Economic Impacts of Climate Change in South Africa: A Preliminary Analysis of Unmitigated Damage Costs

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February 2002

This research paper is sponsored by USAID and administered by the Joint Center for Political and Economic Studies Inc. under a subcontract agreement from Nathan Associates Inc.

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EXECUTIVE SUMMARY

This study aimed to provide a preliminary desktop estimate of the economic impacts of climate change in South Africa, based on the findings of the Vulnerability and Adaptation Study for the South African Country Study on Climate Change (1999). Damages are those predicted for 2050 and are valued in year 2000 rands, unless otherwise stated. Predicted impacts from this study include changes in terrestrial and marine ecosystems which will have profound impacts on agriculture, forestry, rangelands and fisheries, as well as on biodiversity. In addition, changes n hydrology may have immense consequences in terms of human health by increasing suitable habitat for waterborne diseases, as well as affecting water supply and the maintenance of ecosystem functioning.

Prediction of the economic impacts of climate change is particularly difficult because of the global scale of the impacts and the long time horizon involved. Such studies have mostly been carried out in developed countries, and often only concentrate on market impacts such as agriculture. Impacts are typically divided into market and non-market impacts, with ecosystem and health damages relegated to the latter category, but this study recognises that all impacts have their basis in changes to natural systems, and that all types of impacts have both market and non-market components.

This study was undertaken primarily as a desktop study, based on the findings of the South African Country Study and other available information, but also included the opportunity for a case study to examine an area which was not addressed in the Country Study, namely the loss of existence value attached to biodiversity. We provide a broad-brush, or first-cut estimate of the magnitude of potential damages in the absence of adaptive action. Impacts are addressed as impacts on natural, agricultural, human-made and human capital. Most estimates use the change in production approach. The case study, which measures existence value of the natural heritage that may be lost, uses Contingent Valuation Methods.

Changes in ecosystem function and the loss of biodiversity are brought about by changes in temperature and precipitation, with a general aridification of conditions in the western half of the country. This study uses the predictions made on the basis of the HADCM2 model. Conditions lead to a significant decrease in river flow in the southern and western catchments. Aridification leads to a shrinkage of areas amenable to the country's biomes to about half of their current extent, with huge losses in biodiversity. The productivity of rangelands increases, however, due to a CO_2 fertilisation effect. Changes in terrestrial animal diversity could not be predicted accurately, but the Country Study suggests huge losses of species due to range shifts. Predictions of changes to marine biodiversity were least successful, due to a lack of oceanic and other models.

The value associated with natural systems is based on the goods and services they provide, as well as their attributes. The total value of these systems can be divided into use values and non-use values, with use values being consumptive, from the harvest of resources, or non-consumptive, such as from recreation. Non use values are more intangible, and include option value (potential future use value) and existence value, or the satisfaction that people have from knowing something exists, partly for the sake of its being accessible to future generations. We address each of these values in turn.

Consumptive use values vary between biomes and habitats, each of which is also threatened to a different extent by climate change. Forests are small but locally valuable in terms of commercial production of timber and non-timber products. This biome stands to be entirely lost. Savannas, which cover a large part of the country, are important for grazing and the subsistence harvest of numerous resources. The biome may be radically reduced by climate change, leading to large losses of productive value. The value of the Grassland and Karoo Biomes, lies mainly in livestock production (see below), and little is known of other values. The rich diversity of the fynbos biome is utilised for harvests of several types of resources, but most notably for the flower trade. The potential loss is significant, but requires more detailed spatial analysis. Estuaries west of the Transkei region are threatened with significant reductions in water flow which will affect mouth conditions and the recruitment of fish. Based on a reanalysis of estuarine fishery production data, it is estimated that the national estuarine catch may be reduced by as much as 35%. Very little can be said about offshore marine fisheries at this stage, but inshore fisheries are likely to be affected by the change in estuarine functioning, with an expected loss of about 18% of fishery value.

Tourism may be impacted by climate change due to a loss of habitats and biodiversity, and due to changes in temperature, humidity and malaria risk. South Africa relies heavily on its natural resource base to attract tourism, and wildlife is the primary reason for visiting the country for some 36% of international tourists. Estimation of tourism impacts is difficult in the absence of sophisticated demand and supply models, and also because this needs to be done in a global context, and with the recognition of the fickle nature of the industry. Nevertheless, since tourism may contribute as much as 10% of GDP, the potential impacts are very large indeed.

The existence value of biodiversity threatened by climate change was measured using a Contingent Valuation study, in which 814 residents of the Western Cape Province were interviewed. The findings of the case study are briefly summarised in this report. Existence value is strongly influenced by awareness, experience and interest in nature, and these factors varied significantly according to race and income groups. Nevertheless, three-quarters of respondents were willing to pay towards biodiversity conservation in South Africa, and the same proportion were in favour of a policy to reduce the impacts of climate change by passing external costs onto consumers of products such as fuel. Both referendum and open ended questions indicated an average willingness to pay of about R370 per annum in terms of these sorts of charges, to prevent the predicted losses of habitats. The potential loss of existence value to South Africans was estimated to be R2.63 billion per year.

The impact of climate change on rangelands is predicted to be positive, with the fertilisation effect of CO_2 outweighing the negative effects of reduced precipitation. The resultant increase in cattle productivity is expected to be worth R191 – 1344 million per year, but there would also be a loss in the cattle herd, worth between R100 million and R200 million per year.

Agricultural systems are not nearly as impacted as natural systems. Agricultural crop yields are also expected to be affected by changes in precipitation, temperature and CO_2 levels. Some predictions have been made for the change in productivity of some of the country's most important crops in their main growing areas. These data were aggregated to a national level as far as possible. The most detailed biophysical study was conducted for maize, the country's largest field crop. The total value of lost maize production due to climate change impacts is R681 million without the CO2 fertilisation effect, but a considerably smaller loss of R46 million with the effect. Overall, because of the positive effect of CO_2, the impacts on crop production are relatively minor in relation to the value of the sector as a whole. There is likely to be a significant reduction in the areas suitable for plantation forests as a result of the predicted change in climatic conditions. However, the actual area occupied by plantation forests is a fraction of these suitable areas, and may not be as severely affected.

An additional impact of climate change is that of potential damage to infrastructure due to sea-level rise and associated increased damage capacity of storm surges. One study has been carried out in South Africa which examines the potential impact on selected sites, but the data only permitted a cursory estimation of impacts, and could not be extrapolated to a national level.

Finally, the impacts of climate change on human health were considered for the case of increased incidence of malaria. Previous studies indicated that there will be a four-fold increase in the size of the population at risk within the next ten (not fifty) years. With increased incidence, the proportion of deaths is also expected to increase. This problem is costly in terms of the treatment costs of sick people and the loss of earnings of the sick or their carers. All in all, these costs are expected to come to some R1 billion per year. In addition, deaths due to malaria lead to the loss of those individuals' contribution to the economy.

Overall, the greatest potential impact for South Africa is that of a decrease in tourism income, for which up to 3% of GDP is at risk. Apart from that, the greatest impacts are to traditionally non-market impacts: the existence value of biodiversity, the subsistence use of natural resources and the impacts on human health. This is particularly interesting since most studies tend to concentrate on conventional market impacts. The overall scale of losses as a proportion of GDP are likely to be closer to those of Europe and America than for the rest of Africa, thanks to South Africa's dependence on healthy mining and manufacturing sectors.

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1. Introduction

1.1 Background and aims

The Vulnerability and Adaptation study for the South African Country Study on Climate Change (1999) has recently made qualitative and quantitative predictions of the biophysical impacts of climate change up to 2050. Predicted impacts include changes in terrestrial and marine ecosystems which will have profound impacts on agriculture, forestry, rangelands and fisheries, as well as on biodiversity. Furthermore, changes in river flow may have immense consequences in terms of human health by increasing suitable habitat for water-borne diseases, as well as affecting water supply and the maintenance of ecosystem functioning. A combination of reduction in freshwater inputs and sea level rise is expected to impact on estuaries, affecting the production of estuarine and inshore marine fisheries. The economic implications of these changes have never been estimated in South Africa, and the Country Study now provides the opportunity to produce some first-cut estimates.

The economic impacts of climate change in South Africa will mainly be felt in terms of changes in production throughout the primary sector, which will affect value added to national income as well as people's livelihoods within this sector. However, impacts will be felt right through to the tertiary sector, especially if tourism values are affected by a loss of biodiversity and certain habitats. Loss of biodiversity is also likely to have more intangible effects such as the loss of existence value and a loss of options for values to be realised from as yet unutilised components of biodiversity in future.

The aims of the study were to provide a preliminary desktop estimate of the economic impacts of climate change based on the findings of the country study and any other available data, and to make at least one new estimate on the basis of a case study. The study concentrates on estimation of the potential economic impacts of climate change should no preventative action be taken, and does not include an economic analysis of the costs and benefits of mitigation.

1.2 The economic analysis of climate change impacts

Compared to most pollution problems, the analysis of which helped shape the origins of environmental economics, climate change impacts will be much wider reaching, both spatially and temporarily (Fankhauser & Tol 1996). The global nature of the problem demands the analysis of impacts on a global level, though without neglecting spatial variation. Analysis of regional or national-level impacts could be seriously flawed if they do not take global changes into account. However, the estimation of global level impacts requires detailed estimation impacts at a regional scale, and adjustments can be made at this level. With regard to the temporal scale of the problem, the analysis is particularly difficult because many impacts will not be felt for another 50 years, and thus affect a different generation of people. The long tme horizon makes any economic assessment highly sensitive to assumptions about the preferences of future generations.

Studies on the economic impacts of climate change have mostly been carried out for developed countries, especially the USA. Moreover, most of these are partial impact studies, concentrating on areas such as agricultural impacts or the cost of sea level rise. Comprehensive monetary valuations are rare and usually restricted to the USA (Fankhauser & Tol 1996).

Most studies, including the IPCC WGIII study, tend to classify the economic impacts of climate change into market and non-market impacts (e.g. Fankhauser & Tol 1996, 1997). The basis of this classification is described in Table 1.

Table 1. Typical classification of the economic impacts of climate change

Market impacts	Primary sector impacts	Agriculture
		Forestry
		Fisheries
	Other sector impacts	Water supply
		Energy demand
		Leisure activity
		Insurance
		Construction
		Transport
		Energy Supply
	Property loss	Dryland loss
		Coastal protection
		Urban infrastructure
	Damage from extreme events	Hurricanes, droughts, storms, floods, etc
Non-market impacts	Ecosystem damage	Wetland loss
		Forest loss
		Species loss
		Other ecosystem loss
	Human impacts	Human life
		Air & water pollution
		Migration
		Morbidity, physical comfort
		Political stability
		Human hardship
	Damage from extreme events	Hurricanes, droughts, storms, floods, etc

Source: IPCC WGIII (1995)

Market impacts are those impacts that would be reflected in the national accounts, and include impacts such as the change in output of economic sectors such as agriculture and forestry, damages such as property losses, and impacts leading to increased expenditure such as the earlier provision of water-supply schemes. These impacts will affect the overall GDP of the country. Non-market impacts are those which affect ‘intangibles’ and are associated with the loss of ecosystems, habitats and species, and with the impacts on human amenity. Impacts on health and the loss of human life are usually also considered to be non-market impacts.

This relegation of ecosystem damages to the ’non-market impacts’ category reflects rather an old school way of thinking, however. An ecological economics perspective would emphasise the connection of both market and non-market impacts to ecosystem damages. We would rather assert that all kinds of damages, whether to functional ecosystems, man-made ecosystems, infrastructure or human health, have both market impacts, reflected in conventional national accounting statistics such as GDP, and non-market impacts, such as discomfort and other less tangible impacts on human wellbeing. The structure of this report thus follows this line of reasoning, starting with an examination of the impacts on functioning natural ecosystems (see methods section).

1.3 The South African Country Study

This study is heavily based on the findings of the South African Country Study. The South African Country Study used outputs from 3 General Circulation Models (GCM's), namely Genesis (origins presently unclear), CSM (developed by NCAR, USA), and the UKMO, developed by the Hadley Center, UK (termed HadCM2, a revised version of the original GCM HadCM). The HADCM2 scenarios were developed using two assumptions regarding sulphate aerosols, one assuming their presence and gradual decline during the simulation period, the other assuming their complete absence during the simulation period. Sulphate aerosols are a product of fossil fuel (especially coal) burning, and ironically act to reflect radiation and therefore counteract warming due to increasing CO2. These scenarios are termed HadCM2S (with sulphate effect), and HadCM2N (sulphate effect excluded).

Of the four models, Genesis tended to produce the most unique and contradictory results, and was therefore often not used by the study contributors. Responses of rainfall and temperature trends are summarised below for all the models. In general, the results for temperature are more in agreement than those for rainfall.

Rainfall: Summer rainfall is projected to decrease over most of the country by both HadCM2 simulations (projections for the summer rainfall region lie between a 15% decrease to a 5% increase), in contrast to Genesis which predicts an increase for most of the country. CSM projections and spatial patterns are similar to HadCM, and range between a 10% increase and 10% decrease. Winter rainfall is projected by CSM to decrease by more than 25% in the northern winter rainfall area, and increase slightly in the southwestern region, while HadCM2 projects a similar pattern, but a 25% decrease in the southwestern regions. Genesis simulates an increase in winter rainfall throughout the winter rainfall region.

Temperature: All four GCMs project temperature increases for the entire country, with highest increases (up to 4°C) over the north-central parts of the country. On average, the highest projected mean annual temperature increases range between 2.5° and 3°C, with lower increases projected for the coastal regions.

The overall consensus was that the HadCM2 simulations provided the most plausible and accurate predictions. Thus much of the rest of the country study was based on those predictions. In addition to the climate scenarios, the country study included the following impact studies: water resources, agriculture, human health (malaria and Schistosomiasis), commercial forestry, rangelands, and biodiversity (plant, animal and marine). These sections were chosen as areas with a close relationship with climate. The findings of these studies are summarised in the relevant sections of the results.

In general, it must be stressed that the country study was a vulnerability and adaptation assessment. The impacts of climate change were described in terms of sensitivity (how much change in sector indicators may occur?), vulnerability (do the potential changes cause increased risk for the sector or populations associated with it?), and potential adaptation responses (what options are available to counteract any negative effects?). Authors were not pushed to provide highly quantitative estimates, mainly due to the levels of uncertainty involved, especially concerning the key drivers such as temperature and rainfall. Indeed, the question is not so much of whether or how the climate is changing, but how much it will change over a given period of time. The behaviour of many of the response variables was also difficult to predict, often since the type of scientific research required to make such predictions has not been done. Thus, in general, the country study tends to give rather rough, and often only qualitative predictions of the biophysical impacts of climate change.

2. Study approach and methods

This study was undertaken primarily as a desktop study drawing primarily on the findings of the South African Country Study on Climate Change, but with the opportunity for one case study to examine an area which was not addressed in the Country Study. The whole study is thus highly reliant on the existence and quality of previous estimates of the biophysical and other impacts of climate change. If available, other material is used where necessary and/or possible. Our estimates are thus rough, intended only to provide an idea of the order of magnitude of damage costs.

This study provides estimates for unmitigated damage costs. Whereas it is to be expected that there will be a large adaptive response to climate change that will mitigate these impacts, the adaptive response is in itself costly. The measurement of adaptation costs plus residual damages is thus more accurate, but a much more complex way of analysing the impacts of climate change. This study is a broad-brush estimate of the magnitude of potential damages in the absence of adaptive action, and can thus be seen as a worst-case estimate of the impacts of climate change in the event of a government policy failure such as a laissez faire approach. Estimating the costs of adaptation to climate change would require a separate study.

In order to standardise the measurements of different impacts, the country study, and this study, estimates impacts for the year 2050 as far as possible. This corresponds to the doubling of CO_2 from pre-industrial levels, i.e. from 275 ppmv to 550 ppmv, and all biophysical changes are predicted based on this doubling. Higher concentrations and greater impacts are entirely possible. There is nothing ‘magic’ about the $2xCO_2$ level, but it has become a figure often used in the literature. No ‘safe’ level of atmospheric CO_2 has been identified by the IPCC. Our estimates are based on the HADCM2 model (see above).

We use a different primary classification of impacts, based on the source of value: natural, agricultural, man-made or human capital. The impacts on each of these areas that were considered in this study, and the general approach to valuation is described in Table 2. This is given in more detail in each of the relevant sections of the report. Note that we have not valued losses of water supply separately, since it is included as a critical input to other economic activities, e.g. agriculture, and is essential to ecosystem functioning.

Over time, the relative impact of climate change on South African GDP is expected to increase as damages increase. One might expect that economic growth, technological and other advances will lead to changes in some of the outputs we are valuing, independent of climate effects. For example, there may be more development at the coast, genetically modified crops (independent of adaptive measures) may induce higher production, and in the opposite direction, greater poverty may lead to greater incidence of malaria, etc. In other words, without climate change, the country’s economic activity would not remain static, and different sectors may change in different ways. Because it is impossible to predict these changes within a study such as this, it is necessary to work under a general (though unrealistic) *ceteris paribus* assumption that all else remains equal.

To be consistent with other studies, we report the 2050 level of damages, except in the case of health impacts, which are assessed up to 2010. These are reported in year 2000 Rands and the values are comparable to nominal 2000 GDP. Note that this assumes that the structure of economy in 2050 is basically the same as it is today, and that any real growth in the economy would be impacted by proportionately larger losses from climate change damages.

Table 2. Summary of the impacts considered and the approaches to estimation of economic valuation used in this study

Damage to:	Impacts	Study approach
Ecosystems & biodiversity	Consumptive use values (harvesting of resources)	Collation of existing data on value of the commercial and subsistence use of resources, such as indigenous forestry and fisheries; assessment of losses in terms of predicted loss of extent an/or productivity of relevant biomes/habitats. The market value of grazing is considered separately, for all areas combined, on the basis of expected changes in primary productivity of grasses.
	Non-consumptive use values (tourism & recreation)	Collation of existing data on extent and value of nature-based tourism, assessment of losses in terms of predicted loss of habitats and biodiversity.
	Impacts on option and existence value	Estimated by means of a case study, using Contingent Valuation Methods.
Agricultural systems	Rangelands	See consumptive use values of ecosystems, above.
	Crops	Impacts predicted by the country study on crop productivity per unit area for different crops and in different parts of the country are extrapolated to the country as a whole and valued on the basis of current agricultural statistics.
	Plantation forests	Maps presented in the country study showing predicted changes in the suitable ranges of plantation species are analysed in their original GIS form to produce quantitative data, and impacts are valued on the basis of recent estimates of the contribution of forestry to the national economy.
Infrastructure	Property losses due to sea level rise	Predictions on the impacts of selected sites around the coast are converted into monetary terms. These data could not be extrapolated to a country level.
Human health	Health & loss of life due to Malaria	Increased incidence of malaria predicted by the country study are valued on the basis of cost-of-illness and human capital approaches, the latter valuing the temporary loss of earnings due to illness. Loss of human life is valued on the basis of average contribution to GDP.

