Climate change, groundwater and intensive commercial farming in the semi-arid northern Sandveld, South Africa

Abstract:

Progress in the area of international climate negotiation has been the site of substantively increased activity of late, yet the task of utilizing appropriate spatial scale climate change projections to understand climate change impacts on sensitive sectors remains challenging. The study described here, undertaken in semi-arid south western South Africa, shows how downscaled climate change projections may be used to characterize climate change impacts in an area that is both valuable from a conservation point of view, yet at the same time serves as host to input intensive commercial agribusiness in the form of potato and rooibos tea production. Such potentially polarized land management objectives have given rise to initiatives to develop better practice guidelines for undertaking intensive commercial agriculture in a sensitive biodiverse environment. The study suggests that climate change may make the achievement of such better practice significantly more challenging. Climate change is here seen as one of a number of critically interacting multiple stressors affecting the area; including the trend to input intensive farming.

1. Introduction

While progress in the mitigation arena and at the international and multilateral policy level shows signs of significant recent increased activity, the work of making appropriate spatial scale climate change predictions accessible to understand impacts and support adaptation, remains a challenge. In southern Africa, significant progress has been made in making regional climate scenarios available (Erasmus, 2007; Hewitson and Crane, 2006; Tadross *et al.*, 2005 [1]). Much remains to do, however, in translating these downscaled scenarios into meaningful impacts on climate sensitive sectors (such as agriculture, water and health) that may be used for policy and decision-making.

As is documented extensively in the literature, and as further highlighted in the IPCC Fourth Assessment Report Working Group 2 report released in November 2007 (Boko *et al* ., 2007), agriculture in Africa remains highly sensitive to current climate variability and projected

[1] http://support.awhere.com/downloads/CCETool/publish.htm

climate change (e.g. Arnell, 2006; Benhin, 2006; Bharwani *et al*., 2005; Boko *et al*., 2007; de Wit & Stankiewicz, 2006; Kurukulasuriya & Mendelsohn, 2006; Parry *et al*., 2005; Reid & Vogel, 2006; Seo & Mendelsohn, 2007; Stige *et al*., 2006; Thomas *et al*., 2005; Tubiello *et al*., 2007; Vogel *et al*., 2005; Washington *et al*., 2006; Ziervogel *et al*., 2006). The focus in this study is on commercial agriculture and, more specifically, on rooibos tea and ground water intensive potato farming.

The focus on rooibos tea (*Aspalathus linearis*) and climate change comprises a long-standing research interest in semi-arid southwestern South Africa (Archer *et al*., 2008; Malgas *et al*., 2007) and has evolved partly in response to the gap identified by Easterling *et al* (2007), namely that '….there is practically no literature on the impact of climate change on grubs and resins, and medicinal and aromatic plants' (pg 288). Although tea has been the focus of certain climate change studies (e.g. Jährmann, 2007; Wijeratne, 1996); rooibos tea, as a plant also used in the medicinal and aromatic trade, has received little attention to date. Early work (Archer *et al* 2008, Louw 2006, Malgas 2007) has shown that rooibos tea has been impacted by climate variability and is expected to be impacted by climate change).

A range of authors have investigated relationships between climate variability and/or change and potato production. Rosenzweig *et al* (1996), for example, simulate potential impacts of climate change on potato yield in the United States, finding that autumn potato production in the northern US appears particularly vulnerable to rising temperature. Hijmans (2003) uses the LINTUL simulation model to analyze potential effects of climate change on global potato production, finding that regions in the (sub)tropics may be expected to risk the highest declines in potato yield. Similar studies for potatoes in South Africa have not been published as yet.

The study described in this paper makes use of downscaled climate change scenarios to understand implications of climate change for two primary commercial agricultural businesses (potatoes and rooibos tea) in the semi-arid Sandveld, south-western South Africa (shown in Figure 1). Climate change impacts on groundwater are a particular focus of the study, given Sandveld commercial agriculture's heavy reliance on such water for irrigation (described below). Areas of potato and rooibos cultivation are shown in Figure 2. Water uses of different Sandveld activities are described in more detail below. It should be noted that climate change is here seen as one of multiple stressors affecting the area, critically interacting with and exacerbating each other.

Figure 1: The Sandveld, South Africa

Figure 2: Areas of potato and rooibos cultivation in the study area.

