Anticipating potential biodiversity conflicts for future biofuel crops in South Africa: incorporating spatial filters with species distribution models

Journal:	*GCB Bioenergy*
Manuscript ID:	Draft
Manuscript Type:	Original Research
Date Submitted by the Author:	n/a
Complete List of Authors:	Blanchard, Ryan; CSIR, Biodiversity and Ecosystem Services; Centre of Invasion Biology, Botany and Zoology, Stellenbosch University O'Farrell, Patrick; CSIR, Biodiversity and Ecosystem Services Richardson, David M; Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University
Keywords:	bioenergy crops, land suitability, biodiversity, spatial filters, spatial analysis, agricultural land, MaxEnt, conflict

Anticipating potential biodiversity conflicts for future biofuel crops in South Africa: incorporating spatial filters with species distribution models

Running title: Biodiversity conflicts for future biofuel crops

Ryan Blanchard[ab*], Patrick J. O'Farrell[a] and David M. Richardson[b]
[a] NRE, CSIR, PO Box 320, Stellenbosch 7599, South Africa. E-mail: Rblanchard@csir.co.za;
[b] Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa. Email: rich@sun.ac.za
* Author for correspondence

Ryan Blanchard (Author for correspondence)
NRE, CSIR, PO Box 320, Stellenbosch, 7599, South Africa.
Telephone: 021 8882626
Fax:
Email: Rblanchard@csir.co.za;

Keywords: Bioenergy crops, Land suitability, Biodiversity, Spatial analysis, MaxEnt, Conflict, Agricultural land, Spatial filters

Primary research article

Abstract

Liquid biofuel production will likely have its greatest impact through the large-scale changes in land use that will be required to meet the production of this energy source. In this study, we develop a framework which integrates species distribution models, land cover, land capability and various biodiversity conservation data to identify natural areas with (1) a potentially high risk of transformation for biofuel production and (2) potential impact to biodiversity conservation areas. The framework was tested in the Eastern Cape of South Africa, a region which has been earmarked for the cultivation of biofuels. We expressly highlight the importance of biodiversity conservation data that enhances the Protected Area Network to limit potential losses by comparing the overlap of areas likely to become cultivated with 1) protected areas; 2) biodiversity hotspots not currently protected; and 3) “ecological corridors” (areas deemed important for the migration of species and linkages between important biodiversity areas). Results indicate that the introduction of spatial filters reduced available land from 54% to 45%. Including all biodiversity scenarios reduced available land to 15% of the Eastern Cape should avoiding conflict with biodiversity conservation areas be prioritised. The assumption that agriculturally marginal land offers a unique opportunity to be converted to biofuel crops does not consider the biodiversity value attached to these areas. We highlight that decisions relating to large-scale transformation and changes in land cover need to take account of broader ecological processes. Determining the spatial extent of threats to biodiversity facilitates the analysis of spatial conflict. This paper demonstrates a proactive approach for anticipating likely habitat transformation and provides an objective means of mitigating potential conflict with existing land use and biodiversity.

Introduction

Almost all scenarios for energy provision into the future include some focus on the emergence of a bioeconomy that includes large-scale bioenergy and biofuel production that offers lower greenhouse gas emissions than fossil fuels (Alkemade *et al.*, 2009, Slade *et al.*, 2011, Tilman *et al.*, 2009). There is a strong focus on bioenergy crops that can be grown on lands that will not directly compete with existing agricultural resources. Plant biomass, including traditional wood use, is currently the largest contributor to renewable energy (Tollefson, 2011). Projections indicate increasing demand for biomass fuel sources which are seen as crucial for a low-carbon future (Fischer *et al.*, 2009). The emergence of this new economic sector will entail radical and extensive changes in land use and land cover (Wiens *et al.*, 2011). To help meet this demand, dedicated energy-crop cultivation is expected to follow large-scale and diversified practises similar to that of agriculture and forestry (Firbank, 2008, Koh *et al.*, 2009, Richardson & Blanchard, 2011). However, regions with suitable soil and climatic conditions which are currently considered marginal for conventional agriculture are likely to be targeted as potential production areas (Hoogwijk *et al.*, 2003, Wicke *et al.*, 2011). This potential increase in land conversion is likely to have severe consequences for biodiversity (Evans *et al.*, 2010, Wilcove *et al.*, 2000), as a wider range of land types can be brought into production when compared to conventional agricultural areas (Beringer *et al.*, 2011, Field *et al.*, 2007, Righelato & Spracklen, 2007). One of the challenges is to find suitable land to grow bioenergy crops in a manner that does not threaten biodiversity.

Among the innovative ways of selecting suitable land for bioenergy are methods that involve spatial planning (Li *et al.*, 2012). To avoid biodiversity losses the designation of biodiversity areas have been linked to protected areas or areas of high biodiversity conservation value.

However, judging from recent literature, there is little consensus as to which biodiversity information should be included. For example, Beringer *et al.* (2011) rely on the overlapping of global biodiversity datasets to inform land use restrictions. More importantly, Wicke *et al.* (2011) highlights the fact the biodiversity data is under-represented for some regions within global datasets. In this paper we aim to illustrate that assumptions regarding areas of biodiversity importance are crucial for identifying areas that are suitable for biofuel production. Despite the many examples of innovative frameworks adopting a spatial approach to anticipate and reduce land use conflicts (Nelson *et al.*, 2009, O' Farrell *et al.*, 2012, Schweers *et al.*, 2011, Stoms *et al.*, 2011), none of these have focused solely on biodiversity and the value of data availability to the overall impact analysis.

Attempts at estimating the extent to which biofuels can contribute to global energy supplies has produced informative global estimates that include the spatial distribution of potential biofuel producing areas (Fischer *et al.*, 2007, Smeets *et al.*, 2004). To accomplish this either mechanistic models have been calibrated with established crop species or broad-scale vegetation models have been adapted to indicate areas with the greatest potential for energy production (Beringer *et al.*, 2011, Hoogwijk *et al.*, 2005, Lapola *et al.*, 2010, Smeets *et al.*, 2004, van Vuuren *et al.*, 2009). The focus of this work has often been at a global scale, typically overestimating potential biomass supply, returning estimates regarded as being in the upper range of biomass potentials (Beringer *et al.*, 2011, Lapola *et al.*, 2009, Slade *et al.*, 2011, van Vuuren *et al.*, 2009). The need to generalise model parameters stem from the large pool of potential energy crops for which little physiological information exists making the individual calibration of these models difficult (Lapola *et al.*, 2009). This is often addressed as a limitation of mechanistic models (Estes *et al.*, 2013, Fischer *et al.*, 2010, Smith *et al.*, 2010).