3. Change in ecosystem function and loss of biodiversity

Jane Turpie

3.1 General overview

The HadCM2 model, favoured by the South African Country Study on Climate Change, predicts an increase in temperatures of about 2.5˚ C by 2050. Along with this, major changes in rainfall are expected, most notably a decrease in precipitation in the western half of the country. These patterns tend to mean that most biophysical impacts predicted by the country study are greatest in the western half of the country, which was generally considered to be highly sensitive and vulnerable to climate change.

3.1.1 Water resources

According to the country study, in which water resources were modelled using the ACRU hydrological modelling system, changes in rainfall and temperature patterns will lead to significant shifts in hydrological functioning within South Africa.

Projections of mean annual runoff (MAR) and recharge into the vadose zone (representing groundwater recharge, GR) vary widely between models, with Genesis the only model projecting significant increases of these measures over the entire country. HadCM2 (both versions) suggests reductions of MAR especially in the western parts of the country, HadCM2N projecting catastrophic reductions of up to 70%, and HadCM2S reductions of between 10 and 30%. CSM patterns are similar to those for HadCM2S.

Threshold analyses for MAR suggest a 10% reduction in runoff in the western parts of the country by 2015, with this threshold only reached by 2060 in the east.

For GR, most of the country has presently very low values of around 5mm, except for the western Cape, which has GR values up to 90mm per annum. All models predict subtle changes in absolute values of this measure, except for the western Cape Cape Fold mountains, where they all predict large decreases. However, when expressed in relative terms, large decreases are predicted for much of the country by CSM and HadCM2S, and lower decreases for Genesis and HadCM2N.

Projections of sediment yield (index of soil erosions) show large absolute increases on the eastern seaboard (Transkei coast) and extreme north eastern regions, but no change to small decreases of throughout most of the rest of the country.

Taken together, these result suggest that runoff into the main rivers are likely to be reduced over much of the country, or to become less predictable. A possible increase in fire frequency and drought deaths in Fynbos vegetation in the south (although not yet simulated) will lead to dam siltation problems and a less predictable water storage. There is also likely to be a significant increase in demand for irrigation from the agricultural sector – for example, water intensive evaporative cooling in the fruit areas of the Cape is already being introduced.

Studies of two major catchments were carried out in detail, namely the Orange River catchment in the northwest, and the Mgeni River catchment in the east. The Orange River is projected to have a 12 – 16% decrease in outflow at the mouth by 2050 using HadCM2S. The Mgeni is predicted to have a 20% reduction in outflow at the mouth by 2050.

3.1.2 Terrestrial Vegetation

Changes in the terrestrial plant diversity were indicated using bioclimatic modelling techniques, providing spatially-explicit predictions of the future distributions of South African biomes and selected key plant species. The study suggested significant shifts in habitat ranges and species losses.

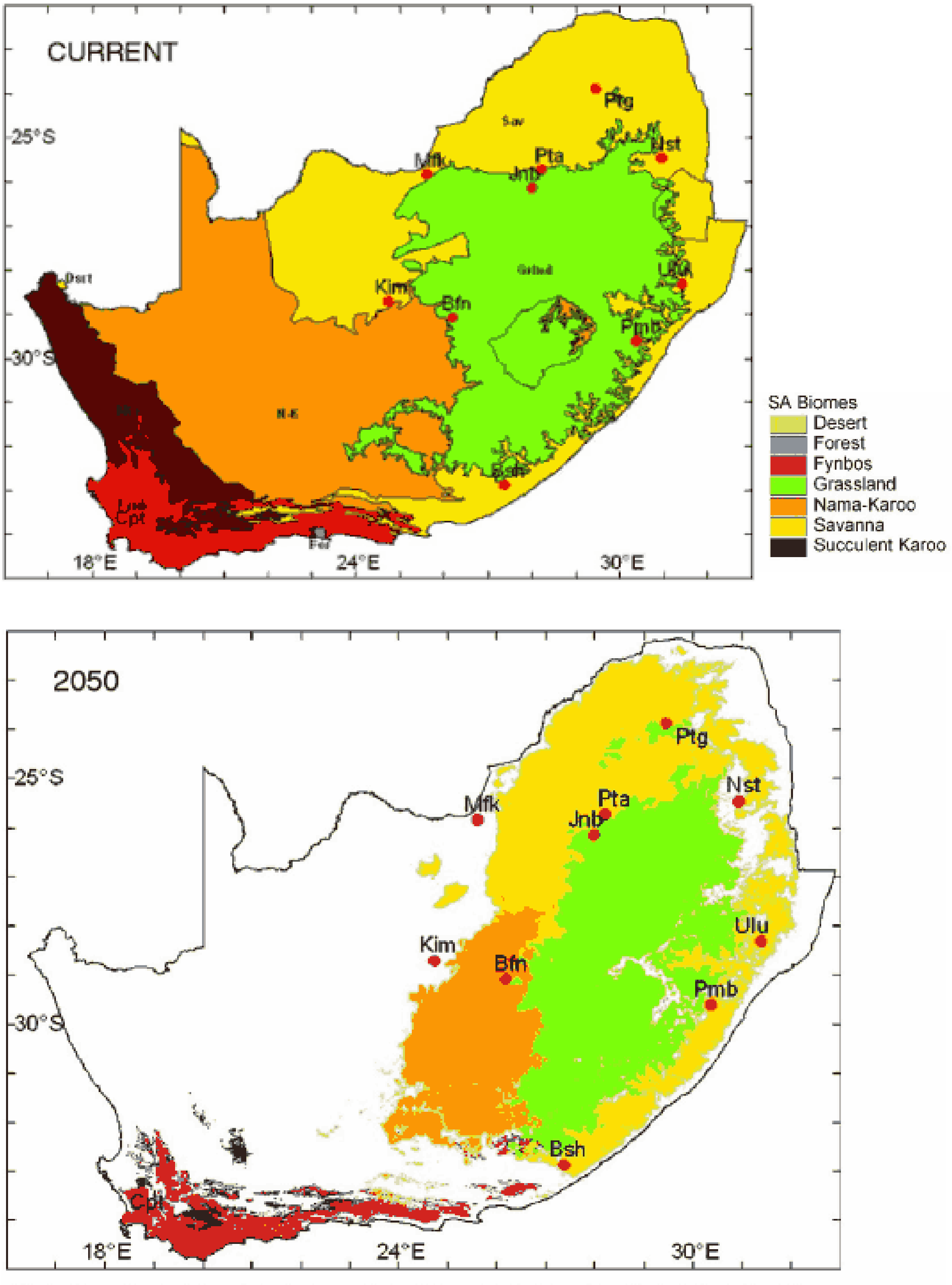
The warming and aridifiation trends result in a shrinkage of the areas amenable to the country's biomes to between 38% and 55% of their current combined area (Fig. 1, Table 3). The 'vacated' areas would support a much more arid-adapted and relatively species-depauperate vegetation. The largest losses occur in the western half of the country, and the findings suggest a complete loss of the unique succulent Karoo biome by 2050 (which contains 5500 endemic species). The Nama Karoo biome is also radically contracted. The fynbos biome does not contract as much as these, but stands to lose a large number of species. Modeling suggests that 33% of the endemic Proteaceae will lose 100% of their current ranges, and are thus likely to become extinct. If this family is representative of the entire biome, the costs can be calculated for related industries. Much of the existing grassland biome ill be susceptible to a potentially large number of invading savanna tree species. Elevated CO_2 may encourage bush encroachment in much of the eastern part of the country, in combination with the increasing minimum temperatures this will lead to a switch from grassland to woodlands and savannas, with concomitant loss of grassland specialists. It is also speculated that increasing temperatures may increase the incidence of fire, which is an important determinant of habitat structure and species diversity, but no studies have quantified this effect.

Several protected areas are likely to lose a significant portion of their plant species complements, although those in the eastern and highland regions will be better buffed against climate change.

In addition, the impact of climate change on the rangeland productivity of natural habitats is an issue affecting 70% of the land surface of South Africa, but is described in a separate chapter.

Table 3. Estimated current and predicted future (2050) extent of the major vegetation Biomes in South Africa. Data supplied by National Botanical Institute.

Biome	Current area	Area remaining in 2050	% remaining in 2050
Forest	721 154	-	0%
Fynbos	7 720 960	2 915 069	38%
Grassland	33 340 446	14 320 700	43%
Nama Karoo	29 768 902	8 211 192	28%
Savanna	42 525 186	30 608 402	72%
Succulent Karoo	8 257 625	1 557 116	19%
Thicket	4 156 647	-	0%
TOTAL	126 490 920	57 612 479	46%



White areas represent climatic conditions not encountered in South Africa today

Figure 1. Current and predicted future distribution of biomes in South Africa. The future scenario is based on climate changes brought on by an increase in the concentration of atmospheric carbon dioxide to 550 ppm.

3.1.3 Terrestrial Fauna

As with the plant study, the terrestrial animal diversity study suggested significant species losses and shifts in species ranges. The animal study used a modified climate envelope model to explore the consequences of climate change for the distributional ranges of 179 selected species. The results showed that 17% of species expanded their ranges, while 80% displayed range contractions of up to 98%, and only 3% did not respond to climate change. Most of the range contractions were due to eastward retreat from aridification in the western half of the country. The study also suggests major species losses from the Kruger National Park, with 66% of species having a high probability of extinction, including 97% of bird species. However, because the models did not allow for the filling of 'vacated' areas due to range shifts from areas to the north of South Africa, the degree of species extinction is probably seriously overestimated in the Country Study.

3.1.4 Marine biodiversity

The prediction of biophysical impacts on the marine environment is poor in comparison to that for terrestrial environments. This is due to the fact that these systems are heavily dependent on atmospheric and oceanic circulation systems which are likely to be affected by climate change, but for which inadequate information exists with which to model marine systems accurately. Moreover, the interaction between marine biodiversity and these systems is still in itself rather poorly understood. This part of the country study was unable to provide many quantitative estimates, and in many cases, even the direction of the potential impacts is uncertain. Although range changes are expected, with tropical species moving southward along the coast, these could not be modelled due to their close association with ocean currents, whose change in movements have not been predicted. Estuaries will be impacted by a decrease in freshwater runoff, particularly those whose main catchment areas are in the western half of the country.

3.2 Types of value associated with natural systems

The value of natural systems lies in their supply of goods and services that are 'consumed' by society, and their attributes. Goods are the tangible products provided by these areas, such as firewood, and services encompass benefits such as those associated with ecosystem functioning, for example, water purification. Natural systems also have attributes, such as biological diversity, which contribute to their value, such as ecotourism value, or sense of place, contributing to the overall quality of life for South Africans and even people living further afield.

Table 4. A comparison of ecological and economic characteristics of natural ecosystems (adapted from Aylward & Barbier 1992)

System characteristics	Ecosystem characteristics	Economic characteristics
Stocks	Structural components	Goods
Flows	Environmental functions	Services
Organisation	Biological and cultural diversity	Attributes

Goods, services and attributes all contribute to the total value of and environmental amenity. In the environmental and resource economics literature, the total economic value of environmental amenities such as nature reserves or urban open space areas is categorised into different types of value in order to simplify the description and measurement of value (Fig. 2).

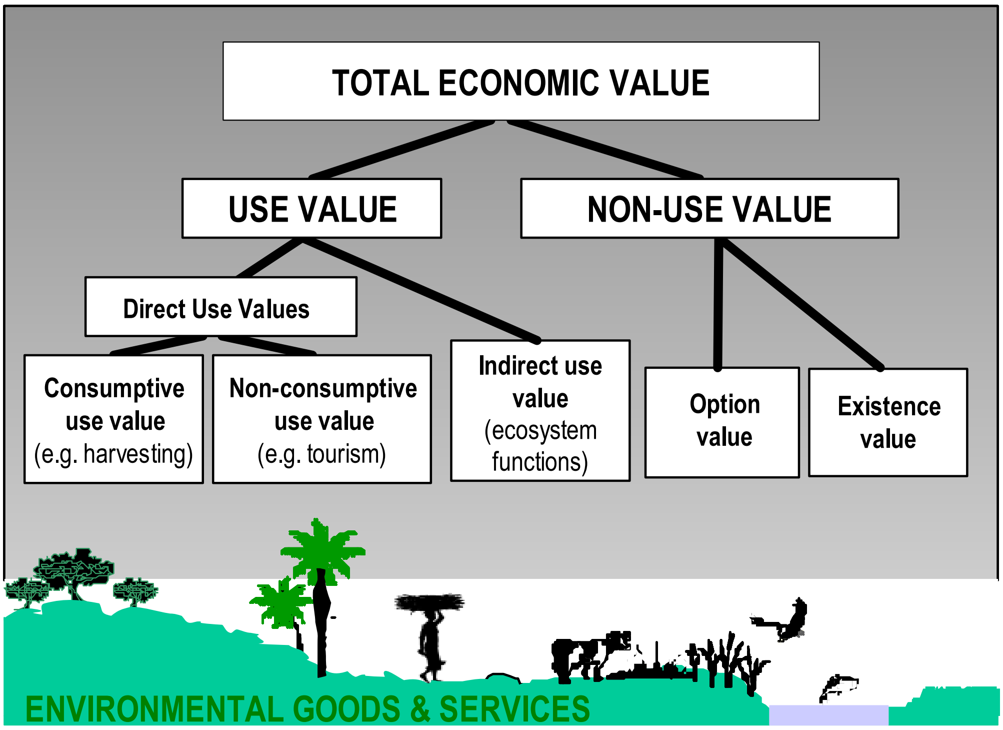


Figure 2. Conventional classification of the values of environmental amenities

3.2.1 Consumptive use value

This is the value associated with direct harvest of 'goods' from an area. These include firewood, medicinal plants, food plants, animals, flowers, and building materials such as reeds *Phragmites australis*. The value of this consumptive use is the gross monetary value of the harvest net of harvesting costs.

3.2.2 Non-consumptive use value

Non-consumptive use value is the value obtained from any use of a resource which does not involve the removal of goods. This includes the value of most tourism and recreation, and also includes the value that natural areas add to property transactions. Both recreational and property values of natural areas are associated mainly with the 'attributes' of ecosystems.

3.2.3 Indirect use value

Indirect use values are the benefits obtained from ecological functions, or 'services', of ecosystems. The magnitude of these values is often dependent on the ecological integrity of the areas concerned, or the degree to which they are altered or transformed. Some of the values associated with ecosystem functions have been identified in the international literature as follows:

- Gas regulation
- Climate regulation
- Disturbance regulation
- Water regulation
- Water supply
- Erosion control
- Soil formation
- Nutrient cycling
- Waste treatment
- Pollination
- Biological control
- Refugia

Indirect use values are so called because they values that are realised outside of the study area, and the ecosystem in question thus actually just provides an input into a value realised elsewhere. For example, the value added to marine fisheries by estuaries is an indirect value of estuaries. However, in the context of this study, it is unnecessary to distinguish between direct and indirect use values, since the study is carried out at the scale of the country as a whole.

3.2.4 Option and existence value

Option value, sometimes called future use value, is the value that people place on retaining the option to use a resource in the future, irrespective of whether it is any use to them at present. The value is variously described as a use value or a non-use value, but its classification is not important in the issue of valuation.

Existence value is the value of knowing that a resource exists, even if that resource is remote and is never used directly. Existence value is often expressed as peoples' willingness to pay for the conservation of endangered species in far-off places. This would include conservation value as perceived by society.

3.2.5 Total economic value

Whether or not the different types of values associated with natural ecosystems can actually be summed is a contentious issue. In particular, expressed existence values are fairly difficult to decouple from other types of values. It is also necessary to recognise that many of the values identified are conflicting values or trade-offs. For example, the value of grazing or thatching may compete, if livestock graze the same species used for thatching. Similarly, the recreational value of an area may conflict with its conservation value.

3.3 Impacts on consumptive use values

3.3.1 Forest and Savanna Biomes

South Africa has relatively little indigenous forest, with the total cover being less than 500 000 ha, or 0.5% of the country (Midgley *et al.* 1997), although some estimates are as low as 400 000 ha (Fairbanks *et al.* 1999). These include a number of different types of forest, but they can be roughly grouped into coastal forests, found in discontinuous patches within 50km of the coast from Knysna to the Mozambiquan border, and Afromontane forests, which occur in patches in sheltered areas of most mountain ranges.

Natural woodlands, or savannas, differ from forests in that their canopy is more open and they include a co-dominant herbaceous (grassy) layer. Woodlands cover about a 41.75 million ha, roughly a third of the country. Consequently, they include a variety of types, ranging from sparsely wooded grasslands to dense moist woodlands, this variation making generalisation about responses to climate change and about values rather difficult.

Forests and woodlands are notable areas for extraction of multiple resources such as timber, fuelwood, medicinal plants and food plants, on a commercial or subsistence basis. In addition, woodlands are managed as extensive livestock-ranching areas throughout much of South Africa. Commercial livestock production is discussed separately in the following chapter. The value of forests tends to be predominantly commercial, and mainly ascribed to timber extraction, while that of woodlands includes a significant subsistence value component. The commercial and subsistence values are discussed separately below.

3.3.1.1 Commercial extraction of timber

Most commercial extraction of indigenous timber takes place in the forests of the southern Cape. This is the largest indigenous forest complex in southern Africa, forming the southern end of a chain of Afromontane forests along the eastern escarpment and the coastal forests of South Africa (Vermeulen 1999). These forests cover about 60 500 ha. Of this, about 35 700 ha are controlled by DWAF. Forests on private land are protected under the Forest Act (Act 84 of 1984). Forests under DWAF are divided into compartments, each of which is assigned a management class, which are based on forest type and identify the management objective (Table 5). None of these forests are under communal lands: there are very few communal land areas in this region.

Table 5. Management classification of Southern Cape & Tsitsikamma forests (areas in hectares). From Vermeulen (1999).

Forest Type	A Timber Production	B Protection	C Nature Reserve	D Recreation	E Research	Total
TOTAL AREA (ha)	9 276.1	16 033.0	9 879.1	127.0	441.4	35 756.6
% TOTAL	26.0	44.8	27.6	0.4	1.2	100.0

All timber harvesting is currently carried out by DWAF, and timber is sold in block form on auction. Most of this timber is used in the well-established local furniture industry, with a small amount finding its way further afield (Mogaka *et al.* 2001). In 1998, a total of 3589 m^3 of timber was auctioned, realising a total income of almost R3.3 million in 2000 rands. According to the predictions of the South African country study (Rutherford *et al.* 2000), this value could be lost in its entirety.

3.3.1.2 Commercial extraction of non-timber forest resources

In addition to timber, the main non-timber forest product harvested from these forests is the seven-weeks fern *Rumohra adiantiformis*. This species is common in the southern Cape forests, especially in the moist and wet High Forest types and on moister areas of dry High Forest (van Dijk 1987). The long-lasting fronds are used in flower arrangements. *Rumohra* is harvested by private contractors over a total area of 14 500 ha, under the control of DWAF. The harvest of this species is strictly controlled by a quota system in order to ensure its sustainability. In the Western Cape, a total of roughly 1.7 million fern fronds were harvested during the 1997/8 picking cycle, realising a total income of approximately R378 000 in the region (Vermeulen 1999), and about R700 000 is realised annually in the country (DWAF 1996). There is some degree of illegal harvesting, but its extent is unknown. This value would be expected to be entirely lost under the climatic conditions predicted for 2050.

