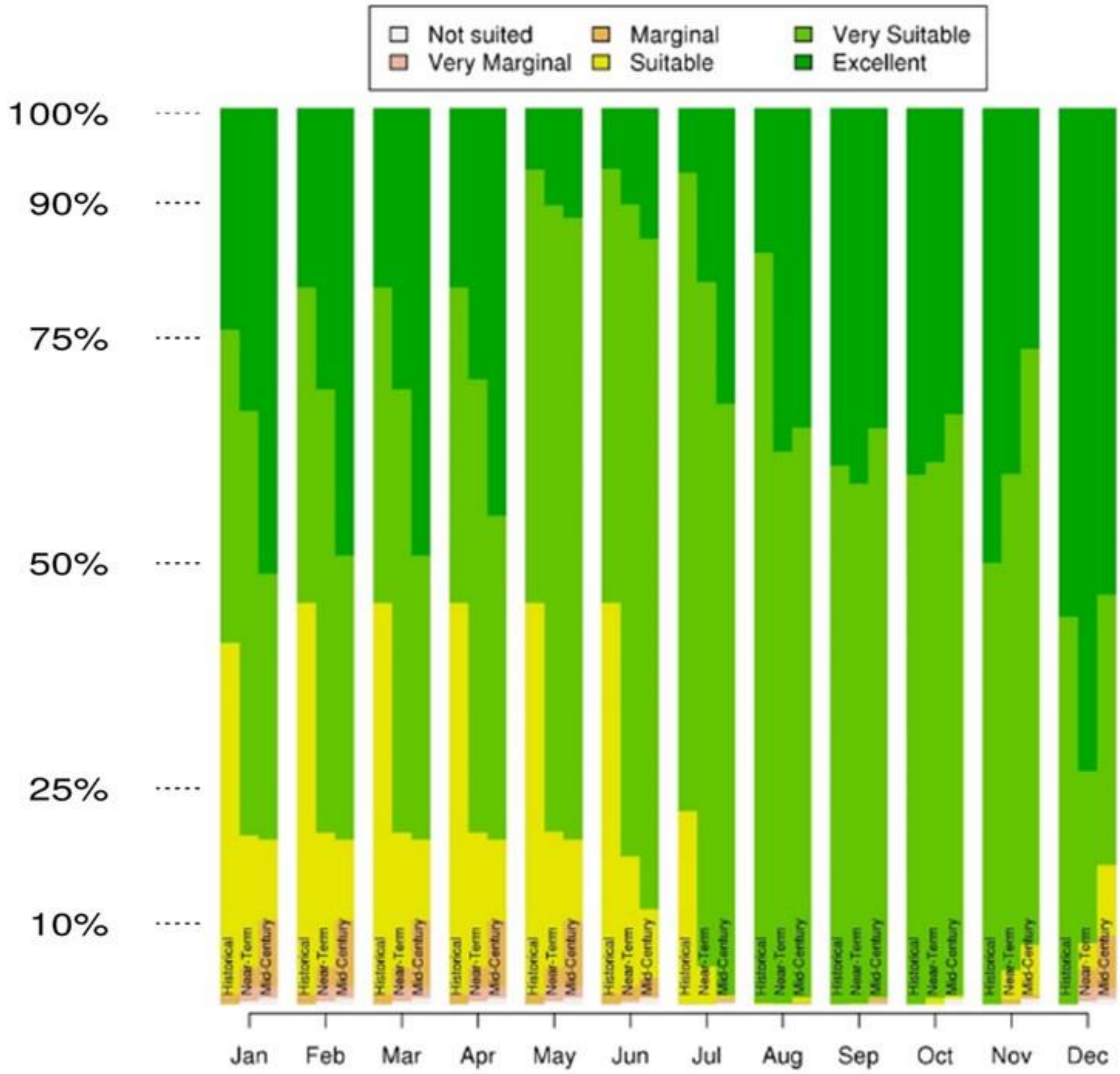


Figure 125. Mean suitability changes of Sorghum, high altitude variety (*Sorghum bicolor* (L) Moench) in Malanje

In general there are predicted to be only relatively minor changes in the total area of suitability of Malanje province for production of sorghum (high-altitude variety) in the month of October. However, Ecocrop analyses predict a decrease in the extent of land area considered 'excellent' from 'Baseline' to 'MC 2050' time points, and a simultaneous increase in 'very suitable' areas during the same time period for sorghum productivity in Malanje.

5. Summarised Climate Risk Analysis and Recommendations

The analyses presented in Chapters 3 and 4, above, describe the current and predicted future variability in climate and crop suitability across the study area. These analyses aim to guide the identification of appropriate subsistence and cash crops to prioritise in the context of the six provinces assessed in the *planalto* region. It is emphasised that these analyses present a theoretical guideline of likely crop suitability, rather than an absolute definition of 'suitable' and 'unsuitable' crops in each province. These results will be complemented by field observations of crop performance and yield, local crop preferences, and emerging impacts/vulnerabilities related to climate change.

