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METHODS

Valuing the impacts of climate change on protected areas in Africa

Sandra J. Velarde[a], Yadvinder Malhi[b,c], Dominic Moran[d,*], Jim Wright[e], Salman Hussain[d]

[a]*Alternatives to Slash-and-Burn Programme, World Agroforestry Centre, Nairobi, Kenya*
[b]*School of Geography and the Environment, University of Oxford, UK*
[c]*School of Geosciences, University of Edinburgh, UK*
[d]*Land Economy, Scottish Agricultural College, Kings Buildings, West Main Rd., Edinburgh, EH9 3JG, UK*
[e]*Department of Geography, University of Southampton, UK*

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Abstract

This study quantifies the economic costs of climate change impacts on protected areas in Africa. Downscaled results from four Global Circulation Models (GCMs) are used to classify different ecosystems in accordance with the Holdridge Life Zone (HLZ) system. A benefits transfer approach is then used to place an economic value on the predicted ecosystem shifts resulting from climate change in protected areas. The results provide approximations for the impacts on biodiversity in Africa under the "business-as-usual" scenario established by the Intergovernmental Panel on Climate Change (IPCC) for the middle and end of the 21st century. The geographical analysis shows that there are twenty HLZs in Africa and all of them are represented in the protected area network. Three of these HLZs do not change in extent as a result of climate change. Assuming initially that the willingness to pay (WTP) values and the preferences for different ecosystem services remain constant, three of the GCM models show an (undiscounted) negative economic impact of climate change for protected areas in Africa for the year 2100. The worst-case damage scenario totals USD 74.5 million by 2100. However, the model for the year 2065 shows a *higher* undiscounted value than the present. The finding of positive net impacts from warming is consistent with the predictions of other macro models that show potential gains from warming scenarios.

Keywords: Climate change; Holdridge life zones; Ecosystem shifts; Benefits transfer; African protected areas

1. Introduction

There is growing evidence that biodiversity and ecosystem functions are influenced by climate change and that species ranges are shifting (McCarthy et al., 2001; Parmesan and Yohe, 2003). There have been

* Corresponding author. Tel.: +44 131 535 4128; fax: +44 131 667 2601.
E-mail address: d.moran@ed.sac.ac.uk (D. Moran).

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over 2500 studies of an observational nature documented by the Intergovernmental Panel on Climate Change (IPCC) Working Group II: Impacts, Adaptation and Vulnerability. Some climate change studies predict an increase of temperature throughout the year with an annual average of +2.8 °C over tropical Africa and an associated precipitation increase of 4.2 mm/month. If the effects of deforestation are added to global warming, evapotranspiration reduction would occur by about 6 mm/month and total precipitation is also reduced in most months by 10–20 mm/month (Zhang et al., 2001). Some parts of tropical Africa may diverge from this continental trend. For example, some tropical rainforest areas of western Africa have become drier since 1960 (Malhi and Wright, 2004). Based on this evidence, it is reasonable to infer that there are likely to be shifts in ecosystems or species habitats over the whole of Africa owing to climatic change.

Relative to other sectoral impacts (e.g. sea level rise and agriculture), less progress has been made in translating the impacts of climate change on economic endpoints that can influence the cost–benefit case for mitigation options. This study is intended to contribute to this rather scant literature, focusing on Africa. While querying the limited policy role of such economic analysis, Tol (2002) notes that this slow progress is largely due to the compounded uncertainties attached to both regional and local climate modelling and economic valuation. The difficulties in regional scale climate and ecosystem modelling are extensively documented (e.g. Giorgi, 2001; McCarthy et al., 2001). The use and interpretation of impact valuation is also problematic because of both the time horizons involved and the complex mix of impacts on ecosystem functions and species distribution. These impacts are not well covered by the existing body of non-market valuation studies, which are far more limited both in scale and in the nature of goods and services covered.

In this study, we consider these impacts only on designated protected areas in Africa. Studies in Kenya, Zimbabwe and Namibia reveal that between 73% and 90% of tourists visit these countries primarily for nature tourism (Filion et al., 1994; MET, 1997; Wells, 1996). According to the World Tourism Organisation (2002), there is a significant demand for nature tourism that is not as yet fully exploited. Protected area designation remains an important management tool for achieving conservation goals, for maintaining biodiversity and as a consequence for meeting this demand. We would thus contend that our focus on protected areas is appropriate.

The effect of climate change on protected areas is not a recent concern for the international community. In 1992, IUCN–The World Conservation Union–organised a workshop on the implications of climate change and sea level rise for national parks and protected areas globally (Pernetta et al., 1994). Taylor and Hamilton (1994) suggest that the survival of forests ecosystems would not be seriously threatened by predicted climate changes over tropical Africa. More recently, Turpie et al. (2002) use secondary sources to calculate the effects of climate change in South Africa. The estimations in their study relate to impacts from predicted rainfall and temperature changes derived from global climate model (GCM) analysis. For a forecast scenario of 50 years they note that the largest impact on the South African economy (amounting to some 3% of GDP) is related to tourism. The attractiveness of the country as a tourist location is diminished through impacts on biodiversity and landscape in designated areas and increased malarial incidence.

The analysis presented here is similar in spirit to Turpie et al. (2002). However, in this study GCM output is downscaled to provide a finer resolution to the economic endpoints of interest—the ecosystem classifications that characterise African protected areas. This paper combines Geographical Information Systems (GIS) and benefits transfer. GIS is used to classify the land according to the Holdridge Life Zone (HLZ) system, a widely used vegetation classification system for climatic change impact analysis (Yates et al., 2000). The HLZs are not only basic bio-climatic units but also zones describing similar human activities (Holdridge, 1978). These properties make them adequate for benefit transfer purposes and the associated inferences about use and non-use values pertaining to vegetation change. Vegetation change is derived from GCM outputs for a ‘business as usual’ scenario for emissions. The application in this study is novel in terms of scale, resolution and the applicability of the methods and the results to decision-making.

The outline of this paper is as follows. Section 2 reviews the literature on integrated climate-biodiversity-valuation modelling. In the methods section (Section 3) we first outline our data sources, then outline the methodology for the spatial analysis and finally discuss the HLZs that pertain to this study. We then present the results of the spatial analysis in Section 4. The economic valuation of these results is presented in Section 5. Section 6 provides a discussion and conclusions.