3.3.1.3 Subsistence harvesting of resources

There is relatively little human habitation within intact forest areas, but resources are extracted from natural forests by people living close to them (Shackleton *et al.* 1999). Woodlands tend to be more densely populated. In South Africa, human population densities in woodlands are high, particularly in the former homeland areas to which people were forcibly removed during the Apartheid era. Here, typical densities are about 150 people per km^2, reaching over 300/km^2 in some places (Shackleton *et al.* 1999). Because of their direct reliance on natural resources for survival, the livelihoods of a large number of South Africans stand to be affected by climate change impacts on savanna and forest ecosystems. Shackleton *et al.* (1999) carried out surveys of natural resource use in a variety of wooded areas in three different parts of the country. Natural resources harvested from these areas include the following:

- Fuelwood,
- construction timber and poles,
- carving timber,
- bush meat,
- medicinal plants,
- edible fruits,
- edible herbs and vegetables,
- thatching grass, and
- reeds.

In addition, a substantial portion of the woodland area is used for subsistence production of livestock, which generate income in the form of meat and milk, as well as providing a traditional form of wealth.

Based on the quantities of resources extracted and their values in the different areas, Shackleton *et al.* (*op cit*) derived an estimate of the total use value of woodlands to be between R2 673 and R3 633 million (1998 prices). Timber (including fuelwood and poles) makes up a mere R4.7 million of this value (Shackleton *et al.* 1999). With an expected loss of up to 72% of the Savanna Biome (Table 3), this translates to a potential loss in use value of R1 924 million – R2 616 million per annum. This loss is a non-market value and would not be reflected directly in the national accounts.

3.3.2 Grassland Biome and Karoo Biomes

The predominant value of the Grassland and Nama Karoo Biomes is commercial livestock grazing, which is discussed separately in the following chapter. Most of the land area is under private commercial ownership, but significant parts of the grassland area, and some part of the nama karoo, lies within communal areas. Within these areas, the biomes have a subsistence use value for the harvest of resources as well as for grazing. However, no studies have attempted to estimate these values.

The Succulent Karoo Biome is more arid than the Nama Karoo, and has a lower grazing value, with grazing being predominantly by small stock. A significant portion of the Succulent Karoo Biome is under communal ownership. In these areas, there is a high reliance on the natural veld for harvesting of resources such as fuelwood and medicinal plants, as well as for subsistence livestock production. The aggregate value of these uses is, however, unknown.

3.3.3 Fynbos Biome

Harvesting of the rich biodiversity of the Fynbos Biome makes a substantial contribution to the national economy (Turpie *et al.* 2001). Although fynbos is largely unsuitable for grazing, several resources are harvested from this biome. Wild flowers such as *Protea* spp. and greens for the ornamental industry constitute the most valuable harvest from fynbos, with over 100 species being harvested (Turpie *et al.* 2001). Other resources harvested include sour figs (*Carpobrotus* spp), honeybush tea (*Cyclopia* spp.), buchu (*Agathosma* spp.) for its essential oils used in flavouring, perfumery, medicine and brandy, and thatching reeds (*Thamnochortus* spp).

The total contribution of these harvests to the South African economy is estimated to be R73.679 million per year (Turpie *et al.* 2001). With most of the biome under private ownership, virtually all of this harvest is commercial. With an estimated loss of 38% of the fynbos biome, the loss in use value of the fynbos could equate to up to R28 million per year. However, since the use value of fynbos is not evenly distributed across the biome, but tends to be concentrated within the southern-most areas, it is possible that the loss is much lower than this. Nevertheless, even if the shrinkage of fynbos habitats was proportionally lower in the most productive areas, the country study also predicts a significant extinction of species such as Proteas, which could be important to the wildflower trade.

3.3.4 Estuaries

South Africa has roughly 255 functioning estuaries along its approximately 3100 km coastline. Estuaries are productive systems which provide a valuable supply of goods and services, ranging from fisheries to recreational opportunities, but there have been few attempts to estimate the economic value of these ecosystem services, with the result that their contribution to the national economy has been under-appreciated. One of the most important values of estuarine systems is their contribution to fisheries. About 160 fish species occur in estuaries of which 80 species are utilised. Resident estuarine fish populations are exploited directly in recreational, subsistence and limited commercial fisheries. In addition, estuaries provide nursery areas for numerous species of fishes which are exploited in inshore marine fisheries.

Estuaries are uniquely complex ecosystems in that their biodiversity and functioning is closely tied to the interaction between freshwater inflows and marine inflows, as well as to biogeographical zonation. The coast is divided into three biogeographic zones: the Cool Temperate zone on the west coast, the Warm Temperate zone between Cape Point and the middle of the former Transkei, and the Subtropical zone on the east coast. (Turpie *et al.* 2000, Emmanuel *et al.* 1986); each zone supporting a relatively different complement of species. It is also very difficult to generalise about estuarine functioning, as this delicate balance may work in very different ways depending on whether an estuary is perched, and thus freshwater dominated, or marine dominated with strong tidal influences. Substantial effort has been made in South Africa to classify estuaries in relation to their ecosystem functioning (Whitfield 1992). This and other assessments stress that estuarine functioning is very strongly influenced by the magnitude and timing of freshwater runoff reaching them. Even the abstraction of water for agricultural, domestic and other uses has had profound effects in some cases. The impact of climate change on rainfall, and thus on catchment runoff, is thus likely to have a significant impact on estuarine functioning. Both Hadley models (with and without sulphate forcing) predict a decrease in annual rainfall in the western and central parts of the country by about 5 – 15%. What is to happen further east is less certain, but runoff may well increase slightly. Changes in seasonality of rainfall would also be important, but attempts to model such changes show wide discrepancies.

In the South African Country Study on Climate Change, Clark *et al.* (2000) simulated runoff from 23 catchment systems around the country by running the ACRU geohydrological modelling system (Schulze 1995) using precipitation data for present and future (2x CO2) climates predicted by the Hadley GCM excluding sulphate forcing. The model predicted that west coast estuaries would experience the greatest reductions in flow of up to 84%, with the effect being significant, but slightly less at about 50% moving eastward to a roughly 20% decrease in flow along the south coast. Estuaries east of Port St Johns are more likely to experience a slight increase in freshwater inflow, although this increase was very small in most cases.

Reduced freshwater flow into estuaries may often lead to a change in mouth condition, with estuaries closing more frequently than under natural flow conditions. The extent to which estuary mouth conditions are sensitive to flow is determined by geomorphological features of the estuary such as how perched it is. While river mouths and estuarine bays and lakes are unlikely to change, permanently open estuaries may start to close occasionally and temporarily open estuaries may become closed for longer periods or more frequently. Accurate predictions can only be made with detailed, estuary-specific models. Several such models have been developed in South Africa for the determination of the freshwater requirements of estuaries. The experts responsible for these models (Piet Huizinga & Lara van Niekerk, CSIR Environmentek), were thus consulted to give expert opinion as to what extent the estuarine systems considered in Clark *et al.* (2000) and other permanently open estuaries in South Africa would be subject to a change in mouth conditions due to the predicted levels of change in catchment runoff. The results are summarised in Table 6.

Table 6. Major estuaries along the west and south coast, their type, the approximate reduction in flow predicted by Clark *et al.* (2000), and the extent to which this might impact on mouth conditions.

Estuary (West to East)	Estuary type	Flow change	Verdict based on professional opinion
Orange	River mouth (open)		Probably no change
Olifants	Permanently open	-65%	About a 50% chance of closure. A reduction of 80% would close it but 40% reduction would not.
Diep	Temporarily open	-84%	This estuary is kept open by sewerage base flows, so would be unaffected.
Sand	Temporarily open	-60	Will be closed more often.
Bot	Lake (Temporarily open)	-50	Currently breaches only very occasionally. Will become permanently closed.
Klein	Lake (Temporarily open)	-50	Would experience a 50% reduction in open mouth conditions, will not open annually any more.
Heuningnes	Permanently open	-40	Will become temporarily open/closed.
Breede	Permanently open	-43	Will stay open due to rocky mouth and strong tidal conditions
Knysna	Bay	-38	Will not be affected due to the heads at mouth.
Keurbooms	Permanently open		Will definitely close (would do so with -5%)
Gamtoos	Permanently open	-35	Has closed in the past, so definitely will become a temporarily open system
Sundays	Permanently open	-25	May become a temporarily open system
Bushmans	Permanently open		May become a temporarily open system
Kariega	Permanently open		May become a temporarily open system
Great Fish	Permanently open	-20	Will become a temporarily open system
Keiskamma	Permanently open	-10	Will stay open
Bashe	Permanently open	-8	Will stay open

The Country Study was not able to predict impacts on fisheries. However, it has recently been established that estuarine fish catches are strongly linked to the geographic location, size and mouth condition of estuaries (Lamberth & Turpie 2001), and these findings are reworked here in order to estimate the potential impacts of climate change on estuarine and inshore fisheries.

Of the 255 functional estuaries in South Africa, catches have been estimated for about half the estuaries (n = 129): all 9 estuaries on the west coast, 24 out of 52 estuaries on the south coast, 23 out of 54 on the east coast, none of the 67 Transkei estuaries, and all 73 estuaries in KwaZulu-Natal. In terms of biogeographical regions, data exist for all 9 estuaries in the Cool Temperate region, 47 out of 125 in the Warm Temperate region, and 73 out of 121 in the Subtropical region. The relationships between estuarine catches and estuary size, type and biogeographical region were analysed using simple and multivariate models. The best predictive models were obtained by analysing data separately for each biogeographical region. The St Lucia estuary in KwaZulu-Natal, and the Bot and Klein estuaries on the south coast, were excluded from analyses: these are large estuaries in which catches are disproportionately low (in the case of St Lucia this is partly due to exclusion zones).

With the exclusion of the abovementioned estuaries, estuary size alone explains over 80% of the variation in catch in the Warm Temperate region and over 90% of variation in catch in the Cold Temperate and Subtropical regions (Lamberth & Turpie 20001; Fig. 1). The steeper slope in the Cold Temperate region reflects greater productivity in that region as compared with the other two, which have similar slopes.

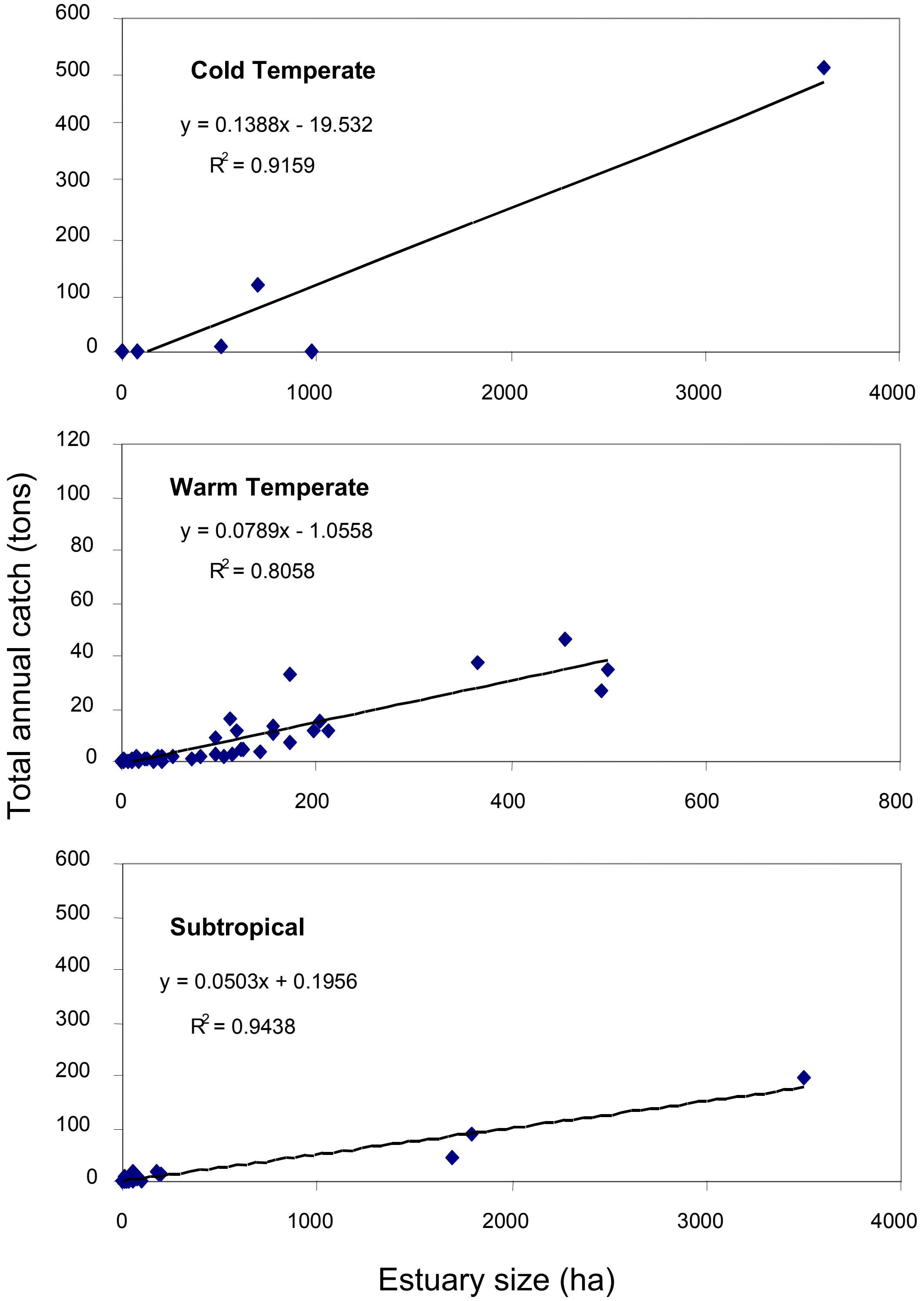


Figure 1. Relationships between estuary size and catch in each of the three biogeographical regions of the South African coast (after Lamberth & Turpie 2001).

Data for the two most common types of estuaries, permanently open and temporarily closed, were then further analysed to examine the effect of estuary type on catches. The slope of the regression between estuary area and catch is steeper for permanently open estuaries (Figure 2), indicating higher productivity of open estuaries.

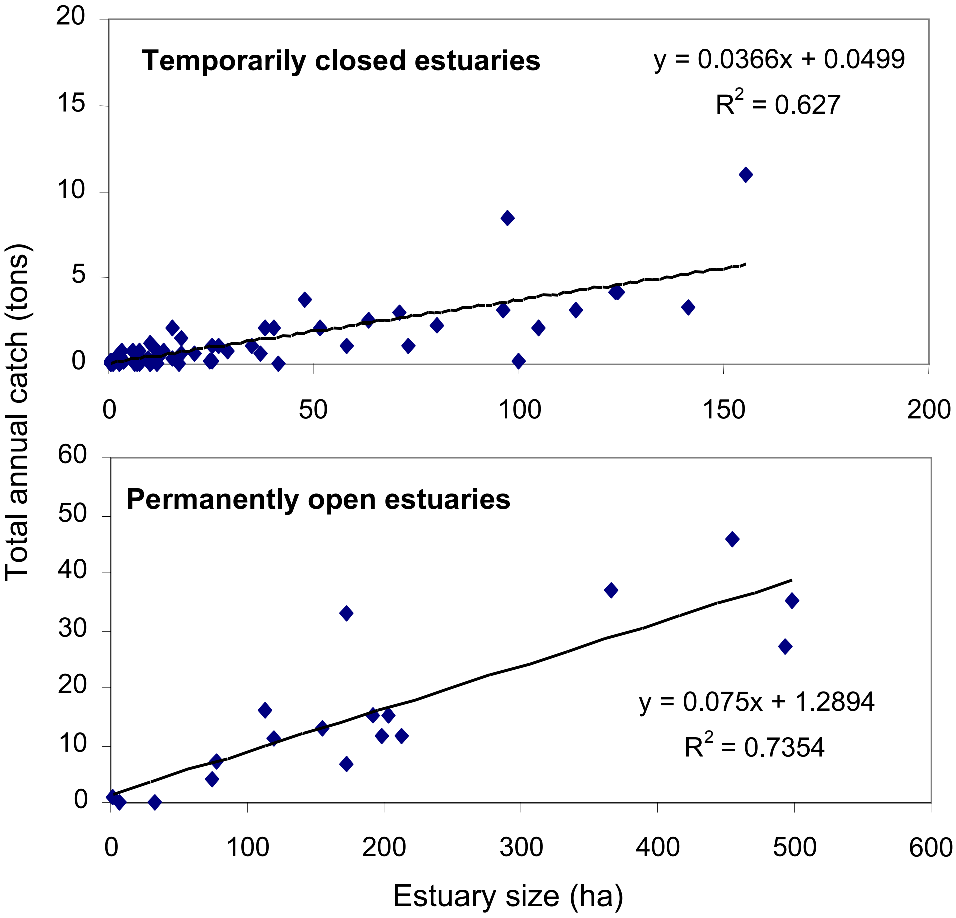


Figure 2. Difference in the relationship between estuary size and catch for permanently open and temporarily closed estuaries in the Warm Temperate and Subtropical regions (after Lamberth & Turpie 2001). The slopes can be compared as the ratios of the x- to y-axis scales are the same.

These variables can be combined in general linear models as follows (Lamberth & Turpie 2001):

Warm Temperate region:

Catch (tons) = 0.904 + 0.068*Size + 2.510 (if Permanently open) ($r = 0.82$, $P < 0.001$)

Subtropical region:

Catch (tons) = -3.461 + 0.055*Size + 8.213 (if Lake) -27.23 (if Bay)

+ 5.605 (if Permanently open) + 10.140 (if River mouth) ($r = 0.98$, $P < 0.001$)

Turpie & Lamberth (2001) used the above models to estimate the total estuarine fish catch in South Africa (Table 7). West coast estuaries have the highest yields per ha, reflecting the generally high fishery productivity of this region, and the high overall catch comes from a small number of large estuaries, mainly the Berg and Olifants estuaries. In KwaZulu-Natal, most of the catch is from Kosi and St. Lucia estuaries.

Table 7. Estimated total catches (tons) per fishery for all estuaries in each of five coastal regions in South Africa.

	Estuaries	Ha	Angling	Castnet	Gill-net	Seine	Traps	Spear	Total	kg/ha
West	9	5 884.0	14.0	2.2	625.0	-	-	-	641.2	109.0
South	52	12 865.9	409.6	31.1	151.6	12.0	-	-	604.3	47.0
East	54	3 763.9	223.5	19.9	51.5	-	-	-	294.8	78.3
Transkei	67	2 611.8	141.1	12.5	32.5	-	-	-	186.1	71.2
KZN	73	46 810.6	245.4	52.4	296.5	72	73	16	755.3	16.1*
TOTAL	155	71 936.2	1033.6	118.1	1157.0	84.0	73.0	16.0	2481.7	34.5

* excluding St Lucia, the average yield for KwaZulu-Natal is 58.1kg/ha

Based on the above findings, it can be shown that a 500 ha temporarily closed estuary would be half as productive as a similar-sized permanently open estuary, and a 20 ha temporarily closed estuary would be less than a third as productive as a similar-sized permanently open estuary (Figure 3). This infers that if a permanently open estuary becomes temporarily closed, a significant change in productivity will occur due to reduction in fish recruitment and a change in estuarine conditions.