The recent comparison of mechanistic and empirical models has positioned the latter as useful tool to determine potential distribution of certain agricultural species (Estes *et al.*, 2013). In particular, current species distribution modelling (SDM) techniques that rely on presence-only records have been shown to provide a useful screening tool to determine suitable climatic environments for potential dedicated energy crops (Evans *et al.*, 2010). The recent use of SDMs in determining suitable areas for biofuel feedstock production demonstrates the potential for estimating the broad climatic suitability for species with limited known physiological data (Barney & DiTomaso, 2011, Evans *et al.*, 2010, Trabucco *et al.*, 2010). For example, the modelling tool MaxEnt has been shown to perform well when compared with other SDMs (Edgerton, 2009, Elith *et al.*, 2006, Elith *et al.*, 2011, Evans *et al.*, 2010, Phillips *et al.*, 2006) and more recently mechanistic models themselves (Estes *et al.*, 2013). Since many countries are seeking to adopt and establish renewable energy strategies, the matching of suitable feedstocks to available areas is likely to become increasingly prominent in the literature. SDMs may therefore have the potential to act as a first-cut analysis to determine the broad climatic suitability of dedicated energy crops that rely on a rain-fed water supply. Dedicated energy crops are a potential solution to the challenge of producing sufficient biomass for biofuel production, without competing for similar resources or affecting the pricing and availability of food (Fischer *et al.*, 2009).

To fully address potential impacts of biofuel production on biodiversity (Barney & DiTomaso, 2011, Dauber *et al.*, 2010, Groom *et al.*, 2008, Wiens *et al.*, 2011) there is a need to include limiting factors which act as spatial filters that ultimately constrain the location of bioenergy cultivation in the landscape (Beringer *et al.*, 2011). However, the quality of information used as limiting factors could potentially underestimate future impacts (Smith *et al.*, 2010, Tilman *et al.*, 2009). We focus on biodiversity as an example of one such spatial filter that has important implications for limiting potential future land uses (Beringer *et al.*, 2011, Schweers *et al.*, 2011, Slade *et al.*, 2011, van Vuuren *et al.*, 2009, Wicke *et al.*, 2011). There are multiple biodiversity datasets available, often generated at global scales, and there is little consensus on which datasets to include in modelling scenarios (Beringer *et al.*, 2011, Brooks *et al.*, 2006). Consequently, biodiversity is usually accounted for through the identification and exclusion of formal protected areas. Although this can avoid critical biodiversity losses, the question of whether this approach is adequate for biofuel production has not yet been addressed in the literature. Assessing the vulnerability of untransformed land that has no formal protection, yet is easily accessible, is a worthy conservation objective (Reyers, 2004, Wessels *et al.*, 2000).

Although protected area networks aim to safeguard existing biodiversity for future generations, the location and configuration of these areas often arose haphazardly, rather than following decisions based on rigorous science (Wicke *et al.*, 2011). Conservation areas are often in areas with poor agricultural potential. Consequently, tradeoffs with agriculture or other potential land uses have mostly been avoided until now (Gabriel *et al.*, 2009). Whilst these areas may be relatively high in diversity, they may not adequately conserve the required regional taxa or important ecosystem functions that drive evolutionary change in landscapes (Berliner & Desmet, 2007). For example, in South Africa, the need to increase the Protected Area Network has resulted in the identification of additional areas needed to meet conservation goals (Government of South Africa, 2008). However, the management and procurement costs limit the total inclusion of all suitable areas (Gallo *et al.*, 2009). To avoid future tradeoffs with food and feed production, biofuel production strategies have typically highlighted these marginal areas as key production sites (Romijn, 2011, Wicke *et al.*, 2011). Research interest in dedicated energy crops that may fill this potential niche is increasing,

increasing the potential for future land transformation in these areas. Where conventional biofuel crops may be required to occupy arable areas, the diversification of the industry may need marginal areas to be brought into production as well. This provides an excellent opportunity to test a framework regarding biodiversity as a spatial limiting factor. Given that land use has a severe impact on biodiversity integrity, it would be useful to understand potential impacts that biofuels, as a land use option, present (O' Connor & Kuyler, 2009).

In this paper, we present a framework that combines the outputs of global scale species distribution models with a localised land suitability analysis, to identify areas with a potentially high risk of transformation for biofuel production. To demonstrate the effect of biodiversity as a spatial filter for bioenergy suitability we use the Eastern Cape province of South Africa. The framework aims to simplify the complex issues surrounding land use planning that are likely to be typical for developing world scenarios. We use biofuel production as one proxy for agricultural expansion which is a known driver of habitat loss. Additional spatial layers and socio-economic variables can be added to the framework to further increase the resolution of conflict between biodiversity and biofuel production. More specifically, we illustrate that spatial filters could prove useful in model predictions which are aggregated on broad scale climate data. These provide a much more realistic estimate of available land and potential conflict. This proactive approach anticipates likely habitat transformation and provides an objective way of mitigating potential conflict with existing land use and biodiversity (Lindborg *et al.*, 2009, Wessels *et al.*, 2003).

In summary, our objectives were to: 1) determine the potential spatial extent of land available; 2) identify potential biofuel crops based on species distribution models; and 3) test a biodiversity-impact framework aimed at highlighting the importance of inclusive biodiversity data.

Material and methods

Study area

The Eastern Cape province of South Africa (Fig. 1) was chosen as our study area because it is earmarked to undergo large-scale changes in land use as a result of national developmental policies, which include possible biofuel production (Berliner & Desmet, 2007, Blanchard *et al.*, 2011). This region is also recognised as a biodiversity hotspot that is threatened by a long history of cultural and politically enforced land use practices (Critical Ecosystem Partnership Fund, 2010, Evans *et al.*, 1997). As a result, the dichotomy of development pressures and conservation are prevalent in this region.

South Africa's biofuel policy forms part of its Renewable Energy portfolio which includes wind and solar energy production (Department of Minerals and Energy, 2003). Concurrently, biofuel production is meant to contribute to enterprise development and on going job creation programmes. Biofuels, which are as yet an untested industry in South Africa, are therefore likely to compete with alternative land use options for reducing poverty. The expansion of conventional agricultural practices or increased livestock farming are among alternative potential land use options. However, the Government has declared support for biofuel production within the former "homeland" areas of South Africa, to facilitate job creation and the improvement to the socio-economic status of informal, small-scale or enterprising farmers in the region (Department of Minerals and Energy, 2003, Department of Minerals and Energy, 2007). On going research into biofuel viability are currently underway in the Eastern Cape with projects currently in the establishment phase (Musango *et al.*, 2010). A stable market for biofuels would not exclude the commercial farming sector, which has the capacity to increase production of candidate crops should prices allow for it (Von Maltitz & Brent, 2008). The expected potential for agriculture, forestry and agro-processing initiatives in the former homeland areas are considered to be large, but currently unrealised (Lynd *et al.*, 2003). Reasons include a strong traditional focus on livestock farming and a land tenure system based on tribal or communal land ownerships (Hoffman & Ashwell, 2001). The current trend of rural de-agrarianisation may also contribute to the recent increase in abandoned land, as well the slow uptake of new farming activities (Andrew & Fox, 2004, Davis *et al.*, 2008). Both commercial and subsistence farming are practised in the Eastern Cape, with the latter achieving significantly lower yields in some areas (Shackleton *et al.*, 2001). It is anticipated that biofuel production could supply the needed investments to increase yields in some regions through the supply of much needed technical knowledge and infrastructural investments within former homeland areas (Biggs & Scholes, 2002).