2. Integrated climate-biodiversity-valuation modelling

The role that economic assessment plays in the determination of policy to mitigate climate change has been much scrutinised, particularly with respect to time discounting, income weighting (distributional issues) and mortality impacts (Pearce, 2003). While much of the debate has centred on the estimation of the marginal social costs of carbon emissions, the impetus for policy discussions on mitigation has been predictions of *aggregate* global damage, particularly so when regional modelling scenarios indicate significant economic damages arising in vulnerable environments in developing countries. However, the construction of these integrated "end to end" assessment models is challenging.

The approaches adopted for integrated climate impact modelling differ in three respects: reliance on baseline scenarios; manipulation of GCMs; and the assignment of values to impact endpoints. Tol (2002) presents a comprehensive critique. He notes that early cost benefit attempts (e.g. Fankhauser, 1995; Pearce et al., 1996) rely on dated climate impact studies and often are not transparent vis-à-vis detailing how costs and benefits were built up from a myriad of impact studies. Other studies (e.g. Nordhaus and Boyer, 2000), though methodologically robust in a top-down sense, are limited in terms of regional impact details. Studies that use economic information inevitably entail the reconciliation of top-down and bottom-up approaches and have to make somewhat heroic extrapolations to account for welfare change in the absence of global or specific local willingness to pay studies. It is therefore possible to identify a number of weaknesses in all integrated modelling approaches and the approach applied in this paper is no exception. However, we do attempt to map the output of GCMs in such a way as to enable the best use of existing willingness to pay (WTP) information.

3. Methods

3.1. Data sources

Mean monthly temperature and precipitation data for the 20th century were obtained from the Climate Research Unit (CRU) at the University of East Anglia. These data consist of a high-resolution ($0.5^\circ \times 0.5^\circ$ latitude/longitude) global-mean climatology from surface observations for the period 1961–1990, tested for quality and validated by the CRU (New et al., 1998). With regard to future climatic patterns, mean monthly temperature and precipitation data from four widely used GCMs were obtained through the IPCC Data Distribution Centre. Four different GCM runs based on the IPCC-IS92a (or similar) emission scenarios are used, as shown in Table 1. Three of the four GCM models forecast climate until the end of the 21st century (CGCM, CSIRO, CCNI), whilst one forecasts climate until the year 2065 (GFDL). The GCM runs all indicate a warming climate throughout the African continent in the 21st century, but vary significantly in the pattern of simulated precipitation changes. Changes in tropical and subtropical temperatures are largely driven by changes in the radiative balance (greenhouse effect) of the Earth's atmosphere, whereas changes in precipitation are driven by changes in the atmospheric circulation. The latter are inherently more difficult to predict that the former, and hence the range of precipitation changes encompassed by the four GCM simulations reflects the uncertainty in magnitude and direction of possible precipitation changes on the African continent.

The IS92a emission scenario is the reference "business-as-usual" or "unmitigated" global energy scenario of the Intergovernmental Panel on Climate Change (IPCC, 1998; Arnell et al., 2002). This scenario specifies equivalent greenhouse gas (GHG) concentrations and sulphate aerosol loadings from 1850 to 2100. Despite limitations, IS92a has been

Table 1
Characteristics of GCMs used in the study

Model	Institution	Experiment name	Resolution of flux correction	Scenario and period
CGCM1	Canadian Centre For Climate Modelling and Analysis (CCCma)	An ensemble of 3 greenhouse gas (CO_2, NO_x, CH_4) plus sulphate integration (CCGSa3)	High	IS92a 2000–2099
CSIRO-Mk2	Australia's Commonwealth Scientific and Industrial Research Organisation	A greenhouse gas (CO_2) plus sulphate integration	Medium	
CCSR/NIES (CCNI)	Center for Climate Research Studies (CCSR) and National Institute for Environmental Studies (NIES), Japan		None	
GFDL-R15[a]	Geophysical Fluid Dynamics Laboratory, US		None	CO_2 initialized at the 1958 amount and increased approx. 1% each year thereafter 1766–2065

Sources: IPCC, 2002. The IPCC Data Distribution Centre Access to the GCM Archive (ISA92 and similar scenario runs) http://www.ipcc-ddc.cru.uea.ac.uk/dkrz/dkrz_index.html.
ftp://ftp.ncdc.noaa.gov/pub/datasets/gcm/readme.
[a] NOAA/NCDC (2002). GFDL Global Climate Model (GCM) [100 year run].

widely used as a framework for understanding the climate change challenge by those who have contributed to the IPCC Third Assessment Report (Williams, 2001; Nakicenovic and Swart, 2000). IS92a has effective CO_2 concentration increasing at 1% per year after 1990. In the model, the concentrations are specified by linear interpolation between specified values at 2000, 2025, 2050 and 2100. The economic growth assumptions of the IS92a are at the low end of the ranges forecast by the World Bank in 1991. It averages 2.3% per annum between 1990 and 2100, with a mix of conventional and renewable energy sources being used and with population rising to 11.3 billion by 2100. IS92a assumes only those emissions control policies aimed at mitigating climate change that were agreed as of December 1991 (IPCC 1998).

A spatial database of the natural protected areas of Africa for the year 1994 was obtained from the World Conservation Monitoring Centre (WCMC) (World Resource Institute and World Monitoring Centre, 1995). These protected areas are classified into 7 protection categories based on their primary and secondary objectives (scientific research, tourism, recreation, etc). The WCMC database does not include information for South Africa, the Seychelles, Sao Tome and Principe and Libya, so these countries do not form part of the analysis presented in this study.

3.2. Spatial analysis

The GCM models used in the study were spectral models, which produce output grids where cell size varies with latitude. Since most GIS systems use a constant grid cell size, the GCM results were reprojected into a constant cell size format of $0.5^\circ \times 0.5^\circ$ latitude/longitude by interpolating using distance-weighted averages. An exponent of 10.0 was used to weight distance within this averaging process. The output resolution of each model was thus standardised to 720 columns and 360 rows.