The study was commissioned by the Greater Cederberg Biodiversity Corridor (GCBC) project of Cape Nature (Western Cape provincial nature conservation), Potato South Africa and the South African Rooibos Council. Cape Nature has been involved with these stakeholders in the area of establishing better practice guidelines for intensive commercial farming in a sensitive and biodiverse environment. Stakeholders were aware that climate change may mean that undertaking better practice in commercial agriculture in the area becomes more challenging (for example, increased temperature might require more irrigation, challenging better practice use in water conservation). The study thus arose out of the need for such guidelines to be informed by the challenges that climate change might impose both now and in the future. The key research question for the study comprises the extent to which climate change is likely to impact key water users in the area (tea and potato farming). As described further below, the particular component of water supply focused upon is groundwater; with an expanded focus on other aspects of water balance in proposal for future work. The paper is organized around an introduction to commercial agriculture in the Sandveld, followed by a description of the data used and analyses undertaken, and is concluded by a discussion of the results and future research directions.

1.1 Commercial Agriculture in the Sandveld

The Greater Cedarberg Biodiversity Corridor (Figure 1) lies at the transition zone between two ecologically highly significant biomes – the Fynbos and Succulent Karoo biomes. Both biomes have high numbers of endemic species, and have been recognized by the South African government as comprising areas where conservation is a priority. The corridor is managed by provincial nature conservation (CapeNature) as a partnership with local stakeholders in an initiative to secure conservation of biodiversity in the area.

The Northern Sandveld is a key lowland biodiversity area (for example, Rouget *et al* 2004 show that a number of critically endangered vegetation types in South Africa fall within this area) within the Greater Cederberg Biodiversity Corridor and is at the same time, as mentioned earlier, also host to potato and rooibos production as the core economic activities in this area. According to Knight *et al* (2007), an average of 6 591 ha were planted annually for the production of seed potatoes, ware potatoes (fresh market) and potatoes for the processing industry during the last three years. The total turnover for the industry can reach R 400 million (currently trading at between 9 and 11 South African rands to the US dollar) per annum and offers job opportunities to some 3250 workers. Significantly, 90% of the potatoes supplied to the Cape Town urban area are sourced in the Sandveld.

The rooibos industry is currently valued at R 150 million and employs over 6 000 people. Engelbrecht (2006) indicates that approximately 40 000 ha of Rooibos tea was planted during 2005/2006 in the Western Cape, of which 5 000 ha were planted within the Sandveld. This has grown dramatically from the 14 000 ha that was planted in 1991 (Hanson, 2006). A sample study of the Sandveld by CapeNature demonstrates that over the past 15 years, an average of 2.7 ha of Northern Sandveld has been cleared for agriculture per day, which entails that over 50% of natural habitat has already been transformed.

As mentioned above, the Sandveld is characterised by a huge diversity of plant and animal species, 80% of which occur on private property. At least 65 rare and threatened plant species as well as various rare and endangered animals occur in this area. Leipoldtville Sand Fynbos is regarded as one of the key threatened habitats in the region (about 50% is already lost to cultivation) and it supports at least 40 threatened plant species. Further, the Verlorenvlei Ramsar wetland on the west coast of the Sandveld is an important wetland system of international significance harbouring 14 fish species in its estuary, as well as various aquatic birds and waders.

Low rainfall and nutrient poor soils in this area mean that commercial-scale agriculture requires high volumes of groundwater abstraction and the application of fertilizers. Low relief topography, sandy soils, abundant good quality groundwater and good economic returns have all added to expansions in the potato and rooibos growing industries in the Sandveld. Expansion of center-pivot irrigation followed the introduction of Eskom power lines to the area in the mid-1980s. Water use figures below indicate that such an expansion may have shifted use patterns amongst users in the Sandveld, possibly along a less sustainable trajectory.

Agriculture is by far the largest water use sector in the Sandveld, accounting for more than 90% of the total water requirement, versus municipal use. The annual average recharge of groundwater has been estimated, based on the Groundwater Recharge Assessment of the Department of Water Affairs and Forestry (DWAF) in 2005, as 233 Mm^3/annum. Water use by the potato industry in the Sandveld is conservatively estimated at 46.9 Mm^3/annum. This implies that 20% of the annual recharge is abstracted for potato production. Tea cultivation uses water for processing, as a dry land crop (see details below)
The municipalities use 1.8 Mm^3/annum (i.e. 4% when compared directly to the use of groundwater by the potato industry) and 1% of recharge.