The Eastern Cape is renowned for its biological diversity containing five of the seven biomes in South Africa, and includes the Maputaland-Pondoland-Albany biodiversity hotspot (Critical Ecosystem Partnership Fund, 2010, Driver A. *et al.*, 2012, Mucina & Rutherford, 2006). Large areas of grassland and savanna ecosystems are strongly underrepresented in the province’s formal protected area network and are at risk of current and future land transformation (Driver A. *et al.*, 2012, O' Connor & Kuyler, 2009). The lack of formal protection and extensive land use practices have led to some vegetation types in the grassland biome being proclaimed vulnerable or critically endangered (Mucina & Rutherford, 2006). The expansion of forestry, agriculture and urbanisation of rural areas are among the key threats to biodiversity. Furthermore overgrazing, alien plants and poor management of agricultural lands have resulted in degraded and transformed areas (Evans *et al.*, 1997, Hoffman & Ashwell, 2001). Despite this only 5% of the area is protected within 190 nationally declared Protected Areas (0.69Mha) and 79 informal conservation areas (0.25Mha) that gives responsibility of conservation to landowners operating private game or nature reserves.

The dynamic setting of the Eastern Cape provides a unique opportunity to validate a conceptual framework taking advantage of a large biodiversity network and the potential impacts of land use change represented by biofuel production. The inclusion of biofuels as a possible land use option raises additional awareness of potential biodiversity threats. Species outlined in the biofuel strategy include traditional agricultural crops such as soya or canola, which are expected to be grown on fertile soils, to achieve maximum yields. In this study we model biofuel crops which are meant to be grown with fewer inputs than conventional agricultural crops. These species are considered suitable for degraded or marginal areas with the potential to offer greater benefits to farmers in such landscapes. Although there is much uncertainty regarding the viability of these crops (Achten *et al.*, 2010) or the willingness to cultivate such crops (Amigun *et al.*, 2011), the potential land resources may exist in Eastern Cape.

Description of the modelling framework

We propose the framework presented in Fig. 2 which provides a schematic outline of the methodology used in this study. The framework builds on existing methodologies used to determine land availability (Fiorese & Guariso, 2010) and includes the use of species distribution models to provide a potential biofuel layer with which to investigate biodiversity conflicts. The framework also highlights the use of localised spatial filters to analyse conflict. Unfortunately, we are not able to capture the full complexity of land tenure and other socio-political issues in the region as explained above but rather focus on a limited set of issues. The framework presents a simplified approach to this complexity which has the capacity to incorporate more complexities should the need arise. We summarise these logical components of the framework in more detail below:

Species selection and data preparation

South Africa's biofuel strategy aims to produce bioethanol and biodiesel but excludes the use of staple food crops, such as maize, for biofuel production. Recognised species are conventional agricultural crops like sugar cane, sugar beet, sunflower, canola and soya bean, intended for production on unutilised arable land (Von Maltitz & Brent, 2008). Our species choice therefore focuses on likely alternative energy crops based on international interest as gauged by a literature search on the ISI Web of Science. These species are anticipated not to compete with conventional agricultural crops for resources intended for food and feed production. The keywords, 'biofuel', 'biomass' and 'bioenergy', were used to determine the most common crop candidates as found in searches of articles, titles or abstracts. Characteristics that make some energy crops attractive as biofuel feedstocks include a wide environmental tolerance, rapid growth, ease of establishment, low water demand and the potential to generate a high biomass or prolific seed production. We included current plants listed as invasive in South Africa, as these may also provide a source for biomass production. The plants were: *Acacia mearnsii*, *Sorghum halepense* and *Arundo donax.* Suitable locations for selected biofuel species not currently cultivated in South Africa were modelled using MaxEnt ver. 3.3.3 (Phillips *et al.*, 2006). To reduce the possibility of sampling bias, we used location records from many online global data sets to estimate the potential global range. The online databases used include: the Global Biodiversity Information Forum (GBIF, www.GBIF.org); the Australian Virtual Herbarium (AVH, www.ersa.edu.au/avh); The National Commission for Knowledge and Use of Biodiversity (CONABIO, www.conabio.gob.mx) and the Southern African Plant Invaders Atlas (SAPIA, www.agis.agric.za, (Henderson, 2007)). Downloaded data were screened for geo-referenced records only and where possible erroneous records were removed from the dataset following analysis in a GIS (ARCGIS 9.3). To further reduce sampling bias, records were regularised to the 5-minute WorldClim environmental data, resulting in one record per grid cell using the ENMT Tools package version 1.3 (Warren & Seifert, 2011).

Modelling methodology and calibration

Our decision to use MaxEnt as our single species distribution model is based on the evidence that MaxEnt can model the relative suitability of a species (including some agricultural crops), to accurately predict the potential spatial distribution (Estes *et al.*, 2013, Evans *et al.*, 2010). MaxEnt determines the environmental requirements of a species by matching globally available temperature and rainfall variables to the closest empirical average of the species habitat provided (Phillips *et al.*, 2006). The outputs are indicated as relative suitability within the region modelled, indicative of the climatic suitability for a particular species. The full set of nineteen bioclimatic variables, downloaded from the WorldClim database (http://www.worldclim.org, (Hijmans *et al.*, 2005)), were used to train the models and to determine the most important environmental variables. The relative performance of each variable was firstly determined by MaxEnt by means of 'training gain', which is the improved predictability of MaxEnt based on the incorporation of a particular variable (Phillips *et al.*, 2006, Trabucco *et al.*, 2010). Following this we reduced the overall number of explanatory variables to a limited set of more significant and less correlated variables to increase the transferability of model results (moving from the realized to the fundamental niche). The use of correlated environmental variables can result in model overfitting (model being too constrained) which can be exacerbated in areas outside of the training range (Elith & Leathwick, 2009, Phillips *et al.*, 2006, Trabucco *et al.*, 2010). Important variables were selected following a correlation analysis using Pearson's correlation with a cut-off of >0.8 (Blach-Overgaard *et al.*, 2010). In addition to climate variables, we included soil variables obtained from the Harmonised World Soil Database (FAO, 2012), if it was shown to be important and provided a better model fit.