Global climate models are typically run at a resolution far too coarse to provide useful information at a regional scale due to computational constraints. Therefore, regional climate downscaling is a critical component linking prediction to application. GCM output was therefore further downscaled to the resolution of the current climate data. Each GCM depicts present climate slightly differently and the GCM-based predictions of current climate do not exactly match the present observed distribution of temperature and precipitation. Therefore, the change in climate was estimated by calculating the difference in temperature and precipitation between any given future decade and 2000–09 (GCM predictions for the present-day were unavailable). This difference was smoothed using a mean low-pass filter and then added to the current climate data. The implicit assumption in this approach is that the absolute spatial variation of climate between points within a GCM grid cell caused by, for example, topography, proximity to sea, etc., remains constant with climate change, and that the mean values of each point within the same GCM grid cell are shifted up or down by the same amount. New et al. (1998) demonstrated that changes or anomalies in climate are coherent over much larger spatial scales than mean values of climate. This approach was chosen because of the simplicity of its application over large scales. An alternative, more rigorous approach, would involve statistical down-scaling that predicts localised climate parameters through regression or similar analysis, based on the large-scale climate state, topography, land use, and land/sea configuration (von Storch, 1995). Such a detailed procedure was beyond the scope of this analysis, and in reality is unlikely to yield very different results from our "conservative anomalies" approach.

3.3. Identifying Holdridge life zones

The downscaled GCM files of temperature and precipitation were used as inputs to the Simple Holdridge Implementation (SHI) of ecosystem classi-

Table 2
Life Zone parameters according to Holdridge Simple Implementation

L.Z. No	Holdridge life zone (L.Z.)		Biotemperature (°C)		Precipitation (mm)	
			Lower limit	Upper limit	Lower limit	Upper limit
12	Cool Temperate	Desert	6	12	0	112.5
13	Cool Temperate	Desert Bush	6	12	112.5	225
14	Cool Temperate	Steppe	6	12	225	450
15	Cool Temperate	Moist Forest	6	12	450	900
16	Cool Temperate	Wet Forest	6	12	900	1800
17	Cool Temperate	Rain Forest	6	12	1800	4000
18	Warm Temperate	Desert	12	17	0	112.5
19	Warm Temperate	Desert Bush	12	17	112.5	225
20	Warm Temperate	Thorn Steppe	12	17	225	450
21	Warm Temperate	Dry Forest	12	17	450	900
22	Warm Temperate	Moist Forest	12	17	900	1800
23	Warm Temperate	Wet Forest	12	17	1800	3600
24	Warm Temperate	Rain Forest	12	17	3600	8000
25	Subtropical	Desert	17	24	0	125
26	Subtropical	Desert Bush	17	24	125	250
27	Subtropical	Thorn Steppe	17	24	250	500
28	Subtropical	Dry Forest	17	24	500	1000
29	Subtropical	Moist Forest	17	24	1000	2000
30	Subtropical	Wet Forest	17	24	2000	4000
31	Subtropical	Rain Forest	17	24	4000	8000
32	Tropical	Desert	24	30	0	112.5
33	Tropical	Desert Bush	24	30	112.5	225
34	Tropical	Thorn Steppe	24	30	225	450
35	Tropical	Very Dry Forest	24	30	450	900
36	Tropical	Dry Forest	24	30	900	1800
37	Tropical	Moist Forest	24	30	1800	3600
38	Tropical	Wet Forest	24	30	3600	7200
39	Tropical	Rain Forest	24	30	7200	8000

fication (Yates et al., 2000). Two variables are necessary for this: annual mean bio-temperature and total annual precipitation. The bio-temperature was calculated from the average monthly values with a slight modification which pertains to the Holdridge rules, viz. temperatures of less than 0 °C are eliminated, as well as those above 30 °C. Temperatures above 30 °C are reclassified as 30 °C. The original Holdridge classification (Holdridge, 1947) included values above 30 °C but this approach was modified (Holdridge, 1967) to eliminate those values above 30 °C to adapt the system to the subtropics. None of these systems is totally precise. Therefore, an intermediate approach that gives more reasonable values of biotemperature for dry areas (of particular relevance in this study) was applied, according to the formula.

Mean annual biotemperature

$$= \Sigma[30^\circ\mathrm{C} \geq T > 0^\circ\mathrm{C}]/12;\, T < 0^\circ\mathrm{C}$$

$$= 0^\circ\mathrm{C} \text{ and } T > 30^\circ\mathrm{C} = 30^\circ$$

where T=monthly average temperature in °C.

Total annual precipitation was calculated from the GCM model output as the mean for the period of 2000–2099 (for the CGCM, CSIRO, and CCNI models) and 2000–2065 (for the GFDL model) and used in the SHI matrix derived from the Holdridge diagram. African ecosystems were classified according to the parameters in Table 2 for the present and the four GCM models.

The next methodological stage was the overlaying of African protected areas. Since many of the protected areas are too small to be represented in a $0.5^\circ \times 0.5^\circ$ grid, a much smaller $1.5' \times 1.5'$ grid was used. The resolution of the current and forecast HLZs was also increased to match this resolution. The percentage of each protected area lying within the different HLZs was then calculated within the GIS. These results were corrected particularly for coastal areas. Finally, the corrected rates were multiplied by the size of the protected area in hectares, obtaining the area in hectares of each HLZ in each protected area. The results were summarised by life zone and GCM model.

4. Spatial analysis results

4.1. Current Holdridge life zones for Africa

The classification of current precipitation and biotemperature according to the SHI system (Yates et al., 2000) suggests that Africa possesses 20 of the 38 HLZs in the world (Leemans, 1990). The most important HLZs in terms of area coverage in Africa are Tropical Dry Forest (L.Z. No. 36), Sub-Tropical Moist Forest (L.Z. No. 29), Sub-Tropical Desert (L.Z. No. 25) and Tropical Desert (L.Z. No. 32). These areas in aggregate occupy 56.32% of the African land surface. The summarised results are shown in Table 3.

The total amount of land lying in protected areas in Africa is 1 827 514 km^2. However, due to the limitations of the scale, there are some areas that were not analysed by the GIS resulting in an error of 1695 km^2 or approximately 0.1% of the total area. These areas were too small to be represented at the chosen grid resolution of 0.5° of latitude/longitude.