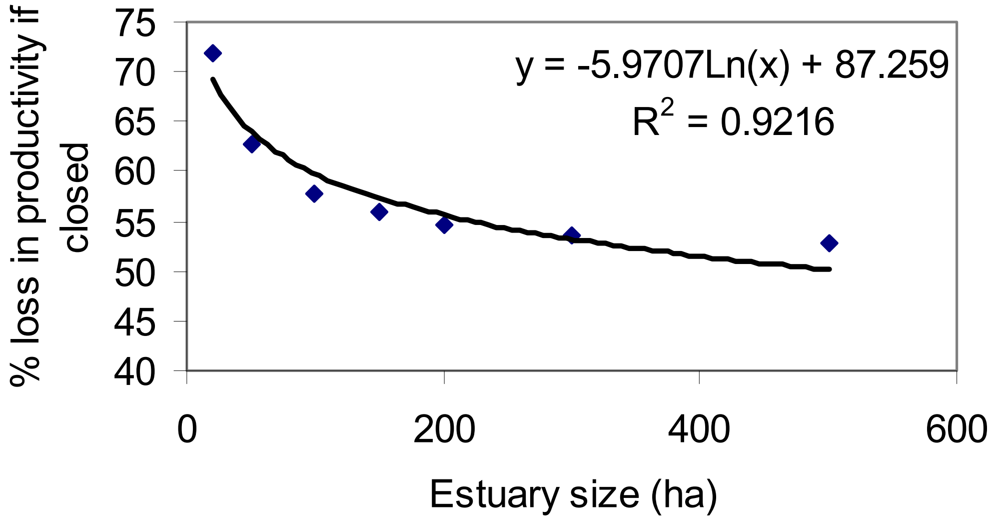


Figure 3. Percentage reduction in estuarine fishery productivity if a permanently open estuary becomes closed, as a function of estuary size. Calculated from data in Lamberth & Turpie (2001).

The above graph describes the reduction in productivity from an estuary that never closes to one that closes for an average amount of time experienced by temporarily closed estuaries, for any given size of estuary. This model was then applied to predict catches given a change in mouth conditions predicted on the basis of the expert opinion regarding future mouth closure (Table 6). According to the latter, almost all estuaries west of the Bashee that are not prevented from closing by a rocky mouth structure such as the Knysna heads, are likely to become temporarily closed systems. It is also assumed that those estuaries that are already temporarily closed systems will close more often, but the relationship between degree of fish production and duration of mouth closure for this type of estuary is unknown due a general lack of data on mouth closure periods for South African estuaries. In extrapolating the above model to predict change in estuarine productivity, we assume that the impact on fish productivity is linearly related to duration of mouth closure, irrespective of timing, although it must be borne in mind that seasonality of closure is an important determinant of productivity. Under these assumptions, the model was applied to all estuaries which were vulnerable to increased closure, including estuaries which are already temporarily closed. The total estuarine fish catch is estimated to be reduced by 35% by 2050, even though there is no reduction in catches from estuaries in the subtropical zone.

The total value of the estuarine fish catch at present is estimated to be R463 million per year (2000 Rands), with 99% of this being the value of recreational angling. At worst, the loss of 35% of estuarine catches might translate to a proportional loss of value, or R162 million per year. However, in reality, the demand for angling is not very sensitive to catch rates, and the loss of value may be somewhat less than this.

In addition to the above fisheries, there is a substantial mariculture industry in South African estuaries, mainly for shellfish. Mariculture will certainly be affected by sea-level rise, however, much of the impact may be positive, in that the area suitable for mariculture in estuaries may increase, and pumping costs of shore based operations might be reduced (Crawford & Barnes 1996). Increased temperature might lead to increased growth rates, increasing mariculture outputs. However, there are no quantitative estimates of this expected change in productivity.

3.3.5 Marine resources

South Africa's marine resources include a large number of vertebrate, invertebrate and plant species exploited along different parts of the entire coastline (all generally referred to as 'fisheries'). On the west coast, the Benguella upwelling system supports a low diversity, but highly productive, fishery sector, while further east, productivity is reduced and the diversity of fisheries is much higher. Large-scale commercial fisheries are concentrated west of Agulhas, mainly on the west coast, while recreational and subsistence fisheries become more intense towards the east. In addition, the mariculture industry produces high-value seafoods, mainly for export. All of these fisheries are likely to be impacted by sea-level rise, increased UV-B radiation, increased air and possibly marine temperatures, altered wind stress and changed advective and convective processes (Crawford & Barnes 1996), as well as changed catchment hydrology.

Because marine ecosystems are so complex to model, no single study has been able to predict the physical impacts of climate change on fisheries. As yet, the ways in which the major commercial fish stocks are influenced by environmental factors are not well understood, not least because these environmental factors are themselves often extremely complex and difficult to model.

It is generally agreed that a temperature increase would lead to a clockwise redistribution of many organisms, such as southward shifts of tropical and subtropical species distributions, and even including shifts of kelp and associated species (e.g. abalone). The spotted grunter *Pomadasys commersonnii*, has already extended its range by a considerable distance over the past decade or so (Lamberth, pers. comm.). Spawning areas for fish populations would shift westward to stay in areas optimal for development of ichthyoplankton (Crawford & Barnes 1986). Increase temperatures may well lead to improved growth rates of many fishery species. However, increased UV radiation may inhibit phytoplankton production, thereby decreasing overall productivity of marine systems (Crawford & Barnes 1996).

3.3.5.1 Offshore fisheries

Wind is a very important factor in bringing nutrients to the productive west coast Benguella system, and is thus the single most important factor determining the abundance of many of the most important commercial fish stocks as well as ecosystem functioning. However there is currently no agreement as to how wind patterns may change. Should the offshore winds on the west coast increase slightly, productivity may increase (Verheye 2000). However, there is an upper threshold beyond which any further increase in wind would be expected to interfere with current ecosystem processes to the detriment of the productivity of the system. The lack of ability to predict the change in wind strength is a critical factor which prevents estimation of the impacts on the offshore pelagic and demersal fisheries, which are the most valuable commercial fisheries. Declining zooplankton populations on the east coast are a cause for concern.

3.3.5.2 Inshore fisheries

Inshore fisheries could potentially be impacted by climate change in a number of different ways. These include changes in productivity due to changes in temperature and circulation, and changes in productivity due to change in estuary inputs. The former is difficult to estimate given the current level of information.

Inshore fisheries include major valuable fisheries such as rock lobster and abalone. These species have already been found to be highly vulnerable to environmental changes, either directly, in the case of rock lobster, or indirectly, in the case of abalone which is affected by a change in rocklobster distribution. However, the future possible catches of these species have not been modelled under climate change scenarios, and are complex to estimate.

Although the Country Study does not provide predictions on fishery effects, some effects can be predicted on the basis of changes in estuary functioning. In particular, we provide a rough estimates of the impact of changes in inshore fish productivity due to a change in estuarine functioning, since an estimate of the contribution of estuarine fishes to inshore catches has already been made (Lamberth & Turpie 2001).

Inshore or coastal fish resources are targeted by recreational shore and boat angling, recreational spearfishing, commercial boat-based linefishing and commercial gillnet and beach-seine netting fisheries. The total inshore marine fish catch is estimated to be 28 107 tons per year (Lamberth & Turpie 2001), of which 60% is by the commercial linefish sector, 23% by the commercial net fisheries, and the remainder by recreational fishers. More than half of the catch (53%) is taken on the west coast, which is predominantly commercial, while recreational anglers increase in predominance eastwards around the coast.

Numerous estuary-associated species have been recorded in all types of inshore marine fisheries. Indeed, recreational shore-angler catches and commercial gill- and seine-net catches are dominated by estuary associated species (83% of both numbers and mass), whereas they make up only about 7% of boat-based and spearfishing catches. As pointed out in the above discussion, estuary associated species are likely to be impacted by changes to estuarine ecosystems effected by reduced freshwater runoff from their catchments. The degree to which this may affect recruitment of fish into inshore marine fisheries, depends on the degree of estuarine dependence of the fishes involved. Not all estuary-associated fishes would be affected, but those with high dependence on estuaries are likely to be strongly affected by an increase in mouth closure. Indeed, some species are only able to utilise permanently open estuaries for breeding. Estuarine fish species have been classified into five different degrees of dependence on estuaries (Table 8).

Table 8. The five major categories and subcategories of fishes which utilise southern African estuaries (Whitfield 1994).

Category	Description
I	Estuarine species which breed in southern African estuaries. Ia. Resident species which have not been recorded spawning in marine or freshwater environments. Ib. Resident species which also have marine or freshwater breeding populations.
II	Euryhaline marine species which usually breed at sea with the juveniles showing varying degrees of dependence on southern African estuaries. IIa. Juveniles dependent on estuaries as nursery areas. IIb. Juveniles occur mainly in estuaries, but are also found at sea. IIc. Juveniles occur in estuaries but are usually more abundant at sea.
III	Marine species which occur in estuaries in small numbers but are not dependent on these systems.
IV	Freshwater species, whose penetration into estuaries is determined primarily by salinity tolerance. This category includes some species which may breed in both freshwater and estuarine systems.
V	Catadromous species which use estuaries as transit routes between the marine and freshwater environments but may also occupy estuaries in certain regions. Va. Obligate catadromous species which require a freshwater phase in their development. Vb. Facultative catadromous species which do not require a freshwater phase in their development

Category I species, which are largely resident in estuaries, hardly feature at all in inshore marine catches. Category IIa species, which are entirely dependent on estuaries, generally make up a relatively small percentage of catches – 4-6% of commercial catches and up to 7% of recreational catches, although they are locally important in certain regions. The majority of estuary-associated fish biomass is made up of category IIc species, which make up 64% of the recreational shore fishery, although only a small portion of other fisheries. Category III species make up over 10% of shore-angling catches and 4-5% of boat-based recreational and spearfishing catches, but barely feature in commercial catches (Lamberth & Turpie 2001). Category IV and V are not of significance for this study.

The total value of all inshore marine fisheries is estimated to be R2 389 million per year. Approximately 21% of this value is derived from estuaries (Table 9), although a much larger percentage is made up of estuarine associated fish.

Under the climate change scenario described for estuaries, there would be a massive drop in recruitment of category II species west of the Bashee estuary. In most cases the increased closure of estuaries is likely to impinge directly on the recruitment period for estuarine depended fishes. Even for estuaries that remain open during this time, significant reductions in freshwater inflow mean reductions in freshwater inputs into the marine inshore zone, a factor which is essential in providing cues for the recruitment of juveniles into estuaries. For the Breede estuary, which will not close under climate change conditions, major losses in freshwater inflow are predicted to have a major impact on estuarine-dependent fishes, particularly commercially-important species such as Kob *Argyrosomus japonicus* (Cateogory IIa) whose numbers are likely to be halved (Lamberth 2001).

Taking into account the contribution made by permanently open estuaries that will not close, it is estimated that the current catch that is attributed to estuaries would be reduced by some 90% (S.J. Lamberth, MCM, pers. comm.). This translates to an overall loss of 18% of the current value of inshore fisheries, or R441 million per year (Table 9).

Table 9. Estimated value of different sectors of the inshore marine fishery in South Africa, the percentage and actual contribution to this value by category II species, assuming 100%, 90% and 30% dependence on estuaries by category IIa, IIb and IIc fishes, and the estimated value of losses (R millions) incurred under the climate change scenario described for estuaries, above (based on Lamberth & Turpie 2001).

%	Total regional fishery value (R millions)	IIa	IIb	IIc	Contribution from estuaries	% value	Value lost under climate change
Recreational shore							
W. Coast	105.70	0.60	0.03	18.05	6.39	6.0%	5.75
S. Coast	825.70	7.29	0.29	38.32	157.29	19.0%	141.56
E. Coast	513.00	16.25	1.13	46.15	159.63	31.1%	143.67
S. Transkei	87.25	23.22	0.89	36.65	30.55	35.0%	27.50
KZN	233.29	11.47	4.46	69.15	84.50	36.2%	76.05
Total	1764.93	11.42	1.09	43.05	438.36	25.3%	394.53
Recreational boat							
W. Coast	112.06	0.00	0.00	0.39	0.13	0.1%	0.12
S. Coast	14.48	0.37	0.00	3.77	0.22	1.5%	0.20
E. Coast	0.88		0.02	1.66	0.00	0.5%	0.00
KZN	0.58			1.08	0.00	0.3%	0.00
Total	128.00	0.04	0.00	0.79	0.36	0.3%	0.32
Recreational spear							
W. Coast	7.24	0.12		0.06	0.01	0.1%	0.01
S & E Coast	43.23	0.19		0.41	0.13	0.3%	0.12
KZN	18.30	4.79	0.44		0.95	5.2%	0.85
Total	68.77	0.53	0.03	0.34	1.09	0.7%	0.98
Commercial boat							
W. Coast	188.89	0.04	0.00	0.78	0.53	0.3%	0.47
S. Coast	82.09	11.09	0.00	2.50	9.72	11.8%	8.75
E. Coast	86.00	36.52	0.01	0.16	31.45	36.6%	28.31
KZN	50.64	7.09	0.04	0.21	3.64	7.2%	3.28
Total	407.62	11.05	0.00	0.97	45.34	11.3%	40.81
Seine & gillnet							
W. Coast	11.92	3.89	0.02	72.90	3.07	25.8%	2.76
S. Coast	7.49	10.99	0.01	46.25	1.86	24.9%	1.68
E. Coast	0.41	9.12	0.50	90.04	0.15	36.6%	0.14
KZN	0.25	57.48	2.70	25.15	0.17	67.5%	0.15
Total	20.07	7.30	0.06	62.72	5.25	26.2%	4.73
Overall							
TOTAL	2389.39				490.41		441.37
% fishery value					21%		18%

3.4 Impacts on tourism

Until recently, tourism played a relatively small role in the economy of South Africa, with an estimated value added to GDP of no more than 2% in 1994. Nevertheless, about 7.9 million domestic tourists who took 17 m trips in 1994. International tourism changed dramatically since the change of government in 1994. In 1995 an estimated 4.48m people visited South Africa, providing the fourth largest source of foreign exchange in the country. Tourism was estimated to contribute 4% to GDP in 1995, contributing 480 000 jobs directly or indirectly (DEAT 1996). Since then, tourism has continued to grow towards the global average of about 10.5% of world GDP. The South Africa Foundation (www.tradeport.org) estimates that by 1998, tourism's direct contribution to GDP, arising from spending on goods and services in the tourism industry, came to R44.3 billion, and provided 615 375 jobs. However, the multiplier effect contributed another R36.3 billion and 504 246 jobs. In total, tourism was responsible for R80.6 billion or 10.9% of GDP and supported 1.12 million jobs in the formal sector. By 1999, the direct contribution from tourism (domestic and international) was estimated to be R53.2 billion, and the direct contribution of the country's 5.7 million visitors to GDP in 2000 (which was R873.637 billion - SARB) was estimated to be 5% - implying R43.7 billion (KwaZulu-Natal Tourism Authority 2001 - www.kzn.org.za). Thus, including multiplier effects, it is assumed that the contribution to tourism is still in the region of 10.9%.

Tourism activities in South Africa may be impacted by climate change in three main ways:

- Change in supply due to loss of habitat (e.g. estuaries, coastal resorts);
- Change in supply & demand due to loss of biodiversity (e.g. loss of species from Kruger National Park); and
- Change in demand due to increase in temperature, humidity and malaria.

Thus, in order to estimate the impacts of climate change on tourism and recreational values, it is necessary to understand these supply and demand functions. This kind of comprehensive analysis has yet to be carried out in South Africa, but various studies and reports, as well as common sense, provide some idea as to the possible magnitude of these impacts.

South Africa's resource base for tourism is considered phenomenal, with its attractiveness lying in its diversity (DEAT 1996). Accessible wildlife, varied and impressive scenery, unspoiled wilderness areas, diverse cultures and a warm climate were the first of a long list of attractions listed by the government's White Paper on tourism (DEAT 1996), and several other biodiversity features appear in the rest of the list. Indeed, wildlife (36% of visitors) and scenic beauty (33% of visitors) are the most important and enduring factors that motivate international tourists to visit South Africa, and even greater numbers rate these features as top when leaving the country (SATOUR - www.satour.com). In addition, among the country's 33 million domestic trips by 14.7 million people, which account for an expenditure of some R9 753 million, approximately 5 million trips are taken by the game-and-bush lovers segment, and another 4.8 million by 'upmarket campers' who enjoy outdoor attractions.

Climate change, through its impact on natural habitats and biodiversity, thus threatens to damage some of South Africa's primary tourist attractions, and given the importance of tourism to the national economy, could have a significant impact on the country's GDP and foreign exchange. It is extremely difficult to estimate the actual contribution of biodiversity to tourism value, since visitors are often attracted by multiple features of their destinations. There is as yet no published quantitative work on the demand for biodiversity which would allow an estimate of the marginal tourism value of biodiversity, although such work is in progress, and estimates may be possible in future. A recent survey in Hluhluwe, which might be expected to experience similar losses, estimates that the diversity of species *per se* contributes 16% of the recreational value of the park and that the demand for tourism would be reduced by a reduction in overall species numbers, and particularly by the loss of charismatic species. The South African Country Study estimates that Kruger National Park stands to lose an enormous percentage of its species. However, even with accurate demand models, the predictions of species losses in the country study are not sufficiently accurate to attempt a quantitative estimate of the impact on tourism.

The escalation of health risks such as malaria as a result of climate change are also likely to have significant impacts on the tourism trade. The incidence of malaria in South Africa has increased dramatically in the past decade, and the impact of this on tourism is strongly visible. Tourists are increasingly opting to travel to malaria-free areas such as the Eastern Cape province for game viewing, despite the absence of very large parks there, and this increasing demand for wildlife tourism is resulting in the establishment of increasing numbers of private game reserves in that part of the country. As the risk of malaria expands into these areas under climate change, so one can expect to see tourist seeking their nature experiences elsewhere, perhaps even on other continents such as Australasia.

The estimation of tourism impacts is particularly difficult as it has to be done in a global context and bearing in mind the fickle nature of tourism tastes and preferences at a global scale. If South Africa suffered severe losses to its biodiversity in isolation, it would certainly lose a major proportion of tourists attracted by natural features. However, the loss of habitats and species is likely to occur all over the world, and to affect most countries that offer this type of tourism. The latter countries, which include South Africa, may well lose tourists to developed countries which offer other attractions. Nevertheless, it is the amount of biodiversity and associated scenery that South Africa retains relative to other countries that will be important here. The nature-based tourism market, like any tourism market, is fickle, and moves readily to alternative destinations when conditions change.

