GREENBOOK
adapting settlements for the future

CLIMATE CHANGE IMPACTS ON AGRICULTURE, FORESTRY & FISHERIES

WORKSTREAM 4: RESEARCH REPORT

2019

CSIR
our future through science

www.greenbook.co.za

Project partner

Funded by

IDRC | CRDI
International Development Research Centre
Centre de recherches pour le développement international

Canada

Authors	Daleen Lötter
Date	2019
ToDB reference	CSIR/NRE/ECOS/ER/2019/0004/C
Suggested citation	Lötter, D. 2019. *Green Book – Climate change impacts on agriculture, forestry and fisheries.* Technical report, Pretoria: CSIR

Disclaimer and acknowledgement: *This work was carried out with the aid of a grant from the CSIR Long-term Thematic Programme, Pretoria, South Africa and the International Development Research Centre, Ottawa, Canada. The views expressed herein do not necessarily represent those of the IDRC or its Board of Governors.*

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The primary sector of an economy utilises the natural resource base directly for revenue generation, whilst the secondary sector produces manufactured goods, and the tertiary sector produces services. Together with mining, agriculture, forestry and fisheries represent the bulk of the primary sector in South Africa. This sector acts as a catalyst for economic development of the secondary and tertiary sectors, and many of the smaller settlements in South Africa are strongly dependant on this sector. Climate change and variability impacts the primary sector, and will unavoidably affect such settlements in a direct and indirect way. The key towards understanding such impacts on settlements lies in understanding climate change impacts on agriculture, forestry and fisheries itself, before trying to identify and understand those impacts affecting settlements' ability to adapt to climate change.

1.1 The role of agriculture, forestry and fisheries in the economy

1.1.1 Agriculture

Agriculture contributes to economic development through food (and other commodity) production, providing a market for produced goods, providing employment and as a net exporter of agricultural products. Primary commercial agriculture contributes about 2.5% of South Africa's gross domestic product (GDP), but through strong linkages to other sectors of the economy, it is estimated to comprise about 14% of the GDP (DAFF, 2016b). Agriculture's prominent, indirect role in the economy is a function of backward and forward linkages to other sectors. Purchases of goods such as fertilisers, chemicals and agricultural implements form backward linkages with the manufacturing sector, while forward linkages are established through the supply of raw materials to the manufacturing industry. Approximately 70% of agricultural output is used as intermediate products in the sector. Agriculture is, therefore, a crucial sector and serves as an important engine of growth for the rest of the economy. South African agriculture is comprised of mainly two categories — a predominantly subsistence-oriented sector in the rural areas (small scale), and a well-developed commercial (large scale) sector. In recent years the number of commercial farmers has however dropped from 66 000 in 1990 to around 35 000 at the time of publication. In 2011 Absa Agribusiness (2011) predicted this figure to drop to 15 000 over the next 15 years.

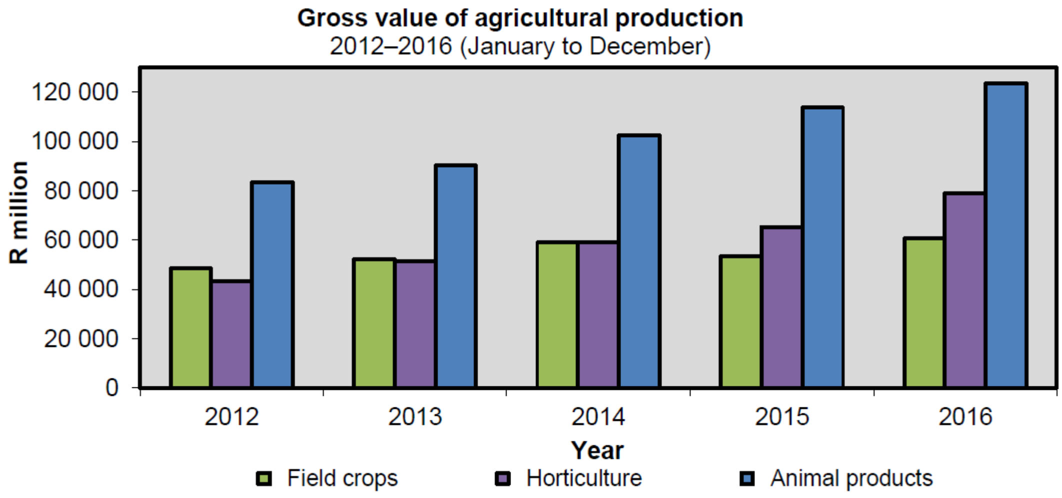


Figure 1: Gross value of agricultural production from 2012-2016

For statistical purposes, the agricultural sector in South Africa is divided into three main branches - namely field crops, horticulture and animal products. In 2016, animal products contributed 46.9% to the total gross value of agricultural production, while horticultural products and field crops contributed 30.0% and 23.1%, respectively (Figure 1). Within the animal products branch, the poultry meat industry made the largest contribution, with 15.2%, followed by cattle and calves slaughtered with 12.5% (DAFF, 2016). 2010 statistics show 13.6 million beef cattle, 1.4 million dairy cattle, 24.6 million sheep, 7 million goats, 3 million game species (farmed), 1.1 million pigs, 113 million broilers, 31.8 million layers and 1.6 million ostriches (Meissner, Scholtz and Palmer, 2013). Maize is the most important field crop produced in South Africa, followed by wheat, soya beans and sunflower seed. Within the horticulture branch, deciduous fruit, vegetables and citrus fruit make the most significant contributions.

This range of animal, crop, fruit and vegetable production takes place across South Africa under various climate conditions, ranging from arid to sub-tropical. The high summer rainfall areas of Mpumalanga, Gauteng and the Free State, and the midlands of KwaZulu-Natal are principal crop or mixed farming regions. In these areas, the production of maize, sorghum, groundnuts and potatoes is combined with dairy production and pig farming. The winter rainfall region of the Western Cape is well known for its vineyards, wine and deciduous fruit production. The main deciduous fruit-producing areas of South Africa are situated in the Western and Eastern Cape provinces, mainly in areas where warm, dry summers and cold winters prevail (Department of Agriculture, 2003). The semi-arid to arid parts of the Northern and Western Cape mainly support extensive sheep farming, while the typically dry savanna of Limpopo Province and the semi-arid North West are essentially extensive cattle farming regions, with some game production.

In 2016, the agricultural sector employed almost 900 000 people (DAFF, 2016a). This implies that it employs around 4.7% of the total labour force, while it constitutes only 2.4% of the economy (Greyling, 2012), and is therefore quite significant. If the workers in the agricultural services, food manufacturing and trade are included, agricultural and agriculturally related employment represent 9% of national employment. As a share of all jobs created in the rural formal areas, 52% fall within agricultural and agriculturally related industries (Liebenberg and Kirsten, 2013).

1.1.2 Forestry

Mpumalanga and KwaZulu-Natal are the two major forestry production provinces, while the Eastern Cape, Western Cape and Limpopo also include some forestry areas (Figure 2). In 2011, forestry and forest products contributed 0.80% and 0.26% respectively to the national GDP (IDC, 2014). Although this is quite a modest figure, forestry makes a key contribution to the development of local economies, particularly in rural areas. The most important species being cultivated are Pinus species, Eucalyptus species and *A. mearnsii*. The forestry industry employs approximately 170 000 people, of which 67 500 are informally employed, 30 000 are contract workers, and 39 500 are small growers and their helpers (Godsmark, 2013) (Figure 4). These workers are mainly employed in the sawmilling, mining timber, pulp and paper industries. When considering downstream value add, between 390 000 and 560 000 people are dependent on plantation forestry for employment (Godsmark, 2008, 2013). Most people reliant on forestry for an income are based in KwaZulu-Natal and Mpumalanga (Figure 3).

Awareness and interest surrounding climate change are increasing within the forestry industry. Of particular concern in this regard is the increase in insect and disease outbreaks, as well as a greater likelihood of wild fires associated with increasing temperatures (Fibre Processing and Manufacturing SETA, 2014).

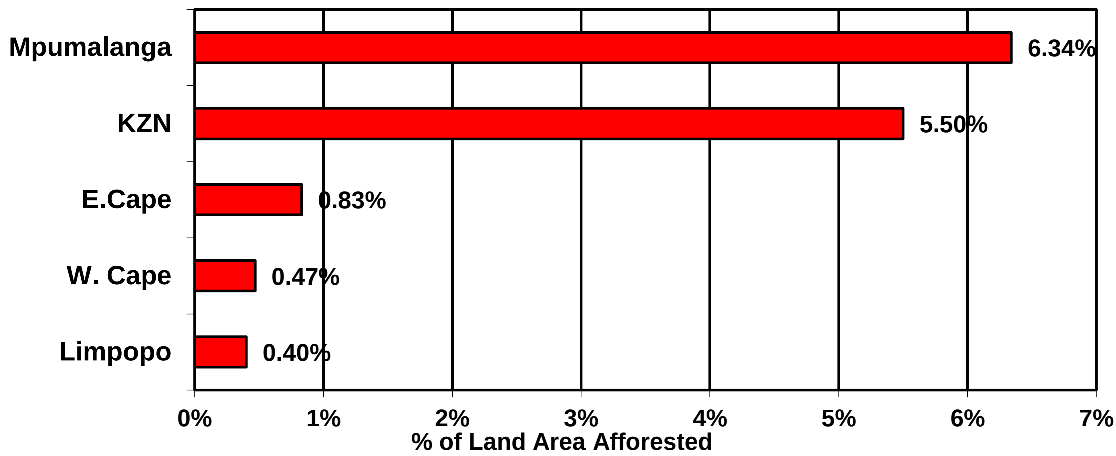


Figure 2: Plantation area as % of land area by province 2011 (Godsmark, 2008)

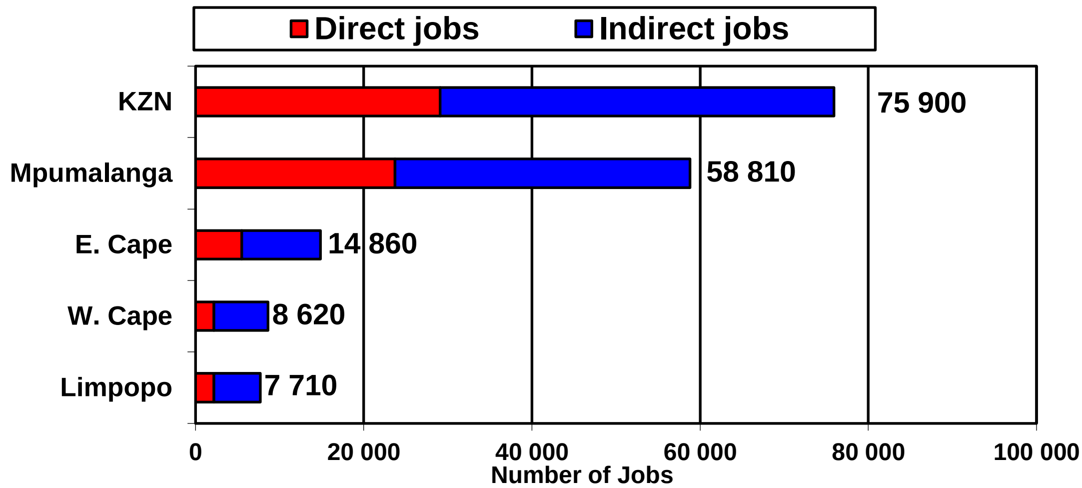


Figure 3: Direct and indirect jobs in the forestry industry by province 2011 (Godsmark, 2008)

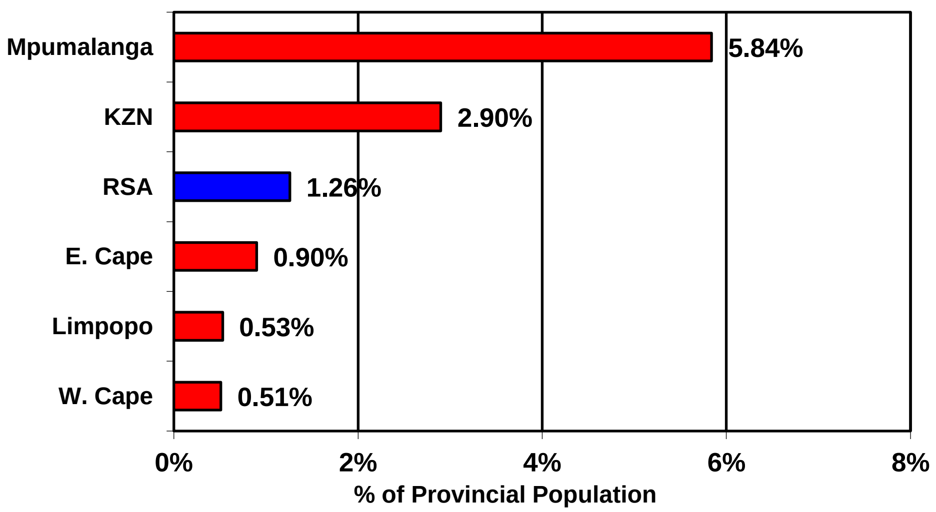


Figure 4: Estimated % of population dependent on the forestry industry 2011 (Godsmark, 2008)

1.1.3 Fisheries

The fishery sector comprises both a wild capture and an aquaculture component. Wild capture fisheries include commercial, recreational and subsistence fishing. These three main branches include 24 700 commercial, 750 000 recreational and 29 000 subsistence line fishers, as well as 2 000 small scale gillnet and seine net fishers (Potts, Götz and James, 2015). South Africa's major fishing grounds are situated along the continental shelf between St Helena Bay and Port Elizabeth. The industry's major fishing ports, processing factories and service industries are similarly found in the Western Cape (Table 1). Port Elizabeth, Port St Francis, Durban and Richards Bay are the other ports of significance in this sector outside of the Western Cape.

Subsistence and small-scale fishing play an important role in the provision of employment and food security – particularly by providing protein – to poor coastal communities (Isaacs and Hara, 2015).There are around 147 fishing communities and 29 000 individuals that have been identified as genuine subsistence fishers, with many more individuals being dependent on these fishermen (DAFF, 2014a).

Direct employment across all fishery sectors is estimated to be 27 000, while indirect employment in industries linked to the fishery sector is estimated to be between 81 000–100 000 (StatsSA, 2013; DAFF, 2014b). Although currently underdeveloped, it is predicted that the aquaculture industry will experience substantial regional growth in the coming years, helping to reduce the pressure on natural wild stock.

Climate change-associated impacts of concern for the fishing industry include changing sea surface temperatures; changes in wind strength and direction that influence water circulation; elevated CO_2 and ocean acidification; current speed and strength; and sea level rise. Depending on the species in question and geographic location, such changes are likely to affect species distribution, species growth rate and reproduction(DEA, 2013b).

1.1.3.1 Important commercial fish species

Table 1 gives an indication of the most important commercial fish species and areas of operation. The demersal (offshore and inshore) trawl fishery (targeting Cape hakes) and pelagic-directed purse-seine fishery (targeting pilchards, anchovy and red-eye round herring) have both the highest economic value and greatest landed tonnage (Japp and Wilkinson, 2015). South Africa’s purse-seine fishery for small pelagic species is the country’s largest in terms of volume landed while anchovy and sardine have alternated as the dominant component of this fishery.

The fishery of West Coast rock lobster (Jasus lalandii) forms an area extending along the West Coast (from Port Nolloth) southwards to Cape Point, and then eastwards towards Hermanus (refer to Figure 8). The West Coast rock lobster (J. lalandii) fishery is economically the most important rock lobster fishery in South Africa, contributing approximately R260 million per annum in market value (StasSA, 2013). Abalone is a small but highly profitable fishery, and is widely distributed along the South African coastline, from St Helena Bay on the West Coast to just north of Port St Johns on the east coast. South coast rock lobster (Palinurus gilchristi) is a small fishery that operates predominantly between East London and Cape Point (Kaiser EDP, 2012; Brick and Hasson, 2016; WWF, 2016). Squid (locally better known as “chokka”) occurs around the coast from Namibia to the Wild Coast off the Eastern Cape. It is landed mainly between Plettenberg Bay and Port Alfred. Line-fishing is a low-earning, labour-intensive industry, but important from a human livelihood point of view. Line-fishing in South Africa is defined as the capture of fish with hook and line, but excludes the use of longlines. Together, the three sectors of the line-fishery (commercial, recreational and subsistence) target between 95 and 200 of South Africa’s 2 200 marine fish species (Kaiser EDP, 2012; Brick and Hasson, 2016; WWF, 2016).