The maps of suitability presented for each crop in Section 3 provide an indication of current and future distribution of suitability for each of the 14 crops assessed. For example, the arid and semi-arid regions in the south of Huíla and the western lowlands of Benguela/Cuanza Sul are consistently noted to be the limit of the suitable range of most crops analysed. As a result, the spatial range of suitability for a number of climate-sensitive crops such as coffee, maize and plantain bananas are predicted to be reduced in low-lying, coastal and southerly parts of the study area. An additional effect of climate change on some crops will be to reduce the duration, or delay the onset, of the growing season for rainfed crops such as maize. In these regions, the primary options for adaptation include promotion of improved, climate-resilient cultivars and the promotion of alternative cereal crops such as millet or sorghum. A final impact of climate change that is likely to reduce the productivity of certain of the crops analysed is increased incidence of pests and disease. In the case of cassava, sweet potato and banana, there are multiple soil-borne pathogens that may become more frequent or severe as a result of climate change. For example, crops are likely to be more vulnerable to *Fusarium* or *Phyophthora* as a result of increased temperature and humidity, or as a result of waterlogging during periods of prolonged rainfall.

Despite the potential negative impacts of climate change, Angola's *planalto* region nevertheless has extensive and diverse agricultural potential, with multiple opportunities to be explored in each province. The effect of climate change on crop suitability, potential adaptation options and opportunities for promotion of each crop are summarised in the tables below. In addition to the crop- and province-specific recommendations detailed below, potential adaptation options to be considered for Angola's agriculture sector may include *inter alia* promotion of rural finance, development of irrigation infrastructure, increased access to extension services, development of early warning systems, and development of rural transport infrastructure.

Table 2. Benguela – Crop suitabilities, climate risks and adaptation options.

Table 3. Benguela – Changes to crop suitability, climate risks and adaptation options

Province	Benguela
Summarised climate change effects	- Increased mean temperature, throughout the year. - Increased average 'minimum temperature', throughout the year, particularly in the period ~May to August. - Reduced average 'monthly precipitation' at the onset of the rainy season in the period ~September to November. - Increased average 'monthly precipitation' in the middle of the summer growing season, in the period ~November to January. - Effective growing season will become increasingly delayed or shortened as a result of delayed onset of summer rainfall.

Crop	Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)	Effect and scale of impact	Opportunities	Adaptation options
Cassava	**Baseline**: Extensive areas of moderate suitability **Future**: *Positive change* **(net increase)** in total suitable area; *Positive change* **(proportional increase)** in crop suitability index scores.	The predicted increases in suitability primarily occur in the central and eastern interior highlands of the province, stretching northwards towards Cuanza Sul and Malanje. The net effect is a moderate increase in potential for cassava production.	Cassava is predicted to be tolerant to increased temperatures and reduced precipitation. Widespread staple crop which is climate-resilient relative to other rainfed staples. Can be harvested at any time to meet short-term food security needs.	Promotion of cultivars with increased resistance to pathogens and water-logging. Promotion of improved post-harvest storage and processing.
Coffee *robusta*	**Baseline**: Extensive areas of marginal to moderate suitability in the interior highlands. **Future**: **No change** in total suitable area; **Minor** positive change in crop suitability index scores.	The eastern highlands interior of the province is likely to remain an important production area.	Considerable area with suitable potential which is currently underexploited.	Prioritise engagement with private sector to support research & development, strengthening of value chain. Promotion of multiple varieties of robusta and arabica in the same production areas to reduce exposure to unknown climate risks. Promotion of shade trees and other forms of intercropping and
Coffee *arabica*	**Baseline**: Extensive areas of marginal to moderate suitability in the interior highlands.		Already widely grown, mild potential for expansion.	

Crop	Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)	Effect and scale of impact	Opportunities	Adaptation options
	Future: **Minor** positive change in total suitable area; **Minor** positive change in crop suitability index scores.			agro-forestry in new coffee plantations.
Sugar cane	**Baseline**: Some areas of marginal to moderate suitability. **Future**: **No change** in total suitable area; **Minor** *positive change* in crop suitability index scores.	The net effect is a small increase in sugarcane production potential, with no change in total production area.	Prioritise engagement with private sector to support research & development, strengthening of value chain.	
Sweet potato	**Baseline**: High to excellent in the interior, unsuitable in the arid lowlands and coastal region. **Future**: **No change** in total suitable area; **Minor** *positive change* in crop suitability index scores.	The net effect is a small increase in sweet potato production potential, with no change in total production area.	Promote as a climate-resilient, easily grown perennial crop (particularly as an alternative or complement to cassava). Promotion of improved post-harvest storage and processing.	
Banana (Cavendish)	**Baseline**: Extensive areas of marginal to moderate suitability for Cavendish table banana **Future**: *Positive change* in total suitable area; *Positive change* in crop suitability index scores.	The net effect is a small increase in banana production potential and total production area (for Cavendish table bananas as well as plantains).	Considerable area with suitable potential which is currently underexploited.	Promotion of cultivars with increased resistance to pathogens and water-logging. Promotion of irrigation for plantation-scale producers. Prioritise engagement with private sector to support research & development, strengthening of value chain.
Banana (plantain varieties)	**Baseline**: Isolated areas of marginal to moderate suitability for cooking plantain. **Future**: *Positive change* in total suitable area; *Positive change* in crop suitability index scores.			