In practice, a farmer wanting to cultivate 20 hectares of seed potatoes would need to clear eight 20 ha circles (160 ha) and would cultivate one circle per season (i.e. two seasons per year), moving the center pivot to the appropriate field each year. Indigenous vegetation, mostly Strandveld, is being cleared for the cultivation of potatoes. The total number of centre pivots in the potato production area of the Sandveld has been calculated as 1 773 (with a combined area of 30 740 ha) using satellite imagery (2003/4). Analysis of the trend of expansion of the industry over the last 10 years shows that, in the core of the production area (Wadrif to Paleisheuwel to Moutonshoek to Elandsbaai) the number of centre pivot fields has increased from 599 to 1 355 and the area from 12 384 ha to 22 871 ha. This is an increase of 84 % in area and 126 % in number of circles.

The entire land surface of South Africa has been subdivided into Primary Drainage (or Catchment) regions. These have then been further subdivided into Secondary, Tertiary and then Quaternary catchments. The catchment boundaries are based on watersheds or river basin divides. There are 1946 Quaternary catchments in South Africa. The study area catchment, Quaternary Catchment G30F (Figure 2) is the most intensively cultivated and is considered the fastest growing agricultural area in the Sandveld.

While serving as a key biodiversity resource, then, the Sandveld supports input intensive commercial agricultural that has critical local economic significance. As stated earlier, such potentially polarized land management objectives have given rise to the current initiative to develop better practice guidelines for commercial agriculture in this area. Climate change may, however, make the achievement of better practice more challenging.

2. Data and analyses

The study focussed first on downscaled climate change scenarios; with an emphasis on working interactively with staff at Cape Nature [2]. For this reason, scenarios were imported

[2] The Sandveld project forms part of a larger loosely grouped initiative that places an emphasis on decentralizing analysis of climate change data, such that 'macro' stakeholders such as provincial nature conservation may undertake, as far as possible, their own analysis. Further explanation, as well as the data

into GIS and scientists then worked interactively with both potato and rooibos agricultural representatives to determine indicators and thresholds of concern to their productive activities.

2.1 Climate history and downscaled scenarios

The Sandveld is a coastal region, which mostly experiences dry summer and wet winter conditions, similar to other regions of the Western Cape. Whilst there have been no detectable trends in annual mean rainfall since 1900, there has been a noticeable increase in annual mean temperature (≈ 1ºC, Figure 3). Such an identified trend reflects temperature increases noted for the rest of South Africa (Kruger and Shongwe, 2004) and southern Africa more widely (New *et al.*, 2006).

Figure 3: Monthly rainfall and temperature (6 year mean filter) for the Sandveld (1900-1998).

This temperature increase is consistent with that expected from climate change. Simulations of future climate using global and regional dynamical models, as well as statistical downscaling of global dynamical models, also suggest that winter rainfall will decrease in the future (Christensen *et al.*, 2007; Midgley *et al.*, 2005). Such changes in temperature and rainfall can only be expected to increase water stress in what is an already highly stressed environment.

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itself, may be found at http://www.csag.uct.ac.za/gisdata and .http://support.awhere.com/downloads/CCETool/publish.htm.

As stated previously, downscaled scenarios - at a finer spatial resolution than coarse resolution global models (GCMs) – utilizing a variety of techniques were imported into GIS. Broadly speaking, 2 different downscaling techniques are used: 1) 2 Regional Climate Model (RCM) downscalings of the same GCM (HadAM3P) using the MM5 and PRECIS RCMs (Tadross *et al*., 2005); and 2) a statistical downscaling (Hewitson and Crane 2006) of 5 GCMs (see Table 1). As the statistical downscalings were only available for rainfall, temperatures are taken from the MM5 and PRECIS downscaling.

2.2 Analysis

The study was initially intended to undertake an analysis of climate-yield relationships for potatoes and rooibos tea; using measured historical climate and yield data.
However, it was determined early on that the yield data available from both potato and rooibos producing organizations would not be sufficient (typically only 10 years of yield data were available for rooibos) to develop statistically significant climate-yield relationships.

In the case of rooibos farming, interviews with rooibos farmers and representatives of industry showed that the winter rainfall season (described by participants as May through August) is critical to stages of rooibos phenology (see also Archer *et al* ., 2008; Louw, 2006, Malgas *et al*., 2007). In addition, high temperatures (usually over 32 C º) in the summer months may induce heat stress. Rooibos stakeholders also highlighted wind speed as important, since this may dry and stress cultivated rooibos lands; as well as relative humidity, which can have significant implications for pests and pathogens.