Table 1: Important landing places and associated fish species

Town	Species1	Species2	Species3	Species4	Species5	Species6	Species7	Species 8	Species 9	Species 10	Species 11
CAPE TOWN	Linefish	Cape Hake						Large Pelagic	Horse Mackerel	South Coast Rock Lobster	Tuna Bait and Pole
SALDANHA	Linefish	Cape Hake		Sardine		Anchovy					Tuna Bait and Pole
MOSSEL BAY	Linefish	Cape Hake		Sardine							
PORT ELIZABETH	Linefish	Cape Hake					Squid	Large Pelagic	Horse Mackerel	South Coast Rock Lobster	
GANSBAAI	Linefish	Cape Hake		Sardine		Anchovy					
ST HELENA BAY	Linefish		West Coast Rock Lobster	Sardine		Anchovy					
HOUT BAY	Linefish		West Coast Rock Lobster	Sardine		Anchovy					
KALK BAY	Linefish		West Coast Rock Lobster								
PORT ST FRANCIS	Linefish						Squid				
DURBAN	Linefish				Shrimp			Large Pelagic			
RICHARDS BAY	Linefish				Shrimp			Large Pelagic			
LAMBERTSBAY	Linefish		West Coast Rock Lobster								
PORT NOLLOTH			West Coast Rock Lobster								
LAAIPLEK	Linefish		West Coast Rock Lobster								
HERMANUS	Linefish										
ARNISTON	Linefish										
STRUISBAAI	Linefish										
STILBAAI	Linefish										

1.1.4 Agriculture and its link to settlements

The agriculture sector's link to settlements may be assessed in the context of its role in the larger South African society and economy. According to Greyling (2012) the agricultural sector acts as a provider of food; earner of foreign exchange; employment source or provider; source of capital; and buyer of goods or provider of inputs to the manufacturing sector. Vink (2003) further describes the sector's benefits to the society as the provisioning of food security to the poor, the provision of rural amenities that form the basis of agrotourism, the provision of a better balance between rural and urban populations, and the attraction of foreign investment.

The agriculture sector as a provider of food plays a prominent role in the broader theme of food security. Food security encompasses all activities from agricultural production, through to processing, packaging, storage, and distribution. Settlements are, however, not always directly connected to the agricultural products in their surrounding area. In many instances, crops that are grown in a specific area are processed in and distributed to other regions.

The export of agricultural products plays a crucial role in earning valuable foreign exchange for the country. Such earning improves a country's capacity to import other essential inputs, machinery, raw material, and other infrastructure that is helpful for the support of the country's economic development.

Agriculture, as mentioned earlier, also provides employment opportunities and livelihoods to a large percentage of the population, especially in rural areas. The primary agricultural sector accounts for approximately 7% of formal employment in 2013, of which a significant share is unskilled labour (DAFF, 2013b). Elementary workers make up 77% of the agricultural workforce. Of those, 22% are considered unskilled.

As mentioned earlier, the agricultural sector has very important backward and forward linkages to the rest of the economy. Agriculture buys inputs from the manufacturing sector, provides raw materials for manufacturing and purchases several other services (Greyling, 2012). Agriculture also makes and supports important investments in infrastructure. The development of agriculture requires roads, storage facilities, power generation and transmission, transportation railways, amongst others, which can also lead to investments in schools and healthcare facilities.

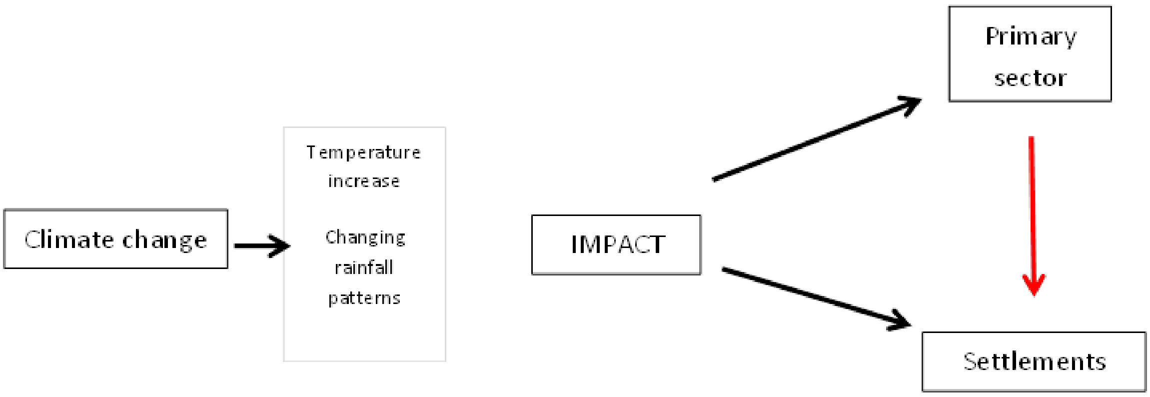
In areas where farming is the primary economic activity, it will support the vast majority of the population in employment and indirect linkages. Where farming is the primary economic activity, the entire rural economy, including services such as health care, education and basic infrastructure, may depend on the productivity of the sector. In such regions, it is clear that overall social and political stability is inextricably linked with the state of the agricultural sector. Where settlements are, therefore, located in areas where farming is the primary economic activity, any change in the profitability of the sector will also impact on the settlement and its sphere of influence.

A stable, well-developed agricultural sector is, therefore, vital to the social and economic stability of a region. As mentioned earlier, climate change is one aspect that poses a significant threat to South Africa's agricultural sector, which could contribute in destabilizing the sector (and ultimately the settlements and regions around it) if it fails to implement successful adaptation strategies. Several variables (of which climate change is only one) affect the way agriculture is practised. Increased temperature and changing rainfall patterns may fundamentally impact agriculture if the natural threshold of the commodities that are being farmed are breached (a key farmer or land management objective would be to prevent this). The nature and extent of these impacts depend, however, on the type of commodity being farmed and the relative position of the farmer with regard to the industries that are served. The same climate impact may have different impacts on different commodities and farms.

Overall, climate change may make it more difficult to grow crops, raise animals, and catch fish in the same way and/or in the same places as it was done in the past. In addition to climate change, factors such as rising electricity prices; a lack of subsidies and extension support; a high crime rate; increasing tenure insecurity (land reform); and a decline in the health and functioning of supporting and underpinning natural systems can also undermine the sustainability of agriculture in a specific area, with multiple stressors often compounding each other. Such multiple stressors may have direct and indirect consequences for settlements and their spheres of influence.

The aim of this study is to identify areas, regions or towns where agriculture makes a significant contribution to the production of goods and services, and to assess to what extent climate change may impact upon the main agricultural activities in that area. As mentioned earlier, a negative impact on agriculture would not only affect employment and labour, but could also have broader consequences for areas that are largely dependent on local agriculture.

The agricultural sector in South Africa is significantly diverse, incorporating more than twenty major field crop types; over fifteen main horticulture types; several animal divisions; and game farming. It is beyond the scope of this study to assess each crop or animal type. The study therefore focuses on the most important farming sectors in the context of contribution to a region's gross value added productivity. This study makes an initial contribution towards linking the impacts of climate change on key agricultural sectors to implications for settlements.



2 METHODOLOGY

The methodological approach for the study was subdivided in three main components:

- Screening of relevant agricultural sectors for further analysis,
- Climate change scenario analysis,
- Agricultural modelling and area based climate impact assessment.

The basic approach for the study included a screening process to determine which industries can realistically be modelled within the allocated timeframe. This was followed by an agricultural risk assessment of climate change scenarios over a specific area, to give more detail on how predicted climate changes translate into location specific impacts. More detail on each component follows below.

2.1 Screening of relevant agricultural sectors for further analysis

Since time limits prevented modelling of all industries of the primary sector, we proposed a screening process to identify which areas and which sectors would need to be further assessed. Such scoping also reduced the number of crops which would be most useful to model in the context of the study .The first task was to rank magisterial districts according to the economic contribution and level of employment that agriculture, forestry and fisheries comprise relative to other sectors. To this end, the Geospatial Analysis Platform (GAP) data produced by the CSIR's Built Environment Unit (2010) was used to extract Gross Value Added (GVA) and employment figures for the agriculture, forestry and fisheries sector. GVA is used as a measure of the value of goods and services produced in an area, industry or sector of an economy. According to the CSIR (2010), this category includes establishments which are primarily engaged in farming activities, such as the growing of field crops, the raising of livestock and the production of milk, wool and eggs. Establishments rendering agricultural services such as harvesting, baling, threshing and spraying are also classified under this major division. Also included are establishments engaged in commercial hunting and game propagation, and forestry, logging and fishing. This provided an indication of which areas are most dependent on agriculture, forestry or fisheries for economy and employment.

Since GVA data does not differentiate between agriculture, forestry and fisheries, additional data sources were used to determine which agricultural industries or sectors are most significant to a specific area. This information was derived from the Census of Commercial Agriculture (Statistics South Africa, 2007), and is available at magisterial district level for the entire South Africa. It provides statistics on employment, production, finance and general information with regard to active commercial farming enterprises in South Africa. The report further provides details of field crop and horticultural production, and animals and animal products produced on magisterial district level. Since this census did not include small scale farming, and considering the fact that production figures may have changed since the last census, several other literature sources were consulted to ensure that the data reflects the most accurate representation of production types across South Africa. The data was extracted for the two most important farming sectors based on their contribution to the income generated for a specific magisterial area. Using ArcGIS software, the census data in table format were joined with a spatial data set depicting the boundaries of magisterial areas as they were designated in 2007. This allowed for the spatial visualization of the most prominent agricultural sectors across the country, as well as for input in the climate risk analysis.

2.2 Climate change scenario analysis

Characterization and understanding of trends in historical climate variables, in conjunction with viable multi-model projections of future climates, help to identify specific climate-related risk factors within regions. This ability to anticipate alterations in climate patterns and trends is critically important in developing adaptation strategies for resource management. This project analysed detailed projections of future climate change over South Africa towards informing the agricultural sector assessment on climate change impacts and adaptation. Detailed projections (8 km resolution) of future climate change over South Africa derived from regional climate models (that is, from dynamic downscaling procedures) produced by the CSIR were used to perform statistical analysis of the CORDEX ensemble of regional projections (for both low and high mitigation futures). Analysis was performed for the period 1961-2100, with projected climate change futures discussed for both mid-future (2020-2050) and far-future (2070-2100) periods. The climate metrics considered included average temperature; minimum temperature; maximum temperature; rainfall; extreme convective rainfall events; prolonged rainfall events that lead to large-scale flooding; rainfall intensity; run-off; wind velocity; high fire-danger days; and heat-wave days. This information was then inputted into the agricultural impact assessment for several climate scenarios.

2.3 Agricultural modelling and area based climate impact assessment

As shown earlier, climate change is projected to have widespread impacts on the climate suitability and geographical distribution of crops, livestock and fish species. The aim of this modelling is to create maps/scenarios of future crop suitability for each of the sectors/industries identified in the screening process. These maps may then be overlaid onto the settlement typology map, and therefore address the spatial relationship of how a change or shift in a specific industry would relate to surrounding settlements.

2.3.1 Crop climate envelope modelling

Climate envelope modelling shows how a crops climatic distribution might shift or expand under scenarios of future climate change. It should, however, be acknowledged that modelling a crop's suitability to basic climate and soil traits is only an initial step in identifying potential change impacts. Climate envelope modelling for suitability is a relative measure of a location's ability to meet a crop's abiotic environmental requirements, and does not account for biotic and economic factors that further impact on suitability, productivity and profitability.

Bio-climatic envelope modelling using the maximum entropy method was used to develop an estimate of the current geographic distribution of areas suitable for commercially production. This method estimates a crop's actual or potential geographic range through relating field observations of crop occurrences to environmental and climatic variables. This relationship may then be used to assess suitability shifts under different climate scenarios to undertake risk assessments in specific focal areas. The Maxent software (version 3.3.3k http://www.cs.princeton.edu/~schapire/maxent/) was used in this study to model crop suitability. It is a machine learning technique that uses a data matching algorithm to make predictions from incomplete information (Phillips et al., 2006). Subject to known constraints, Maxent estimates a probability distribution which has the maximum entropy, while matching the value of each environmental variable as closely as possible to the empirical values observed at the crop's occurrence records. The output can either be raw (relative occurrence rate), cumulative or logistic (probability of presence). This study presented the results as logistic output, which is an estimate of the suitability (scaled from 0-1) of each grid cell within the study area as a function of the values of the climatic and environmental variables in that grid cell. Based on known occurrences of crops in the area that it actually occupies, Maxent therefore gives an approximation of the suitability for the crops which approximates its realized environmental niche. It therefore fits the model in an environmental space which is a conceptual area defined by climatic and environmental variables and then projects it back to geographic space (Pearson, 2006).

2.3.2 Livestock modelling

Although Maxent modelling can also be applied to model geographical areas for optimal livestock production, the availability of production data on dairy herds are not readily available. Heat stress is one of the major factors affecting milk production, reproduction and general health of a dairy cow. Many attribute heat stress only to temperature, but it is, in fact, a combination of air temperature and humidity. This study therefore used the Temperature Humidity Index (THI) to assess heat stress in livestock. The THI accounts for the combined effects of environmental temperature and relative humidity, and is a useful and easy way to assess the risk of heat stress.

2.3.3 Fisheries

Predicting climate change impacts on marine fisheries is difficult and uncertain due to the complex interaction between species productivity and spatial distribution, as well as the complicating impacts of overfishing and other stressors (DEA, 2013). Distribution models have been used to predict the effects of climate change on the range of terrestrial species. but are less common for marine species. This report therefore reviewed existing literature for important changes and potential impacts on marine resources for the Southern African coastal ocean by 2050. A list of marine resource dependent settlements (commercial and small scale) was developed.

2.3.4 Local municipality climate impact assessment

The climate impact assessment was developed at local municipal level, and guided by the outcome of the agricultural industry sector screening and climate scenario analysis described in sections 2.1 and 2.2. Using the spatial statistics geoprocessing tool in ArcGIS, each of the 213 local municipalities was assigned an average value in terms of changes in relevant climate variables e.g. annual rainfall, extreme rainfall, average temperature, very hot days, relative humidity and high fire-danger days. These climate variables were used to assess the potential impact on the main agricultural activities in each local municipality. These agricultural activities were assigned to each local municipality based on the magisterial district census data.

3 RESULTS AND DISCUSSION

3.1 Economic contribution of agriculture, forestry and fisheries across the country

Most of the regions with high GVA scores and where agriculture makes the largest contribution to the economy of the district are located in the Western Cape and Northern Cape provinces (Figure 5). This is coincident with the fact that the Western Cape is the largest contributor in terms of gross farming income in the country, and most farming activity occurs in this area. Although the absolute GVA value may be substantially higher in certain other areas, such as in Limpopo, compared to areas in the Western Cape, the relative contribution that it makes to the total GVA is lower. This may be due to the fact that other sectors such as mining and manufacturing are more important in these areas - certainly a general trend in Limpopo, Gauteng and parts of North West provinces where most of South Africa's mining activity is concentrated. In the Northern Cape, agriculture and mining are the dominant economic activities. Most of the province is utilised for game and sheep farming, while intensively cultivated grape and fruit production occurs within the Orange River Valley. Only 2% of the province is used for crop farming, while 96% of the land is used for livestock farming (Department of Agriculture, 2003). The Northern Cape has, by far, the smallest population and economy of any of the provinces.

Considering specific agricultural sectors at magisterial district level, almost 43% of magisterial districts reported that animals and animal products make the most important contribution to the total gross value of agricultural production in the district (Table 2 and Figure 7). Such a finding is coincident with the results of an economic review of agriculture in 2016 (DAFF, 2016) which indicated that animal products made the largest contribution (46.9%) to the total gross value of agricultural production in South Africa. Animal production includes poultry farming—which is currently the single largest agricultural sector in the country—and cattle farming for beef. According to the agricultural statistics data, as mentioned earlier, the poultry meat industry made the largest contribution (15.2%), followed by cattle and calves slaughtered (12.5%). Although earning marginally less income than poultry, the sheep and cattle industry are far more widely represented throughout the country - due to the fact that approximately 80% of agricultural land in South Africa is mainly suitable for extensive livestock farming (Department of Agriculture, 2003).