Crop	Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)	Effect and scale of impact	Opportunities	Adaptation options
Maize	**Baseline**: Extensive areas of high to excellent suitability for all varieties of maize in interior midlands and uplands. Unsuitable in the arid lowlands and coastal region. Planting season is limited to October – November. **Future**: **Minor** *negative change* in total suitable area; **Minor** *negative change* in crop suitability index scores.	The net effect of climate change is a minor reduction in production potential and total production area for all varieties of maize.	N/A	Promotion of improved drought-tolerant varieties. Increase access to weather forecasts and early warnings. Promotion of sorghum, millet as climate-resilient alternatives to maize.
Millet	**Baseline**: Extensive areas of good to high suitability in interior midlands and uplands. Marginally suitable in the arid lowlands and coastal region during the late rainy season (December – January). **Future**: **No change** in total suitable area; *Positive change* in crop suitability index scores.	Climate change results in a small positive change in production potential, and no change in total production area, for all varieties of millet and sorghum.	Large potential area of high suitability, noted as climate-resilient alternative to maize.	
Sorghum				

Table 4. Bié – Changes to crop suitability, climate risks and adaptation options

Province	Bié
Summarised climate change effects	- Increased mean temperature, throughout the year. - Increased average 'minimum temperature', throughout the year, particularly in the period ~May to August. - Reduced average 'monthly precipitation' at the onset of the rainy season in the period ~September to November, and again at the end of the rainy season in the period ~March to April. - Increased average 'monthly precipitation' in the middle of the summer growing season, in the period ~December to February. - Effective growing season will become increasingly delayed or shortened as a result of delayed onset of summer rainfall.

<table>
<tr><th>Crop</th><th>Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)</th><th>Effect and scale of impact</th><th>Opportunities</th><th>Adaptation options</th></tr>
<tr><td>Cassava</td><td>Baseline: Poor – EcoCrop indicates no suitable areas

Future:
Positive change (small net increase) in total suitable area;
Positive change (proportional increase) in crop suitability index scores.</td><td>A small area of Bié will become 'excellent' or 'very suitable' for the cultivation of cassava, primarily in the north-east along the provincial border with Malanje.

The total suitable area for cassava in Bié remains almost negligible.</td><td>Cassava is predicted to be tolerant to increased temperatures and reduced precipitation.

Widespread staple crop which is climate-resilient relative to other rainfed staples.

Can be harvested at any time to meet short-term food needs</td><td>Promotion of sweet potato as a climate-resilient alternative</td></tr>
<tr><td>Coffee robusta</td><td>Baseline: Mostly or totally unsuitable.

Future:
Positive change in total suitable area;
Positive change in crop suitability index scores.</td><td>A relatively large proportion of the province (~25%) in the northwestern extent is predicted to become suitable for robusta coffee production.</td><td>Possible opportunity to establish new plantations and production areas.</td><td rowspan="2">Prioritise engagement with private sector to support research & development, strengthening of value chain.
Promotion of multiple varieties to reduce exposure to unknown climate risks.
Promotion of shade trees and other forms of intercropping and agro-forestry in new coffee plantations.</td></tr>
<tr><td>Coffee arabica</td><td>Baseline: Extensive areas of marginal to moderate suitability.

Future:
No change in total suitable area;</td><td colspan="2">Already widely grown, considerable potential for expansion</td></tr>
</table>