The area where MaxEnt draws climate samples from is known as the background; the choice of this area has a major influence on the outcome of the model (Elith *et al.*, 2011, Vanderwal *et al.*, 2009). We chose the global Köppen-Geiger climate classification system, as this provides a uniform background layer and is widely used to determine agronomic potential of plant species (Trabucco *et al.*, 2010, Webber *et al.*, 2011). The Köppen-Geiger classifications, as applied to the 5-minute resolution WorldClim global climatology (www.worldclim.org), were downloaded from the CliMond set of climate data products (www.climond.org, (Kriticos *et al.*, 2011)). Backgrounds were produced by intersecting occurrence records for each of the different biofuel species with the Köppen-Geiger polygon layers in a GIS (ARC-GIS 9.3). Following Webber *et al.* (2011), Köppen-Geiger polygons were included in the background if they contained one or more records of the biofuel species. This inclusive approach allows for the full ecological range of the species to be used. This reduces the need for extrapolation to areas unsampled that might cause the model to be ecologically questionable.

The modelling procedure followed that of Elith *et al.* (2011) using only hinge features with default regularization parameters. Final models were tested using 20% of the dataset whereas variation in the environmental variables was tested using 5-fold cross validation. Model outputs were tested for goodness of fit with training data using the threshold independent Area Under the receiver operating characteristics Curve (AUC), which provides a measure of model accuracy commonly used in predictive distribution models. Where a value of 0.5 indicates that the model is no better than random, a more accurate model value are >0.75 (Phillips & Dudík, 2008). As a measure of model suitability, threshold indicators were evaluated using Fischer's exact 1-tailed binomial test (see below) as applied to model prevalence and sensitivity to verify the model (Thompson *et al.*, 2011, Webber *et al.*, 2011).

This method tests for the sensitivity of the model using the proportion of the model background estimated to be climatically suitable (Webber *et al.*, 2011).

Suitability

For the purpose of this study, thresholds were used to convert the continuous output of MaxEnt model predictions to indicate suitable and unsuitable areas. The choice of threshold affects the mapped results and could significantly affect perceived implications of environmental impacts of modelled biofuels. For example, increasing this threshold value has the negative effect of reducing the predicted suitable area as the criteria for suitability increases (Evans *et al.*, 2010). There is currently no dominant method for choosing a threshold value and current options are either based on subjective or objective methods depending on the research question (Liu *et al.*, 2005, Pearson, 2007). For example should the potential range of a species need to be calculated, an inclusive measure such as the lowest presence threshold (LPT) would be appropriate. This approach maximises sensitivity, whereby all presence points are included in the model prediction. If relative suitability was to be maximised, then we may opt for a higher threshold value or balancing presence point omissions and sensitivity. For this study, we choose threshold values that indicate suitable locations with a higher relative suitability, which we assumed to be a requirement for indicating agricultural potential. To illustrate uncertainty in determining suitability, suitable areas were calculated for threshold values associated with the LPT, cut-offs at 95% and 90% of presence points and where sensitivity equals sensitivity. The use of thresholds were evaluated using the binomial test (Pearson, 2007). More conservative threshold values exclude the lowest probability cells. Subsequently, all areas that fell below these threshold values were excluded from further analyses.

Spatial filter – Available and suitable land

Land availability was determined by current land use patterns (derived from land-cover) and limited to include terrain with a slope less than 16 degrees (equation 1). Land-cover classes representing natural and non-natural habitats were selected from the South African National Land Cover database (Fairbanks *et al.*, 2000) and re-classified in ARC-GIS 9.3. Land-cover classes representing potential food or production areas (rain-fed and irrigated croplands, forestry plantations) and areas totally unsuitable for biofuel production (water bodies, urban and mining areas) were excluded from further analysis. Excluding steep slopes, as calculated from a 90m SRTM DEM, retains areas which are suitable for conventional cultivation and plantation forestry offering lower production risks and costs (Fischer *et al.*, 2007).

Maximising the economic viability of biofuel production requires landscapes to have some potential for plant growth (Achten *et al.*, 2010). To determine land suitability, a measure of economic viability, we limited our analysis to likely agro-ecosystems using the Land Capability Classification for South Africa (Schoeman *et al.*, 2000) (equation 2). Land capability class units act as a third spatial filter to indicate the technical potential of the available land as well as to identify current or future land transformation threats. Land capability classification identifies eight classes associated with decreasing levels of agricultural potential. Each class represents similar production potential and physical limitations (i.e. soils risk of erosion, physical terrain constraints and climate). Three classes were derived here, Arable (Class 1-4), Marginal (Class 5 and 6) and Excluded (Class 7 and 8).

The calculations were carried out using raster grids in ARC-GIS 9.3:

$$\textbf{Availability}_i = \textbf{Landuse x Slope} \qquad \textbf{(1)}$$

$$\textbf{Suitability}_i = \textbf{Availability}_i \textbf{ x Land Capability}_i \qquad \textbf{(2)}$$

Where *i* is the grid cell that spatial filters such as land use, slope and land capability are applied to derive an estimation of suitability, indicating natural areas with high potential for cultivation based on soil and land use characteristics.

Another form of land use in the region is commercial livestock farming, carried out over large areas. Whilst potential livestock carrying capacities have been mapped in the Eastern Cape (Scholes, 1998), the locations of ranches are not available and we exclude this land use from our analysis. However, accounting for this land use will further reduce land availability.

Spatial filter - Biodiversity

South Africa has large tracts of untransformed land, much of it suitable for cultivation of crops or for some forms of forestry (Reyers, 2004). Our approach is based on the assumption that intact habitat is indicative of higher habitat quality, translating to greater ecosystem health. Any changes to land cover through cultivation, reduces the habitat quality and in turn results in biodiversity losses. Usually areas of high biodiversity, indicated by the location of protected areas, are excluded from land availability assessments.

We used three synergistic data sources for identifying and capturing biodiversity features: 1) the formal Protected Area network (PA), 2) the National Protected Area Expansion Strategy (NPAES) and 3) a region-based systematic conservation plan, The Eastern Cape Biodiversity Conservation Plan (ECBCP) (Berliner & Desmet, 2007). The data were extracted from an online database supplied by the South African National Biodiversity Institute online geographic information database (www.BGIS.co.za).These datasets provided the necessary information to produce three biodiversity scenarios (Table 1) used as spatial filters for biodiversity.