A further 25% of magisterial districts reported field crops as the dominant sector, while 15% reported horticulture as being dominant (Table 2 and Figure 7). For the other 5% there was either no data, or forestry was dominant (Pilgrim's Rest, Kranskop, Umvoti, Paulpietersburg and Alfred Alfred), whereas aquaculture was reported as most important for only one district - namely Hermanus (Table 2 and Figure 7). Several magisterial districts in the Eastern Cape, KwaZulu-Natal and Limpopo reported subsistence farming as the main agricultural activity (Table 2 and Figure 7). In these rural areas, households mainly engage in cattle ranching, maize, sorghum, vegetables and fruit crop production.

Table 2: Representation of the two most important agricultural industries across magisterial districts in South Africa.

Main use	Total Magisterial Districts	Sub use	Total Magisterial Districts
Beef cattle	70	Beef cattle	69
Maize for grain	63	Maize for grain	54
Small-scale	48	Small-scale	49
Sheep	40	Sheep	43
Deciduous	22	Milk and cream	28
Milk and cream	21	Chickens	12
Sugar-cane	16	Sugar-cane	10
Wheat	12	Potatoes	8
Citrus	11	Wheat	7
Chickens	8	Chicken eggs	6
Subtropical	7	Deciduous	6
Other	5	Forestry	5
Forestry	5	Other animal products	5
Chicken eggs	4	Citrus	5
Potatoes	3	Other	4
Carrots	2	Pigs	4
Mohair	2	Tobacco	4
Mushrooms	2	Tomatoes	4
Ostriches	2	Cultivated and wild flowers	3
Other animal products	2	Mushrooms	3
Tobacco	2	Game farming	3
Wool	2	Ostriches	3
Aquaculture	1	Wool and Mohair	3
Cucumbers	1	Mohair	2
Cultivated and wild flowers	1	Dried fruit	2
Lettuce	1	Asparagus	1
Sunflower seed	1	Dried vine fruit	1
		Other	1
		Cabbage and red cabbage	1
		Lucerne	1
		Grain sorghum	1
		Green mealies and sweet corn	1
		Lettuce	1
		Aquaculture	1
		Cotton	1
		Nuts	1
		Sub-tropical	1

Upon further investigation, it was decided to model the crops/livestock that make the largest contribution within each division. Maize, wheat and sugar cane are the most important earners of gross income in the field crops category. The majority of maize (83%), wheat (53%) and sugarcane (73%) are produced under dryland conditions, making them especially vulnerable to periods of drought (Schulze and Durand, 2016). As mentioned earlier, maize (Zea mays L.) is the country's most important field crop, and the staple food of the population. Estimates for the 2017 production year, forecasted the crop harvest at 14.73 million tonnes, which is an 89% increase from the 7.78 million tonnes realized in 2016, when an El Nino-triggered drought significantly impacted yields and plantings. Wheat is generally a winter rainfall crop. There are approximately 26 400 registered sugarcane growers in South Africa, covering the provinces of KwaZulu-Natal, Mpumalanga and the Eastern Cape (Shulze and Kunz, 2016). Of the 26 000 sugarcane growers, more than 25 000 are small-scale growers, producing about 10% of the total crop. Large-scale growers (approximately 1 400) produce approximately 83% of the total sugarcane crop, while milling companies, with their own sugar estates, produce approximately 7% of the crop.

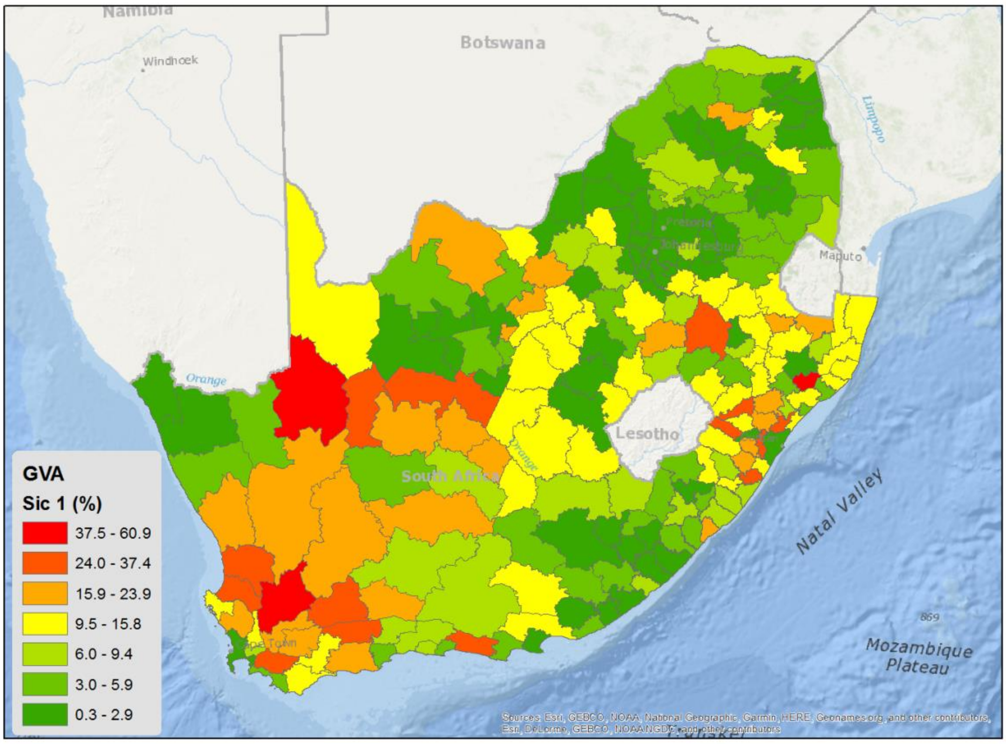


Figure 5: Average GVA contribution (%) of agriculture, forestry and fisheries relative to the total GVA per local municipality

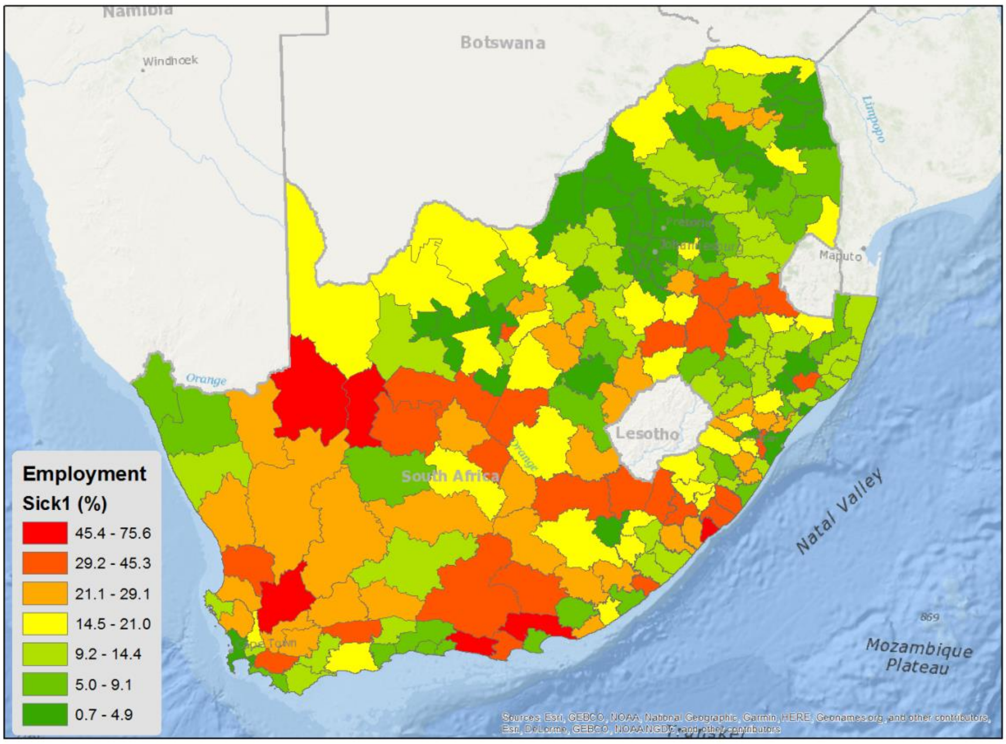


Figure 6: Average contribution (%) of agriculture, forestry and fisheries to employment relative to the total employment per local municipality

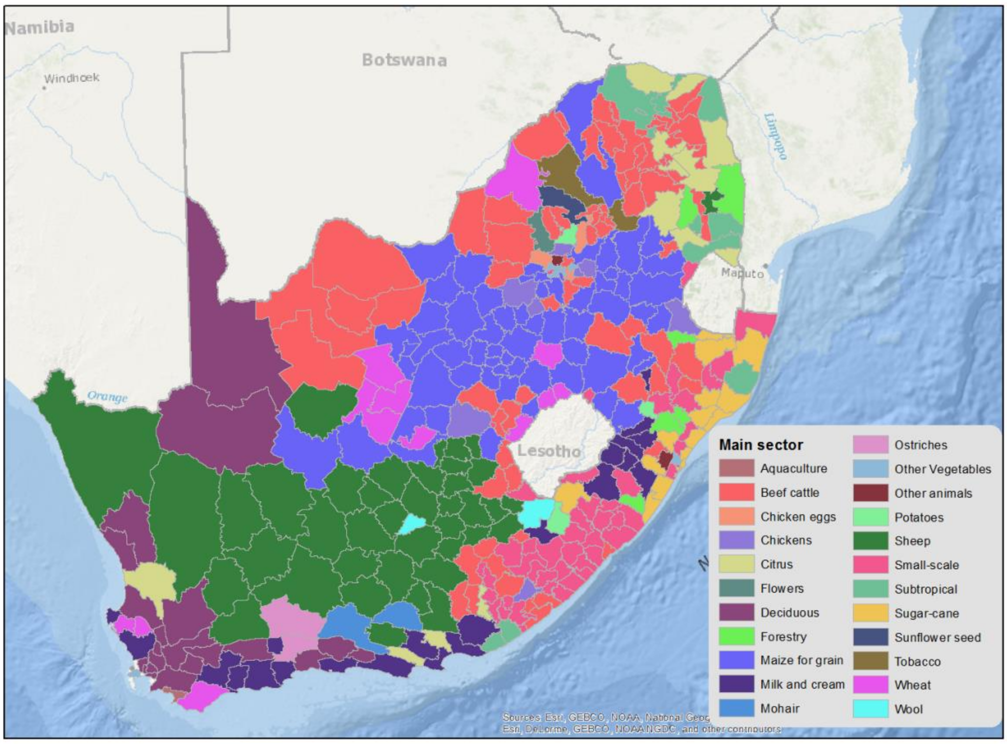


Figure 7: Main agricultural commodities per magisterial district

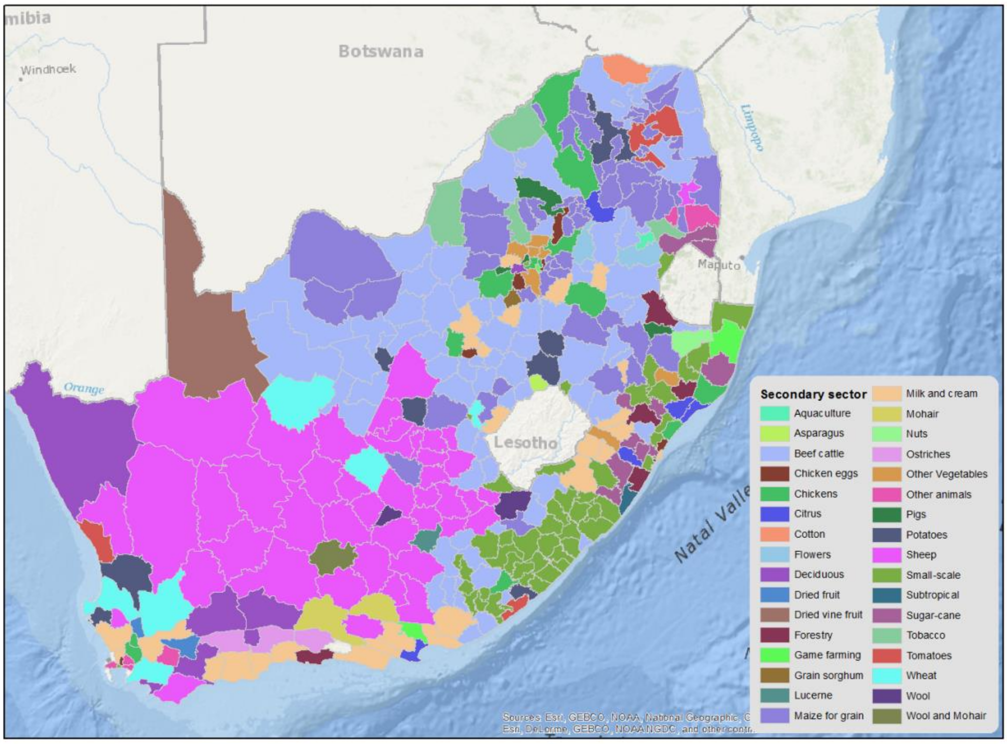


Figure 8: Secondary agricultural commodities per magisterial district

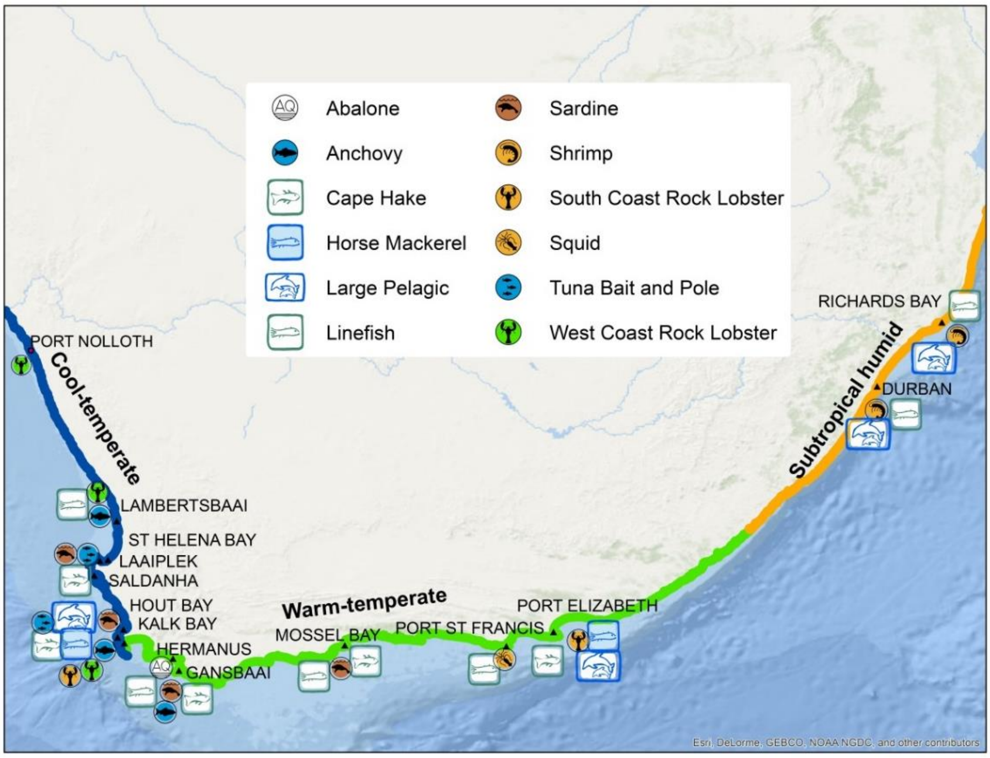


Figure 9: Main landing places and associated marine species

Although the South African fishery industry contributes only a small proportion of the country's GDP, it has, as mentioned earlier, an important role as a provider of employment in specific coastal regions, in particular in semi-arid areas where alternative employment options are scarce (Hutchings et al., 2009). It is also a critical source provider of protein, without using excessive volumes of scarce fresh water (Hutchings et al., 2009). The scale of the fishing sub-sectors varies considerably in terms of production, value employment and locality. While the hake fishery is South Africa's most valuable resource and a significant employer, the only fishing harbour that plays a significant role is Saldanha Bay. The small pelagic fishery is the largest in terms of tonnage and second largest in terms of value, employing over 5000 people (Brick and Hasson, 2016). The industry is based at five fishing harbours (Figure 8). The West Coast rock lobster fishery, as mentioned earlier, generates significant value and employment and utilises three fishing harbours. Aquaculture is a significant growth industry which is now comparable to the medium size fishing sectors in terms of value and employment.