Crop	Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)	Effect and scale of impact	Opportunities	Adaptation options
	No change in crop suitability index scores.			
Sugar cane	**Baseline**: Some areas of marginal to moderate suitability. **Future**: *Positive change* in total suitable area; *Positive change* in crop suitability index scores.	The net effect is a small increase in sugarcane production potential and total production area.	Prioritise engagement with private sector to support research & development, strengthening of value chain.	
Sweet potato	**Baseline**: Excellent throughout the province. **Future**: **No change** in total suitable area; **Minor** *positive change* in crop suitability index scores.	The net effect is a small increase in sweet potato production potential. Sweet potato remains well-suited to the entire province.	Promote as a climate-resilient, easily grown perennial crop (particularly as an alternative or complement to cassava). Promotion of improved post-harvest storage and processing.	
Banana (Cavendish)	**Baseline**: Extensive areas of marginal to moderate suitability for Cavendish table banana **Future**: **No change** in total suitable area; **Minor** *positive change* in crop suitability index scores.	The net effect is a small increase in Cavendish banana production potential, with no change in total production area.	Considerable area with suitable potential which is currently underexploited.	Promotion of cultivars with increased resistance to pathogens and water-logging. Promotion of irrigation for plantation-scale producers. Prioritise engagement with private sector to support research & development, strengthening of value chain.
Banana (plantain varieties)	**Baseline**: Unsuitable for cooking plantain, marginal suitability for hybrid plantain. **Future**: **Minor** *positive change* in total suitable area; *Positive change* in crop suitability index scores.	The net effect is a small increase in production potential and total production area for plantain banana.	Considerable area with suitable potential which is currently underexploited.	Promotion of cultivars with increased resistance to pathogens and water-logging. Promotion of irrigation for plantation-scale producers. Prioritise engagement with private sector to support research & development, strengthening of value chain.

Crop	Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)	Effect and scale of impact	Opportunities	Adaptation options
Maize	**Baseline**: Extensive areas of moderate, high and excellent suitability for all varieties of maize. Potential planting season of September – November. **Future**: **No change** in total suitable area; **Minor** ***negative change*** in crop suitability index scores.	The net effect of climate change is a minor reduction in production potential, and no change in total production area, for all varieties of maize.	N/A	Promotion of improved drought-tolerant varieties. Increase access to weather forecasts and early warnings. Promotion of sorghum, millet as climate-resilient alternatives to maize.
Millet Sorghum	**Baseline**: Good to high suitability throughout the province. **Future**: **No change** in total suitable area; *Positive change* in crop suitability index scores.	Climate change results in a small positive change in production potential, and no change in total production area, for all varieties of millet and sorghum.	Large potential area of high suitability, noted as climate-resilient alternative to maize.	

Table 5. Cuanza Sul – Changes to crop suitability, climate risks and adaptation options

Province	Cuanza Sul
Summarised climate change effects	- Increased mean temperature, throughout the year. - Increased average ‘minimum temperature’, throughout the year, particularly in the period ~May to August. - Reduced average ‘monthly precipitation’ at the onset of the rainy season in the period ~September to October. - Increased average ‘monthly precipitation’ in the middle of the summer growing season, in the period ~November to April. - Effective growing season will become increasingly delayed as a result of delayed onset and termination of summer rainfall season.

Crop	Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)	Effect and scale of impact	Opportunities	Adaptation options
Cassava	**Baseline**: Extensive areas of moderate suitability. **Future**: *Positive change* **(net increase)** in total suitable area; *Positive change* **(proportional increase)** in crop suitability index scores.	The predicted increases in suitability primarily occur in the central and eastern interior highlands of the province, stretching northwards from Benguela to Malanje. The net effect is a small increase in potential for cassava production.	Cassava is predicted to be tolerant to increased temperatures and reduced precipitation. Widespread staple crop which is climate-resilient relative to other rainfed staples. Can be harvested at any time to meet short-term food security needs.	Promotion of cultivars with increased resistance to pathogens and water-logging. Promotion of improved post-harvest storage and processing.
Coffee *robusta*	**Baseline**: Extensive areas of marginal to moderate suitability in the interior highlands. **Future**: **No change** in total suitable area; **No change** in crop suitability index scores.	Already widely grown, considerable potential for expansion. Climate change is not anticipated to influence the total suitable area.		Prioritise engagement with private sector to support research & development, strengthening of value chain. Promotion of multiple varieties of robusta and arabica in the same production areas to reduce exposure to unknown climate risks. Promotion of shade trees and other forms of intercropping and
Coffee *arabica*	**Baseline**: Extensive areas of marginal to moderate suitability in the interior highlands. **Future**:	The net effect of climate change is to expand the suitable range, from the central highlands of the province eastwards towards Bie and Malanje provinces.	Already widely grown, considerable potential for expansion.	