There is a recognised need to expand the existing network of protected areas in South Africa, so as to account for complementarity (being representative of distinctive features in the landscape), irreplaceability (a measure of conservation option lost in a landscape) and to allow for habitat shifts under future climate projections. The NPAES indicates areas of highest priority for future conservation needed to meet representative biodiversity targets as well as protect areas under future climate change (Government of South Africa, 2008). The ECBCP is based on the systematic conservation planning approach of identifying areas needed to maintain corridors and ecological processes (Driver *et al.*, 2005, Margules & Pressey, 2000). This plan identifies critical biodiversity areas and important *ecological corridors* (areas deemed important for migration and linkages between important biodiversity areas). For this analysis we defined *important biodiversity areas* by combining the critical biodiversity areas of the ECBCP with the NPAES to create a single biodiversity priority map.

Analysis of conflict

Two measures of threat status are shown 1) *Vulnerability* - determined as the total overlap of each biodiversity scenario with agricultural potential (equation 3) and 2) *Conflict* - calculated as the spatial overlap of modelled suitability of energy crops with vulnerable areas (equation 4). Each model was converted into a binary (0=feature absent, 1=feature present) surface layer and used to indicate positive interactions with vulnerable grid cells. All SDM outputs (derived from above) were re-sampled to the coarsest resolution used in the land availability assessment (i.e. 90m of the SRTM DEM). Model results provide a measure of suitability at the scale of the input variables, which in this case is 5 minute data. The assumption that all land within a suitable cell is available contributes to the overestimation of land availability (Evans *et al.*, 2010).

$$\mathbf{Vulnerability}_{b} = \mathbf{Suitability}_{i} \text{ x } \mathbf{Biodiversity}_{b} \qquad \mathbf{(3)}$$

$$\mathbf{Conflict}_{species} = \mathbf{SDM}_{output} \text{ x } \mathbf{Vulnerability}_{b} \qquad \mathbf{(4)}$$

Where *b* represents biodiversity scenario.

Results

Model evaluation and prediction of suitability

The potential distribution of the nine biofuel species are presented in Fig.3. The MaxEnt models performed adequately, with AUC values ranging between 0.78 and 0.92 for training data, based on a 5-fold cross validation (Table 2). Perfect models produce an AUC value close to 1, whereas models with a value less than 0.5 are considered random. All models were statistically significant using the exact binomial test for the threshold values indicated (Table 2).

Matching plant species to novel climates requires careful consideration especially when training and prediction areas do not overlap. The multivariate environmental suitability surface (MESS) map is a feature included in MaxEnt that allows the user to identify areas where environmental variables fall outside the training range, thus indicating caution during model evaluation (Elith *et al.*, 2010). However, the modelled environmental variables for each species matched those within the Eastern Cape and were within accepted limitations according to the MESS maps.

Suitability maps were produced using the threshold model values associated with the LPT, 95%, 90% and where sensitivity was equal to specificity for display purposes. These values indicate an increasingly stricter threshold that can affect the area displayed as suitable or unsuitable. Increasing the threshold value for predictions of relative suitability results in a decrease in the area projected to be suitable (Fig. 4). Values at the LPT incorporate all presence points resulting in large overlaps within the study region for all species. The species with the largest suitable climatic range within the Eastern Cape are locally present such as *Arundo donax*, *Acacia mearnsii* and *Sorghum halepense* (Table 2). These results are likely to be explained by the high percentage of presence points occurring in the region. Other species with international interest have among the smallest ranges such as *Camelina sativa* and *Panicum virgatum.*

Land availability

A large portion of the study area is untransformed with natural areas accounting for ~82% of the province (Table 3). Of the remaining area, ~16% is transformed or degraded (Fig. 1). Arable areas cover ~18% of the Eastern Cape, with ~5% currently in use following the selection criteria described (Fig. 2). These arable areas are scattered throughout the eastern half of the province (Fig. 1). Despite the perceived condition of marginal areas which covers ~38% of the Eastern Cape, ~40% of cultivation is indicated to occur here (Table 3). For this reason, we include marginal areas within the current analysis. Excluding steep slopes and accounting for the technical ability of the land reduced available land from ~54% to ~46% of the Eastern Cape province. The resulting spatial filter that can be applied to modelled outputs account for ~18% of arable land and ~41% of marginal land. The remaining area has been characterised as excluded, with limited potential for future land use transformation.

Biodiversity scenarios

The three biodiversity spatial layers used to indicate conservation scenarios revealed sizeable differences to the overall area considered important for biodiversity conservation (Table 4). The majority of Protected Areas (including informal protected areas) are found in the south-western half of the region and account for ~6% of the province. These Protected Areas have low cultivation potential and are distributed across marginal and excluded areas. Important biodiversity areas, represented by merging the NPAES with Critical Biodiversity areas of the ECBCP, account for ~25% of the province. Approximately 39% of IBA's are considered either arable or marginal representing increased vulnerability to future land use transformation. Recognised ecological corridors identify a further ~41% of the land area contributing to important functions needed for biodiversity conservation, approximately half of which are potentially vulnerable to future land use transformation. Accounting for all biodiversity scenarios highlights ~72% of the Eastern Cape as contributing to biodiversity conservation, as compared to 5% if only Protected Areas were to be considered. Figure 5 shows the increasing vulnerability of suitable land as biodiversity scenarios are included in the land availability assessment. Should all biodiversity scenarios be accounted for in the suitability analysis then potential available land is reduced from 7.6 Mha to 2.6 Mha. The remaining arable or marginal areas have that no recognised biodiversity features account for ~15% of the province, of which marginal areas make up the largest proportion.

Biofuel conflict analysis

In order to match climatically suitable areas with available land the spatial filters described above were applied to each MaxEnt model projection. The climatic projections were reduced to coincide with available land, excluding climatically suitable areas where commercial cultivation may be unfeasible. The range of biofuel species projections that overlap with available areas and in particular vulnerable areas are presented in Table 5. The overlap analysis showed that, depending on the species chosen, between 0-98% of arable areas and remaining marginal areas are predicted as climatically suitable for the biofuel species chosen. Similarly, IBA's and EC's provide climatically suitable habitat for the biofuel species modelled, resulting in significant potential conflict with biodiversity conservation areas.

The difference between arable and marginal areas is reflected as threshold values are increased to indicate higher relative suitability. The level of potential transformation within arable areas remains higher than marginal areas. This can be related to more favourable climatic conditions within the arable classes used to determine land capability. However marginal areas account for a larger proportion of the Eastern Cape that reflect climatic suitability for biofuel cultivation. These areas coincide with EC's and IBA's that are not protected under the formal conservation network.

Discussion

Outcomes of the modified framework

A framework incorporating species distribution models and land suitability analysis was tested to determine biodiversity conflict in a region of South Africa where the production of biofuel is being considered. This approach demonstrates the importance of spatial filters as applied to species distribution model estimates. It is important to note that while MaxEnt provides an overall climatic niche for a species the application of spatial filters can identify areas with the most likelihood of being converted. However, these results do not infer the potential to reach high abundance or in this case high yield and environmental factors that achieve this goal are outside the scope of this study. The framework presented allows for the spatial extent of potential biofuel crops to be visualised and placed within a localised land use context. More importantly, we highlight the importance of biodiversity elements as spatial filters to reduce potential impacts of biofuel production on biodiversity.