Important fishing harbours on the West Coast of South Africa that are crucial for local economic development and socio-economic benefit to communities are Lamberts Bay, Laaiplek, St. Helena Bay, and Saldanha Bay. Saldanha Bay is a major harbour for demersal fish processing. Saldanha Bay is home to Sea Harvest Corporation - one of South Africa' two biggest demersal trawl companies. The socio-economic impact of Sea Harvest's operation in Saldanha is significant, according to the company website: "Sea Harvest is the single largest employer in the Saldanha Bay and West Coast District, responsible for between 4 000 and 5 000 direct and indirect jobs. The company accounts for an estimated 15% of all employment in the Saldanha Bay Municipality. These jobs represent more than 15% of all household income in the greater West Coast district and nearly 30% in the town of Saldanha." (Sea Harvest Corporation website: www.seaharvest.co.za). Aquaculture is also a major marine activity in Saldanha Bay, where companies mainly engage in growing mussels and oysters.

In other settlements such as Papendorp and Elands Bay, subsistence fishing is critical to the livelihoods of the local community. The Cape Town Metropolitan area hosts fishing harbours in Hout Bay, Kalk Bay and Gordon's Bay. The south coast harbours fall within the jurisdiction of the Overberg District Municipality, and include Hermanus, Gansbaai, Arniston, Struisbaai, and Stilbaai. This area is especially important for aquaculture production. The Western Cape is the main province involved in aquaculture, both in terms of number of farms and production. The focus of aquaculture is on high value species such as abalone, mussels and oysters.

The smaller active fishing harbours and landing points include Port Nolloth (rock lobster) on the West Coast, then moving to the south and sast: Hondeklip Bay, Lamberts Bay, Elands Bay (rock lobster and linefish), Laaiplek/St Helena (small pelagic, snoek and lobster), Yzerfontein (snoek, lobster), Hout Bay (small pelagics, rock lobster, recreational tuna, eco-tourism charter), Buffels Bay (snoek), Kalk Bay (rock lobster and linefish), Gordon's Bay (recreational fishing and lobster), Kleinmond (snoek), Gansbaai (small pelagic and fishmeal processing), Hermanus (whale watching), Struisbaai (linefish) and Stilbaai (linefish).

According to Sowman (2006), there are at least 147 fishing communities along the South African coast, comprising approximately 28 300 fisher households and approximately 29 200 individual fishers who could be considered subsistence. They are an integral part of the rural and coastal communities where they reside (DAFF, 2014a). Kwa-Zulu-Natal and the East and West Coast comprise the largest subsistence communities.

Small scale fishers derive their livelihoods from a wide variety of activities apart from fishing, such as low pay labour, state grants and limited employment in the services sector. Organisms such as fin-fish, mussels, octopus, rock lobster, sand and mud prawns, limpets and red bait, periwinkle (alikreukel), crabs, oysters, seaweed, sea lice, worms and abalone are generally and traditionally the most frequently harvested resources by small scale fishers (Sowman, 2006; DAFF, 2012, 2014a). Small scale fisheries may provide substantial job creation and livelihood opportunities, if these fishers and communities are involved in and are part of the entire supply chain and related activities.

3.2 Climate change modelling and scenario analysis

3.2.1 Field crops (maize, wheat, sugarcane and soybeans)

Although some areas in central South Africa are predicted to experience some expansion in areas suitable for wheat and maize production, mainly as a result of an increase in rainfall, towards the end of the century yield may start to decrease, since maximum temperatures can become a limiting factor (Figure 10). This is in line with the findings from Johnston et al. (2012), which predict that until 2035, yields are expected to rise, thereby increasing total production, but that after this production will succumb to the decline in planted area, and South Africa will become a maize importing country. These impacts will be even more severe during years of extreme weather (Johnston et al., 2012).

According to Challinor et al (2016), crops may incur heat stress at certain threshold temperatures, which would not be able to be offset by increasing rainfall. This is especially true under a low mitigation scenario, where temperatures are predicted to increase by up to 6°C by the end of the century in certain maize production areas. This is also associated with a sharp increase in extreme temperatures, especially over areas of North West, the western Free State and the Northern Cape.

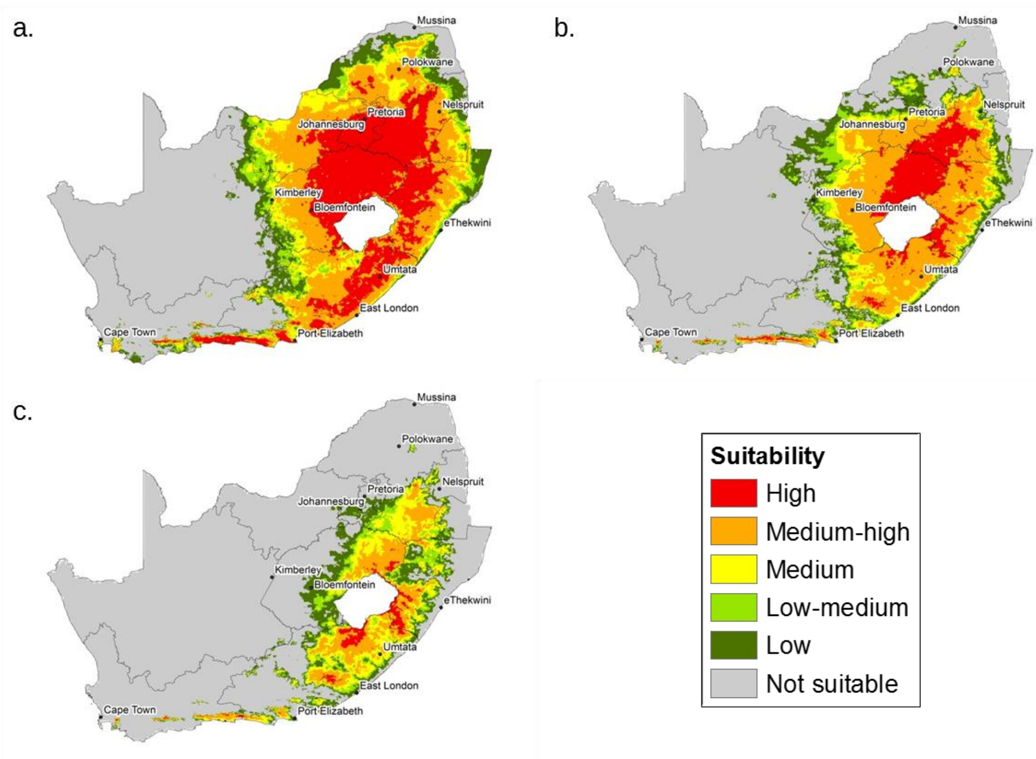


Figure 10: Suitability for maize production under a (a.) baseline (1990), (b.) mid future (2040) and (c.) far future (2070) RCP 8.5 climate change scenario

According to Hatfield and Prueger (2015) pollination is one of the most sensitive phenological stages to temperature extremes across all species, and during this developmental stage, temperature extremes would greatly affect production. As temperatures start to exceed 35 °C, maize pollen viability decreases significantly causing reduced pollination rate, grain fill and yield (Hatfield and Prueger (2015).

In wheat, excessive heat can cause reduction in grain number and reduced duration of the grain-filling period. Wheat is predominantly produced in the winter rainfall region of the Western Cape. The most significant decrease in rainfall is expected over the Swartland production (western) region, and could result in negative yield changes. As illustrated in Figure 11 of the crop suitability modelling, these western areas become marginal for crop production, while the south and south-eastern part of the province are projected to be less severely affected and might even show some positive yield increases in the near future (Wallace, 2013).

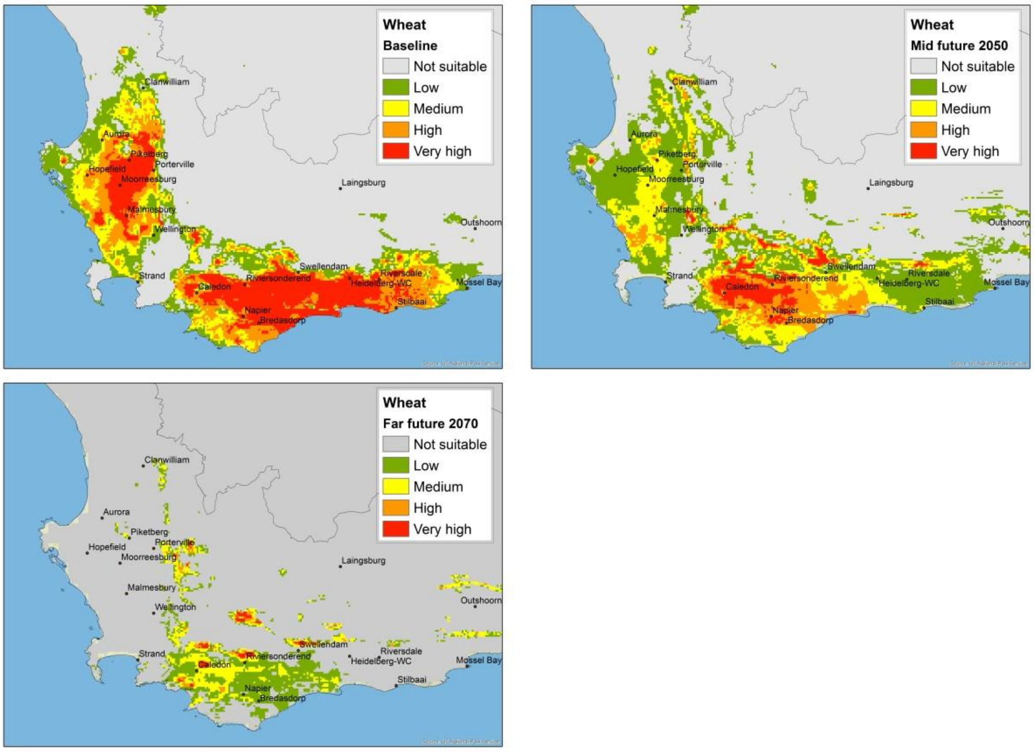


Figure 11: Suitability for winter wheat production under a (a.) baseline (1990), (b.) mid future (2040) and (c.) far future (2070) RCP 8.5 climate change scenario

While a reduction in precipitation is expected over the South Western Cape, other areas such as the central and inland parts of Kwa-Zulu-Natal can expect an increase in precipitation. This would improve the outlook for sugarcane, since it has been shown that an increase in temperature of 2°C associated with an increase in rainfall could increase sugarcane yields by about 7%. The crop suitability maps (Figure 12) show that the climatically optimum growth areas for sugarcane are expected to expand further inland in KwaZulu-Natal (Schulze and Kunz, 2016).

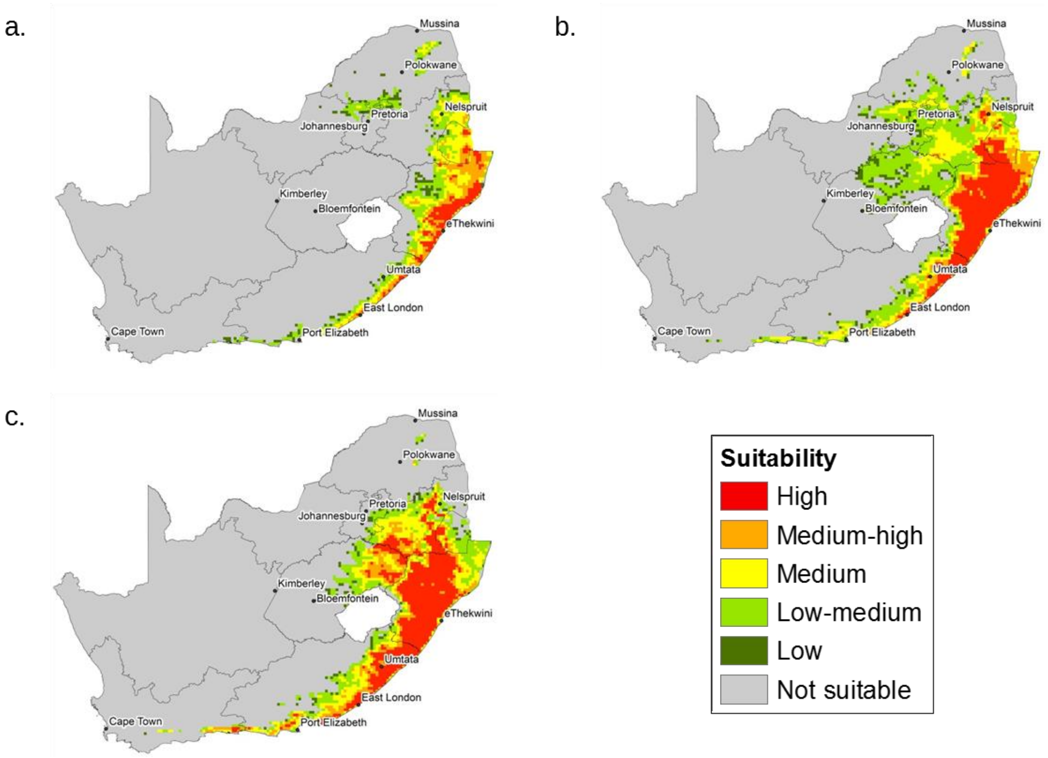


Figure 12: Suitability for sugarcane production under a (a.) baseline (1990), (b.) mid future (2040) and (c.) far future (2070) RCP 8.5 climate change scenario

South Africa is an important soybean producer, with approximately 150 000 ha under production. It is a valuable crop in terms of its importance as food source, animal feed, as well as many industrial applications (Talacuece et al., 2016). Soybean yield is sensitive to temperature and rainfall variations, with a 1.3% decrease in soybean yield per 1 °C increase in temperature. Since soybean is a C3 crops, it can also benefit from increasing concentration of atmospheric CO_2 (Talacuece et al., 2016). In the intermediate future, soybeans are likely to benefit from the increase in rainfall predicted over the central parts of the country, with an increase in climatically suitability areas towards the western parts of the production area (Figure 13). Towards the more distant future, the radical increase in temperature will limit the climatically suitable areas for soybean production.