Crop	Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)	Effect and scale of impact	Opportunities	Adaptation options
	Positive change in total suitable area; *Positive change* in crop suitability index scores.			agro-forestry in new coffee plantations.
Sugar cane	**Baseline**: Some areas of marginal to moderate suitability. **No change** in total suitable area; **Minor** *positive change* in crop suitability index scores.	The net effect is a small increase in sugarcane production potential, with no change in total production area.	Prioritise engagement with private sector to support research & development, strengthening of value chain.	
Sweet potato	**Baseline**: High to excellent in the interior, unsuitable in the arid lowlands and coastal region. **Future**: **No change** in total suitable area; *Positive change* in crop suitability index scores.	The net effect is a small increase in sweet potato production potential, with no change in total production area.	Promote as a climate-resilient, easily grown perennial crop (particularly as an alternative or complement to cassava). Promotion of improved post-harvest storage and processing.	
Banana (Cavendish)	**Baseline**: Extensive areas of marginal to moderate suitability for Cavendish table banana. **Future**: **No change** in total suitable area; **Minor** *positive change* in crop suitability index scores.	The net effect is a small increase in production potential, with no change in total production area, for plantain bananas.	Considerable area with suitable potential which is currently underexploited.	Promotion of cultivars with increased resistance to pathogens and water-logging. Promotion of irrigation for plantation-scale producers. Prioritise engagement with private sector to support research & development, strengthening of value chain.
Banana (plantain varieties)	**Baseline**: Marginal suitability for cooking and hybrid plantains. **Future**: *Positive change* in total suitable area; *Positive change* in crop suitability index scores.	The net effect is a small increase production potential and total production area for plantain banana.		
Maize	**Baseline**: Extensive areas of high to excellent suitability for all varieties of	The net effect of climate change is a minor reduction in production potential, and no	N/A	Promotion of improved drought-tolerant varieties.

Crop	Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)	Effect and scale of impact	Opportunities	Adaptation options
	maize in interior midlands and uplands. Unsuitable in the arid lowlands and coastal region. Planting season is limited to October – November. **Future**: **No change** in total suitable area; **Minor** ***negative change*** in crop suitability index scores.	change in total production area for, all varieties of maize.		Increase access to weather forecasts and early warnings. Promotion of sorghum, millet as climate-resilient alternatives to maize.
Millet Sorghum	**Baseline**: Extensive areas of good to high suitability in interior midlands and uplands. Marginally suitable in the arid lowlands and coastal region during the late rainy season (December – January). **Future**: **No change** in total suitable area; ***Positive change*** in crop suitability index scores.	Climate change results in a small positive change in production potential, and no change in total production area, for all varieties of millet and sorghum.	Large potential area of high suitability, noted as climate-resilient alternative to maize.	

Table 6. Huambo – Changes to crop suitability, climate risks and adaptation options

Province	Huambo
Summarised climate change effects	- Increased mean temperature, throughout the year. - Increased average 'minimum temperature', throughout the year, particularly in the period ~May to August. - Reduced average 'monthly precipitation' at the onset of the rainy season in the period ~September to October/November. - Increased average 'monthly precipitation' in the middle of the summer growing season, in the period ~December to March. - Effective growing season will become increasingly delayed or shortened as a result of delayed onset of summer rainfall season.

Crop	Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)	Effect and scale of impact	Opportunities	Adaptation options
Cassava	**Baseline**: Poor – EcoCrop indicates no suitable areas **Future**: *Positive change* **(net increase)** in total suitable area; *Positive change* **(proportional increase)** in crop suitability index scores.	A small area of Huambo will become 'very suitable' or even 'excellent' for cultivation of cassava. The areas which are predicted to be suitable for cassava production are restricted to the eastern and northern interior of Huambo	Cassava is predicted to be tolerant to increased temperatures and reduced precipitation in a small area of Huambo. Can be harvested at any time to meet short-term food security needs.	Promotion of sweet potato as a perennial starch-rich alternative. Other rainfed staples such as cereals and sweet potato could be promoted
Coffee *robusta*	**Baseline**: Extensive areas of marginal to moderate suitability in the interior highlands **Future**: **No change** in total suitable area; **No change** in crop suitability index scores		Prioritise engagement with private sector to support research & development, strengthening of value chain. Promotion of multiple varieties to reduce exposure to unknown climate risks.	
Coffee *arabica*	**Baseline**: Mostly or totally unsuitable **Future**: *Positive change* in total suitable area;	The net effect of climate change is to expand the suitable range, from the central highlands of the province north towards Bie and Malanje provinces.	Opportunity for establishment of new production areas	Prioritise engagement with private sector to support research & development, strengthening of value chain. Promotion of multiple varieties to reduce exposure to unknown climate risks.

<table>
<tr><th>Crop</th><th>Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)</th><th>Effect and scale of impact</th><th>Opportunities</th><th>Adaptation options</th></tr>
<tr><td></td><td>Positive change in crop suitability index scores.</td><td></td><td></td><td>Promotion of shade trees and other forms of intercropping and agro-forestry in new coffee plantations.</td></tr>
<tr><td>Sugar cane</td><td>Baseline: Some areas of marginal to moderate suitability.

Future:
Positive change in total suitable area;
Positive change in crop suitability index scores.</td><td>The net effect is a small increase in sugarcane production potential and total production area.</td><td colspan="2">Prioritise engagement with private sector to support research & development, strengthening of value chain.</td></tr>
<tr><td>Sweet potato</td><td>Baseline: Excellent throughout the province.