Accurate predictions cannot be distilled from existing knowledge of the South African tourism industry, and future studies should address this issue. However, it is clear that the magnitude of the potential loss in tourism value is great. South Africa stands to lose income from a sector which contributes 5% directly to GDP, and possibly as much as 10% when its contributions to other sectors are taken into account. With wildlife being the primary reason for visiting of at least 36% of tourists, this means that up to 3.6% of GDP or R26.2 billion, is at stake, and based on preliminary understanding of the contribution of biodiversity to tourism values, this loss would probably be at least R4 billion per year.

3.5 Impacts on option and existence value

3.5.1 Introduction to the case study

In addition to the largely tangible values cited above, the loss of ecosystem functioning and biodiversity can have a negative impact on people's welfare in terms of a loss of option or existence value. Option values include the potential development of new, as yet unknown, products from biodiversity. This value is particularly difficult to measure, although some researchers have attempted to assign values to rare species on the basis of the probability of a species being found to be useful for some purpose, such as development of new medicines. These measures tend to be from developed countries, and there is really no reliable way in which one could attach this type of option value to South Africa's biodiversity without much more thorough research. Option value, in the sense of people wanting to retain the option to enjoy or utilise biodiversity in future, is closely linked to existence value, and the two are often considered together in stated preference surveys. This study on the economic impacts of climate change in South Africa, although otherwise a desk-top study, included a case study to estimate the existence value of the biodiversity at risk of loss due to climate change. The results of the study are summarised very briefly below, and the full details are found in a separate report (Turpie 2002).

The case study aimed to establish to what extent South Africans are aware of and interested in biodiversity, and to estimate the existence value of South African biodiversity and of the biodiversity threatened by climate change, in monetary terms. A questionnaire survey methodology was used, in which Contingent Valuation Methods (CVM) were used to estimate existence value. The questionnaire began with questions about awareness and interest in biodiversity, before moving onto three willingness to pay questions. The first was an open ended question which considered willingness to pay for conservation in South Africa as a whole, and how that should be allocated among different areas. The second was a referendum question in which respondents were introduced to the climate change problem and asked to choose different alternative payment options to prevent the effects. The third was an open ended question on the same issue.

A total of 814 residents of the Western Cape were interviewed. The sample was compared with estimates of the 2001 targeted population (income earning households) and was found to be representative in terms of Capetonian *versus* the rest of the province, and in terms of racial breakdown and income groups.

3.5.2 Public awareness, experience and interest in nature

Interest and awareness of nature was relatively high, with half of respondents having visited at least one national park and 8% belonging to a nature-related club. Only 10% of respondents said they had no interest in nature, while 39% and 36% said they had a passive or active interest, respectively, and 15% said they were passionately interested. Interest in nature was positively related to income category, and there was a highly significant relationship between the probability of having visited a national park and household income.

Knowledge of the Fynbos Biome, which dominates the Western Province, was also investigated. 72% of respondents had heard of fynbos, but less than half could recognise it and much fewer could identify species or vegetation types. Level of knowledge differed between race groups, with only 45% of black respondents having heard of fynbos, as compared with 81% of coloured and 91% of white respondents. When respondents who had heard of fynbos were asked to estimate how many species were contained in this, the world's most species-rich terrestrial biome, only 1.2% of respondents got within 15% of the correct answer and .6% within 50% of the answer. 75% of respondents were out by an order of magnitude, with most grossly underestimating the number of species.

3.5.3 Willingness to pay for conservation of different biomes: a Western Cape perspective

Most (76%) of respondents were willing to pay towards biodiversity conservation in South Africa. The amount offered was strongly correlated to both monthly income and level of interest. The overall mean willingness to pay (WTP) was R211 per year. The total WTP, representing at least part of the existence value of South African biodiversity, was R224 million per year for Western Cape residents, and if extrapolated, could indicate a total WTP for RSA of about R1.5 billion per year. 39% was allocated to fynbos, 19% to marine areas and 15% to the fynbos biome, with roughly 7% being allocated to each of the grassland, savanna, nama karoo and succulent karoo biomes. Thus WTP for conservation of fynbos was estimated to be about R88 million per year.

3.5.4 Reaction to predictions and existence value of threatened biota

Most respondents indicated that they would visit Western Cape reserves, namely the West Coast National Park, De Hoop Nature Reserve and the Cedarberg Wilderness Area, slightly less if the vegetation had to become desertified, but nearly a quarter said it would make no difference. Yet when shown the map of predicted shrinkages of existing biomes under climate change by 2050, 60% of respondents claimed to be very disturbed by the prospect and only 8% said they were not at all concerned. Many of the latter group were sceptical of the predictions, but the majority were simply not interested in nature. Some 76% of respondents said they were in favour of a policy to reduce the impacts of climate change by passing external costs onto consumers. These respondents were asked to select among three options involving different levels of prevention of loss of vegetation at different prices, and with different price levels being spread among 5 different versions of the questionnaire.

The results, analysed using a logit model, suggested an overall willingness to pay to prevent the loss of vegetation in the region of R367 per annum. The results of the similar open-ended question yielded a very similar result of R374 per annum. Total existence value of the biodiversity threatened by climate change was thus estimated to be R393 million per year to Western Cape households, and R2.63 billion per year to South Africans. This is a more complete estimate of the existence value of the biodiversity threatened by climate change than the stated WTP (above) for nature conservation alone.

The estimates gained in this way were almost double those obtained by asking about WTP for conservation, as it includes the possibility of totally losing the vegetation, a scenario which had previously probably not entered the respondents' minds. However, the first line of questioning was necessary in order to establish the relative value of different vegetation types. Thus, the corresponding value of fynbos is estimated to be at least R153 million per year.

Full details are given in Turpie (2002).

3.6 Summary of market and non-market impacts

The impacts described above are summarised in qualitative terms in Table 10. The market impacts of grazing are described in the following chapter.

Table 10. Summary market and non-market impacts of consumptive and non-consumptive use losses that might be expected as a result of loss of different types of biomes or habitats.

Biome/habitat	**Market Impacts**			**Non-Market impacts**	
	Harvested products	Grazing	Nature-based tourism	Harvested products	Grazing
Fynbos	Moderate: Flowers, buchu, thatch, etc	Very little	High	Very little	None
Forest	High: Timber, ferns, etc	None	High	High: Timber, poles, food, medicinal plants, etc	None
Savanna	Very little	High	High	High: Timber, poles, food, medicinal plants, etc	High
Nama Karoo	Very little	High	Low	Moderate: Firewood, medicinal plants, etc	Moderate
Succulent Karoo	Very little	High	Moderate	Moderate: Firewood, medicinal plants, etc	Moderate
Grassland	None	High	Moderate	Very little	High
Rivers & Wetlands	Very little	Moderate - high	Moderate	High: Reeds, fish, etc	Moderate
Estuaries	Very little	None	High	High: Reeds, fish, bait, etc	Some
Marine	High	None	Localised	High: Reeds, fish, bait, etc	Some

4. Rangelands

Harald Winkler

Livestock production is dependent on the net primary productivity (NPP) of vegetation on the rangelands. A simple estimate of the damages from climate change translates changes in NPP into lost production of livestock, under the assumption that an estimate incorporating higher input costs to maintain current production levels would lead to a similar change in net value.

Direct impacts of climate change on animals are likely to include increasing heat stress and water requirement, though these have not been estimated. A positive direct impact of increasing temperatures will be to reduce stock losses through extreme low temperatures in the lambing season in the Nama- and Succulent Karoo rangeland areas. Since the biophysical impacts have not been quantified, they cannot be valued in this study.

4.1 Impacts on NPP and value of lost animal production

Impacts on NPP are sensitive to the ameliorating effect of rising atmospheric CO_2 on the potential reduction of NPP by water stress. This effect is a major unknown, but is likely to be correlated with existing vegetation cover. In the sparse vegetation of the western half of the country, for example, the effect is likely to be minimal, and it would tend to increase with increasing leaf area index towards the east.

A worst case scenario assumes no ameliorating CO_2 effect, and a best case scenario assumes an effect which has been recorded in greenhouse trials. Studies of the effect under field conditions are needed to reduce uncertainty. As Table 11 shows, the impact on NPP in semi-arid sweet grassland ranges from a large reduction of NPP (almost halving) without the CO_2 effect, to a modest positive impact with the effect.

The western part of the country stands to lose NPP and animal production in the absence of a CO_2 fertilising effect. The effect of climate change alone in the east is to increase NPP, probably because of the increasing air and soil temperatures that improve herbaceous plant growth rates, and increase the supply of soil nitrogen for several decades through organic matter mineralization. The CO_2 amelioration effect strongly counteracts increasing aridity in the western parts of the country – but this is unlikely to be effective in mixed grass / shrublands of the semi-arid Karoo region, and significant NPP losses can be expected there.

Table 11. Changes in Net Primary Productivity for different biomes and value of national lost animal production

Site	*Biome*	*Biome as percentage of total*	*Change in NPP*		*Change in value of national animal production in R million per year*	
			without CO_2 effect	*with CO_2 effect*	*without CO_2 effect*	*with CO_2 effect*
Bloemfontein	Semi-arid sweet grassland	4.6%	-45%	8%	-420	75
Pietermaritzburg	Mesic, sour grassland	13.7%	-5%	2%	-139	56
Nylsvley	Savanna, mixed grass and woodland	17.6%	21%	34%	750	1 214
TOTAL					191	1 344

Sources: Changes in NPP from Midgley (2001), value of animal production (NDA 2000: 84), biome percentages (Low & Rebelo 1996; CSIR 1999)

A simple estimate of the impact of NPP is to assume that changes in NPP translate into loss of production of livestock. Total animal production in 1999 was R47 087 million when adjusted to 2000 Rands (NDA 2000: 84). The predicted changes in NPP for different biomes with and without the CO_2 fertilisation effect are shown in Table 11. It should be noted that sheep rangelands are not included in this estimate (Namakaroo and succulent karoo shrublands, ~ 26% of the country), since no changes in NPP were available. These rangelands are likely to be most negatively affected, due to high levels of drying, and no CO_2 boost.

A first-order estimate of the value of these damages is simply to relate the value of total animal production directly to the changes in NPP, adjusted for the percentage of the biome as a total of vegetation land-cover. The value of these changes is indeterminate, ranging from a loss of R420 million to a benefit of R1 214 million. Results differ by region and are highly sensitive to the CO_2 effect. On aggregate, however, a modest benefit ranging between R191 million to R1 344 million is likely for rangelands.

4.2 Damages to national cattle herd

The Country Study predicts an overall negative impact on the national cattle herd, which is less indeterminate that the impacts through NPP. All in all, and taking the CO_2 effect into account, a modest decrease in the size of the national free range cattle herd (roughly 10%) is predicted (Midgley 2001). The gross value of cattle and calves slaughtered in 1998/99 was R 3 287 million in 2000 Rands, so that a 10% decrease would have a gross value of R329 million per year. However, this must be adjusted to a measure of gross margin, since gross value does not take into account allocatable costs. Gross margins vary between 30% to 60% of the gross income (DoA: FS 1996), so assuming that gross margin is half of gross income, a simple estimate of the value of climate damages to the cattle herd would be R164 million per year (within a range of approximately R100 million to R200 million).

5. Agricultural crops

Harald Winkler

5.1 Introduction

Climate change has projected impacts on the yield of various agricultural crops and on the productivity of rangeland. The Country Study provides estimates of changes in crop yield by 2050 for some crops, while animal production on rangelands is affected by changes in Net Primary Production (NPP) (Midgley 2001). The value of this lost production reflects the potential damages from climate change.

Of the total land area of South Africa of 122.3 million hectares, 13.7 % is potentially arable, (16.7 million ha), 68.6% is grazing land (83.9 million ha), 9.6% protected by nature conservation (11.8 million ha), 1.2% under forestry (1.4 million ha) and 6.9% used for other purposes. Of the arable portion, 2.5 million hectares is in the former homelands and 14.2 million is farmed by commercial agriculture. 9.5 million hectares are used for field crops (NDA 2000: 5-6).

Agricultural statistics divide production into field crops, horticulture and animal products. The relative contribution of these three sectors to the overall gross value is shown in Figure 4. These numbers should be understood in the context of agriculture declining as a contributor to Gross Domestic Product (GDP). In 1998, agriculture and forestry contributed 4.0% of GDP, significantly lower than in 1965 at 9.1% (NDA 2000).

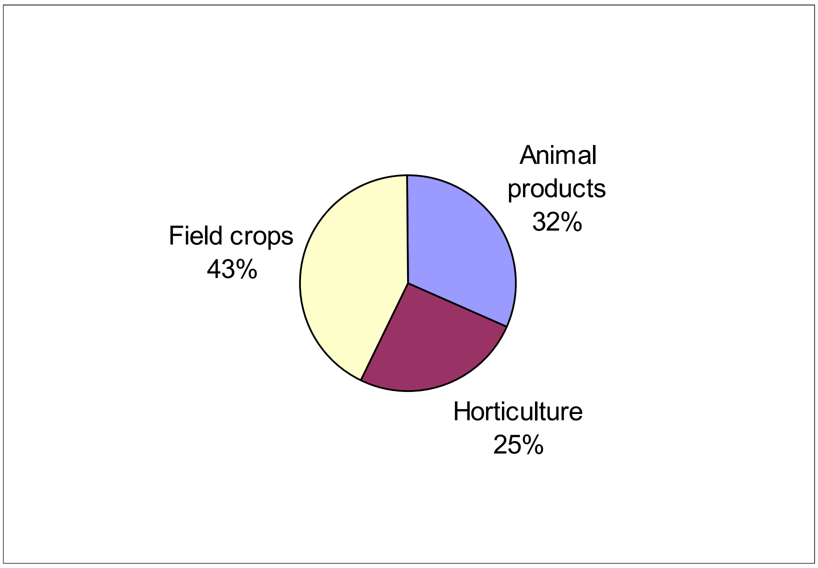


Figure 4. Gross value of agriculture by component, 1998/99

Source: Data from (NDA 2000: 85)

Field crops in turn are dominated by maize at 36% and sugar cane at 20% of gross value, as shown in Figure 5. Our analysis begins with maize, the largest field crop, for which climate impacts were extensively modelled in the Vulnerability & Adaptation study (Du Toit *et al.* 2000).

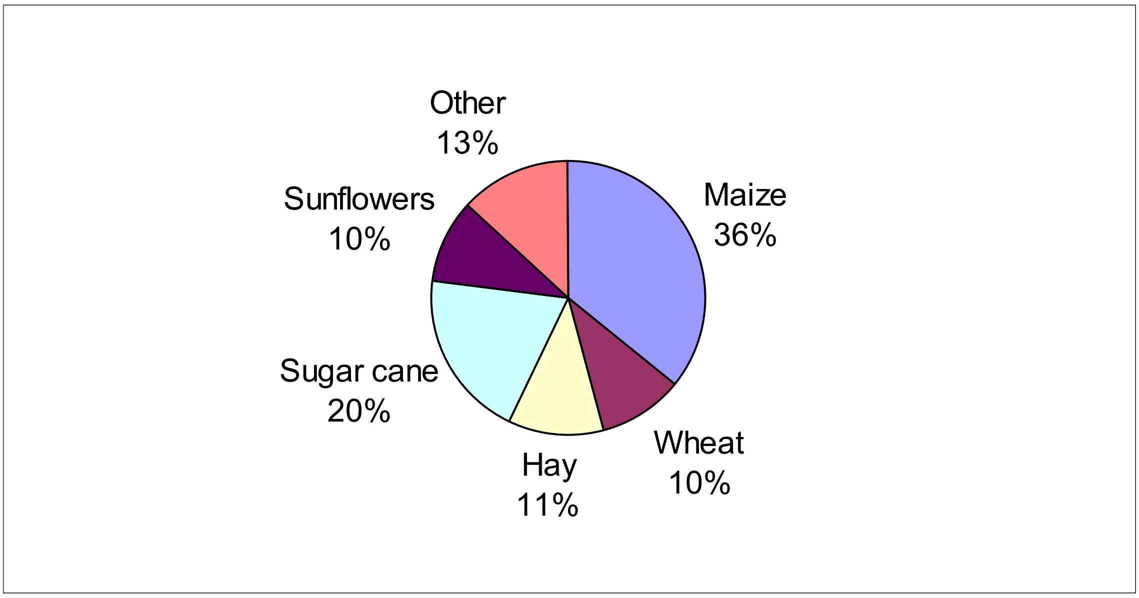


Figure 5. Major field crops contributing to gross value

Source: Data from (NDA 2000)

5.2 Maize

Total maize production varies strongly with changing weather conditions, with a low of 3.3 Mt in 1991/2 and a high of 14.8 Mt in 1980/1 (NDA 2000). Production in the 1997-8 and 1998-9 was fairly constant. The estimated planting area for 2000 was 3 205 million hectares[1], an increase of 300 300 hectares from the previous year (RSA 1999: 2). At a yield between 2.6 and 2.8 tons per hectare, total production was estimated to be between 8.3 and 8.9 million tons (RSA 1999: 2). The gross income from maize in 1999 was R4 966 million (RSA 1999: 4), which adjusted by the index for production prices of the Reserve Bank translates to R 5 155 million in 2000 values (SARB 2001).

Part of this valuable crop might be lost due to climate change. On the other hand, crop yields might increase if the CO_2 fertilisation effect is strong. For this analysis, predicted losses (or increases) of crops are derived using climate projections from the H2n model. This General Circulation Model (GCM) is considered a leading edge model among the GCMs developed globally. one of the most reliable of the GCMs available. We choose the run of the Hadley model without sulfates (H2n as distinct from the H2s version), since the sulfate effect is relatively short-lived.

The impacts on agricultural crops are sensitive to the much-debated CO_2 fertilisation effect, which indicates that plants may become more productive at enhanced levels of CO_2. CO_2 fertilisation tends to increase crop yield and increase water use efficiency, as increased CO_2 reduces water release by leaf stomata, and can increase carbon assimilation rates. However, these effects have not yet been quantified for maize grown under South African field conditions, and it is possible that the CO_2 fertilisation effect saturates at certain temperatures. Using a

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[1] Total area planted is not consistent with that reported in other NDA statistics, which give the total area planted to maize in 1998/99 was 3.491 million hectares, producing a total of 7.720 million tons of maize with a gross value of R5 148 million (NDA 2000: 7). Using the figures above, total area planted in 1999 would have been 2 .905 million ha (RSA 1999). We use the lower figure to be conservative in our valuation estimates, and because the source is more recent.

sophisticated hydrological and production model, the Country Study suggests that with the fertilization effect, maize production may be largely unaffected, while without it, an average decrease of 10-20% is expected (Du Toit *et al.* 2000; Midgley 2001). We compare results with and without this effect.These averages, however, do not significantly alter impacts in different parts of the maize-producing regions.

Maize is grown in two main zones, a marginal western belt, and a reliable and higher productivity eastern core. Much of the marginal western belt may become unsuitable for maize production with a decrease in rainfall and soil moisture (Midgley 2001). Table 12 shows the 19 districts for which the Country Study identified changes in crop yield. The current crop yield is given together with the predicted changes in yield with and without the CO_2 fertilisation effect.