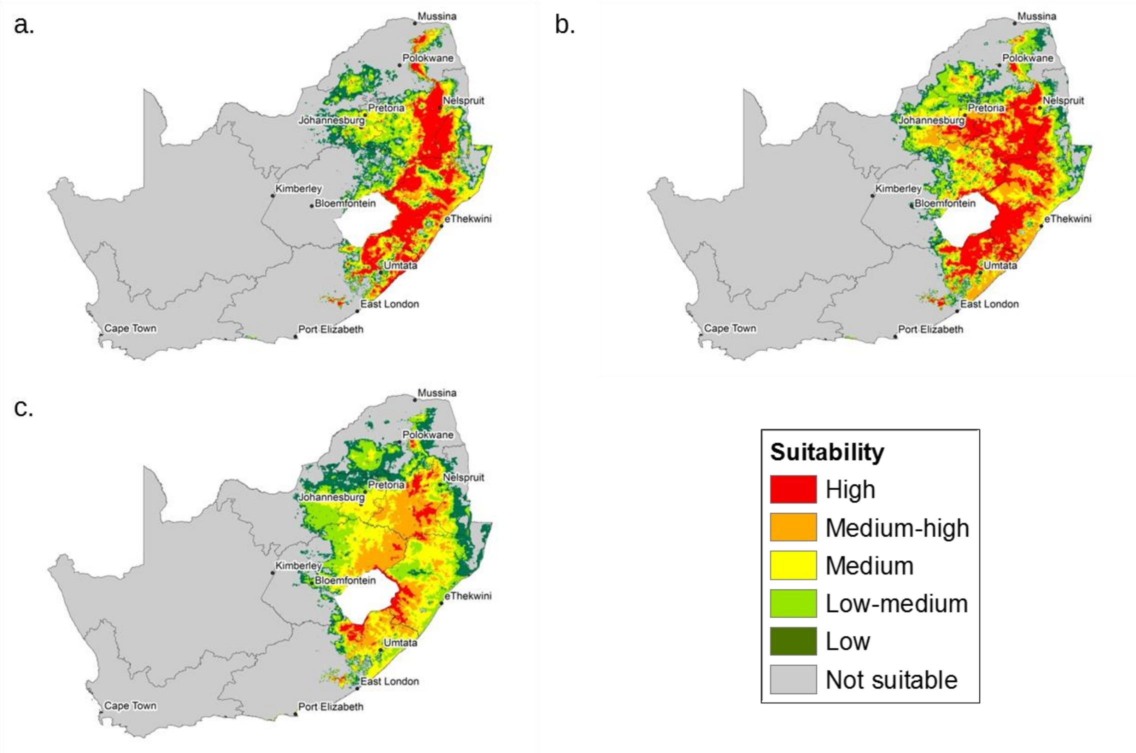


Figure 13: Suitability for soybean production under a (a.) baseline (1990), (b.) mid future (2040) and (c.) far future (2070) RCP 8.5 climate change scenario

3.2.2 Other field crops

3.2.2.1 Cotton

At present, cotton is produced in all provinces except the Western and Eastern Cape (Figure 14). Important production areas are parts of Limpopo (e.g. Marble Hall, Mookgopong, Roedtan, Alldays, Steelpoort), North West Province (Taung, Stella, Delareyville and Mareetsane), KwaZulu-Natal (in the Makhathini Flats), Mpumalanga and Northern Cape (in the Lower Orange River, Vaalharts, Douglas and Prieska districts). In these areas, cotton creates thousands of jobs from raw material production through to processing. The cotton industry produces raw material for the processing industry worth about R136 million (NDA, no date). The agriculture census results indicate that for Musina, cotton is the second most important sector in terms of gross farming income earned. Cotton is produced under irrigation (13 121 ha), and under dryland (8 866 ha) conditions. Dryland cotton production levels have been observed to decline, as precipitation decreases and temperatures increase. Increased evapotranspiration due to increasing temperatures will increase water demand for irrigated cotton.

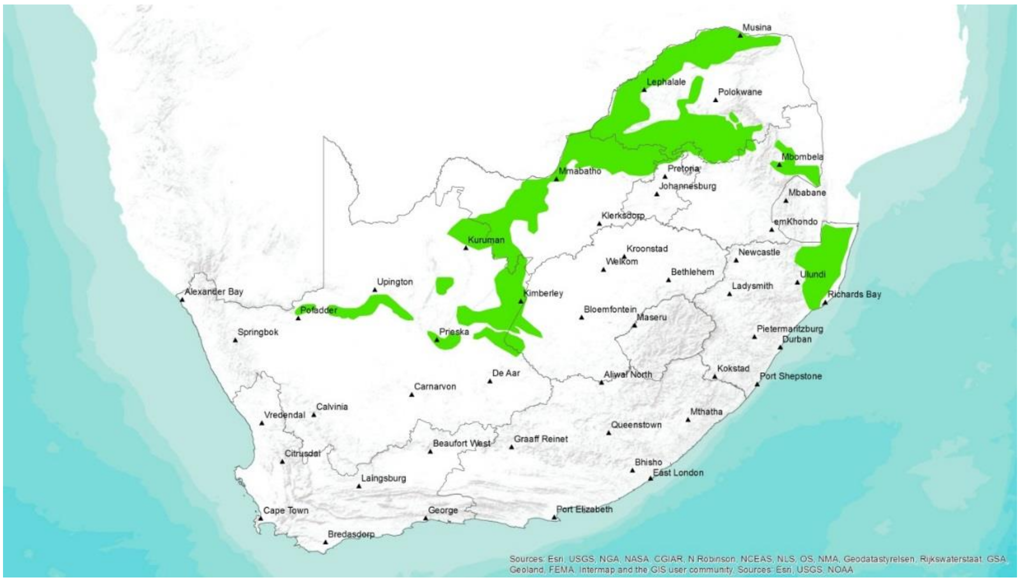


Figure 14: Cotton production areas

3.2.2.2 Sorghum

Sorghum will be able to take advantage of projected rainfall increases in certain areas. Sorghum is relatively drought resistant and new climatically suitable areas are projected to be gained in the Free State and Eastern Cape in the mid-future (Kunz and Schulze, 2016).

3.2.2.3 Potatoes

Projections in terms of potato production are for increases in yield due to positive effects of elevated atmospheric CO_2 and increased rainfall, especially over the central parts of the country. However, high temperature reduces tuber yield. On the west coast of South Africa, in the Sandveld region, yield reduction in summer and yield increase in winter is expected, as well as increases by about 30% in the Free State (Cossio et al., 2012).

3.2.3 Rangelands and pasture crops

Livestock production, both large and small-scale commercial, depends largely on rangelands. Rangelands are used as the main source of feed for livestock in communal areas. Climate change is likely to significantly impact rangeland productivity. In combination with grazing pressure and land cover change, temperature, rainfall, and atmospheric CO_2 can influence rangeland quality and composition (Hoffman and Vogel, 2002). Warmer temperatures and rising CO_2 levels could enhance bush encroachment, and increase the cover of shrubs and trees in grassland and savannah.

3.2.3.1 Weeping lovegrass/oulandsgras (Eragrostis curvula)

Eragrostis curvula is a highly productive pasture grass indigenous to Southern Africa. It is the most commonly planted pasture for grazing and haymaking (Schulze and Taylor, 2016). Predictions are that areas climatically suitable for production of Eragrostis will expand towards the western parts of its growth area, with some losses on the eastern part of the production region (Figure 15).

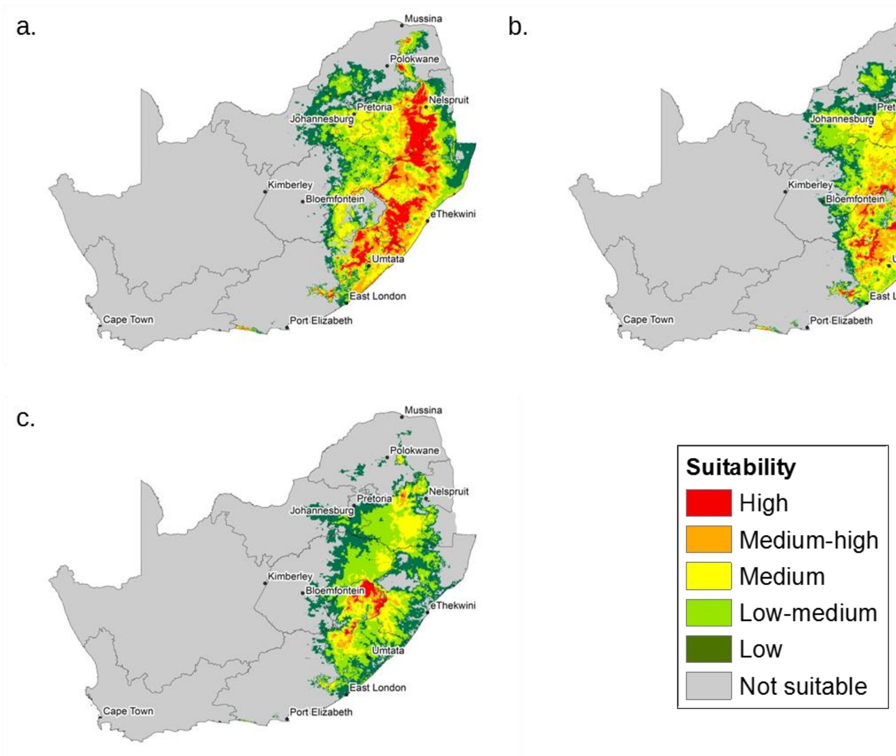


Figure 15: Suitability for pasture grass (Eragrostis curvula) production under a (a.) baseline (1990), (b.) mid future (2040) and (c.) far future (2070) RCP 8.5 climate change scenario

3.2.3.2 Smuts Finger Grass (Digitaria eriantha)

Regarded as one of the best grazing grasses, *Digitaria eriantha* is also native to Southern Africa (Schulze and Taylor, 2016). Similarly to Eragrostis, climatically suitable areas for this grass will also expand towards the western parts of its growth area in the future.

3.2.4 Horticulture

3.2.4.1 Deciduous

Certain biennial plants, which have a dormant season during winter, require a certain period of winter chilling for completion of their seasonal dormancy in order for fruit quality to be high. This chilling is estimated by positive chill units (PCUs), derived from hourly temperatures above / below critical thresholds. According to sensitivity studies as indicated in LTAS (DEA, 2013a), a 2°C temperature increase results in PCU reductions ranging from 14% to > 60% in South Africa. This will have significant consequences for the main apple production regions in South Africa, where accumulation of chill units will decrease, eventually reaching a critical threshold at which apple production would no longer be commercially sustainable in the warmer areas (DEA, 2015). Areas of concern are the Elgin-Grabouw-Vyeboom-Villiersdorp region (SmartAgri, 2015a) (Figure 16).

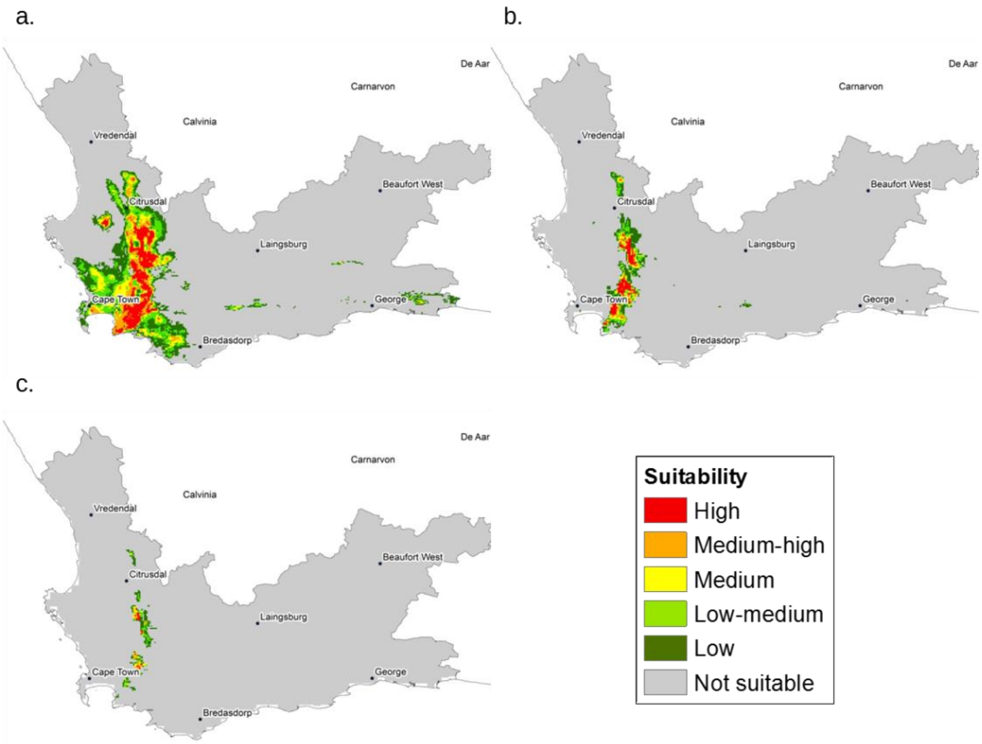


Figure 16: Suitability apple production under a (a.) baseline (1990), (b.) mid future (2040) and (c.) far future (2070) RCP 8.5 climate change scenario

3.2.4.2 Viticulture

The Western Cape is the dominant wine grape production region of South Africa. In the light of the anticipated reduction in rainfall expected over the Western Cape, water shortage will become a crucial factor determining future viability of the Cape's wine industry. Wine grape production in this region is sensitive to extreme temperatures and prolonged heat waves, longer dry spells, more frequent and heavier late spring and early summer rainfall, and rising CO_2 levels. Shorter, warmer winters will impact on grape quality through reducing the period of positive chill unit accumulation that vines need for dormancy. More benign winters are also likely to encourage vine diseases (SmartAgri, 2015d). Large swathes of areas currently suitable for viticulture are marked as showing significantly decreased viability by mid-century: much of the West Coast (the Swartland and Olifants River regions), down through Paarl and Stellenbosch, as well as the Breede River Valley further inland (SmartAgri, 2015d) (Figure 17).

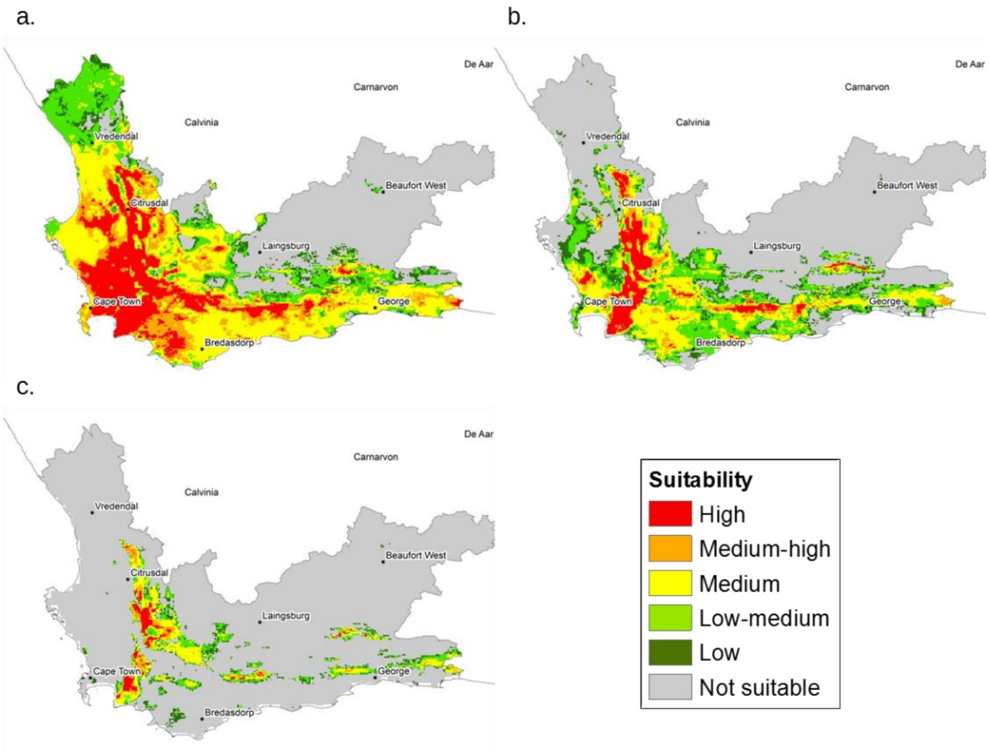


Figure 17: Suitability viticulture under a (a.) baseline (1990), (b.) mid future (2040) and (c.) far future (2070) RCP 8.5 climate change scenario.

3.2.4.3 Citrus and subtropical

Significant threats of climate change to citrus relate to the effect of heat stress and extreme temperatures on fruit quality, reduced water availability on fruit yield and changes in humidity and temperature on the distribution and intensity of pest species (SmartAgri, 2015c).