In the case of potato farming, as mentioned earlier, scientists and stakeholders focused on climate change impacts on the availability of groundwater. Potato farming in the Sandveld is, as mentioned earlier, an extensive user of groundwater for irrigation. A below average winter rainfall season and/or above average set of summer temperatures can result in a potato farmer increasing irrigation. As a result, the team focused on groundwater stress, as shown in Figure 4 below:

Figure 4: Conceptual model of groundwater stress interaction with climate change

Given that calculating expected changes in abstracted amounts is complicated (necessarily including changes in evaporation, plant transpiration, area planted etc.), it was decided to focus on changes in the amount of groundwater recharged, given projected anomalies in precipitation. Such a focus only provides insights as to water availability; and the authors plan to include a broader focus on water balance in future work under development.

Since the climate change scenarios were in GIS format, hydrogeologists were able to use precipitation anomalies to calculate changes in groundwater recharge (selected sources describing similar work include Eckhardt and Ulbrich 2003; Holman 2006 and Jyrkama and Sikes 2005). As part of a groundwater resource assessment project carried out for the Department of Water Affairs and Forestry in 2005 (DWAF, 2005) a comprehensive process was undertaken in which groundwater recharge for the whole of South Africa was calculated combining a modified Chloride Mass Balance method with GIS filters. Figure 5 provides a schematic overview of the process.

Figure 5: Overview of the recharge calculation process used in the GRAII project (DWAF, 2005)

A recharge percentage (based on point values from literature) was determined per $1km^{2.}$ Recharge depth (mm/annum) per km^2 was calculated using mean annual precipitation (MAP) and expected annual recharge volume per quaternary catchment was computed. The recharge depth grid can be seen in Figure 6, reflecting the recharge depth (mm/annum) for the study area based on MAP from Schulze (1997).

The monthly rainfall anomaly grids per model were then summarized to produce an annual anomaly grid per model. Each annual anomaly grid was re-sampled to a cell size of $1km^2$ using Arcview's nearest neighbor interpolation re-sampling method to match the cell size of the recharge percentage grid. The value of the output cell was not changed and the maximum spatial error was one half the cell size of the output grid. The recharge percentage was applied to each of the annual rainfall anomaly grids to obtain the annual recharge anomaly per model (mm/annum) (Figure 9). The expected recharge anomaly volume (mm^3/annum) for each model was calculated for the study area (18 306 km^2). This can be seen in Table 1.

Table 1 Recharge anomaly per annum per climate change model for GCBC domain compared to recharge per annum based on MAP (Schulze, 1997).

Figure 6: Recharge depth (mm/annum)

3 Results

Figure 7 indicates the projected downscaled change in precipitation from 5 GCMs (using the technique of Hewitson and Crane, 2006). The GCM simulations all assumed a future A2 SRES emissions scenario - i.e. the world develops in quite distinct regions, there is little integration and the income differential between developing and developed countries remains large (IPCC, 2007). Downscaled changes are presented for 2 future periods (2046-2065 and 2070-2100) as these are the periods for which daily data, required for the downscaling, are archived by the IPCC.

Two periods are used due to the fact that one set of GCMs (CSIRO MK II, ECHAM4.5 and HadCM3) were used as part of the IPCC third assessment report, data from which were not available for the earlier 2046-2065 period, as was the case for the other two GCMs which were used as part of the later IPCC fourth assessment report.

Figure 7: Downscaled winter rainfall anomalies for May-August

Figure 7 shows a clear spatial pattern of greater negative anomalies in winter rainfall to the south of the study area. In addition, all five downscalings show reduced December (summer) rainfall; of concern to those in the north of the area (not shown), who rely on a certain amount of transitional rainfall from the summer rainfall region to the east. Whilst all 5 downscaled models suggest reductions in winter rainfall in the future, GFDL and MRI suggest greater reductions for the mid-century period than the 3 model downscalings for the later (2070-2100) period. Unfortunately at the time of writing, downscaled data was not available for the 2070-2100 period for the GFDL and MRI models, neither was it available for the remaining 3 models for the earlier (2046-2065) period. This means that we are unable to distinguish whether the relative differences in magnitude between the two periods are a genuine signal across all models or are simply due to the choice of model - i.e. for the earlier period we happen to have chosen two models that simulate large reductions.

Temperature changes simulated using Regional Climate Models (RCMs, Tadross *et al.*, 2005) show higher monthly average temperatures, minimum temperatures and maximum temperatures – particularly towards the interior. Figure 8 below shows, using the PRECIS downscaling as an example, the average maximum temperature anomaly for December and January, among those months identified by rooibos farmers as critical in terms of heat stress. Whilst this is consistent with expected global climate change, these downscalings are from one GCM and therefore should be treated as one estimate from a range of possible future change (though all estimates will show an increase in temperature).