Parts of all the HLZs in Africa are protected under some sort of scheme and in variable intensity. Under current HLZs, Subtropical Dry Forest (L.Z. No. 28), Subtropical Moist Forest (L.Z. No.29) and Tropical Dry Forest (L.Z. No.36) together represent 55.87% of the overall protected area in Africa, but only 3.27% of the total area of the continent as a whole. The areas which have a relatively higher representation in protected areas are Cool Temperate Wet Forest (L.Z. No.16), Warm Temperate Wet Forest (L.Z. No.23) and Warm Temperate Moist Forest (L.Z. No.22), as summarised in Table 3.

4.2. Predicted future Holdridge life zones for protected areas in Africa

Life zone output derived from the four GCM models was compared to the current climate HLZs in protected areas for Africa (Fig. 1). The main significant changes are showed in Table 4. One of the highlights from the results is that the tropical moist forest decreases by the same area as the increase in subtropical wet forest under CGCM. Therefore, it is reasonable to think that there is a shift in life zone from Tropical moist forest (L.Z. No

Table 3
Protected life zones in Africa ranked by proportion of continental life zones

L.Z. no.	Life zone	A Total area of L.Z. in Africa (km²)	B Total protected area in each life zone (km²)	C % of L.Z. in Africa (%)	D % of L.Z. in protected area (B/total B) (%)	E % protected of L.Z. in Africa (B/total A) (%)	F % protected of each L.Z. (B/A) (%)
36	Trop Dry	5 314 258	320 730	17.05	17.57	1.03	6.04
29	SbTrp MsF	4 254 593	338 877	13.65	18.56	1.09	7.96
25	SbTrp Des	4 048 583	166 720	12.99	9.13	0.53	4.12
32	Trop Des	3 936 726	102 611	12.63	5.62	0.33	2.61
35	Trop Vdry	2 599 739	170 831	8.34	9.36	0.55	6.57
28	SbTrp Dry	2 562 377	360 493	8.22	19.74	1.16	14.07
34	Trop ThnS	1 881 334	63 254	6.04	3.46	0.20	3.36
27	SbTrp Thn	1 482 705	115 357	4.76	6.32	0.37	7.78
33	Trop D/B	1 422 444	3722	4.56	0.20	0.01	0.26
37	Trop MsFo	1 024 612	109 763	3.29	6.01	0.35	10.71
26	SbTrp D/B	1 022 021	20 894	3.28	1.14	0.07	2.04
21	WmTmp Dry	499 754	396	1.60	0.02	0.001	0.08
20	WmTmp Thn	434 508	1141	1.39	0.06	0.004	0.26
30	SbTrp Wet	329 687	7393	1.06	0.40	0.02	2.24
22	WmTmp MsF	178 248	26 623	0.57	1.46	0.09	14.94
19	WmTmp D/B	76 036	2284	0.24	0.13	0.01	3.00
18	WmTmp Des	61 019	8707	0.20	0.48	0.03	14.27
15	ClTmp MsF	26 575	246	0.09	0.01	0.001	0.92
16	ClTmp Wet	8463	3760	0.03	0.21	0.01	44.43
23	WmTmp Wet	6170	2062	0.02	0.11	0.01	33.43
Total		31 169 852	1 825 864	100.00%		5.86	

37) to Subtropical wet forest (L.Z. No 30). Also, none of the four models analysed showed any significant change in Cool temperate moist forest (L.Z. 15), warm temperate wet forest (L.Z. No 23) and warm temperate thorn steppe (L.Z.No 20). Warm temperate dry forest shows the same increase (81%)

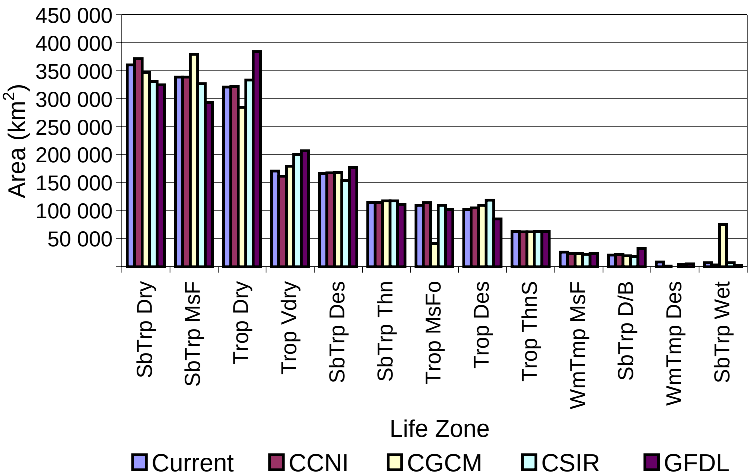

Fig. 1. Life zones in protected areas of Africa as at present and as forecast by four different global circulation models (note: life zones occupying an area of less than 7500 km^2 under all scenarios are not shown to simplify the figure).

Table 4
Significant absolute and relative changes in life zone areas within protected areas in Africa after climate change

L.Z. no.	Life zone	GCM			
		GFDL	CCNI	CGCM	CSIRO
		Year			
		2065	2099	2099	2099
32	Trop Des				+16 576 km^2
35	Trop Vdry		−8 831 km^2	−35 634 km^2	+29 899 km^2
28	SbTrp Dry		+11 022 km^2		
33	Trop D/B	+77%	+107%		
37	Trop MsFo			−68 220 km^2	
26	SbTrp D/B	+56%			
21	WmTmp Dry	+81%	0%	+81%	+81%
20	WmTmp Thn	0%	0%	0%	0%
30	SbTrp Wet	−60%	−59%	+68 220 km^2 (+923%)	
19	WmTmp D/B		−40%	−93%	−40%
18	WmTmp Des	−41%	−86%	−100%	−45%
15	ClTmp MsF	0%	0%	0%	0%
16	ClTmp Wet	−95%			
23	WmTmp Wet	0%	0%	0%	0%

for the CGCM, CSIRO and GFDL models and no change in the CCNI model.