Table 12. Changes in maize yield in 19 district projected by the H2n model by 2050, with and without CO_2 fertilisation effect

Source: Data from Vulnerability and Adaptation study (Du Toit et al. 2000)

District	*Planting date*	*Present yield*	*Yield in 2050 (H2n)*		*Yield % change H2n*	
			no fertilisation effect	*With CO_2 fertilisation effect*	*no fertilisation effect*	*with CO_2 fertilisation effect*
		Kg/ha	*kg/ha*	*kg/ha*	*%*	*%*
Bethlehem	late	5 796	4 161	5 240	-28%	-10%
Bethal	late	6 294	4 754	5 419	-24%	-14%
Bloekomspruit	early	3 489	2 265	2 964	-35%	-15%
Bultfontein	late	1 545	837	1 598	-46%	3%
Cedara	early	6 735	4 280	5 367	-36%	-20%
Ermelo	early	5 188	4 832	6 001	-7%	16%
Glen	late	2 625	2 310	3 205	-12%	22%
Greytown	late	6 739	4 819	5 627	-28%	-17%
Koppies	early	2 486	1 551	2 242	-38%	-10%
Kroonstad	early	3 333	2 030	2 739	-39%	-18%
Lichtenburg	early	3 923	2 510	3 424	-36%	-13%
Petit	early	6 730	4 435	5 854	-34%	-13%
Petrusberg	late	2 903	2 118	2 935	-27%	1%
Ottosdal	early	4 305	2 996	3 887	-30%	-10%
Potchefstroom	late	4 102	2 590	3 258	-37%	-21%
Setlagole	late	2 381	1 791	2 345	-25%	-2%
Viljoenskroon	late	3 644	2 251	3 111	-38%	-15%
Wesselsbron	late	2 835	1 948	3 077	-31%	9%
Wolmaranstad	early	1 821	1 173	1 613	-36%	-11%

Some sites reported both early and late planting dates. We assumed that the current planting date with the higher yield was the current practice, in other words that farmers time planting for optimum yield.

To estimate the total damages based on these 19 sites, we needed to aggregate from these local sites to the total planting area for maize. This was done geographically, with the areas of districts closest to the sites being attributed to the site, the site area calculated as a percentage of the total area per province, and converted to a proportional share of the total maize planting area (NDA 2000: 9) in that province. The simplifying assumption is that the entire maize area is like the 19 study sites, for which the Country Study models predictions for changes in maize yield in 2050.

Using the planting area, the total tonnage of production lost (or gained) could be calculated for each of the 19 'sites'. To estimate the value of crop production, we used the gross margin as the best estimate of production at or near each site. The Combud Enterprise Budgets of the provincial departments of agriculture (DoA: FS 1996; DoA: KZN 1996; DoA: NW 1996) define gross margin as the difference between Gross Production Value and directly allocatable costs. In other words, variable costs that can be easily determined from simple records are deducted from gross income of the farm. Variable costs may include, for example, fertiliser, chemicals, temporary (seasonal) labour, contract work, etc. Regular labour, which is sometimes considered a fixed cost, is also included here and deducted. The Combud budgets report gross margins both in R/ha and in R/ton; we use the latter since the yield per hectare is expected to vary with climate change. An average gross margin was assumed stations for which no gross margins could be found, either in Combud reports or from local experts[2]. Gross margin gives a better picture of the value of (lost) production than a simple selling or export price, since costs are deducted. Finally, the gross margin (R/ton) multiplied by the total production lost (or gained) provided the value of the climate change damages from crop loss.

Table 13 shows significant variation in the losses / gains in maize production due to climate change impacts. Results range from a loss of –R77 million for the year in Lichtenburg without the CO_2 fertilisation effect, to a gain of R143 million in Ermelo with the CO_2 effect. Ermelo exemplifies the sensitivity of results to the CO_2 fertilisation effect, with the gain cited turning into a –R51 million loss without the effect. Bultfontein, Glen, Petrusberg and Wesselsbron also change sign (from a loss to a gain) due to inclusion of the CO_2 fertilisation effect.

Overall, the total value of lost maize production due to climate change impacts is –R681 million in current Rands without the CO_2 fertilisation effect, but a considerably smaller loss at –R46 million with the effect. Over the 19 sites modelled in the Country Study, however, the balance shows a loss of 10s to 100s of millions of Rands.

The estimates of changes calculated may be argued to be conservative in so far as they do not take into account areas that are completely taken out of production. Below some threshold return, farmers would presumably stop production entirely. However, when reducing the gross margins for each area by the percentage of lost yield predicted for 2050, none of the areas show a gross margin below R85/ton. This value is the lowest gross margin for maize reported in the 1996 Combud reports (DoA: FS 1996; DoA: KZN 1996; DoA: NW 1996), adjusted to 2000 Rands.

Establishing a more precise threshold for each area would be complex and would require a separate study. Even without climate change, when an area becomes marginal depends on a number of factors determining yield potential (climate variability, soil , efficiency of the farms, rainfall), and changes to production costs (e.g. distance to market, transport costs), but also just exogenous changes. Several of these factors (e.g. soil moisture, rainfall) are expected to change with climate change, making the threshold a changing value. Calculating a more precise threshold and associated losses is beyond the scope of this study.

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[2] No Combud reports were available for Mpumalanga. For some stations not covered in the Combud reports, additional information was obtained from local farming co-operatives and Grain SA. Average of stations with data wasR318/ton.

Table 13. Value of lost yield in 2050, based on lost production and gross margins for selected sites (in 2000 Rands)

	Change in yield in 2050 (- loss; + gain)		***Gross margin In 2000 Rands***	***Value of changed yield in 2050 Rand million In 2000 Rands***	
	no fertilisation effect (tons)	*with CO_2 fertilisation effect (tons)*	*R / ton*	*no fertilisation effect*	*with CO_2 fertilisation effect*
Bethlehem	-290 611	-124 452	244	-71	-30
Bethal	-117 186	-75 897	318	-37	-24
Bloekomspruit	-49 663	-27 875	318	-16	-9
Bultfontein	-69 200	9 890	259	-18	3
Cedara	-82 522	-57 662	157	-13	-9
Ermelo	-158 907	450 693	318	-51	143
Glen	-46 694	119 287	606	-28	72
Greytown	-98 999	-66 950	157	-15	-10
Koppies	-46 055	-17 373	318	-15	-6
Kroonstad	-129 305	-79 534	284	-37	-23
Lichtenburg	-278 472	-134 153	278	-77	-37
Petit	-94 524	-47 624	318	-30	-15
Petrusberg	-45 631	2 578	606	-28	2
Ottosdal	-144 021	-59 667	485	-70	-29
Potchefstroom	-152 729	-107 242	228	-35	-24
Setlagole	-86 036	-6 873	215	-19	-1
Viljoenskroon	-113 618	-60 083	321	-36	-19
Wesselsbron	-82 253	35 447	131	-11	5
Wolmaranstad	-154 459	-68 177	485	-75	-33
TOTAL				-681	-46

5.3 Crops for the brewing industry

This industry depends on four crops – barley, hops, maize and sorghum. The effects on maize have been described above. For *barley,* yield reductions of 20 to 50% are predicted for warmer regions, but this effect might be somewhat compensated for by rising atmospheric CO_2, suggesting a reduction in the order of 10 to 40% (modeling in Uruguay (Baethgen cited in Reilly 1996) supports the upper bound) (Midgley 2001). Warming will also lead to a reduction in malting quality. Responses for *hops* are presently unknown, but likely similar to barley in terms of production and quality. Hops is an irrigated crop, so will subject farmers to greater irrigation costs. Given the lack of detailed data (e.g. gross margins) for hops, we do not quantify potential damages here. Finally, *sorghum* is likely to benefit from increasing temperatures and higher atmospheric CO_2 levels, but no estimates are available yet (Midgley 2001).

5.3.1 Barley

Statistics from the National Department of Agriculture indicate that the total area of barley planted in 2000 was 141 250 ha . Taking maize output as the average of the last four years reported, 176 000 tons of maize were produced, bringing a total gross income of R150 million. Gross income per ton was therefore R851/ton of maize, but the basic selling price was R789/t (NDA 2000: 22). After deducting directly allocatable variable costs, the gross margin in the Western Cape in 1998 varied between R402 and R612 per ton, and was taken at an average of R540 per ton of barley (DoA: WC 1998). The value of the output (production times gross margin) is therefore R95 million per year.

The Country Study estimated that yield reductions due to climate change would range between 10% and 40% per year by 2050 (Midgley 2001). The value of this lost yield would range from -R9.5 million to -R38.0 million per year in 2050, in 2000 Rands.

5.3.2 Grain sorghum

The total area planted to grain sorghum in 1998/99 was 99 000 hectares, yielding on average over four years 378 750 tons of sorghum per year (Based on data in NDA 2000: 13). The total gross income over the period averaged R210 million per year in 2000 Rands. While gross income per ton was R553 /t on, the gross margin was significantly lower, deducting costs. averaged across values for KwaZuluNatal, Free State and NorthWest was taken as R170 / ton of sorghum. The value (output * gross margin) was R64 million per year.

The Country Study does not estimate yield losses for sorghum. If losses from climate change were assumed to be 10 to 20%, the value of damages from climate change to wheat production would be between -R6.4 to -R12.9 million per year by 2050 in present day Rand.

5.4 Other crops

For other major crops, the estimates of values are rough approximations, or ‘back-of-the-envelope’ calculations. Several factors contribute to this. Most importantly, detailed crop modelling was undertaken in the Country Study only for maize, and hence disaggregated prediction of changes in yield are only available for this crop. Secondly, other agricultural statistics (gross margin, area planted) are less readily available for other crops. The figures should be treated as indications of the order of magnitude of economic impact, rather than as precise predictions. Taking into account these limitations, the figures can provide an indication of the potential scale of economic damages from climate change in the agricultural sector.

5.4.1 Wheat

The total area planted to wheat in 1999/2000 was 718 000 ha, yielding a total production of 1.56 million tons (RSA 1999: 3). The gross value of production the previous season was R1 445 million, for 1.53 million tons produced (NDA 2000: 10). The gross margins for wheat in the Free State and Western Cape varied from R46 to R569 per ton, with an average of R385/t (DoA: FS 1996; DoA: WC 1998).

Wheat is not discussed in the Vulnerability & Adaptation studies. If losses from climate change were similar to those for barley at 10 to 20%, the value of damages from climate change to wheat production would be between -R60 to -R120 million per year by 2050 in present day Rand.

5.4.2 Sugar cane

For sugar cane, neither estimates of lost yield from the Country Study, nor gross margins from the Combud reports are available. Sugar cane is, however, the second largest field crop in terms of contribution to gross value, and contributes to sugar exports. A *very rough* approximation of possible impacts would be to assume a 10% to 20% loss from climate change and apply this to lost exports. The value of lost exports ranged from -R1 187 to -R1 738 million per year between 1996 and 1998, with an average of -R1 520 million per year in 2000 Rand. Hence lost exports from climate damages, if the assumption holds, would be in the order of -R150 to -R300 million per year.

5.4.3 Fruit

Major industries in the winter rainfall region are the fruit and wine industries. Rising minimum temperatures are a problem for the fruit industry, especially for apple farming. Certain amounts of chilling units during autumn and winter are needed to ensure co-ordinated budburst, and subsequent harvest. In their absence, hormone sprays are used to ensure this co-ordination, but EU countries demand that these be phased out within the next few years, due to possible health reasons. Developing and replanting appropriate cultivars which are less sensitive to this effect may take several years, although this analysis has not been carried out.

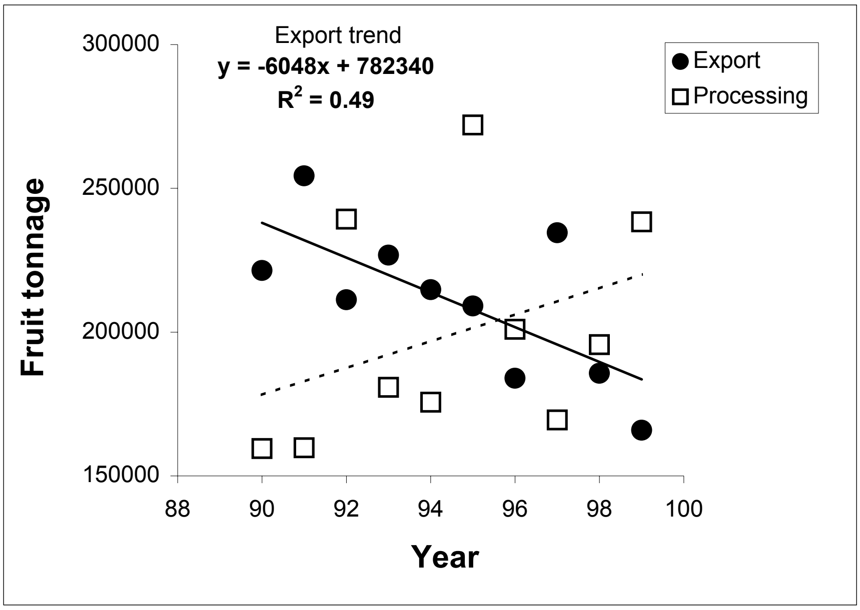

Figure 6. The decrease in tonnage of export grade apples produced in the western Cape, and the concomitant increase in processed fruit, in the decade of the 1990's. This period was associated with a warming of monthly temperature means in summer of roughly 0.1ºC per year.

An accelerating increase of minimum temperatures during autumn (1 to 2°C since the 1960's) (Wand 2001; Wand & Midgley in prep) has also led to reduced fruit quality due to sunburn and heat stress, and this appears to have decreased the critical export-grade apple production in this region (Figure 6). It is clear that export grade tonnage has dropped (by ~6050 tons per year), and tonnage supplied for processing (mostly juicing) has increased concomitantly during the decade of the 1990's. Export-intended fruit which does not make grade (mean value over the decade of R1900 per ton) is processed at a value to the producer of R286 per ton, which is an 85% reduction in value. Analysis of summer minimum temperatures over this decade indicates an increase of roughly 0.08 to 0.1ºC per year for the main apple-producing areas. Therefore, one can interpolate an export-grade tonnage loss of ~6000 tons per 0.1ºC temperature increase (with the current planting intensity), representing a loss to the producer community of R9.7 million per year during the 1990's (not inflation adjusted).

5.5 Summary of estimated climate change damages to crops

The estimates of climate change damages outlined above have varying degrees of certainty. Both the modelling of climate change impacts and general statistical information is best for maize, which is also the largest field crop. A reasonable estimate for barley is possible, but this is a relatively small contributor to agricultural GDP. For wheat, sorghum and sugar-cane, increasing numbers of assumptions need to be made, making the estimates less certain. The estimate for losses in the fruit industry are based on lost exports and are not denominated in 2000 Rands, and therefore are not included in the comparison below. The estimates are summarised in Table 14, with comments on some of the data constraints and assumptions to indicate the level of confidence that should be attached to them.

Table 14. Summary of estimates of climate change damages from field crops, with assumptions

Crop	*Low estimate*	*High estimate*	*Confidence*	*Comments / assumptions*
Maize	-46	-681	Good	Based on detailed modelling, low estimate assumes CO_2 fertilisation effect, H2n model
Barley	-10	-38	Fair	Yield losses from V&A: low 10%, high 40%
Sorghum	-6	-13	Indicative only	No estimates of yield loss from V&A, assumed low 10%, high 20%
Wheat	-60	-120	Indicative only	No estimates of yield loss from V&A, assumed low 10%, high 20%
Sugar cane	- 150	-300	Indicative only	Lost value of exports; no estimates of yield loss from V&A, assumed low 10%, high 20%

The summary shows that large damages can be expected with a reasonable degree of certainty in the maize sector. The main cause of uncertainty relates to the CO_2 fertilisation effect. Expert opinion on likely damages for other sector would be important to make damage estimates for wheat and sugar-cane more reliable. Given that these are large sectors within agriculture, they would merit further research.

6. Plantation Forestry

Jane Turpie

6.1 The current extent and value of plantation forests

The industrial forest subsector, mostly based on afforestation of grassland and fynbos areas with exotic pines, eucalypts and wattles, makes the largest contribution to the national economy. In 1995, the total afforested area was about 1.487 million ha (DWAF 1997), of which most is in Mpumalanga (41%) and KwaZulu Natal (37%). Plantations currently cover about 1.1% of the surface area of South Africa. Some 15% of South Africa is suitable for afforestation, but much of this is also suitable for other agricultural activities (DWAF 1997). Further afforestation has been taking place at rate of about 10-12 000 ha per annum, mostly in KwaZulu-Natal (DWAF 1997), but this seems to be tailing off. Some 19 million cubic metres of roundwood are produced annually, of which about 43% is hardwood (eucalypts and wattle) and the rest is softwood pines (DWAF 1997). About 69% of the total roundwood production is used for pulp, 21% for sawn timber and 17% for mining timber (DWAF), with the rest being used for matchwood, firewood, and treated poles (Fairbanks & Scholes 1999).

Commercial forests have an annual turnover of about R1200 million (Hassan 2000, 1996 value), off an asset base valued at about R20 billion (Mogaka *et al.* 2001). 70% of this value is from export sales (Fairbanks & Scholes 1999). The industrial forestry sector contributes about 1.8% of South Africa's GDP and 8.1% of the output of the manufacturing sector. Plantation forestry accounts for 5% of South Africa's agricultural output and 3.3% of total exports from South Africa (Christie & Gandar 1995). The annual increment in the value of standing stocks is worth some 7% of the total value added by agriculture, forestry and fisheries combined (Hassan 2000).

Much of the forest plantation area is fully or partially government owned. However, following recent policy changes, there is a move towards the privatisation of these assets. Small-scale farmers are also starting to take part in this industry. The plantation forestry industry is looking to afforestation of community-owned lands as a critical growth area, and the industry is thus beginning to establish joint ventures with communities (Bethlehem *et al.* 1998). This can provide substantial opportunities for economic development in rural areas, but benefits to the communities could be constrained by unequal partnerships due to lack of capacity on the part of the communities unless government plays a role (Kruger 1998).

6.2 The impact of climate change on commercial forests

An assessment of the physical impacts of climate change on plantation forests was made by Fairbanks & Scholes (1999) as part of the South African Country Study on Climate Change, based on the HADCM2 model. The study reported that trees will be affected by CO_2 concentration, temperature and rainfall, as follows:

- With a doubling in CO_2 concentrations, growth rates could increase by about 10-20% (de Lucia *et al.* 1999). However, this potential is limited by available nutrients, so increased carbon supply does not necessarily lead to increased growth. In fact it is likely that tree crop yields will increase only marginally, and only on high-potential sites (Fairbanks & Scholes 1999).
- Rising temperatures will stimulate forest production in the areas currently cooler than the growth optimum, and reduce it in areas where forests are already above their optimum.
- Increased rainfall will increase tree production.

Although the change in CO2 is fairly certain, the changes in temperature and especially rainfall are very uncertain, and the magnitude and direction of effects is uncertain (Fairbanks & Scholes 1999).