No change in total suitable area;
Minor positive change in crop suitability index scores.</td><td>The net effect is a small increase in sweet potato production potential, with no change in total production area.</td><td colspan="2">Promote as a climate-resilient, easily grown perennial crop (particularly as an alternative or complement to cassava).
Promotion of improved post-harvest storage and processing.</td></tr>
<tr><td>Banana (Cavendish)</td><td>Baseline: Extensive areas of marginal to moderate suitability for Cavendish table banana.

Future:
Positive change in total suitable area;
Positive change in crop suitability index scores.</td><td>The net effect is a moderate increase in banana production potential and total production area for Cavendish table banana.</td><td rowspan="2">Considerable area with suitable potential which is currently underexploited.</td><td rowspan="2">Promotion of cultivars with increased resistance to pathogens and water-logging.
Promotion of irrigation for plantation-scale producers.
Prioritise engagement with private sector to support research & development, strengthening of value chain.</td></tr>
<tr><td>Banana (plantain varieties)</td><td>Baseline: Unsuitable for plantain production.

Future:
Minor positive change in total suitable area;</td><td>The net effect is a small increase in production potential and total production area for plantain bananas.</td></tr>
</table>

Crop	Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)	Effect and scale of impact	Opportunities	Adaptation options
	Minor *positive change* in crop suitability index scores.			
Maize	**Baseline**: Extensive areas of moderate, high and excellent suitability for all varieties of maize. Potential planting season of September – November. **Future**: **No change** in total suitable area; *Negative change* in crop suitability index scores.	The net effect of climate change is a minor reduction in production potential, and no change in total production area, for all varieties of maize.	N/A	Promotion of improved drought-tolerant varieties. Increase access to weather forecasts and early warnings. Promotion of sorghum, millet as climate-resilient alternatives to maize.
Millet Sorghum	**Baseline**: Good to high suitability throughout the province. **Future**: **No change** in total suitable area; *Positive change* in crop suitability index scores.	Climate change results in a small positive change in production potential, and no change in total production area, for all varieties of millet and sorghum.	Large potential area of good suitability, noted as a climate-resilient alternative to maize.	

Table 7. Huíla – Changes to crop suitability, climate risks and adaptation options

Province	Huíla
Summarised climate change effects	- Increased mean temperature, throughout the year. - Increased average ‘minimum temperature’, throughout the year, particularly in the period ~May to August. - Reduced average ‘monthly precipitation’ throughout the rainy season in the period ~September to April. - Effective growing season will become increasingly delayed as a result of delayed onset of summer rainfall season. - Negative impacts on virtually all crops as a result of increased temperatures and reduced precipitation, particularly in the low-lying southern and western extents of the province.

<table>
<tr><th>Crop</th><th>Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)</th><th>Effect and scale of impact</th><th>Opportunities</th><th>Adaptation options</th></tr>
<tr><td>Cassava</td><td>Baseline: Mostly poor, except for some marginal areas in the north-west.

Future:
Negligible change in total suitable area and crop suitability index scores.</td><td>Huíla remains largely unsuitable for cassava, except for the northernmost extent of the interior highlands.</td><td>Cassava is predicted to be tolerant to increased temperatures and reduced precipitation in a small area of Huíla.

Can be harvested at any time to meet short-term food security needs.</td><td>Promotion of sweet potato as a perennial starch-rich alternative.

In the low-lying and arid southern areas, promotion of increased crop diversification, including sweet potato in combination with cassava and drought-tolerant cereals (millet or sorghum)</td></tr>
<tr><td>Coffee robusta</td><td>Baseline: Mostly or totally unsuitable except for some marginal areas in the north-west.

Future:
Negligible change in total suitable area and crop suitability index scores.</td><td rowspan="2">Huíla remains largely unsuitable for coffee except for the northernmost extent of the interior highlands.</td><td colspan="2" rowspan="2">Promotion of alternative subtropical crops e.g. banana, perennial starch crops such as cassava and sweet potato.

Prioritise engagement with private sector to support research & development, strengthening of value chain.

Promotion of multiple varieties to reduce exposure to unknown climate risks.