5. Economic valuation

5.1. Data and analysis

Our analysis attempts to contribute to the aggregate cost benefit case for mitigation and therefore abstracts from local level welfare changes due to severe climatic events. However, in highly vulnerable environments with limited mitigation options, the loss of direct and functional benefits from ecosystems can compromise livelihoods and exacerbate poverty. For many analysts these direct human impacts are the main reason to be concerned with climate change and should therefore be weighted more highly to reflect the fact that the value of local damages represents a larger proportion of poorer per capita incomes.

In theory the valuation component of this study should discriminate between impacts by modifying the unit benefits transfer method that we use here—specifically by incorporating an equity weight (or inequity aversion parameter) to reflect the elasticity of the marginal utility of income schedules (Pearce, 2003). In practice the values that this parameter might take are as debatable as the discount rate. For the purposes of this study, we restrict our damage calculation to the product of the scale of ecosystem change and unmodified willingness to pay information. We therefore avoid the logical step of aggregating this damage over the potentially damaged population. Avoiding the aggregation calculation obviates the use of an inequity aversion parameter. This methodological simplification should not be taken to suggest that all impacts are valued equally in practice.

In quantifying what we might call the indirect welfare losses associated with an unmitigated “business as usual” scenario we use literature on environmental valuation for Africa to identify use and non use value studies that can be transferred to protected areas within the same HLZ classifications on the continent. Relevant studies were identified through an extensive search through databases of published and unpublished literature. We make rudimentary adjustments to unit values.

Annex Table 1 details the studies used and presents the study value as well as the values expressed per hectare per year. Where the area of the study site is not cited in the original text a figure has been drawn from a protected area database. All values have been transformed to 2000 USD prices using a GDP deflator index from the U.S. Bureau of Economic Analysis (2002). The majority of these studies use the contingent valuation method (CVM) to value protected areas. A large number of them were carried out in southern Africa, particularly Namibia (Krug, 2003), South Africa (Agostini, 1995; Turpie and Siegfried, 1996) and Zimbabwe (Brown et al., 1995; Child, 1990; Department of National Parks

Zimbabwe, 1991) and focussed on nature tourism. Most of these studies include aggregate values and extrapolations for the whole country or its protected areas, which are useful for this paper.

5.2. Benefits transfer

The existing valuation evidence relates to whole protected areas and occasionally to specific ecosystem services. Some method was needed to generalise this information over similar biological resources as characterised by HLZs. The crucial benefits transfer assumption is that the value of a HLZ is the same across different protected areas in Africa. In the first instance, existing studies could be broadly categorised into specific services attributable to protected areas (e.g. tourism value, genetic prospecting). After grouping the studies by service themes, the study sites were then cross-referenced to specific HLZs such that average service values could be estimated for each HLZ. Thus, the value per hectare was the sum of all services present in that HLZ and identified in previous studies. This process was simplified wherever protected areas lay wholly within one HLZ. In this case the protected areas within the same HLZ could be assigned the specific study value, which was typically on a per hectare basis. When a study spanned two or more HLZs, a weighted average was used to ascribe the corresponding study value to the its constituent Zones. Finally the sum of the value of ecosystems services represents the total value of each HLZ (Annex Table 2).

Note that these preliminary results separate out carbon values. Though studies have shown carbon as the largest component of tropical forest value, the per hectare value is still sensitive to the assumed marginal social cost range of between £4 and £70 (Pearce, 2003). This range could substantially alter the values attributed to changes in Very dry forest, Dry and Moist forest (L.Z. Nos. 35, 36 and 37). To avoid the need to report across this range of uncertainty we include a separate total value including carbon based on a published per hectare estimate of USD1300 (Pearce, 1990). In order to report conservative estimates of damage effects, this figure is not inflated to 2000USD terms.

5.3. Discounting in climate change

A range of time horizons are prevalent in the impact modelling literature (e.g. Azar and Sterner, 1996). The horizon adopted here was determined by the GCM output as 100 or 65 years depending on the model used. This means that time preference for damage mitigation assessment has to be addressed with an appropriate discount rate to collapse the net effect of future impacts into current value terms. Much of the debate about the appropriate discount rate is preoccupied with the difference between zero and some positive discount rates. Pearce (2003) also notes a case for using rates that vary over long time horizons. In the climate change context this debate is all the more sensitive, since any positive rates can significantly reduce future impacts to insignificant levels over the relevant warming horizons. Set against the conventional neo-classical assumption of time preference our analysis has to make some allowance for the likelihood that public preferences for biodiversity and protected areas will likely increase. This holds true for local use value and even more so for global non-use values for African megafauna.

Evoking the Krutilla-Fisher model allows for some accommodation of this notional growth in preservation benefits. In essence the model offsets the conventional discount rate by some percentage to accommodate change in preferences. Markandaya and Pearce (1988) state that the Krutilla-Fisher model could be interpreted as a discount rate adjustment procedure arising from environmental consideration. The model inflates preservation benefits, biasing the decision rule more towards preservation options. The authors claim that this approach to handling irreversibility does not qualify as a procedure or justification for adjusting discount rates for environmental reasons. However this form of adjustment seems to be an ethically robust slight of hand to allow positive rates. Side-stepping the theoretical debate about the appropriate rate (e.g. Fearnside, 2002), a range of composite rates are tested for our projected damages.

5.4. Value of life zones

Of the 20 HLZs present in the African protected areas, three did not change in extent as a result of climate change. Furthermore, the economic values for

Table 5
Present value of life zones in protected areas in Africa according to different discount rate and GCMs (USD_{2000} $year^{-1}$)

Year	2000	2065	2100	2100	2100
r (%)	Present	GFDL	CCNI	CGCM	CSIRO
0	1 908 512 175	1 923 946 955	1 882 393 729	1 836 071 729	1 833 951 842
0.9	1 908 512 175	1 074 650 608	768 411 479	749 502 386	748 637 028
1	1 908 512 175	1 007 636 285	695 942 068	678 816 305	678 032 559
3	1 908 512 175	281 691 335	97 946 291	95 536 026	95 425 723
5	1 908 512 175	80 702 810	14 314 644	13 962 389	13 946 268
10	1 908 512 175	3 923 454	136 597	133 236	133 082

r=discount rate.

four zones (Cool temperate wet forest, Warm temperate dry forest, Tropical desert and Tropical desert bush [L.Z. No 16, 21, 32 and 33]) could not be calculated due to lack of data. In effect, the current and future values of protected areas were thus derived from the values for the remaining 13 HLZs.