Our aim in highlighting the need for data that is inclusive of ecological processes has been achieved, and the increased potential conflict with future land use, demonstrated. The large body of evidence that points to inadequate reserve selection based on land use opportunities does not facilitate conservation within productive landscapes (Knight & Cowling, 2007). As a result, the likelihood of not accounting for ecological processes or other important biodiversity areas that occur outside of protected areas may lead to an inflated estimation of available land resources. Biodiversity is often in conflict with developmental requirements and the former is often given low priority by governments (Wilson *et al.*, 2010), with natural habitat acting as maintenance areas often being overlooked within managed landscapes.

Significant biodiversity-development conflicts can only be avoided if sufficient information is included in the spatial analysis. The additional biodiversity information available for the Eastern Cape is not representative of other developing countries, where the best available global data may lack sufficient resolution. In areas where biodiversity information is lacking, the spatial filters approach allows proxy data such as carbon content to be incorporated into the analysis framework (e.g. Schweers *et al.* 2011).

Although a standardised method for determining land availability is needed, the framework proposed in this study emphasizes the importance of using available local and fine-scale data. We argue that to avoid important biodiversity losses, some measure of biodiversity occurring outside of Protected Areas should be incorporated. Where this information is lacking expert opinion (O' Connor & Kuyler, 2009) or modelled scenarios (Esselman & Allan, 2011) should be used to provide additional insight into biodiversity conflicts.

Admittedly the framework adopts a simplified approach to land use issues within the Eastern Cape. For example, the available land calculated, does not necessarily indicate the willingness to cultivate these areas. Amigun *et al.* (2011) have shown that stakeholder engagement is a key factor to the success of large bioenergy projects and in realising any projected future land use transformation or conflict estimates. Similarly, in reality, the proportion of excluded areas, as calculated above, may decrease, as potentially available land could exist in the form of abandoned or slightly degraded lands currently identified as cultivated. Biggs and Scholes (2002) showed that agricultural demand has been met by increasing yields per unit area corresponding with a contraction of farming areas. The abandonment of crop land in the 1990s as well as the de-agrarianization of rural areas has yet to be captured in land use maps.

Observation on energy crops and model predictions

Previous studies have positioned MaxEnt as an empirical model capable of capturing the distribution of agricultural crops (Estes *et al.*, 2013, Evans *et al.*, 1997). Although it is recommended that more than one model be used to determine suitability of a species (Araujo & New, 2007), the outputs provided by MaxEnt were considered robust enough for the goals of this study. Similarly, estimating the climatic potential of as yet undomesticated species and the likelihood of occurrence, we feel that the use of applying a climatic niche approach to potential crop species was justified. Recent reviews have indicated that the relative probability of occurrence should not be interpreted as an absolute probability of occurrence but rather that the areas indicated as suitable have a higher likelihood of accommodating the modelled species. New introductions will likely require the establishment of test sites (Pattison & Mack, 2008) to determine economic viability of species cultivation and to overcome the numerous challenges associated with cultivation. For similar reasons, this modelling procedure does not lend itself to yield predictions despite some innovative attempts that have used MaxEnt for this purpose (Trabucco *et al.*, 2010). The likelihood of yield estimates could be potentially simulated through the selection of high-abundance locations from presence data (Estes *et al.*, 2013), when such information is available.

Our results indicate that the Eastern Cape has potentially suitable areas for the production of biofuel crops that are of global interest. The selected crops have a wide climatic range of which many appear to be potentially suitable within and beyond the borders of the Eastern Cape (not shown here). The species chosen for this analysis also highlight the dominance of temperate species in biofuel research, with few arid and moderate climate species receiving attention in the literature (e.g. *Jatropha curcas*).

A major source of uncertainty is the presence points used in the model prediction. Using multiple online databases to extract presence records results in species backgrounds that are broader than the native habitat from which they are found (Wolmarans *et al.*, 2010). The resulting model outputs may therefore represent a shift in the niche background as compared to the native background, especially when records are obtained from managed populations found outside their natural range (Wolmarans *et al.*, 2010). The results can also be used to indicate potential risk of newly introduced and planted species becoming invasive, which is a major global concern (Barney & DiTomaso, 2011, Raghu *et al.*, 2006, Richardson & Blanchard, 2011). The most promising global energy crops are known to be invasive in some regions (Barney & DiTomaso, 2008). There are many plant species that have escaped beyond their regions of introduction due to inadequate consideration of the other potential impacts that these plants might pose (Simberloff, 2008). Assuming that such risks can be mitigated, lands with soil and climatic conditions that are marginal for conventional agriculture are likely to be targeted as potential production areas.

Biodiversity and implications for conflict

Using a spatial approach to identify areas of potential threat is of real interest to both the conservation community and local authorities as scenarios can be developed to conserve biodiversity based on the spatial arrangement of new and existing farms (Gabriel *et al.*, 2009). One of the key challenges, however, is to account for all available factors within a spatial framework. Land use in the Eastern Cape is dynamic. Commercial game farms and cultural choices are strong drivers of land use patterns. These drivers are set to continue into the future and may contribute to the preservation of biodiversity or act as ongoing threats to it. It is not practical to designate all lands for biodiversity conservation, especially when development is linked to goals such as poverty alleviation, and this increases the need for multifunctional landscapes (Koh *et al.*, 2009). Biofuels are likely to account for a small proportion of land use within the coming decades. However this could change with increasing demands for alternative fuel sources. It is prudent to acknowledge this sector in order to mitigate against extensive losses of important biodiversity areas to productive landscapes, and this stimulates the need for innovative approaches for the future design of productive landscapes (Koh *et al.*, 2009). Similarly, climate change is likely to be a major driver of shifting agricultural landscapes (Bradley. *et al.*, 2012). The projected loss of climatic suitability of current agricultural crops are likely to shift cultivation into as yet uncultivated areas where biodiversity conservation areas coincide (i.e. increased overlap with NPAES areas). Minimising potential conflict through the implementation of farming practises that maintain biodiversity at plot, region and landscape levels is of increasing importance to both current and future biodiversity conservation (Firbank, 2008, Scherr & McNeely, 2008).

Gabriel *et al.* (2009) suggest that farming on slightly poorer agricultural quality areas is linked with more extensive practices compared to intensive farming on arable lands. Extensive farming spreads the risks over a larger area and has a potentially lower impact on biodiversity. However, this depends on the crop and the farming practice adopted. Here, marginal land, not used for conventionally crops, is recognised to have biodiversity benefits. However, the financial benefits of crop diversification may drive expansion into these areas (Bryan *et al.*, 2010). A further consideration is that the potential for energy crops may seem favourable in areas where water demands can only be met by natural rainfed sources. Highlighting these areas could narrow the scope of biodiversity conflicts. Irrigation into the future will most likely be limited since 98% of water in South Africa is already allocated and a proportion of the population still requires improved access to water (Blignaut *et al.*, 2009).