3.2.5 Animals and animal products

Climate change is likely to directly impact livestock production through heat stress, which is determined by ambient temperature, relative humidity and wind speed (Rust and Rust, 2013). An increase in temperature and humidity compromises the ability of animals to dissipate sufficient heat to maintain homeothermy. Most livestock species have an optimal range of temperatures between 10 and 30 °C; but at temperatures above 30 ºC, cattle, sheep, goats, pig and chickens all reduce their feed intake 3-5% for each 1°C increase (Kirilenko and Sedjo, 2007). Heat stress is likely to affect beef and sheep production through reduced growth and reproduction performance, reduced meat yield and quality, reduced wool production and quality, and increased deaths and illnesses, due to heat and nutrition stress. Poultry could be affected through changes in feed consumption, weight gain per unit of feed energy, growth rate, egg production, and reproductive efficiency (Rust and Rust, 2013; Papanastasiou, Bartzanas and Kittas, 2015; Williams, Scholtz and Neser, 2016). There is considerable research evidence that shows significant decline in animal performance when subjected to heat stress (Schoeman, Cloete and Olivier, 2010; Renaudeau et al., 2012; Rust and Rust, 2013; Meissner, Scholtz and Palmer, 2013; Papanastasiou, Bartzanas and Kittas, 2015; Tibesigwa, Visser and Turpie, 2017). These impacts are likely to be lower in sheep compared to cattle. Goats (excluding mohair) on the other hand, may be even more likely to cope with, and adapt to, hot and dry conditions expected in the Western Cape, compared to sheep (SmartAgri, 2015b). This is due to their lower feed and water requirements, ability to utilise low quality forage, ability to browse and disease resistance. Increasing winter temperatures and fewer cold days could be beneficial to livestock farming in the colder areas.

As mentioned earlier, the Temperature Humidity Index (THI) was used to assess likely changes in heat stress levels for livestock over time. It accounts for the combined effects of environmental temperature and relative humidity, and is a useful and easy way to assess the risk of heat stress. Depending on the livestock type, future climate projections indicate that over most of the country there will be a significant increase in heat stress thresholds. For cattle, thresholds to heat stress depend on the genotype as well as production level (Rust and Rust, 2013). Dairy cattle are already experiencing a level of heat stress and associated reduction in performance when the THI value is above 70. At values above 72, milk production is seriously reduced. It thus follows that in the near future, large areas of South Africa are becoming unsuitable for dairy farming, and, further, after 2050, only very small patches in the high lying areas of South Africa remain suitable for dairy production (Figure 18). as temperatures rise, farmers might shift from stocking dairy cows and sheep, to stocking beef cattle and goats, as well as decreasing numbers of poultry.

Indirectly, livestock will be impacted through changes in nutritional status as a result of changes in the quality and quantity of pastures as well as animal health. This is especially true for extensive livestock production (cattle, sheep, goats and ostriches) due to expected rangeland vegetation changes. Beef produced on natural pastures and custom feedlots are extremely vulnerable to climate change. The grazing capacity of South African rangelands is expected to decline by more than 30% under scenarios of rapid temperature increase (Rust and Rust, 2013). Changes in temperature and rainfall may also result in altered patterns of diseases in animals. Such a finding relates to the emergence of new diseases, as well as a change in the prevalence of existing diseases, particularly those spread by biting insects (Scholtz et al., 2013). The increased exposure of livestock to more pests and diseases could lead to a decrease in animal productivity and an increase in animal mortality.

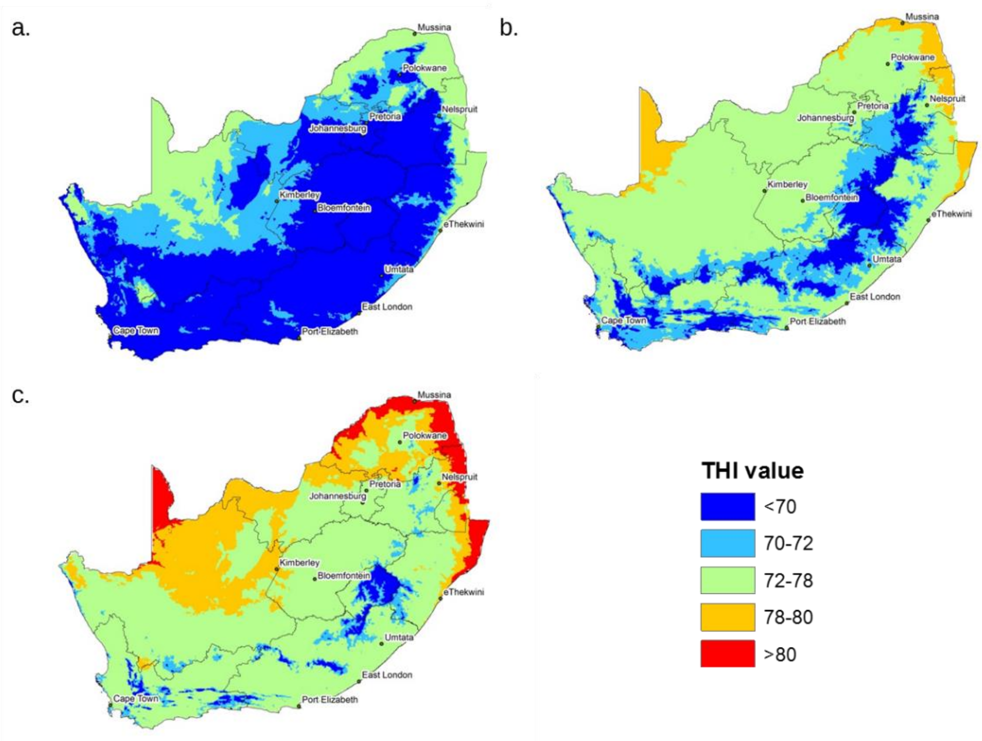


Figure 18: The temperature humidity index for livestock under a (a.) baseline (1990), (b.) mid future (2040) and (c.) far future (2070) RCP 8.5 climate change scenario

South Africa does, however have a high number of indigenous beef cattle, sheep and goat breeds that have adapted to prevailing conditions (Scholtz et al., 2013). It is, thus, becoming increasingly important to develop breeding programs which match the genotype to the environment to ensure a sustainable increase in production and allow breeds to stand a better chance to adapt to future climate conditions.

For the wool industry, climate change is likely to have implications, principally through its effects on forage and water resources, land carrying capacity and sustainability, animal health, and competition with other sectors, in particular cropping. The extent of these impacts will depend on how climate change is expressed in each wool-producing region and the specific way in which it will probably have an effect on both wool quantity and quality. A reduced productivity in marginal areas can be predicted, and a possibly higher productivity in higher rainfall regions.

According to Meissner, Scholtz and Palmer (2013), livestock farming plays a significant role in sustaining livelihoods of poor communities, and stabilizing the economies of towns in non-metropolitan areas. “Towns in non-metropolitan areas came into being largely as a result of the commercial farming activities in the district” (Meissner, Scholtz and Palmer, 2013). Livestock farming comprises nearly 70% of agricultural land in South Africa. Dairy farming is practiced all over South Africa, whereas sheep farming and most of South Africa’s rangelands are to be found in the semi-arid areas of the country. The majority of town economies in these areas are, therefore, dependent on the money spent by commercial and small-scale livestock farmers in the district (Meissner, Scholtz and Palmer, 2013). This trend is clear from the GVA and employment maps, where sheep producing districts such as Namakwaland, Calvinia, Carnarvon, Fraserburg, Loxton, Noupoort, Petrusville, Richmond and Victoria West serve as examples. Farmers and employees spend their income primarily in their local town, while farm requisites are obtained from general and farming equipment stores in the region (Meissner, Scholtz and Palmer, 2013). This suggests that the existence of these businesses is due mostly to the money generated from the farms in the districts.

3.2.6 Forestry

Climate change implications for commercial plantations vary between species and localities. A broad assessment of the vulnerability of commercial forestry to climate change indicates that:

- The climatic variable to which forest species is most sensitive, is rainfall. Coupled with changes in temperature this will have an impact on the extent of land climatically suitable for specific species (Schulze and Davis, 2016) ;
- More erratic rainfall and increased temperature increase the susceptibility of trees to existing and new pests and pathogens (DEA, 2013);
- The climatically optimal areas for plantation forestry within KwaZulu-Natal are likely to move inland, while areas within the Eastern Cape and Mpumalanga may offer opportunities for expansion with increasing temperature;
- Plantations are vulnerable to fire caused by lightning strikes, and climate change could increase the frequency of fires (Schulze and Davis, 2016) as a result of an increase in the high fire-danger days. Pilgrim's Rest (known for forestry) is singled out as an area which is projected to experience a significant increase in fire-danger days.

3.2.6.1 Specific impacts on important commercial forest species

Pinus patula – by the mid-future, the climatically optimum areas for pine forestry shift towards the inland areas of the Eastern Cape and southern Mpumalanga (Figure 19). This is largely due to the projected increase in rainfall over this period. However, in the more distant future, there is a significant contraction in suitable production areas, largely over Limpopo and the coastal areas of the Eastern Cape (Schulze and Davis, 2016).

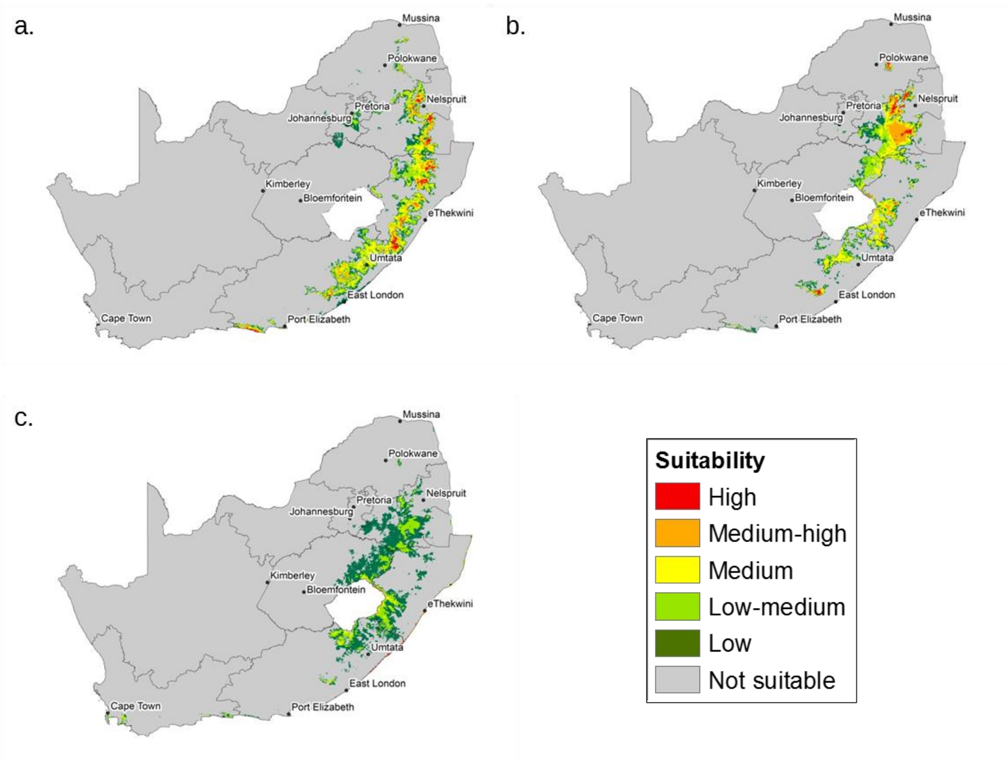


Figure 19: Suitability for Pinus Patula production under a (a.) baseline (1990), (b.) mid future (2040) and (c.) far future (2070) RCP 8.5 climate change scenario

Eucalyptus grandi – A major inland expansion of climatically optimum growth areas is expected in the mid-future, while existing growth areas remain suitable (Figure 20). In the distant future the inland growth areas continue to be suitable, but significant areas along the coastline of the Eastern Cape and KwaZulu-Natal are lost (Schulze and Davis, 2016).

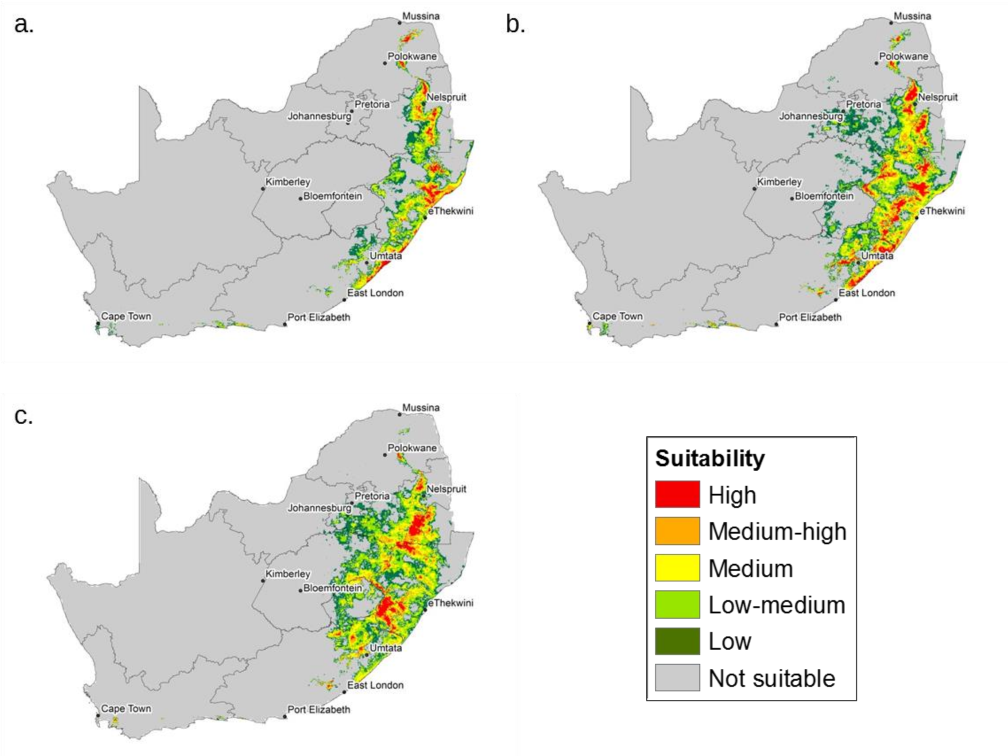


Figure 20: Suitability for Eucalyptus grandi production under a (a.) baseline (1990), (b.) mid future (2040) and (c.) far future (2070) RCP 8.5 climate change scenario

Acacia mearnsii – A substantial shift in the areas climatically suitable for A. mearnsii are expected (Schulze and Davis, 2016). By the mid-future, new climatically suitable areas are gained in the west, while areas along the eastern boundary of the production area are lost (Figure 21). By the end of the century, the total production area will contract significantly, with only a few suitable areas remaining in the inland areas of the Eastern Cape.

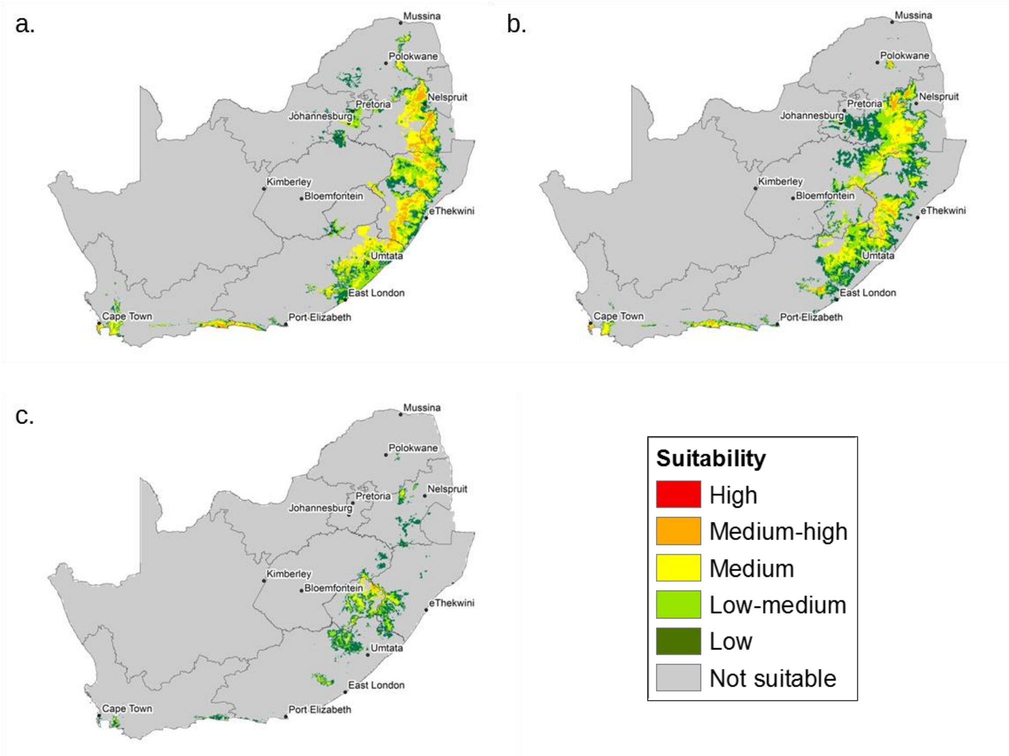


Figure 21: Suitability for Acacia Mearnsii production under a (a.) baseline (1990), (b.) mid future (2040) and (c.) far future (2070) RCP 8.5 climate change scenario

3.2.7 Fisheries

Climate change will have complicated consequences on terrestrial climatic and hydrologic processes; coastal and oceanic circulation processes; ocean acidification; sea surface temperature, sea level rise, sea storminess; and wind systems. This is likely to affect the productivity and diversity of South Africa's fisheries by changing the distribution, abundance and size of resources, their habitat extent, condition and connectivity, their physiology and behaviour and the catchability of resource species. This could result in significant adverse impacts on subsistence fishing livelihoods as well as commercial and recreational industries (DEA, 2013).