The HLZ shifts in terms of area were multiplied by their economic values in USD per hectare per year to provide an undiscounted picture of the damages. These represent annual total economic values for the different HLZs in Africa in 2000 prices (Annex Table 2). Assuming initially that the WTP values and the preferences for different ecosystem services remain constant, three of the models show an (undiscounted) negative economic impact of climate change for protected areas in Africa for the year 2099. The worst case scenario of damages totals USD 74.5 million by 2100 (Table 5). However, the model for the year 2065 shows a *higher* value than the present. The finding of positive net impacts from warming is consistent with the predictions of other macro models that show potential gains from warming scenarios (e.g. Nordhaus and Boyer, 2000).

The present value (PV) for damages was calculated using different discount rates from 0 to 10 and for years 2065 and 2100 (Table 5). Logically the table shows the value of future damages being reduced for higher discount rates. The converse is true for the positive composite rates that account for increasing income elasticity of WTP.

6. Discussion

The geographical analysis showed that there are twenty HLZs in Africa and all of them are represented in the protected area network. The most important in terms of area are tropical dry forest, subtropical moist forest and subtropical and tropical desert. Much of the discussion of their changing values should be qualified by the shortcomings in our modelling approach. Model integration is a process of matching analytical methods, and results are only as good as the way inputs fit together. The main sources of uncertainty here arise from our reference warming scenario (IS92a), which contains specific political and economic assumptions, the limitations associated with GCMs, the limitations of the HLZs as a means of depicting ecosystems, and the use of benefits transfer of unit WTP values. In terms of the warming scenario, Nakicenovic and Swart (2000) provide several reasons why IS92a might not be a central warming trajectory, citing elements that make climate prediction more or less random. Our adoption of IS92a is for demonstrative purposes only and we do not pursue the pros and cons further. Suffice to say that the trajectories will then feed into GCMs that are themselves limited as being gross representations of the geographic, geologic and atmospheric details that lie behind climate simulations (Smith et al., 1995). Indeed, Legates (2002) suggests that GCMs can at best represent only a thumbnail sketch of the real world, with spatial resolutions no finer than regional areas a thousand miles square. Apart from this scale element, the extent to which GCMs can simulate climatic events is an on-going debate. We used the relatively simple method of New et al. (1998) to down-scale GCM output, rather than more complex statistical down-scaling techniques, and this will contribute to uncertainty in our results. Although it is possible to quantify the extent of this uncertainty when using statistical downscaling, it is not possible to do so with the New et al. (1998) methodology used here.

As mentioned above, the primary cause of the diverse results arising from the four GCM scenarios arises from the intrinsic difficulty of simulation precipitation patterns and changes in these patterns. This problem is a feature of all analyses based on GCM simulations and can only be addressed at the moment by using a number of GCMs to capture the range of variability, as has been done here. Hence our study should be viewed as an examination of the economic costs of a *variety of given changes* in precipitation patterns, rather than a specific prediction.

Furthermore, the HLZ classification assumes climax conditions in vegetation. Predicted vegetation coverage under the classification is therefore not accurate, since it takes no account of the lag between climate change taking place and any resultant species migration.

Our use of WTP information and the process of benefits transfer are open to considerable improvement with more time and money. While there are numerous protected area valuation studies, the coverage is still limited and we make some admittedly heroic assumptions about the way they are matched to HLZs. First, we make no assumptions for increasing income elasticity of WTP. Second, we also hold back from any suggestion that WTP for continent-wide consideration may be subject to diminishing marginal WTP. The latter is highly plausible. Third, we avoid the question of equity weighting the WTP values.

Finally, we assume that designated protected areas are not subject to other external impacts. The reality is that African protected areas are subject to a range of pressures including agricultural encroachment, shifting cultivation, cattle grazing, illegal logging and illegal settlement, political instability and civil conflict, weak institutions and limited budgets. These effects are not incorporated in this analysis, yet over our forecasting horizon, their combined affect may easily overwhelm climate impacts in some areas of the continent.

Having stated these caveats there is much to be said for attempting to integrate disparate literatures and methodologies. With zero discounting, an interesting finding of this analysis is the rather modest aggregate economic impact attributable to climate change in this century. Over this short time horizon underlying habitat shifts appear to balance out and this is reflected in the damage estimate. Note that we do not make any assumptions about mitigation that have not previously been made in other comparable integrated assessments.

Our analysis is a comparative static one. If due consideration were to be given to the *dynamics* of climatic effects then the values–and conclusions–arrived at might differ. We implicitly assume that no shock climate catastrophes occur. This is a limitation of our analysis given recent climate history for the continent and given that some severe events will be accentuated in frequency and impact.

This paper contributes to the knowledge on economic consequences of climate change related to ecosystem loss particularly over natural protected areas in Africa using benefits transfer and GIS. A review of the literature shows that the biodiversity impacts of warming have generally received less attention in the cost–benefit case for global mitigation. From a policy perspective therefore, it is of some interest to address this impact category of potential damages. However, very few studies have previously attempted to integrate similar sources of information and/or methodologies to account for impacts on a regional or local scale. What we show in some respects accords with other top down macro assessments, viz. that there are actually potential gains from global warming. However, our analysis has drawn this conclusion from a consideration of impacts to one type of natural asset, i.e. protected areas. Although protected areas in Africa are without a doubt of considerable significance as measured by the willingness to pay for their preservation, both locally and globally, it would be wrong to make sweeping generalisations about net welfare changes for the whole continent based solely on our study. Africa is possibly the least well-equipped region to mitigate climate change impacts and more complete welfare assessment needs to consider the probabilities attached to climate extremes and catastrophe and associated human costs.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ecolecon.2004.07.024.

References

Agostini, P., 1995. Economic Analysis of Ecologically Sensitive Areas in Developing Countries. Dissertation, University of California, San Diego, California.