Promotion of shade trees and other forms of intercropping and agro-forestry in new coffee plantations.</td></tr>
<tr><td>Coffee arabica</td><td>Baseline: Mostly or totally unsuitable except for some marginal areas in the north-west.
Future:
Negligible change in total suitable area and crop suitability index scores.</td></tr>
</table>

Crop	Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)	Effect and scale of impact	Opportunities	Adaptation options
Sugar cane	**Baseline**: Mostly or totally unsuitable. **Future**: *Positive change* in total suitable area; *Positive change* in crop suitability index scores.	The net effect is a small increase in sugarcane production potential and total production area. In general, the majority of the province remains poorly suited to production of sugarcane.	Promotion of alternative subtropical crops e.g. coffee	
Sweet potato	**Baseline**: High to excellent in the northern and western uplands, unsuitable in the arid lowlands and south. *Negative change* in total suitable area; *Negative change* in crop suitability index scores.	The net effect is a small decrease in sweet potato production potential and total production area. Sweet potato will remain an important staple crop, however the suitable range is reduced by increasing temperatures and reduced rainfall in the southern and western extents.		Promote as a climate-resilient, easily grown perennial crop in the northern and western interior (particularly as an alternative or complement to cassava). Promotion of improved post-harvest storage and processing. In the low-lying and arid southern areas, promotion of increased crop diversification, including sweet potato in combination with cassava and drought-tolerant cereals (millet or sorghum)
Banana (Cavendish)	**Baseline**: Marginal suitability for Cavendish table banana in the centre and north of province. **Future**: *Negative change* in total suitable area; *Negative change* in crop suitability index scores.	In the baseline and future scenarios, Huíla province remains poorly suited to Cavendish and plantain banana varieties.	Promotion of alternative subtropical crops e.g. coffee. Prioritise engagement with private sector to support research & development, strengthening of value chain and identification of locally-adapted varieties.	

Crop	Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)	Effect and scale of impact	Opportunities	Adaptation options
Banana (plantain varieties)	**Baseline**: Totally unsuitable for production of plantain varieties. **Future**: **No change** in total suitable area; **No change** in crop suitability index scores.			
Maize	**Baseline**: Isolated areas of high to excellent suitability for all varieties of maize in the northern and western uplands, moderate to marginal suitability in the centre. Planting season is limited to October – November. **Future**: ***Negative change*** in total suitable area; ***Negative change*** in crop suitability index scores.	The net effect of climate change is a reduction in production potential and total production area for all varieties of maize.	N/A	Promotion of improved drought-tolerant varieties. Increase access to weather forecasts and early warnings. Promotion of sorghum, millet as climate-resilient alternatives to maize.
Millet	**Baseline**: Extensive areas of good to high suitability in northern and western interior. Marginally suitable in the arid southern region. **Future**: ***Negative change*** in total suitable area; ***Positive change*** in crop suitability index scores.	Climate change results in a small positive change in production potential, and a simultaneous negative change in total production area, for all varieties of millet and sorghum.	Large potential area of good suitability, noted as a climate-resilient alternative to maize.	
Sorghum				

Table 8. Malanje – Changes to crop suitability, climate risks and adaptation options

Province	Malanje
Summarised climate change effects	- Increased mean temperature, throughout the year. - Increased average 'minimum temperature', throughout the year, particularly in the period ~May to August. - Reduced average 'monthly precipitation' at the onset of the rainy season, in the period ~September to October. - Increased average 'monthly precipitation' in the middle of the summer growing season, in the period ~November to April. - Effective growing season will become increasingly delayed as a result of delayed onset and termination of summer rainfall season.

Crop	Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)	Effect and scale of impact	Opportunities	Adaptation options
Cassava	**Baseline**: Extensive areas of moderate to high suitability **Future**: *Positive change* **(net increase)** in total suitable area; *Positive change* **(proportional increase)** in crop suitability index scores.	The total area of suitability is predicted to increase significantly.	Widespread staple crop, generally considered to be climate-resilient relative to other rainfed staples. Comparatively less vulnerable to unpredictable rainfall. Can be harvested at any time to meet short-term food security needs.	Promotion of cultivars with increased resistance to pathogens and water-logging. Promotion of improved post-harvest storage and processing.
Coffee *robusta*	**Baseline**: Extensive areas of marginal to moderate suitability. **Future**: **No change** in total suitable area; *Minor positive change* in crop suitability index scores.	Modest increases in suitability are small relative to the baseline	Already widely grown, considerable potential for expansion.	Prioritise engagement with private sector to support research & development, strengthening of value chain. Promotion of multiple varieties of robusta and arabica in the same production areas to reduce exposure to unknown climate risks. Promotion of shade trees and other forms of intercropping and agro-forestry in new coffee plantations.
Coffee *arabica*	**Baseline**: Some areas of marginal to moderate suitability. **Future**: *Positive change* in total suitable area; *Minor positive change* in crop suitability index scores.	The total area of suitability is predicted to increase significantly.		