While we have focused on the biodiversity conflict associated with potential land use change at a regional level, it would be useful to contrast these findings with studies undertaken using internationally available data. The conservation sector recognises the importance of ecological support areas, especially for providing corridors and migration routes, yet global estimates of biofuel production cannot adequately include these areas. The broader impacts of biofuels are likely to impact on ecosystem services in a similar fashion given their direct links to ecological processes (Gasparatos *et al.*, 2011). The potential use of ecosystem service maps should be integrated into future analysis (Freudenberger *et al.*, 2012). Apart from serving as a proxy for the broader landscape processes, this will capture the utilitarian value of biodiversity which is lacking and therefore left out of models.

The need for globally recognised frameworks and standards to guide potential land use changes should be recognised. Being consistent in accounting for conservation actions which address land use, biodiversity and ecological support areas will reduce future impacts associated with land use change. Where global datasets are not available, our results show that enhancing land suitability assessments with available local and fine-scale data can assist in providing a realistic estimation of potentials and conflicts. Similarly, land suitability methods that focus on areas with increased production potential can narrow the scope for estimating threats to biodiversity (Stoms *et al.*, 2011, Wessels *et al.*, 2003). This proactive approach anticipates likely habitat transformation and provides an objective way of mitigating potential conflict with existing land use and biodiversity.

Acknowledgements

This work was supported by the Council for Scientific and Industrial Research. DMR acknowledges the DST-NRF Centre of Excellence for Invasion Biology and the National Research Foundation (grant 85417) for support. We thank David Le Maitre for assistance with species distribution models, and Ilse Kotzee and Lindie Smith-Adao for GIS assistance. We thank the reviewers who commented on the manuscript.

References

Achten W. M. J., Maes W. H., Aerts R., Verchot L., Trabucco A., Mathijs E., . . . Muys B. (2010) Jatropha: From global hype to local opportunity. *Journal Of Arid Environments,* **74**, 164-165.

Alkemade R., Van Oorschot M., Miles L., Nellemann C., Bakkenes M., Ten Brink B. (2009) GLOBIO3: A Framework to Investigate Options for Reducing Global Terrestrial Biodiversity Loss. *Ecosystems,* **12**, 374.

Amigun B., Musango J. K., Brent A. (2011) Community perspectives on the introduction of biodiesel production in the Eastern Cape Province of South Africa. *Energy,* **36**, 2502-2508.

Andrew M., Fox R. (2004) 'Undercultivation' and intensification in the Transkei: a case study of historical changes in the use of arable land in Nompa, Shixini. *Development Southern Africa,* **21**, 687-706.

Araujo M. B., New M. (2007) Ensemble forecasting of species distributions. *Trends in Ecology and Evolution,* **22**, 42-47.

Barney J. N., Ditomaso J. M. (2008) Nonnative species and bioenergy: Are we cultivating the next invader. *Bioscience*, 64-70.

Barney J. N., Ditomaso J. M. (2011) Global climate niche estimates for bioenergy crops and invasive species of agronomic origin: Potential problems and opportunities. *PLoS ONE,* **6**, e17222 doi:17210.11371/journal.pone.0017222.

Beringer T., Wolgang L., Schaphoff S. (2011) Bioenergy production potential of global biomass plantations under environmental and agricultural constraints. *GCB Bioenergy,* **3**, 299-312.

Berliner D., Desmet P. (2007) *Eastern Cape Biodiversity Conservation Plan: Technical Report.,* Pretoria, Department of Water Affairs and Forestry.

Biggs R., Scholes R. J. (2002) Land cover changes in South Africa 1911-1993. *South African Journal Of Science,* **98**, 420-424.

Blach-Overgaard A., Svenning J.-C., Dransfield J., Greve M., Balslev H. (2010) Determinants of palm species distributions across Africa: the relative roles of climate, non-climatic environmental factors, and spatial constraints. *Ecography,* **33**, 380-391.

Blanchard R., Richardson D. M., O' Farrell P. J., Von Maltitz G. P. (2011) Biofuels and biodiversity in South Africa. *South African Journal Of Science,* **107**, 19-26.

Blignaut J., Ueckermann L., Aronson J. (2009) Agriculture production's sensitivity to changes in climate in South Africa. *South African Journal Of Science,* **105**, 61-68.

Bradley. B. A., Estes L. D., Hole D. G., Holness S., Oppenheimer M. G., Turner W. R., . . . Wilcove D. S. (2012) Predicting how adaptation to climate change could affect ecological conservation: secondary impacts of shifting agricultural suitability. *Diversity And Distributions*, 425-437.

Brooks T. M., Mittermeier R. A., Da Fonseca G. a. B., Gerlach J., Hoffmann M., Lamoreux J. F., . . . Rodrigues A. S. L. (2006) Global biodiversity conservation priorities. *Science,* **313**, 58-61.

Bryan B. A., King D., Wang E. (2010) Biofuels agriculture: landscape-scale trade-offs between fuel, economics, carbon, energy, food, and fiber. *GCB Bioenergy,* **2**, 330-345.

Critical Ecosystem Partnership Fund (2010) *Ecosystem Profile: Muputaland-Pondoland-Albany Biodiversity Hotspot*, Conservation International, Southern African Hotspots Programme and South African National Biodiversity Institute, South Africa.

Dauber J., Jones M. B., Stout J. C. (2010) The impact of biomass crop cultivation on temperate biodiversity. *GCB Bioenergy,* **2**, 289-309.

Davis J. K., Ainslie A., Finca A. (2008) Coming to grips with abandoned arable land in efforts to enhance communal grazing systems in the Eastern Cape province, South Africa. *African Journal of Range and Forage Science,* **25**, 55-61.

Department of Minerals and Energy (2003) *White Paper on Renewable Energy,* Pretoria, Online at: http://www.dme.gov.za/pdfs/energy/renewable/white_paper_renewable_energy.pdf.

Department of Minerals and Energy (2007) *The biofuel industrial strategy of the Republic of South Africa,* Pretoria, Online at: www.dme.gov.za/pdfs/energy/renewable/biofuels_indus_strat.pdf(2).pdf.

Driver A., Maze K., Rouget M., Lombard A. T., Nel J., Turpie J. K., . . . Strauss T. (2005) *National spatial biodiversity assessment 2004: Priorities for biodiversity conservation in South Africa,* Pretoria, South African National Biodiversity Institute.