Arnell, N.W., Cannell, M.G.R., Hulme, M., Kovats, R.S., Mitchell, J.F.B., Nichols, R.J., Parry, M.L., Livermore, M.T.J., White, A., 2002. The consequences of CO_2 stabilisation for the impacts of climate change. Climatic Change 53 (4), 413–466.

Azar, C., Sterner, T., 1996. Discounting and distributional considerations in the context of global warming. Ecological Economics 19 (2), 169–184.

Barbier, E.B., 1993. Sustainable use of wetlands. Valuing tropical wetlands benefits: economic methodologies and applications. Geographical Journal 159 (1), 22–32.

Barnes, J.I., 1996. Economic characteristics of the demand for wildlife-viewing tourism in Botswana. Development Southern Africa 13 (3), 337–397.

Barnes, J.I., Schier, C., van Rooy, G., 1999. Tourists' willingness to pay for wildlife viewing and wildlife conservation in Namibia. South African Journal of Wildlife Research 29 (4), 101–111.

Brown, G., Ward, M., Jansen, D.J., 1995. Economic Value of National Parks in Zimbabwe: Hwange and Mana Pools. ZWLMEC Project Report. World Bank, Washington, DC, USA. 55 pp.

Child, B., 1990. Economic analysis of buffalo range ranch. In: Kiss, A. (Ed.), Living with Wildlife Resource Management with Local Participation in Africa. World Bank, Washington, DC, pp. 193–204.

Clark, C., Davenport, L., Mkanga, P., 1995. Designing Policies for Setting Park User Fees and Allocating Proceeds Among Stakeholders: The Case of Tarangire National Park, Tanzania. World Bank, Washington, DC.

Department of National Parks Zimbabwe, 1991. Table 6.3. In: Pearce, D., Moran, D. (Eds.), The Economic Value of Biodiversity. Earthscan, London, pp. 86–91.

Djoh, E., van der Whal, M., 2001. Gorilla-Based Tourism: A Realistic Source of Community Income in Cameroon? Rural Development Forestry Network (RDFN) paper 25e(iii). ODI—Overseas Development Institute, London, 31–37. http://www.odi.org.uk/fpeg/publications/rdfn/25/rdfn-25e-iii.pdf.

Fankhauser, S., 1995. Valuing Climate Change: The Economics of the Greenhouse. Earthscan, London. 180 pp.

FAO, 2002. Forest Valuation Database. http://www.fao.org/forestry/site/valuation/en.

Fearnside, P.M., 2002. Time preference in global warming calculations: a proposal for a unified index. Ecological Economics 41 (1), 21–31.

Filion, F.L., Foley, J.P., Jaquemont, A.J., 1994. The economics of global ecotourism. In: Munasinghe, M., McNeely, J. (Eds.), Protected Areas Economics and Policy: Linking Conservation and Sustainable Development. World Bank, Washington, DC, pp. 235–252.

Giorgi, F, 2001. Modelling Regional Climate Change. Sci Dev. Net, Climate Change Policy Briefs. http://www.scidev.net/dossiers/index.cfm?fuseaction=policybrief&dossier=4&policy=30.

Holdridge, L.R., 1947. Determination of world plant formations from simple climatic data. Science 105 (2727), 367–368.

Holdridge, L.R., 1967. Life Zone Ecology. Tropical Science Center, San José de Costa Rica. 206 pp.

Holdridge, L.R., 1987 c. 1978. Ecología Basada En Zonas De Vida. Instituto Interamericano de Ciencias Agrícolas (IICA), San José, Costa Rica. 216 pp.

Howard, P.C., 1996. The opportunity costs of protected areas in Uganda. Presented at the Economics of Biodiversity Loss, A workshop for the development of a framework for biodiversity loss assessment, April 1996, IUCN, Gland, Switzerland. http://www.biodiversityeconomics.org/pdf/960401-11.pdf.

IPCC, 1998. An Introduction to Simple Climate Models Used in the IPCC Second Assessment Report IPCC Technical Paper II, WMO/UNEP, Geneva, 47 pp.

IPCC, 2002. The IPCC Data Distribution Centre Access to the GCM Archive (ISA92 and similar scenario runs). http://www.ipcc-ddc.cru.uea.ac.uk/dkrz/dkrz_index.html.

Krug, W., 2003. Maximising Sustainable National Benefits from Nature Tourism in Namibia. Thesis submitted for the degree of Doctor of Philosophy. University College London, 335 pp.

Leemans, R., 1990. Possible Changes in Natural Vegetation Patterns Due to a Global Warming. IIASA Working Paper WP—90-08 and Publication Number 108 of the Biosphere Dynamics Project. International Institute of Applied Systems Analysis (IIASA), Laxenburg, Austria, 22 pp.

Legates, D.R., 2002. Limitations of Climate Models as Predictors of Climate Change. Brief analysis, vol. 396. The National Center of Policy Analysis (NCPA). 2 pp.

Malhi, Y., Wright, J., 2004. Spatial patterns and recent trends in the climate of tropical forest regions. Philosophical Transactions of the Royal Society of London, B 359, 311–329.

Markandaya, A., Pearce, D., 1988. Natural environments and the social rate of discount. Project Appraisal 3 (1), 2–12.

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., Kasey, S.W. (Eds.), 2001. Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the IPCC Third Assessment Report. Cambridge University Press, Cambridge, UK. 1032 pp.

Mercer, E., Kramer, R., Sharma, N., 1995. Rain forest tourism—estimating the benefits of tourism in a new national park in Madagascar. Journal of Forest Economics 1 (2), 239–269.

MET, 1997. Namibia visitor survey 1996/7. Ministry of Environment and Tourism, PPMIU, Windhoek, Namibia.

Munasinghe, M., 1993. Environmental Economics and Sustainable Development. World Bank Environment Paper, vol. 3. World Bank, Washington, DC. 111 pp.

Nakicenovic, N., Swart, R. (Eds.), 2000. Special Report on Emissions Scenarios. Cambridge University Press, Cambridge. 612 pp.

Navrud, S., Mungatana, E.D., 1994. Environmental valuation in developing countries: the recreational value of wildlife viewing. Ecological Economics 11 (2), 135–151.