Figure 8: Average maximum temperature anomaly – December and January

The aforementioned groundwater recharge modelling, utilising the projected rainfall anomalies, indicates that all models project reduced groundwater recharge under climate change (Figure 9).

Figure 9: Groundwater recharge depth calculated based on rainfall anomaly using (a) CSIRO model, (b) ECHAM model, (c) GFDL model, (d) HADAM model and (e) MRI_CGCM model.

The three later period downscalings (CSIRO, ECHAM and HADCM3) all indicate increases in recharge to the east (having also simulated the smallest reductions in winter rainfall (see earlier discussion). This indicates that these areas may receive more rainfall further into the future – though importantly the recharge model does not take changes in evapotranspiration into account which will reduce the effective recharge. Given that we are unable to determine if this is a consistent signal across all GCMs (see earlier discussion regarding Figure 7) we are unable to say if this recharge to the east is due to the choice of GCMs for the later versus earlier period. Speculatively, however, the rainfall increases shown may (and this requires further investigation) be due to increases in summer rainfall. An outstanding question here would be whether these eastern regions affect recharge for areas further west in the Sandveld. If this is the case, groundwater availability may initially be negatively affected by climate change, while later in the century, climate change may be beneficial. However, this requires further investigation, using data for the earlier and later period from the same GCMs, as well as including the likely effects of increases in potential evapotranspiration.

4 Discussion and Research Challenges

As described earlier, climate change in this area (as in many other climate change case studies) is superimposed on other existing significant stressors. In the case of the two intensive commercial agribusinesses described here, water use and intensifying agricultural activity challenge both environmental and economic sustainability, even before climate change is taken into account.

Our findings in Section 3 suggest that existing stresses may be exacerbated, perhaps critically. Since the overall picture for the area points to increased temperatures, lower rainfall during critical months and reduced groundwater recharge; heat and water stress risk is likely to increase (although, given our focus only on water availability, such a result should be considered suggestive) In the case of rooibos, increased average, minimum and maximum temperatures in the critical summer months of December-January-February will certainly increase the risk of days over the 32 ºC mark beyond which plants incur heat stress.

The identified projected changes have particular significance for potato farming, with its heavy reliance on irrigation using groundwater. Increased temperatures will increase irrigation requirements, while decreased rainfall will decrease groundwater recharge (already shown). Given the combination of increased temperature and decreased rainfall during critical months, the groundwater stress index is likely to increase markedly for those months. Given that such a projection is superimposed on the existing imbalance in abstraction versus recharge in certain Sandveld areas described earlier, the findings are extremely concerning.

Significant research challenges remain in this area, and the work is likely to be extended through 2009 and 2010 in quite specific ways. Selected tasks are described here. Firstly, as mentioned earlier, irrigation requirements need to be calculated and driven with downscalings to provide a quantitative estimate of changes in irrigation requirements as a result of the projected increased temperature. This will enable us to provide a quantitative indication of increased groundwater stress over the Sandveld under climate change.

Secondly, two separate organizations have produced GIS layers showing areas suitable for growing rooibos, where precipitation is one input into a suitability model. Using the downscaled precipitation anomalies, it may be possible to see how areas suitable for rooibos cultivation may shift under climate change.

Thirdly, much of the work for this area now focuses on the notion of a corridor landscape initiative as an adaptation measure in itself. That is, the creation and coordination of a corridor landscape initiative is often argued to act as a climate adaptation strategy in the form of, for example, providing migration routes and greater connectivity in a highly fragmented landscape. Our work on adaptation in the Greater Cedarberg Biodiversity Corridor area thus increasingly focuses on adaptation measures that range from on farm adaptation strategies for small scale rooibos farming (see Archer *et al* 2008, Louw 2006, Malgas *et al* 2007, for example) to adaptation as landscape scale planning around key climate sensitive parameters such as water and biodiversity.

Lastly, substantive work is underway in the aforementioned area of decentralizing analysis of climate change data. In the case of this study, the ability of stakeholders at Cape Nature to understand both the strengths and limitations of the data, and to undertake their own analysis was greatly advantageous. It allowed the study to move from the rather more typical impact study where a user of climate information is given a generic output and needs to translate that into meaningful terms, to the user being able to query, analyze, critique and translate the data. This appears to be a significant aid for further developing policy relevant climate change research in the future, our ultimate goal.

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