The HADCM2 model predicts a general aridification over southern Africa, and increased annual mean temperatures of 2.5-3.5˚C. Two scenarios were modelled – one with no change in rainfall, and the other with the predicted change in rainfall. The models assumed no mitigation action, such as the introduction of cultivars better suited to the changed conditions (Fairbanks & Scholes 1999). For range shifts, Fairbanks & Scholes (1999) used limits of economic viability, rather than biological limits. The study indicated that the optimum growing areas for the commercial tree species were sensitive to climate change. Impacts on the 8 major plantation species in South Africa were described as follows:

Pinus patula: This species is sensitive to both temperature and rainfall changes. Economically viable growing regions in the northern and eastern Cape provinces are eliminated under conditions of increasing temperature and decreased rainfall, with areas remaining only in northern KwaZulu-Natal. Production modeling for this species at a site near Frankfort, currently an optimal growing region for this species, shows up to a 94% reduction in wood production by the year 2050.

Pinus taeda: This species appears more sensitive to rainfall than temperature change, and lower rainfall amounts could eliminate it from the eastern Cape Province.

Pinus elliottii: Reduced optimal growth areas occur in the eastern Cape province southern KwaZUlu-Natal Drakensberg and midlands, and southern Mpumalanga.

Pinus radiata: This species is grown in several sub-optimal areas in the western Cape. Decreased rainfall will completely eliminate growing this species as a financial proposition in the western Cape region.

Eucalyptus grandis, nitens and *saligna:* All species show reduction in area and range similar to that found for the Pinus species, that is a 40 to 80% reduction in optimum growing area. Production modelling for Eucalyptus grandis at Frankfort shows a 48% reduction in wood production by 2050.

All in all, these results suggest a dramatic negative effect of climate change on forestry potential range and production by 2050.

The GIS outputs of the Fairbanks & Scholes (1999) study were obtained for analysis in this study. The coverage of 1993 extent of different types of plantations suggests that 59% of afforested areas are under pines, 33% under eucalypts and 5% is under wattle. The changes in suitable range of species were quantified to determine the percentage change in suitable and optimal growing areas (Table 15). *Pinus radiata*, which is grown in the winter rainfall area of the Western Cape, was not considered, since the cultivation of this species is being phased out. Only species grown in the summer rainfall areas are considered. Based on analysis of the GIS data, there is roughly a 47% and 50% decline in the total area suitable for *Eucalyptus* and *Pinus*, respectively. The degree of decline differs for different species. Since some 80% of trees are in highly suitable areas (Hassan 2000), the change in these areas is most pertinent. The predicted reduction in highly suitable area is about 43% for both *Eucalyptus* and *Pinus*.

For calculation of economic impact, it should be considered how much of the existing afforested area becomes unsuitable, and hence from which production is lost altogether, and how much of the existing area in highly suitable areas is rendered less productive by climatic changes, but remaining viable. The precision of the data do not allow for such an analysis, but the changes predicted above can be used to estimate the possible magnitude of the impact.

Table 15. The percentage change in viable and highly suitable areas for plantations of different species in South Africa based on maps in Fairbanks & Scholes (1999)

Species	Viable area	Highly suitable area	Overall viable area
Eucalyptus grandis	-34%	-35%	-35%
Eucalyptus nitens	-69%	-51%	-59%
Eucalyptus saligna	-53%	-42%	-47%
Mean for *Eucalyptus*	-52	-43	-47%
Pinus elliottii	-52%	-51%	-52%
Pinus patula	-60%	-62%	-61%
Pinus taeda	-45%	-17%	-38%
Mean for *Pinus*	-52	-43	-50%

Fairbanks & Scholes (1999) went on to model the change in productivity that would occur within a suitable afforestation area under the climate change scenario (including CO_2 enrichment). In the case of *P. patula*, the model incorporated a hypothetical (unknown) upper temperature limit at which the plant might shut down photosynthesis. Two possible temperature limits were considered, and the results of the model were highly sensitive to this assumed temperature threshold (Table 16). A single probable (but unknown) temperature limit was considered for *E. grandis* (Fairbanks & Scholes 1999).

Table 16. Predicted changes in aboveground net primary production (NPP) by 2050 under climate change, including the effect of CO2 enrichment (from Fairbanks & Scholes 1999), under temperature limits of 30˚C and 25˚C.

Species	% change in aboveground net primary production	
	30˚C limit	25˚C limit
Pinus patula	+ 34%	- 95%
Eucalyptus grandis	- 49%	

The results showed a 49% reduction in the productivity of *E. grandis*, even though temperature effects are somewhat balanced by positive CO_2 fertilisation effects. The effects on *P patula* could be positive or negative, depending on the upper temperature threshold for the species.

6.3 Economic impact on forestry sector

Based on the reduction in highly suitable area for forests by 2050, forestry output could be decreased by as much as 43%, implying a loss of value in the order of R724 million per annum. However, the shortcoming of the model outputs is that they are based on suitable areas, which are considerably larger than the current planted area. Even the highly suitable area is much larger than the planted area. Thus, a 43% reduction in the highly suitable area may not impact on the currently planted area, if the current plantations are at the core of the area which is not affected. This problem requires further spatial analysis. However, it is unlikely that the current area will not be impacted by shrinkage of highly suitable areas at all. Furthermore, most plantation areas would be subject to changes in productivity such as those cited above. Although this cannot be predicted for pines at this stage, half of the current productivity of eucalypts could be lost – amounting to a loss of approximately R362 million.

7. Property damage from sea-level rise

Harald Winkler

Increasing temperatures cause sea-level rise, primarily due to thermal expansion of water and secondarily due to melting ice. The IPCC projects that sea-level rise increase by between 9cm and 88cm between 1990 and 2100, for the full range of emissions scenarios (IPCC 2001: 16). For South African conditions, these global projections are applicable, and indeed are conservative estimates compared to other literature (Hughes 1992: 15-16). Extreme events such as storm surges would add to the impact of these average increases, but are not included here due to their unpredictable timing. The value of damage to beachfront property from sea-level rise is assessed, based on damage estimated in a PhD thesis considering the issue (Hughes 1992), which models a slightly higher sea-level rise of 1m. In South Africa, sea-level rise of 10-15 cm has already occurred over the last century, at a similar rate to global increase (Hughes 1992: 2).

The value of coastal ecosystems is recognised in South African policy, notably the White Paper on Sustainable Coastal Development. The annual value of indirect and direct benefits was estimated as R44.8 billion and R134.3 billion respectively (RSA 2000: Appendix 3). The share of GDP was estimated to be about 35% of GDP, although this counts entire coastal magisterial districts up to 60 km inland. However, no value for residential property is given.

7.1 Vulnerability and impacts

Not all sections of the South African coast are equally vulnerable to the impacts of climate change. The high cliffs of the Cape Peninsula are less vulnerable than gently sloping sandy shores. Soft erodible coastlines backed by flat and low lying coastal plains are most vulnerable, meaning that estuaries, tidal inlets, deltas and barrier islands are the natural environments generally most at risk (Hughes 1992: 3).

Sea-level rise due to climate change has a number of impacts on a shoreline:

- increased coastal erosion;
- inundation, i.e. flooding of areas;
- salt water intrusion;
- elevated coastal groundwater tables; and
- reduced protection from storms and floods (Hughes 1992: 140).

The first two effects would contribute to property loss and will tend to be higher were there are greater concentrations of population. Increased coastal erosion is important on soft coastlines, in particular when they are not protected by rocks or backing dunes. Flooding and salt water intrusion affect estuaries, inlets and coastland wetlands, not the open coast. Changes in water-table elevation are a problem in developed areas with high water tables. Reduced protection affects all parts of the coast, but especially sheltered inlets (Hughes 1992: 104-5).

7.2 Case studies of local impacts

Hughes (1992) presented detailed case studies of four ‘type-locations’(Hughes 1992: 40). These included Woodbridge Island, False Bay, Durban and Walvis Bay (then still South African territory). The case studies make clear that major predicted impacts vary with the type of coastline. Hughes’ (1992) maps of these areas are in Appendix 1.

7.2.1 Woodbridge Island (Milnerton, Cape Town)

Woodbridge Island in Cape Town exemplifies a partially developed shoreline with river mouth, estuaries and backing wetlands and lagoon. The most serious problems arising from a 50 cm increase in sea-level would be storm flood damaged to the spit protection the lagoon, the town margin and developing margins of the vlei, as well as potential increased erosion (Hughes 1992: 58). Storm erosion after a 1 m rise in sea level would "probably be sufficient to erode half of Woodbridge Island" (Hughes 1992: 53). Flooding after a 1 in 40 to 50 year storm would completely swamp the island.

The average price of properties on Woodbridge Island was estimated by estate agents to be R 750 000 (PGP 2001). Assuming that approximately half (or all) of the 350 properties on Woodbridge Island will be affected by the sea-level rise (with storm surge), the total damage would be R131 million (R263 million). Given the uncertainties in the estimates of house prices and exact number of houses affected, one could say that the damages from sea-level rise may be in the order of magnitude of hundreds of millions of Rands.

7.2.2 Muizenberg (False Bay)

Another 'type-location' considered by Hughes (1992:40) is a developed coastline with some room for manoeuvring coastal buffer zones. The coastline of False Bay exemplifies this, being exposed and low-lying, with developing close to sandy beaches in many places. A 50cm rise in sea level would lead to increased erosion, storm flooding and groundwater flooding in the Fish Hoek, Muizenberg/ Sandvlei and Zeekoeivlei areas. Lessons to be learned are that highly developed open coasts are vulnerable to erosion, inlets are susceptible to increased storm activity, ribbon development close to the shore should be avoided and buffer zones should be maintained (Hughes 1992: 74-5).

A 1 m rise in sea-level would increase coastal erosion and put the new mean high water mark back about 100m, beyond the first block of property on the west side of Muizenberg (Hughes 1992: 65). The average price in Muizenberg for 3-bedroomed houses was estimated by estate agents at R285 000, while 'big houses' were in the region of R800 000 (PGP 2001). An average of R500 000 per house appears reasonable, given that these are by definition properties close to the beachfront. Estimating approximately 40 houses in the flooded area, this would amount to damages of R20 million. This estimate does not add the impacts of a 1.5 m storm surge, which would threaten a much larger area of property, as shown in Figure #22.

The predicted sea-level rise assumed here is beyond the range predicted by the IPCC this century, but on the other hand, the impacts of extreme events is not considered. The valuation does not count the lost infrastructure (which would not be replaced), nor the increased value of other properties that are subsequently on the sea-front. Given the uncertainties, one could say that the damages from sea-level rise for west Muizenberg would be in the order of magnitude of tens of millions of Rands.

7.2.3 Durban

Durban has a heavily developed coastline with hard structures. Durban's beaches would suffer significantly from sea-level rise, damaging the tourist industry. A 50cm rise of sea-level would seriously erode Durban's beaches and make remaining beaches steeper and thus less suitable for bathing. Such changes are likely to have an impact on the tourism industry. The natural system is probably able to deal with the impacts of a 20 cm rise (without storm events), but beyond that protective measures would be needed (Hughes 1992: 87-8). Serious overall consequences, including inundation of areas of the central business district, would arise from a 1m rise in sea-level, but this is beyond the range predicted by 2100 by the IPCC.

The Durban case study raises the question of costs of adaptation, as distinct from the damages from climate change. Protective walls of 6 m height would be needed for a 50 cm sea-level rise at points on Central and South beaches, and 3.5 m elsewhere. For 1m SLR, this would increase to 9m high walls. This study focuses only on the costs of damages (i.e. losses due to climate change impacts), not on costs of adapting. A larger study would integrate both components. Further work on damage costs would require quantifying the beach area lost, the value of tourism and the importance of beaches to tourism.

7.2.4 Walvis Bay

Walvis Bay has a lightly developed and moderately sheltered coastline. Hughes (1992) considered this case as a typical location of a very open tidal inlet. The major impact is due to increased storm water levels, raising the margin above which development can be considered "safe". Much of the town lies below 1 m elevation and unless protected could be inundated (Hughes 1992: 102). The town is currently sheltered by Pelican Point, but even a 20 cm rise in sea-level would mean that current 1 in 1 000 year storms would occur every 10 years on average, effectively removing this protection. Such a rise in sea-level is at the low end of IPCC projections of 9-88cm for 2100 (IPCC 2001: 16).

For a 20cm (50cm) rise of sea-level, all land below 1.36 m (1.66m) adjacent to the coast would be flooded; for 50cm rise (Hughes 1992: 99). Figure # shows that virtually the whole town lies below 2m elevation and a few locations below 1m.

A detailed case study valuing these impacts would need to quantify the area of Walvis Bay below 1.36 m and derive a value / area. Since Walvis Bay is no longer part of South Africa, we do not pursue this case further here.

7.3 Regional impacts - Coastal Vulnerability Index

Based on the detailed case studies, Hughes (1992) developed a Coastal Vulnerability Index (CVI) which could be applied at a regional level. The CVI was applied to the Southern Cape and KwaZulu-Natal South coasts. The Cape coast is more vulnerable to inundation (esp. during storms) and salt-water intrusion, while the risk on the KwaZulu-Natal coast is more likely to be erosion. Private housing is most at risk in the Southern Cape, but commercial property in KZN. Inlets, estuaries and wetlands are the most vulnerable points, in particular those whose mouths stay open all year, have low bed gradients, wide floodplains and low banks with development within 150m of the high-water mark (Hughes 1992: 135). Overall, the Southern Cape is more vulnerable to the impacts of sea-level rise than the KwaZulu-Natal coast.

7.4 National impacts

Based on the local case studies and regional assessments, Hughes developed a vulnerability assessment at the national level, considering sections of the coast and whether the response would be similar to the two areas or four case studies presented (Hughes 1992: 149-160). Population density was also taken into account as a key variable. These findings are summarised in three maps.

Four particularly sensitive regions were identified: Greater Cape Town (Melkbosstrand to Gordon's Bay); the Cape South coast (Mossel Bay to Nature's Valley); Port Elizabeth; and the KwaZulu-Natal South coast including Durban (Southbroom to Ballitoville) (Hughes 1992: 157). Hughes' summary description of impacts at the national level is worth citing:

> "In reviewing the impacts of sea level rise the first observable impact will probably be an increase in storm damage along the coast. With rising sea level, smaller and therefore more frequently occurring storms will be capable of over-topping existing defences – formal or informal. Soft erodible coastlines will retreat, though not at a constant rate, and must be allowed "room" to retreat. Where there is no room and the profile has been fixed by a structure, the characteristics of the shore/beach will change and the very presence of the structure's protection will results in its own increased vulnerability. Inlets, estuaries river mouths and tidal lagoons will become more tidal with resultant changes to channel and mouth characteristics and nearby shoreline. A greater flooded areas will be formed and this may stress certain wetland habitats if development around these environments is not carefully managed. Some new lagoons/inlets may even be created where they previously did not exist. Associated with the sea level rise will be a rise in the groundwater table. Areas which were previously dry may become marshy or at least suffer from high water-tables, possibly with accompanying engineering problems. This may be particularly important for islands in estuaries. Note that the coastal water-table will rise everywhere along the coast, even in urban areas, unless suitable aquifer management is carried out. Likewise increase saline intrusion into the coastal aquifers must be managed and may also be necessary in some rivers." (Hughes 1992: 170-171)

Despite the significant indications of impacts, Hughes (1992) makes no estimates of infrastructure losses at the regional or national level, neither in Rands nor in area lost. While some work has been done in identifying the most vulnerable sections of the coast, no quantification of impacts at the larger scales has been conducted.

Future research is needed to quantify the impacts of sea-level rise at the national and regional level, before valuation could be attempted. One cannot simply scale up the results from case studies to the whole coast – Hughes (1992) explains clearly the different impacts in different areas, and identifies the most vulnerable segments of coastline. Even in some detailed case studies, damages need quantification per unit area. A further research need is to consider impacts other than the rise of mean sea-level, including extreme events (storm surges) and the ecosystem impacts, e.g. through intrusion of saltwater into estuaries and freshwater bodies.

Despite the limitations in getting national figures in this initial estimate of damages, a picture emerges of potential damages in specific locations. The maps generated by Hughes (1992) study offer a graphic illustration of areas that ma be lost to sea-level rise. In terms of Rand value, initial indications are that the order of magnitude of damages could lie in the 10s of millions of Rands for local areas. While not large compared to national figures, these figures are significant in the local context and to indvidual home-owners.

8. Health impacts – Malaria

Randall Spalding-Fecher

8.1 Introduction

Malaria is one of the world's most serious and complex health problems. More than 40% of the world's population is at risk of malaria, with over 270 million cases per year and more than 1 million deaths (Murray & Lopez 1997; WHO 1998). Malaria is also one of the diseases identified as most likely to be impacted by climate change, because the transmission is sensitive to temperature and rainfall (Kovats et al. 2000). We use a three step methodology to estimate the economic impacts of increased malaria due to climate change:

- Estimate the number of excess cases of malaria due to climate change, based on:
  - increased population at risk of contracting malaria because of climate change
  - incidence ratios within that population at risk
- Estimate the economic cost of malaria morbidity due to climate change, based on:
  - The cost of treating the additional cases
  - Short term productivity losses from patients or their carers being unable to work
- Estimate the economic cost of malaria mortality due to climate change, based on:
  - Lost work years due to premature death from malaria
  - Willingness to pay for reduced risk of death, adapted from the international literature

Malaria risk is governed by a large number of environmental factors, many of which are seasonal, that affect the intensity of transmission and the during of the high risk season. Of all factors, climate is considered the most important limiting factor (Craig & Sharp 2000). The purpose of this analysis, however, is to make a first order estimate of the cost of malaria from climate change, before adaptation has occurred.

Malaria in South Africa have become considerably worse since the 1970s, with exponential growth in incidence of malaria for almost fifteen years. Cases jumped from 4693 in 1991 to 27035 in 1996 to 61253 in 2000 (DOH 2000). This increase is not simply due to changes in climate (e.g. excessively warm and wet years), but to increasing drug resistance, an influx of migrants from neighbouring countries where malaria is not controlled, and reduced spraying with DDT (Craig & Sharp 2000; Sharp et al. 2000).

8.2 Impact of climate change on malaria incidence in South Africa

8.2.1 Increased population at risk

The South African Country Study for Climate Change (SACCCC) Vulnerability and Adaptation Assessment included a chapter on malaria (Craig & Sharp 2000). In this analysis, researchers from the Medical Research Council developed a model that linked temperature (both average and minimum winter) and rainfall to suitability for malaria transmission. This model was checked against historical data for a number of African countries to verify that it gave a reasonable estimate of the area in which malaria is endemic (i.e. stable transmission every year). Climate change impacts in this case were for 2010, unlike other impacts considered in this study.

For future climate scenarios, the SACCCC used the Hadley Centre global circulation models. The Hadley model with no sulphates results are presented here. One difficulty with these global circulation models, however, is that their resolution is quite coarse. Predictions of current average temperature in South Africa from the Hadley models, when compared to more detailed local climate models (Hutchinson et al. 1995; Schultze 1997), for example, vary by 2 to 4 degrees Celsius in many areas (Craig & Sharp 2000). As Craig and Sharp (2000) note, "the difference between the present [Hadley] models and actual climate are therefore much greater than the difference between the present and future [Hadley] scenarios. The predicted populations at risk from the Craig and Sharp (2000) study should therefore be seen as an upper bound.