Ndoye, O., Ruiz Perez, M., Eyebe, A., 1997. The Markets of Non-Timber Forest Products in the Humid Forest Zone of Cameroon. Rural Development Forestry Network (RDFN) Paper 22c. ODI–Overseas Development Institute, London, 20p. http://www.odifpeg.org.uk/publications/rdfn/22/rdfn-22c.pdf.

New, M., Hulme, M., Jones, P., 1998. Representing twentieth-century space–time climate variability. Part I: development of a 1961–90 mean monthly terrestrial climatology. Journal of Climate 12 (3), 829–856.

NOAA/NCDC, 2002. GFDL Global Climate Model (GCM) [100 year run]. ftp://ftp.ncdc.noaa.gov/pub/datasets/gcm/readme.

Nordhaus, W.D., Boyer, J., 2000. Warming the World: Economic Models of Climate Change. MIT Press, Cambridge, MA, USA.

Norton-Griffiths, M., Southey, C., 1995. The opportunity costs of biodiversity conservation in Kenya. Ecological Economics 12 (2), 125–139.

Parmesan, C., Yohe, G., 2003. A globally coherent fingerprint of climate impacts across natural systems. Nature 421, 37–42.

Pearce, D.W., 1990. An Economic Approach to Saving the Amazonian Rainforest. Discussion paper 90-06. London Environmental Economics Centre, London, 30 pp.

Pearce, D.W., 2003. The social cost of carbon and its policy implications. Oxford Review of Economic Policy 19 (3), 362–384.

Pearce, D.W., Moran, D., 1994. The Economic Value of Biodiversity. Earthscan, London.

Pearce, D.W., Cline, W.R., Achanta, A.N., Fankhauser, S., Pachauri, R.K., Tol, R.S.J., Vellinga, P., 1996. The social costs of climate change: greenhouse damage and the benefits of control. In: Bruce, J.P., Lee, H., Haites, E.F. (Eds.), Economic and Social Dimensions of Climate Change, Equity and Social Considerations. Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom, pp. 179–224.

Pernetta, J.C., Leemans, R., Elder, D., Humphrey, S. (Eds.), 1994. Impacts of Climate Change on Ecosystems and Species: Implications for Protected Areas. 4th World Congress on National Parks and Protected Areas: (February 10–21, 1992: Caracas, Venezuela). IUCN, Gland, Switzerland. 104 pp.

Ruitenbeek, H.J., 1989. Social cost benefit analysis of the Korup project, Cameroon. WWF report prepared for the World Wide Fund for Nature and the Republic of Cameroon, London.

Simpson, R.D., Sedjo, R.A., Reid, J.W., 1996. Valuing biodiversity for use in pharmaceutical research. The Journal of Political Economy 104 (1), 163–185.

Smith, T.M., Halpin, P.N., Shugart, H.H., Secrett, C.M., 1995. Global forests. In: Strzepek, K.M., Smith, J.B. (Eds.), As Climate Changes: International Impacts and Implications. Cambridge University Press, Cambridge, pp. 146–179.

Taylor, D., Hamilton, A.C., 1994. Impact of climatic change on tropical forests in Africa: implications for protected area planning and management. In: Pernetta, J.C., Leemans, R., Elder, D., Humphrey, S. (Eds.), Impacts of Climate Change on Ecosystems and Species: Implications for Protected Areas. IUCN, Gland, Switzerland, pp. 77–94.

Tol, R., 2002. Estimates of the damage costs of climate change. Part 1 Benchmark estimates. Environmental and Resource Economics 21, 47–73.

Turpie, J.K., Siegfried, W.R., 1996. The conservation-economic imperative: securing the future of protected areas in South Africa. Africa Environment and Wildlife 4 (3), 35–37.

Turpie, J., Winkler, H., Spalding-Fecher, R., Midgely, G., 2002. Economic impacts of climate change in South Africa: a preliminary analysis of unmitigated costs. Energy and Development Research Center (EDRC), University of Cape Town, South Africa, 58p. http://www.web.uct.ac.za/depts/fitzpatrick/pdf/turpie02.pdf.

US Bureau of Economic Analysis, US Department of Commerce, 2002. National Income and Product Accounts Tables. Table 1.1.4. Price Indexes for Gross Domestic Product. http://www.bea.doc.gov/bea/dn/nipaweb/SelectTable.asp?Selected=Y.

von Storch, H., 1995. Inconsistencies at the interface of climate impact studies and global climate research. Meteorologische Zeitschrift 4, 72–80.

Wells, M., 1996. The Economic and Social Contribution of Protected Areas in New South Africa. Land and Agricultural Policy Centre, Johanesburg, South Africa.

Wilkie, D.S., 1989. Impact of roadside agriculture on subsistence hunting in the Ituri forest of northeastern Zaire. American Journal of Physical Anthropology 78 (4), 485–494.

Wilkie, D.S., Curran, B., 1991. Why do Mbuti hunters use nets? Ungulate hunting efficiency of bows and nets in the Ituri rain forest. American Anthropologist 93, 680–689.

Williams, R.H., 2001. Nuclear and alternative energy supply options for an environmentally constrained world: a long-term perspective, prepared for the Nuclear Control Institute Conference "Nuclear power and the spread of nuclear weapons: can we have one without the other?" April 2001, Princeton Environmental Institute, Princeton University, Washington, D.C.

World Resource Institute and World Conservation Monitoring Centre, 1995. Africa Data Sampler User's Guide. CD-ROM version. A geo-referenced database for all African countries. Word Resource Institute, Washington, DC.

World Tourism Organisation Commission for Africa, 2002. Speech addressed by Mr. Francesco Frangialli Secretary-General of the WTO. Thirty-eight meeting, Abuja, Nigeria 24–27 April 2002.

Yates, D.N., Kittel, T.G.F., Cannon, R.F., 2000. Comparing the correlative Holdridge model to mechanistic biogeographical models for assessing vegetation distribution response to climatic change. Climatic Change 44 (1–2), 59–87.

Zhang, H., Henderson-Sellers, A., McGuffie, K., 2001. The compounding effects of tropical deforestation and greenhouse warming on climate. Climatic Change 49 (3), 309–338.