Crop	Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)	Effect and scale of impact	Opportunities	Adaptation options
Sugar cane	**Baseline**: Extensive areas of moderate to good suitability. **Future**: **No change** in total suitable area; *Positive change* in crop suitability index scores.	The net effect is a small increase in sugarcane production potential, with no change in total production area. Malanje remains very well suited to sugarcane production.	Comparatively high suitability relative to neighbouring provinces	Prioritise engagement with private sector to support research & development, strengthening of value chain.
Sweet potato	**Baseline**: Highly suitable to excellent throughout the province. **Future:** **No change** in total suitable area; **Minor** *Positive change* in crop suitability index scores.	The net effect is a small increase in sweet potato production potential, with no change in total production area. Malanje remains very well suited to sweet potato production.	Promote as a climate-resilient, easily grown perennial crop. Promotion of improved post-harvest storage and processing.	
Banana (Cavendish)	**Baseline**: Extensive areas of good to excellent suitability for Cavendish table banana **Future**: **No change** in total suitable area; *Positive change* in crop suitability index scores.	The net effect is a small increase in banana production potential and total production area (for Cavendish table bananas as well as plantains).	Considerable area with suitable potential which is currently underexploited.	Promotion of cultivars with increased resistance to pathogens and water-logging. Promotion of irrigation for plantation-scale producers. Prioritise engagement with private sector to support research & development, strengthening of value chain.
Banana (plantain varieties)	**Baseline**: Small areas of marginal suitability for production of plantain varieties. **Future**: *Positive change* in total suitable area; *Positive change* in crop suitability index scores.			
Maize	**Baseline**: Extensive areas of high to excellent suitability for all varieties of maize in a planting season. Potential	The net effect of climate change is a minor reduction in production potential, and no change in total		Promotion of improved drought-tolerant varieties.

Crop	Predicted changes in crop suitability (from Baseline to Mid-Century, 2050)	Effect and scale of impact	Opportunities	Adaptation options
	planting season of September – November. **Future**: **No change** in total suitable area; Minor *negative change* in crop suitability index scores.	production area, for all varieties of maize.		Increase access to weather forecasts and early warnings. Promotion of sorghum, millet as climate-resilient alternatives to maize.
Millet	**Baseline**: Good to high suitability throughout the province. **Future**: **No change** in total suitable area; *Positive change* in crop suitability index scores.	Climate change results in a small positive change in production potential, and no change in total production area, for all varieties of millet and sorghum.	Large potential area of high suitability, noted as climate-resilient alternative to maize.	
Sorghum	**Baseline**: Excellent suitability throughout the province. **Future**: **No change** in total suitable area; *Positive change* in crop suitability index scores.			

Appendix 1. EcoCrop definitions of crops analysed

Name	Scientific name	GMIN*	GMAX	KTMP	TMIN	TOPMN	TOPMX	TMAX	RMIN	ROPMN	ROPMX	RMAX
Cassava	Manihot esculenta Crantz.	180	365	7	10	20	29	35	500	1000	1500	5000
Banana	Musa acuminata Colla	180	365	0	12	23	33	42	650	1200	3600	5000
Plantain bananas	Musa balbisiana Colla	365	365	8	16	23	28	38	1000	1300	3000	5000
Banana	Musa acuminata x M. balbis.	180	365	0	15	25	35	40	1000	1400	2400	5000
Sweet potato	Ipomoea batatas (L.) Lam.	80	170	1	10	18	28	38	500	750	1250	5000
Maize	Zea mays L. s. mays	65	365	0	10	18	33	47	400	600	1200	1800
Dent maize	Zea mays v. indentata Sturt	100	140	0	12	20	27	45	500	600	1200	1800
Flint maize	Zea mays v. indurata Sturt	90	140	0	10	18	30	47	450	600	1200	1800
Pod maize	Zea mays v. tunicata Sturt	90	140	0	12	20	27	45	500	600	1200	1800
Sugarcane	Saccharum officinarum L.	210	365	-2	15	24	37	41	1000	1500	2000	5000
Sorghum (med. altitude)	Sorghum bicolor (L.) Moench	90	300	0	10	24	35	40	300	500	1000	3000
Sorghum (high altitude)	Sorghum bicolor (L.) Moench	90	300	0	12	22	32	35	300	500	1000	3000
Common millet	Pennisetum glaucum (L)R.Br.	60	120	2	12	25	35	40	200	400	900	1700
Coffee arabica	Coffea arabica	270	300	5	12	20	30	36	900	1700	3000	4000
Coffee robusta	Coffea robusta	270	365	0	9	13	26	32	800	1500	2400	3500

*KEY:
Ktmp: absolute temperature that will kill the plant
Tmin: minimum average temperature at which the plant will grow
Topmin: minimum average temperature at which the plant will grow optimally
Topmax: maximum average temperature at which the plant will grow optimally
Tmax: maximum average temperature at which the plant will cease to grow
Rmin: minimum rainfall (mm) during the growing season
Ropmin: optimal minimum rainfall (mm) during the growing season
Ropmax: optimal maximum rainfall (mm) during the growing season
Rmax: maximum rainfall (mm) during the growing season
Gmin: minimum days of growing season
Gmax: maximum days of growing season

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