Apart from climate change associated impacts, as mentioned earlier, there are other major threats to the fisheries sector in South Africa. These relate to pollution, habitat destruction, overfishing and destructive fishing practices, which have led to resource declines and shifts. These and other economic factors have resulted in the closure of fishing operations in a number of regional ports. For example, the decline of the rock lobster fishery along the traditional West Coast fishing grounds resulted in the closure of the processing operations at Hondeklipbaai and Lamberts Bay, and a dramatic reduction in landings at Port Nolloth. The transfer of hake quota to Cape Town/ Saldanha Bay led to the closure of the historically important John Ovenstone factory at Port Nolloth in the mid 1990's (Kaiser EDP, 2012). In recent years, the decline of the traditional linefish resource has led to a decline in activity in a number of regional fishing harbours (Hout Bay, Kalk Bay, Gordon's Bay, and Hermanus). Regional fish factories of the Irvin & Johnson Company (serving inshore trawl operations in Port Elizabeth and Mossel Bay) have also closed in recent years. Reasons for this include a decline in resources due to overfishing, increased operational costs and proximity to the service sector. However, climate change is also affecting the composition and productivity of marine species and undermining the profitability of the fisheries sector.

General consequences of climate change:

- Shifts in the spatial distribution of several marine species.
- Changes in wind patterns and upwelling, mainly attributed to increasing/decreasing SST.
- KwaZulu-Natal and West Coast estuaries are likely to be the most affected by climate change from a structural and functional perspective.
- Main impacts are a decrease in primary production and a loss of nursery function.

Climate change consequences relevant to specific coastal regions (DEA, 2013b):

- Cool temperate region
    - Temperate linefish species may be more vulnerable to climate change.
    - West Coast rock lobster - Catch rates of West Coast rock lobster in the traditional fishing grounds along the West Coast declined dramatically during the 1980's and 1990s. At the same time there was an increase in abundance of West Coast rock lobster within the south coast region.
- Warm temperate region
    - Chokka squid fishery – no severe impacts since squid is better able to adapt to changes in their environment than many other taxa.
- Sub-tropical region
    - Prawn trawl fishery - potential loss of nursery habitat (such as mangroves), which is essential for prawns and estuarine fish species, decreased abundance of shallow water prawn species.

3.2.7.1 Offshore fisheries

Hake on West Coast - Increase in wind speed, direction and frequency increase coastal upwelling, which results in reduced oxygen. Any increase in wind speeds will affect upwelling, which may have adverse effects on the fisheries for hake.

Small pelagic fisheries - Agulhas Bank/south coast would become more productive and the West Coast less productive. This could lead to an eastward and southward shift in fish resources.

3.2.7.2 Subsistence fisheries

Subsistence fishing is important, as shown earlier, for coastal community livelihoods, and was formally recognised in the year 2000 to accommodate those fishers who depend on the resource for food directly – usually poor communities or those using traditional methods. There are almost 30 000 subsistence fishers active along the South African coastline, 85% of whom harvest linefish (DAFF, 2014).

Coastal economies where fishing are an important industry are considered to be most vulnerable to climate change. Turpie et al. (2002) argued that the value of South African fisheries could be reduced by up to 18% by the effects of climate change.

3.3 Area based climate impact assessment

Climate change associated impacts on the agriculture and forestry sector will differ significantly across various agro-climatic regions, and are a function of both crop type and adaptive capacity of different regions. The major trends in future rainfall distribution are for a decrease in rainfall over the western parts of South Africa, but with significant increases over the central and eastern parts of the country. In areas where rainfall is predicted to increase, it will also be associated with more extreme rainfall events. The most significant rise in temperatures will be over the central and northern parts of the country. Overall, it is anticipated that future increases in temperature and evaporation will result in an increase in the irrigation demands across the country.

Areas that are generally most at risk in terms of climate impacts are, as shown earlier, those where agriculture makes a large contribution to the GVA and employment of an area, and where rainfall is projected to decrease, while also associated with rapid warming - effectively the north western and central parts of the Western Cape, large areas of the Northern Cape, as well as western parts of the Eastern Cape and south western areas of the Free State.

The Western Cape province has, as shown earlier, the highest gross farming income across all provinces and is therefore a strategic important area for farming in the country. This province also has the highest number of paid employees in South Africa in the agricultural sector, with twice the amount of employees compared to KwaZulu-Natal which has the second most people employed in agriculture. Agriculture makes an important contribution to the economy of the Western Cape, where it also extends to other benefits for the society. It is, however, also the province where climate change could make the most pronounced impact on agriculture through a decline in rainfall, an increased frequency of droughts and significant increases in temperatures. Important rain-fed field crops such as wheat and canola could be most at risk of increased yield variability. This would likely manifest itself initially in the western parts of the province, but also potentially affect the south eastern parts in the distant future. High value crops such as wine grapes, apples and pears, which depend on irrigation, are likely to also be particularly vulnerable to water shortages. These crops are also at risk of temperature changes, which could affect their chilling requirements. High value export crops need specific optimum climate conditions to yield high quality fruit for export.

The central and Hantam Karoo in the Western and Northern Cape is expected to experience higher temperatures and more intense heat waves, more frequent and longer dry spells and droughts. This vast area depends largely on extensive livestock farming (cattle, sheep, goats and ostriches). Livestock farming will be primarily impacted by rangeland vegetation changes, changes in the distribution of pests and diseases and water availability. An increase in maximum temperature will lead to increased heat stress for livestock, but also lower risks associated with low temperatures in colder areas. As shown earlier, livestock farming plays an significant role in providing sustenance to poor communities and stabilizing the economies of towns in these areas.

Certain areas, where agriculture makes a high contribution to GVA such as in the central maize growing regions of South Africa, might not be vulnerable at first. In these areas, rainfall is predicted to increase, and maize yields are similarly expected to increase in the near future. However, towards the far future, areas suitable for maize production (North West and southwestern Free State provinces) start to decline in extent, mainly as a result of significant temperature increases.

Table 3: Representation of 3 main agricultural sectors and associated climate impacts per local municipality. Municipalities are ranked according to the contribution (%) that the agricultural sector makes to the total GVA of the municipality.

Municipality Name	Narrative	Commodity #1	Impacts #1	Commodity #2	Impacts #2	Commodity #3	Impacts #3	GVA (%)	Employ (%)
Kai !Garib	Hotter and wetter but drier towards end of century	Deciduous (Table grapes)	Reduction in available winter chill and increased summer heat stress. Insufficient winter chilling could impact on quality of table grapes in terms of skin colour and berry composition. Increased evapotranspiration and irrigation requirements.	Sheep	Increased availability of forage and water resources. Increased heat stress on livestock towards end of century, leading to reduced growth & reproductive efficiency.			60.9	74.4
Witzenberg	Hotter and drier	Deciduous (Apples and pears)	Reduction in available winter chill and increased summer heat stress. High temperatures cause sunburn damage and reduce fruit quality. Increased evapotranspiration and irrigation requirements. Reduced suitability for apple production in the distant future.	Wheat	Increasing yield variability in the near future, declining over time as rainfall decrease. Areas suitable for wheat production shift south-eastwards.			43.5	49.9
Mthonjaneni	Warmer and wetter with more extreme rainfall events.	Sugar-cane	Potential increase in sugarcane yield. However, increased exposure to pests such as eldana and chilo.	Beef cattle	Increased water availability. Hot and moist conditions cause increased spread of disease and parasites. Reduced growth & reproduction performance due to heat stress.	Forestry	Some yield increases in near future with increasing rainfall and temperature. Projected increase in areas suitable for forestry.	42.3	35.2

!Kheis	Hotter and wetter but drier towards end of century	Deciduous (Table grapes)	Reduction in available winter chill and increased summer heat stress. Insufficient winter chilling could impact on quality of table grapes in terms of skin colour and berry composition. Increased evapotranspiration and irrigation requirements.	Sheep	Increased availability of forage and water resources. Warmer winters could lower cold weather associated livestock mortality but are also conducive to the survival of pests and parasites that threaten livestock.			37.4	50.0
Cederberg	Hotter and drier	Citrus	Increased evapotranspiration and irrigation requirements. An increase in temperature will benefit a more heat-tolerant disease vector.	Rooibos tea	Reduced suitability in marginal, low rainfall areas. High altitude areas remain viable in near future. Increased yield variability.	Potatoes	Yield increase in winter (due to increased concentration of CO_2). Root crop plants benefit from elevated carbon dioxide levels due to higher rates of photosynthesis. In summer, however, positive effects of CO_2 are offset by heat stress which cause tuber yield reduction.	35.5	34.1
Impendle	Hotter and wetter	Milk and cream	Hot and moist conditions cause increased spread of disease and parasites. Potential increase in heat stress which could negatively affect conception rates, milk yield and milk quality.	Potatoes	Increase in tuber yield due to increased concentration of CO_2. Root crop plants benefit from elevated carbon dioxide levels due to higher rates of photosynthesis.			33.2	28.2

Ndwedwe	Warmer and wetter	Beef cattle	Increased water availability. Hot and moist conditions cause increased spread of disease and parasites. Reduced growth & reproduction performance due to heat stress.	Sugar-cane	Potential increase in sugarcane yield. However, increased exposure to pests such as eldana and chilo.	Chickens	Increased production costs (and increased investment will be required in ventilation and cooling) to maintain optimal seasonal temperatures and reduce the risk of heat stress. Heat stress on birds will reduce body weight gain, reproduction efficiency and egg quality.	32.8	29.1
Mkhambathini	Warmer and wetter with more extreme rainfall events.	Sugar-cane	Potential increase in sugarcane yield. However, increased exposure to pests such as eldana and chilo.	Citrus	Increased water availability. Hot and moist conditions will benefit a more heat-tolerant disease vector. Increased exposure to pests.			29.5	30.5
Theewaterskloof	Warmer and drier	Deciduous	Reduction in available winter chill and increased summer heat stress. Increased evapotranspiration and irrigation requirements. Reduced suitability for some deciduous fruit cultivars.	Aquaculture	Water temperature is important in regulating fish species metabolism, reproduction success and disease resistance. Increased water temperatures may impact on the distribution or productivity of fresh water fish stocks.	Wheat	Increasing yield variability in the near future, declining over time as rainfall decrease.	29.4	33.6
Kou-Kamma	Warmer and wetter but drier towards end of century	Milk and cream	Hot and moist conditions cause increased spread of disease and parasites. Potential increase in heat stress which could negatively affect conception rates, milk yield and milk quality.	Deciduous	Reduction in available winter chill and increased summer heat stress. Increased evapotranspiration and irrigation requirements. Production remains viable as long as heat stress is managed and water is available.			29.4	30.1
Kannaland	Warmer and drier	Deciduous	Reduction in available winter chill and increased summer heat stress. Increased evapotranspiration and irrigation requirements. Reduced suitability for some deciduous fruit cultivars.	Milk and cream	Increased risk in spread of disease and parasites. Potential increase in heat stress which could negatively affect conception rates, milk yield and milk quality.	Ostriches	Reduced growth & reproduction performance due to heat and nutrition stress Reduced egg and leather production due to heat and nutrition stress.	28.3	32.9

Siyancuma	Hotter and wetter	Sheep	Increased availability of forage and water resources. Warmer winters could lower cold weather associated livestock mortality but are also conducive to the survival of pests and parasites that threaten livestock.	Wheat	Potential increase in wheat yield for near future. However, yield and crop suitability decline over time as temperatures start to exceed critical crop thresholds.	Beef cattle	Increased water availability. Hot and moist conditions cause increased spread of disease and parasites. Reduced growth & reproduction performance due to heat stress.	28.0	38.5
Umzumbe	Warmer and wetter with more extreme rainfall events.	Beef cattle	Increased water availability. Hot and moist conditions cause increased spread of disease and parasites. Reduced growth & reproduction performance due to heat stress.	Sugar-cane	Potential increase in sugarcane yield. However, increased exposure to pests such as eldana and chilo.	Forestry	Some yield increases in near future with increasing rainfall and temperature. Projected increase in areas suitable for forestry.	27.5	25.4
Bergrivier	Hotter and drier	Wheat	Increasing yield variability in the near future, declining over time as rainfall decrease. Areas suitable for wheat production shift south-eastwards.	Deciduous	Reduction in available winter chill and increased summer heat stress. Increased evapotranspiration and irrigation requirements. Reduced suitability for some deciduous fruit cultivars.	Potatoes	Yield increase in winter (due to increased concentration of CO_2). Root crop plants benefit from elevated carbon dioxide levels due to higher rates of photosynthesis. In summer, however, positive effects of CO_2 are offset by heat stress which cause tuber yield reduction.	26.3	26.8
Phumelela	Hotter and wetter with more extreme rainfall events.	Beef cattle	Increased water availability. Hot and moist conditions cause increased spread of disease and parasites. Reduced growth & reproduction performance due to heat stress.	Maize for grain	Potential increase in maize yield for near future. However, towards 2050, heat stress can negatively impact on production.			26.1	45.3
Mpofana	Hotter and wetter but drier towards end of century	Milk and cream	Hot and moist conditions cause increased spread of disease and parasites. Potential increase in heat stress which could negatively affect conception rates, milk yield and milk quality.	Forestry	Some yield increases in near future with increasing rainfall and temperature. Projected increase in areas suitable for forestry.			25.7	22.3

Laingsburg	Hotter and drier	Sheep	Reduced availability and quality of pastures due to decline in rainfall. Reduced growth & reproductive efficiency due to heat and nutrition stress. Warmer winters could lower cold weather associated livestock mortality but are also conducive to the survival of pests and parasites that threaten livestock.	Ostriches	Reduced growth & reproduction performance due to heat and nutrition stress Reduced egg and leather production due to heat and nutrition stress.	Deciduous	Reduction in available winter chill and increased summer heat stress. Increased evapotranspiration and irrigation requirements. Reduced suitability for some deciduous fruit cultivars.	24.9	26.8
Siyathemba	Hotter and wetter but drier towards end of century	Maize for grain	Potential increase in maize yield for near future. However, towards 2050, heat stress can negatively impact on production.	Sheep	Increased availability of forage and water resources. Increased heat stress on livestock towards end of century, leading to reduced growth & reproductive efficiency.	Wheat	Potential increase in wheat yield for near future. However, yield and crop suitability decline over time as temperatures start to exceed critical crop thresholds.	23.9	34.7
Ubuhlebezwe	Warmer and wetter with more extreme rainfall events.	Milk and cream	Hot and moist conditions cause increased spread of disease and parasites. Potential increase in heat stress which could negatively affect conception rates, milk yield and milk quality.	Sugar-cane	Potential increase in sugarcane yield. However, increased exposure to pests such as eldana and chilo.	Sugar-cane	Potential increase in sugarcane yield. However, increased exposure to pests such as eldana and chilo.	23.8	25.4

3.4 The agricultural sector as employment creator

The agricultural sector employs around 900 000 workers, as shown earlier, which makes a substantial contribution of total employment in the economy. This translates into almost 5% of the total labour force. Compared to other sectors, it is also more labour-intensive. For example, while the mining and manufacturing sectors represent 8.5% and 12.5% of the economy they employ only 2.3% and 11.8% of the labour force respectively. For the agricultural sector, this translates into two units of labour per unit of value added, whilst the ratio is 0.3 for mining and 0.94 for manufacturing (Greyling, 2015).