The projected populations at risk based on the local climate models and the Hadley model with and without climate change are presented below in Table 17 below.

Table 17. Estimates populations at risk based on different climate models

	Present climate		Hadley model no sulphates		
	Hutchinson	Schultze	Present climate	Future climate	Increase
1995	9,101,875	7,854,638	5,049,654		
1996	8,603,783	7,819,266	4,912,228		
2000	10,662,127	9,241,847	5,977,839		
2005	10,622,127	10,966,172	7,174,761	30,637,710	23,462,949
2010	15,133,780	13,211,391	8,703,941	36,300,636	27,596,695

The Hadley models therefore predict that climate change will increase the population at risk of malaria by 417% in 2010 – primarily because the malaria risk area now includes the heavily population Witwatersrand area. Note that, compared to the Hutchinson and Schultze data, the Hadley model underestimates the *present* population at risk – although the Hadley model estimates are closer to more detailed studies of populations at risk in South Africa (Sharp *et al.* 2000; Tren 2001).

8.2.2 Increased morbidity and mortality

8.2.2.1 Methodology

The share of the population at risk that will actually contract malaria is driven by a wide variety of socio-economic, environmental and health factors. Our best reference point for malaria incidence ratios is to look at current cases of malaria relative to populations at risk. We used several estimates of population at risk for different years, along with the actual cases of malaria in South Africa, to derive incidence ratios.

For mortality estimates, we used the average share of malaria cases resulting in death in the last three years in South Africa, or 0.7% of cases (DOH 2000). This is very close to Southern African averages of 1% (Snow et al. 1999).

8.2.2.2 Results

Table 18 below shows the estimated incidence ratios based on different assessments of population at risk in different years. Although the estimates vary by a factor of 3 or 4, most of the sources are close to 10 or 11 cases per 1000, which is the benchmark for Southern Africa (Snow et al. 1999). Because we use the Hadley forecast for population at risk, we will also use this estimated incidence ratio of 10.4 cases per 1000.

Table 18. Incidence ratios based on difference population at risk assumptions

Year	Cases	Population at risk	Source for population at risk	Incidence (cases/1000)
1999	51535	3010451*	(Sharp et al. 2000)	17.1
1998	26445	4000000	(Tren 2001)	6.6
1996	27035	4912228	(Craig & Sharp 2000)-HnS	5.5
1996	27035	7,819,266	(Schultze 1997)	3.5
2000	61934	5,977,839	(Craig & Sharp 2000)-HnS	10.4
2000	61934	9,241,847	(Schultze 1997)	6.7
			(Snow et al. 1999)	11.0

Note: Malaria cases from (DOH 2000; Department of Health 2001)

Applying this incidence ratio to the increased population at risk of malaria in 2010 of 27.5 million gives us 285 918 additional cases of malaria due to climate change. Note that this is about a third higher that what we would estimate if we simply took the current number of cases (62 000) and multiplied by what the Hadley models predict as the proportional increase in population at risk (317%)[3], or 196 000 additional cases.

Out of these 285 918 additional cases, we would expect 2 108 deaths, given current mortality rates.

8.3 Valuation of increased morbidity

To place an economic value on increased morbidity, we have used two tools: the cost of treatment and the opportunity cost of lost work days. The treatment cost is the full costs of treating a particular illness with one or more treatment regimens (Zweifel & Breyer 1997). The opportunity cost of being ill can be measured in terms of lost income from being unable to work. Treatment cost is often called the 'direct' cost of an illness, while lost productivity is referred as the 'indirect' costs. What these two methods do not address, however, is the actual physical and emotional pain and suffering that accompanies illness, or the impacts this has on quality of life and society. These measures, therefore, can only serve as a lower bound of the economic value of morbidity.

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[3] Because total cases under the climate change scenario are 417% of those under the baseline scenario, the additional cases due to climate change are 317% of those in the base year.

8.3.1 Treatment costs

8.3.1.1 Methodology

For our purposes, we are interested mainly in direct and indirect costs of medical treatment for patients contracting malaria. We must assume that the costs of treating the additional future patients due to climate change will be similar to the cost of treating patients today in real terms.

The most detailed recent study on the costs of treating malaria in clinics and hospitals in South Africa is work by Justin Wilkins at University of Cape Town (Wilkins 1999). This study looked at the costs of medical personnel, drugs, and all hospital costs associated with alternative therapies for malaria. Building on this work, Richard Tren of the UK Institute of Economic Affairs analysed the costs of malaria treatment in South Africa including the costs of the Malaria Control Programme (Tren 2001). At least part of the costs of this programme should also be included in treatment costs for malaria, since much of the treatment occurs in the field. It was not possible to identify the share of personnel expenditure (the largest item in the programme budget) that was devoted, but expenditure for insecticides was subtracted, since this is clearly a preventive measure.

8.3.1.2 Results

Table 19 below shows the cost per patient of treatment in hospital and in the field. The malaria control programme is an order of magnitude greater that hospital costs – but this is to be expected because 42% of cases are diagnosed and treated in the field, while another 32% are treated as outpatients in hospitals (Tren 2001).

Table 19. Treatment costs per malaria patient (Rands)

	A	B	C
Cost of treating and hospitalising patients	300	276	260
Malaria Control Programme	2,301	2,925	3,016
- less preventive expenditures	190	242	249
Total (current yr R)	2,410	2,959	3,026
Total (2000 R)	3,097	3,502	3,352

Source: (Tren 2001), own analysis

The average cost per patient is R3 317. For our 285 918 additional cases of malaria due to climate change, therefore, the cost of treatment would be R948 million.

8.3.2 Lost short term productivity

8.3.2.1 Methodology

Lost productivity due to illness depends both on wages and days out of work. For wages, Tren (2001) analysed the average wage of employed persons in the three provinces with endemic malaria. Weighted average wages for those employed were 193 Rand in 1997, which is equivalent to 224 Rand in 2000 (SARB 2001). Only 47% of the population of these districts, however, had formal employment, while a further 12% were employed in the informal sector. Even people who are not formally employed in rural areas would contribute to subsistence agriculture, so we use an agricultural wage (36 R/day adjust to 2000 wages) for the unemployed and informally employed as a proxy for their lost earnings. For the 11% of malaria cases that occur in children under five, we can assume that a carer will need to take time away from work during the illness. Even for those in the 5 to 15 age group (30% of reported cases), it is likely that either a carer will have to take time away or that some of these youth would have been involved in supported subsistence activities. For these reasons, we assume that all malaria cases will result in lost productivity.

Days out of work depends on the severity of the case and treatment regimen, which are also affected by the age of the patient. Children under 5, for example, are always hospitalised for 4 days treatment, so all of these cases will result in 4 lost productive days. For children ages 6 to 15, it is assume that a carer will need to take part of the time off work, or an average of 2 days. For cases ages 16 and up, the days lost depends on severity. Cases identified actively (e.g. through field workers in the Malaria Control programme) will by definition not be as severe, with only one day lost. For those that come to a clinic or hospital, 55% are assume to be treated as outpatients and 40% are treated with oral medication – both of these groups lose 4 days productive time. For the 5% of hospital cases that require IV quinine, 7 days of productive time will be lost (Tren 2001). For each of these groups, we apply the share of employed, unemployed, and informally employed to match wages to days of lost productivity.

8.3.2.2 Results

Table 20 below shows the lost productivity per case, depending on how the case is treated and the employment status or wage of the patient. Using this table and the share of cases falling into the different categories within the matrix, we calculate a weighted average productivity loss of 299 R per case. For our 285,918 additional cases of malaria due to climate change, therefore, the total lost productivity in 2010 is 85 million Rands.

Table 20. Lost productivity per case, based on case type and employment status

	Employed	Unemployed	Informally employed
Case type			
Age <5 years*		142.06	
Age 5-15 years	448.70	71.03	71.03
Age > 15 years			
- Active**	224.35	35.51	35.51
- Passive OP & oral	897.40	142.06	142.06
- Passive IV	1570.44	248.60	248.60

*assume that families will choose to have someone not formally employed to care for sick child

**active and passive refer to how the case is identified – active by fieldworkers and passive by patients coming to hospital

8.4 Valuation of increased mortality

There are two broad approaches to dealing with valuation of reduced life. The first is based on assessing individual's willingness to pay to avoid risks, or willingness to accept compensation for taking on risks. This is based on basic principles in economics that individual preferences are the most important source of value (Zweifel & Breyer 1997). If we know what all individuals in society were willing to pay to avoid a certain risk, we would know exactly how much society should spend on avoidance investments. The practical challenges in designing these studies, and the cost of executing them has meant that relatively few studies have been conducted in developing countries. The only way to utilise this approach in many developing countries, therefore, is to use values from industrialised countries and somehow adjust them for local conditions (discussed in more detail below).

The second method is called the 'human capital approach', and equates the value of the lost life with the net present value of that person's future contribution to Gross National Product (Dixon et al. 1994; Zweifel & Breyer 1997). In other words, when society loses this person, they lose the value added (e.g. wages less personal consumption) that the person would have contributed to the economy for the remainder of their natural life. There are obvious problems with this approach, most importantly that, from an ethical standpoint, there is no reason that an individual's value (to themselves or to others) should be related to their economic output (Zweifel & Breyer 1997; Fankhauser et al. 1998). At best, the human capital approach should only provide an absolute minimum estimate of economic costs (Dixon *et al.* 1994). Despite these serious theoretical drawbacks, the practical reality facing researchers and policy makers in developing countries is that willingness to pay studies simply are not available.

Although the estimation of and inclusion of such estimates is controversial in a study such as this, we provide the estimates that would arise from these two approaches.

8.4.1 Human capital: lost productive years of life

8.4.1.1 Methodology

We use two approaches to estimating human capital. The first is to estimate the average years of life lost and the contribution that the average individual would have made over those years based on GDP per capita. This gives a direct estimate of years of productive life lost. The second possibility is to use the concept of Disability Adjusted Life Years (DALYs), which is a standard health care analytical tool that combines years of life lost and years of life disabled, measured relative to incidence of the illness. From global burden of disease estimates we find that, for sub-sarahan Africa, DALYs for malaria are 0.145 per incidence of illness (Murray & Lopez 1997). This takes into account the age at death, years lost, and a discount rate of 3% for future years lost.

8.4.1.2 Results

For lost work years, age at death is based on Tren's (2001) reporting of deaths from malaria in Mpumalanga in 1997 and 1998, where the average age at death was 22.9 years. According to the UNDP's Human Development Report, life expectancy in South Africa is 54.7 years (UNDP 1999), so this means a loss of 32 years of economically active life.

Because we are evaluating the impacts of deaths in 2010, we should use per capita GDP in 2010, which is estimated by ABSA Group Economic Research (2000) at R22 360 (in 2000 Rands). This value over 30 years, using a real discount rate of 3%, R456 000 per loss of life. Applying this to the additional 2,108 lives lost in 2010 because of climate change, the valuation for loss of life is 962 million Rands.

For the DALY approach, the additional 285,918 cases of malaria in 2010 will result in 41,458 DALYs. Multiplying this by 2010 GDP per capita of 22,360 gives 3242 Rands per incident of malaria, or a total cost of 927 million Rands.

8.4.2 Willingness to pay and benefits transfer

8.4.2.1 Methodology

As discussed above, the willingness to pay approach relies on large scale surveys on individual to ask them to evaluate what they would pay to avoid a certain additional risk, or what they would accept as compensation for that risk ('willingness to accept'). Where primary research is not available in a given country, as is the case for many developing countries, we can adapt these values using the concept of 'benefits transfer' – using relative GDP per capita of the two countries to adjust the valuations. The problem with this approach is obvious, if we are to use to place a value on the loss of life – it appears that we are again setting people's value equal to their economic output, so that people in poor countries are worth less than those in rich countries (Ekins 1995). While economists have proposed ways to address this problem (Fankhauser et al. 1997), this study does not have to tackle the international dimension of the problem because it looks only at domestic health impacts.

8.4.2.2 Results

A survey of economic valuations of health risks by Zweifel and Breyer (1997) found that the 'value of a statistical life' can vary greatly, in part because "considerable risk reductions of about $1{:}10^3$ do not call forth a substantially larger willingness to pay then reductions of around $1{:}10^5$ to $1{:}10^6$."(p. 40) For studies that looked a higher risks, values for two studies were between 120 and 300 000 US dollars (2000 dollars)(cited in Zweifel & Breyer 1997). This is much lower than studies done for lower risks, where values of $1 million were more common. In the case of malaria, however, the risks of dying are on the order of $1{:}10^5$ for those in endemic areas. Zweifel and Breyer also look at valuation studies of observer consumer behaviour – for example, how much additional wages people are willing to accept to compensate for more dangerous work and how much consumers will spend on purchases like smoke detectors, homes in areas with better air quality, or choices they make about driving speed and use of seat belts. Values from the wage risk studies may exceed $1 million, and different studies often differ by several orders of magnitude, but values from consumer behaviour studies tend to range from $300 000 to $900 000 per statistical life.

Our conclusion is that, given the lack of study in South Africa (or Africa) on these issues and the uncertainties in how comparable the overseas studies are, it is difficult to apply these results to the present analysis. For illustrative purposes only we have used a range of $300 000 to $1 million. When adjusted for 2000 exchange rates (SARB 2001) and relative GDP per capita between the US and South Africa (World Bank 2000), this means a value of 228 to 716 000 Rands per life lost. The total loss would therefore be 480 to 1510 million Rands in 2010.

8.5 Conclusions on health costs

The economic costs of increased risk of malaria due to climate change is estimated to be in the order of R1033 million rands in 2010, representing about 0.1% of GDP. On top of this is the substantially increased loss of human life, a value which is difficult to justify expressing in monetary terms.

9. Summary and conclusions

The estimates reached in this study are summarised in Table 21 below. The greatest potential impact is on tourism, with a potential loss of up to almost 3% of GDP due to damages to South Africa's natural heritage, but a reliable estimate of this impact was not possible in this study. Apart from tourism, the greatest impacts are to non-market impacts: the existence value of biodiversity, the subsistence use value of natural resources, and the impacts on human health. This is particularly interesting since most studies concentrate on conventional market-based impacts such as agriculture or forestry. However, this pattern is to be expected for a developing country, and would undoubtedly be even more strongly the case in other African countries.

Put in context of South Africa's GDP these values are not large, but are significant. South Africa's GDP in 2000 was R874 billion. The loss of existence value is equivalent of 0.3% of GDP, and the loss of subsistence harvests, up to 0.3% of GDP. Malaria damages would lead to a loss of just over 0.1% of GDP. In comparison, the loss of crop and forest production would probably amount to less than 0.1% of GDP, fisheries losses are in the same order of magnitude, and livestock production may increase. The overall losses could be at least 1.5% of GDP, but may be considerably higher, possibly over 3%, depending on the impact on tourism. It should be noted that the damage costs are not comprehensive, many climate change damages either have not been quantified biophysically or values cannot be estimated at all. The overall estimates from this study, expressed as a percentage of GDP, are more similar to those for America and Europe, which are around 1.5-1.6% of GDP, rather than those for Africa, which are around 6.9% (Fankhauser *et al.* 1997). It would be expected that the overall impacts on the South African economy would be lower than for the rest of Africa because of the country's high productivity within the mining and manufacturing sectors and their relative contribution to economic output.

We have concentrated on valuing unmitigated damage costs. In other words, it gives an indication of what damages climate change could inflict on the South African economy if no action was taken. This is a contentious issue, as adaptive action will undoubtedly take place, even if it is carried out only be the private sector. Nevertheless, the relative magnitude of different impacts presented here puts an interesting perspective on the argument of whether to assess unmitigated damage costs or adaptation costs plus residual damages. This is because adaptation measures in the case of the highest impacts presented here are difficult, and sometimes impossible. There can be no mitigation of impacts on existence values. Indeed, existence values may even increase as environmental awareness improves, but biodiversity cannot be substituted and therefore there can be little in the way of adaptation to its loss beyond resigned acceptance. Mitigation of the loss of resources which are central to the livelihoods of a majority of South Africans is also nigh impossible. Adaptation measures would involve the substitution of these resources or the reduction of dependence on natural resources through increasing incomes and cultural changes. Any of the latter measures would prove to be vastly expensive, such that adaptation costs would be proven to be even higher than the potential losses indicated in this study. Moreover, they are highly impracticable and in some cases may be undesirable.

Table 21. Summary of preliminary estimates of the unmitigated damage costs of climate change in South Africa made in this study.

Source	Activity/type of value	Mechanism of climate change impact	Estimated impact (R millions per year)	Level of confidence in valuation and comments
Forest & savanna	Commercial harvests – timber	Loss of forest biome	-3.3	Low
	Commercial harvests – ferns	Loss of forest biome	-0.7	Low
	Subsistence use of resources	Reduction in extent of vegetation	-1 924 to -2 616	Low
Fynbos	Commercial harvests – wildflowers, thatch, etc	Reduction in extent of vegetation	Down to -28	Significant potential loss, but requires more detailed study
Estuaries	Estuarine recreational & subsistence fisheries	Increased closure of estuaries	Down to -151	Medium
Marine	Inshore commercial, recreational & subsistence fisheries	Reduced interaction with estuarine nursery areas	-441	Low; unknown range shifts among inshore species
All rangelands	Livestock production		+191 to +1344	Low - Sensitivity of NPP to CO_2 fertilisation effect – for individual regions can change loss to gain
	Cattle herd value		-100 to -200	Medium; Based on direct estimate of lost cattle herd
All habitats & biodiversity	Existence value to South Africans		-2 630	High / Medium; Large sample, but based on stated-preference methods (CVM)
All habitats & biodiversity	Tourism value	Reduction in tourism demand due to loss of biodiversity, risk of disease	-4 000 to –26 000	Low; no sophisticated models, many factors affect tourism, but that's 10% of GDP
Croplands	Maize		-46 to -681	Medium / Low; Based on 19 sites, but sensitive to CO_2 fertilisation
	Barley		-10 to -38	Low; No detailed model in SACS
	Sorghum		- 6 to -13	Very low; Assumed losses
	Wheat		-60 to -120	Very low; Assumed losses
	Sugar cane		-150 to -300	Very low; Large crop, needs further study
Plantation forests	Plantation forests	Reduced area available for plantation forest	-362 to -724	Low; country study expressed low confidence in predictions
Infrastructure	Property damage	Damage due to sea-level rise	> -100	Very low; Not covered in SACS, one PhD thesis, no area quantified, but property values are high
Human health	Malaria	Four-fold increase in population at risk by 2010. Costs half due to mortality, half to morbidity (lost days and treatment)	-1 033	Medium

10. Acknowledgements

This study was sponsored by USAID and administered by the Joint Centre for Political and Economic Studies Inc. under a subcontract agreement from Nathan Associates Inc. We are grateful to the National Botanical Institute and to Dean Fairbanks for the provision of GIS data used in the analysis.

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