The South African government recognizes the importance of the agricultural sector's role in creating employment, specifically in the processing sector (DTI, 2009; NPC, 2011). According to a study by BFAP (2011), the sector could potentially create a million employment opportunities. This could be achieved by expanding irrigation agriculture, bringing underutilised land in the communal areas under production, picking and supporting labour intensive agricultural sectors and regions, and supporting the creation of upstream and downstream industries. It is also argued that 300 000 employment opportunities can be created through better utilisation of land in the former homeland areas, with a further 326 500 potential employment opportunities upstream and downstream of the agricultural sector. This expansion of job opportunities is, however, subject to suitable climate conditions and stable rural environments.

4 CONCLUSION

Agriculture has several direct and indirect links to settlements, as it contributes to the social and economic stability of an area. These include impacts through direct employment of communities in and around settlements, delivering of goods and products to secondary industries depending on agriculture, and investments in infrastructure. Agriculture is also an important purchaser of intermediate goods and services, which is a key driver of growth for the rest of the economy in a settlement.

Several other drivers of vulnerability apart from climate change also affect the ability of farming to remain productive, often interactive as multiple stressors. These largely relate to external factors that the farmer cannot control, such as rising input costs, the oil price and the exchange rate, lack of subsidies and extension support, crimes rates and increasing tenure insecurity (land reform), as well as a decline in the health and functioning of natural resources.

Although there are several distinct negative impacts projected for agriculture, it does not automatically follow that this will impact negatively on settlements. The agricultural sector is continuously adapting to climate conditions and other stressors. Research institutions develop drought resistant cultivars; farmers change to other crops, adopt soil and water conservation practices, amongst other examples. In certain areas, however, the threshold for certain crops might be reached, and even targeted adaptation interventions might be insufficient.

This study made a contribution in developing a more detailed understanding of the location specific impacts of climate change on agriculture at local municipality level, while also highlighting the economic contribution of important sub-divisions of agriculture. The study used the latest high resolution climate change scenario data to project land suitability changes for a range of crop commodities, as well as the livestock sector. These maps can be used in conjunction with the settlement typology data (developed as part of the Green Book project) to further explore spatial links with and impacts on settlements. Quantifying the impacts of climate change on these links is, however, beyond the scope of this study.

5 REFERENCES

ABSA AgriBusiness. South Africa's ever shrinking farmers. Available at: https://www.iol.co.za/mercury/south-africas-ever-shrinking-farmers-1167943

Brick, K. and Hasson, R. (2016) 'Valuing the socio-economic contribution of fisheries and other marine uses in South Africa'.

BUREAU FOR FOOD AND AGRICULTURAL POLICY (BFAP) 2011. Draft report on the contribution of the agro-industrial complex to employment in South Africa.

Challinor, A. J., Koehler, A.-K., Ramirez-Villegas, J., Whitfield, S. and Das, B. (2016) 'Current warming will reduce yields unless maize breeding and seed systems adapt immediately', Nature Climate Change, 6(10), pp. 954–958. doi: 10.1038/nclimate3061.

Cossio, M. L. T., Giesen, L. F., Araya, G., Pérez-Cotapos, M. L. S., Vergara, R. L., Manca, M., Tohme, R. a., Holmberg, S. D., Bressmann, T., Lirio, D. R., Román, J. S., Solís, R. G., Thakur, S., Rao, S. N., Modelado, E. L., La, A. D. E., Durante, C., Tradición, U. N. a, En, M., Espejo, E. L., Fuentes, D. E. L. a S., Yucatán, U. A. De, Lenin, C. M., Cian, L. F., Douglas, M. J., Plata, L. and Héritier, F. (2012) 'Climate change and potato production in contrasting South African agro-ecosystems', Uma ética para quantos?, XXXIII(2), pp. 81–87. doi: 10.1007/s13398-014-0173-7.2.

CSIR, 2010, 'Geospatial analysis platform (GAP)', viewed April 2017, from http://www.gap.csir.co.za

DAFF (2012) Policy for the Small Scale Fisheries Sector in South Africa.

DAFF (2014a) Small-scale fisheries: A guide to the small-scale fisheries sector, Governance of Marine Fisheries and Biodiversity Conservation. doi: 10.1002/9781118392607.ch22.

DAFF (2014b) Status of the South African marine fishery resources 2014. Cape Town, South Africa.

DAFF (2016a) Abstract of Agricultural Statistics 2016. Pretoria, South Africa.

DAFF (2016b) 'Economic Review of the South African Agriculture'.

DAFF, N. W. P. (2012) 'Animal Production', Animal Production, 53, p. 160. doi: 10.1017/CBO9781107415324.004.

DEA (2013a) 'Full technical report on the implications of climate change for the Agriculture Sector in South Africa', pp. 1–50.

DEA (2013b) Long Term Adaptation Scenarios (LTAS). CLIMATE CHANGE IMPLICATIONS FOR MARINE FISHERIES IN SOUTH AFRICA. Pretoria.

Department of Agriculture (2003) State of the Environment Report Workshop 1 : Identification of environmental issues, State of the Environment. Kimberley.

Department of Agriculture Forestry and Fisheries (2012) ‘Policy for the Small Scale Fisheries Sector in South Africa’, (10505), p. 56.

Department of Agriculture, Forestry and Fisheries. (2014) Status of the South African marine fishery resources 2014. Cape Town, South Africa.

Department of Agriculture, Forestry and Fisheries. (2016) ‘Economic Review of the South African Agriculture’.

Department of Agriculture, Land Reform and Environment (2003) State of the Environment Report Workshop 1 : Identification of environmental issues, Environment. Kimberley.

Department of Environmental Affairs. (2013) Long Term Adaptation Scenarios (LTAS). CLIMATE CHANGE IMPLICATIONS FOR MARINE FISHERIES IN SOUTH AFRICA. Pretoria.

DTI (2011) Industrial Policy Action Plan 2011/2012–2013/2014. Department of Trade and Industry (DTI), Pretoria. Available at: http://www.info.gov.za/view/DownloadFileAction?id=144975 [Accessed: 2018-06-19].

Fibre Processing and Manufacturing SETA (2014) ‘Forestry and Wood products Sector: A profile of the forestry and wood products sub-sector’, (December), pp. 1–12.

Godsmark, R. (2008) ‘The South African forestry and forest products industry 2007’, Forestry SA, (February).

Godsmark, R. (2013) The South African Forestry and Forest Products Industry 2011.

Greyling, J. C. (2012) ‘The Role of the Agricultural Sector in the South African Economy’, (December), p. 127. doi: 10.1080/03031853.1963.9524672.

Hatfield, J. L. and Prueger, J. H. (2015) ‘Temperature extremes: Effect on plant growth and development’, Weather and Climate Extremes, 10, pp. 4–10. doi: 10.1016/j.wace.2015.08.001.

Hoffman, B. T. and Vogel, C. (2002) ‘African Rangelands’, Rangelands, pp. 12–17.

Hutchings, L., Augustyn, C. J., Cockcroft, A., Van Der Lingen, C., Coetzee, J., Leslie, R. W., Tarr, R. J., Oosthuizen, H., Lipinski, M. R., Roberts, M. R., Wilke, C., Crawford, R., Shannon, L. J. and Mayekiso, M. (2009) ‘Marine fisheries monitoring programmes in South Africa’, South African Journal of Science, 105(5–6), pp. 182–192. doi: 10.1016/j.pocean.2009.07.046.

IDC. (2014). Retrieved from www.idc.co.za

Johnston, P., Hachigonta, S., Sibanda, L.M. and T.S. Thomas. 2012. Southern African Agriculture and Climate Change: A Comprehensive Analysis -South Africa. International Food Policy Research Institute (IFPRI), Washington, DC.

Kaiser EDP, E.-F. A. (2012) Report on the Economic and Socio- Economic State and Growth Prospects of the 12 Proclaimed Fishing Harbours in the Western Cape Overview of the fishing industry and the impact on fishing harbours and communities.

Kirilenko, A. and Sedjo, R. (2007) ‘Climate Change Impacts on Livestock’, Proceedings of the National Academy of Science, 104(50), pp. 19697–19702.

Kunz, R.P. and Schulze, R.E. 2016. Grain Sorghum Production in South Africa and Climate Change. In: Schulze, R.E. (Ed.) Handbook for Farmers, Officials and Other Stakeholders on Adaptation to Climate Change in the Agriculture Sector within South Africa. Section C: Crops in South Africa and Climate Change, Chapter C5.

Liebenberg, G. F. and Kirsten, J. F. (2013) ‘Statistics on Farm Labour in South Africa’, (March 2008), pp. 1–9.

Meissner, H. H., Scholtz, M. M. and Palmer, A. R. (2013) ‘Sustainability of the South African livestock sector towards 2050 Part 1: Worth and impact of the sector’, South African Journal of Animal Sciences, 43(3), pp. 282–297. doi: 10.4314/sajas.v43i3.6.

NDA (no date) Cotton industry profile. Available at: http://www.nda.agric.za/docs/FactSheet/cotton06.pdf.

NPC. 2011. National Development Plan: Vision for 2030. National Planning Commission (NPC), Pretoria. [Online] Available at:http://www.npconline.co.za/

Papanastasiou, D. K., Bartzanas, T. and Kittas, C. (2015) ‘Classification of potential sheep heat-stress levels according to the prevailing meteorological conditions’, Agricultural Engineering International: CIGR Journal, 2015, pp. 57–64.

Pearson, R. G. et al. 2006. Model-based uncertainty in species range prediction. Journal of Biogeogr. 33: 17041711.

Phillips, S. J. et al. 2006. Maximum entropy modeling of species geographic distributions. Ecol. Model. 190: 231259.

Potts, W. M., Götz, A. and James, N. (2015) 'Review of the projected impacts of climate change on coastal fishes in southern Africa', Reviews in Fish Biology and Fisheries. Springer International Publishing, 25(4), pp. 603–630. doi: 10.1007/s11160-015-9399-5.

Renaudeau, D., Collin, A., Yahav, S., de Basilio, V., Gourdine, J. L. and Collier, R. J. (2012) 'Adaptation to hot climate and strategies to alleviate heat stress in livestock production', Animal, 6(5), pp. 707–728. doi: 10.1017/S1751731111002448.

Rust, J. M. and Rust, T. (2013) 'Climate change and livestock production: A review with emphasis on Africa.', South African Journal of Animal Science, 43(3), pp. 256–267. doi: 10.4314/sajas.v43i3.3.

Schoeman, S. J., Cloete, S. W. P. and Olivier, J. J. (2010) 'Returns on investment in sheep and goat breeding in South Africa', Livestock Science. Elsevier B.V., 130(1–3), pp. 70–82. doi: 10.1016/j.livsci.2010.02.012.

Scholtz, M. M., Mcmanus, C., Leeuw, K., Louvandini, H., Seixas, L. and Melo, C. B. De (2013) 'The effect of global warming on beef production in developing countries of the southern hemisphere', Nat. Sci., 5(1), pp. 106–119.

Schulze, R.E. and Davis, N.S. 2016. Climatically Optimum and Sub-Optimum Growth Areas of Major Production Forestry Species and Hybrids in South Africa Under Present and Projected Future Climate Scenarios. In: Schulze, R.E. (Ed.) Handbook for Farmers, Officials and Other Stakeholders on Adaptation to Climate Change in the Agriculture Sector within South Africa. Section G: Tree Crop Systems in South Africa and Climate Change, Chapter G1.

Schulze, R.E. and Durand, W. 2016. Maize Production in South Africa and Climate Change. In: Schulze, R.E. (ed.) Handbook for Farmers, Officials and Other Stakeholders on Adaptation to Climate Change in the Agriculture Sector within South Africa. Section C: Crops in South Africa and Climate Change, Chapter C1.

Schulze, R.E. and Kunz, R.P. 2016. Sugarcane Production in South Africa and Climate Change. In: Schulze, R.E. (Ed.) Handbook for Farmers, Officials and Other Stakeholders on Adaptation to Climate Change in the Agriculture Sector within South Africa. Section C: Crops in South Africa and Climate Change, Chapter C3.

Schulze, R.E. and Taylor, M.A. 2016. Planted Pastures in South Africa and Climate Change: Kikuyu, Eragrostis curvula and Coastcross II. In: Schulze, R.E. (Ed.) Handbook for Farmers, Officials and Other Stakeholders on Adaptation to Climate Change in the

Agriculture Sector within South Africa. Section D: Natural Grasslands and Pastures in South Africa and Climate Change, Chapter D2.

Schulze, R.E., Schütte, S. and Wallace, M. 2016. Wheat Production in South Africa and Climate Change. In: Schulze, R.E. (ed.) Handbook for Farmers, Officials and Other Stakeholders on Adaptation to Climate Change in the Agriculture Sector within South Africa. Section C: Crops in South Africa and Climate Change, Chapter C2.

SmartAgri (2015a) A Status Quo Review of Climate Change and the Agricultural Sector of the Western Cape Province: Brief for the deciduous fruit sector. Available at: http://bit.ly/2ey8fSL.

SmartAgri (2015b) A Status Quo Review of Climate Change and the Agricultural Sector of the Western Cape Province: Brief for the livestock sector. Available at: http://bit.ly/2ey8fSL.

SmartAgri (2015c) A Status Quo Review of Climate Change and the Agriculture Sector of the Western Cape Province - Brief for the Citrus sector. Available at: http://www.greenagri.org.za.

SmartAgri (2015d) A Status Quo Review of Climate Change and the Agriculture Sector of the Western Cape Province - Brief for the wine sector.

Sowman, M. (2006) ‘Subsistence and small-scale fisheries in South Africa: A ten-year review’, Marine Policy, 30(1), pp. 60–73. doi: 10.1016/j.marpol.2005.06.014.

Sowman, M. (2006) ‘Subsistence and small-scale fisheries in South Africa: A ten-year review’, Marine Policy, 30(1), pp. 60–73. doi: 10.1016/j.marpol.2005.06.014.

StasSA (2013) ‘Fishery Accounts for South Africa: 1990-2011’, National Accounts, (February), pp. 781–798. doi: ABS Cat No. 1301.0.

Statistics South Africa (2007) Census of commercial agriculture.

StatsSA (2013) Fishery Accounts for South Africa: 1990-2011, National Accounts. doi: ABS Cat No. 1301.0.

Talacuece, M., Justino, F., Rodrigues, R., Flores, M., Nascimento, J. and Santos, E. (2016) ‘Modeling of Soybean under Present and Future Climates in Mozambique’, Climate, 4(2), p. 31. doi: 10.3390/cli4020031.

Tibesigwa, B., Visser, M. and Turpie, J. (2017) ‘Climate change and South Africa’s commercial farms: an assessment of impacts on specialised horticulture, crop, livestock and mixed farming systems', Environment, Development and Sustainability. Springer Netherlands, 19(2), pp. 607–636. doi: 10.1007/s10668-015-9755-6.

Turpie JK, Adams JB, Joubert AR, Harrison T, Colloty B, Maree R, Whitfield AK, Wooldridge T, Lamberth SJ, Taljaard S and van Niekerk L (2002). Assessment of the conservation priority status of South African estuaries for use in management and water allocation. Water SA, 28: 191-206.

Vink, N. (2003) Why agriculture is important to the Western Cape Province.

Wallace, M. (2013) University of Cape Town. Available at: https://open.uct.ac.za/handle/11427/4816.

DEA (2015) 'A Status Quo Review of Climate Change and the Agriculture Sector of the Western Cape Province'.

Williams, R., Scholtz, M. M. and Neser, F. W. C. (2016) 'Geographical influence of heat stress on milk production of Holstein dairy cattle on pasture in South Africa under current and future climatic conditions', South African Journal of Animal Sciences, 46(4), pp. 441–447. doi: 10.4314/sajas.v46i4.12.

WWF (2011) 'Fisheries : Facts and Trends South Africa'.