Driver A., Sink K. J., Nel J. N., Holness S., Van Niekerk L., Daniels F., . . . Maze K. (2012) National Biodiversity Assessment 2011: An assessment of South Africa's biodiversity and ecosystems. Synthesis Report. South African National Biodiversity Institute and Department of Environmental Affairs, Pretoria.

Edgerton M. D. (2009) Increasing crop productivity to meet global needs for feed, food, and fuel. *Plant Physiology,* **149**, 7-13.

Elith J., H. Graham C., P. Anderson R., Dudík M., Ferrier S., Guisan A., . . . E. Zimmermann N. (2006) Novel methods improve prediction of species' distributions from occurrence data. *Ecography,* **29**, 129-151.

Elith J., Kearney M., Phillips S. (2010) The art of modelling range-shifting species. *Methods in Ecology and Evolution,* **1**, 330-342.

Elith J., Leathwick J. R. (2009) Species distribution models: Ecological explanation and prediction across space and time. *Annual Review of Ecology, Evolution, and Systematics,* **40**, 677-697.

Elith J., Phillips S. J., Hastie T., Dudı´K M., Chee Y. E., Yates C. J. (2011) A statistical explanation of MaxEnt for ecologists. *Diversity And Distributions,* **17**, 43-57.

Esselman P. C., Allan J. D. (2011) Application of species distribution models and conservation planning software to the design of a reserve network for the riverine fishes of northeastern Mesoamerica. *Freshwater Biology,* **56**, 71-88.

Estes L. D., Bradley B. A., Beukes H., Hole D. G., Lau M., Oppenheimer M. G., . . . Turner W. R. (2013) Comparing mechanistic and empirical model projections of crop suitability and productivity: implications for ecological forecasting. *Global Ecology and Biogeography,* **in press**.

Evans J. M., Fletcher R. J., Alavalapati J. I. (2010) Using species distribution models to identify suitable areas for biofuel feedstock production. *GCB Bioenergy,* **2**, 63-78.

Evans N. V., Avis A. M., Palmer A. R. (1997) Changes to the vegetation of the mid-Fish River valley, Eastern Cape, South Africa, in response to land-use, as revealed by a direct gradient analysis. *African Journal of Range and Forage Science,* **14**, 68-74.

Fairbanks D. H. K., Thompson M. W., Vink D. E., Newby T. S., Van Den Berg H. M., Everard D. A. (2000) The South African land-cover characteristics database: a synopsis of the landscape. *South African Journal Of Science,* **96**, 69-82.

Fao (2012) *Harmonized World Soil Database (version 1.2)*, FAO, Rome, Italy and IIASA, Laxenburg, Austria.

Field C. B., Campbell J. E., David B. Lobell D. B. (2007) Biomass energy: the scale of the potential resource. *Trends in Ecology and Evolution,* **23**, 1-8.

Fiorese G., Guariso G. (2010) A GIS-based approach to evaluate biomass potential for energy crops at regional scale. *Environmental Modelling & Software,* **25**, 702-711.

Firbank L. (2008) Assessing the ecological impacts of bioenergy projects. *Bioenergy Research,* **1**, 12-19.

Fischer G., Hizsnyik E., Prieler S., Shah M., Van Velthuizen H. (2009) *Biofuels and food security* Laxenburg., International Institute for Applied Systems Analysis

Fischer G., Hizsnyik E., Prieler S., Van Velthuizen H. (2007) *Assessment of biomass potentials for biofuel feedstock production in Europe: Methodology and results* Laxenburg, International Institute for Applied Systems Analysis

Fischer G., Prieler S., Van Velthuizen H., Lensink S. M., Londo M., De Wit M. (2010) Biofuel production potentials in Europe: Sustainable use of cultivated land and pastures. Part I: Land productivity potentials. *Biomass & Bioenergy,* **34**, 159-172.

Freudenberger L., Hobson P. R., Schluck M., Ibisch P. L. (2012) A global map of the functionality of terrestrial ecosystems. *Ecological Complexity,* **12**, 13-22.

Gabriel D., Carver S. J., Durham H., Kunin W. E., Palmer R. C., Sait S. M., . . . Benton T. G. (2009) The spatial aggregation of organic farming in England and its underlying environmental correlates. *Journal of Applied Ecology,* **46**, 323-333.

Gallo J. A., Pasquini L., Reyers B., Cowling R. M. (2009) The role of private conservation areas in biodiversity representation and target achievement within the Little Karoo region, South Africa. *Biological Conservation,* **142**, 446-454.

Gasparatos A., Stromberg P., Takeuchi K. (2011) Biofuels, ecosystem services and human wellbeing: Putting biofuels in the ecosystem services narrative. *Agriculture, Ecosystems and Environment,* **142**, 111-128.

Government of South Africa (2008) *The National Protected Area expansion strategy 2008-2012: a framework for implementation,* Pretoria.

Groom M. J., Gray E. M., Townsend P. A. (2008) Biofuels and Biodiversity: Principles for Creating Better Policies for Biofuel Production. *Conservation Biology,* **22**, 602-609.

Henderson L. (2007) Invasive, naturalized and casual alien plants in southern Africa: a summary based on the Southern African Plant Invaders Atlas (SAPIA). *Bothalia,* **37**, 215-248.

Hijmans R. J., Cameron S. E., Parra J. L., Jones P. G., Jarvis A. (2005) A very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology,* **25**, 1965-1978.

Hoffman M. T., Ashwell A. (2001) *Nature divided: Land degradation in South Africa*, University of Cape Town Press.

Hoogwijk M., Faaij A., Eickhout B., De Vries B., Turkenburg W. (2005) Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios. *Biomass and Bioenergy,* **29**, 225-257.

Hoogwijk M., Faaij A., Van Den Broek R., Berndes G., Gielen D., Turkenburg W. (2003) Exploration of the ranges of the global potential of biomass for energy. *Biomass and Bioenergy,* **25**, 119-133.

Knight A. T., Cowling R. M. (2007) Embracing opportunism in the selection of priority conservation areas. *Conservation Biology,* **21**, 1124-1126.

Koh L. P., Levang P., Ghazoul J. (2009) Designer landscapes for sustainable biofuels. *Trends In Ecology & Evolution,* **24**, 431-438.

Kriticos D. J., Webber B. L., Leriche A., Ota N., Macadam I., Bathols J., Scott J. K. (2011) CliMond: global high resolution historical and future scenario climate surfaces for bioclimatic modelling. *Methods in Ecology and Evolution*, doi:10.1111/j.2041-1210X.2011.00134.x.

Lapola D. M., Priess J. A., Bondeaud A. (2009) Modeling the land requirements and potential productivity of sugarcane and jatropha in Brazil and India using the LPJmL dynamic global vegetation model. *Biomass and Bioenergy,* **33**, 1087-1095.

Lapola D. M., Schaldach R., Alcamo J., Bondeaud A., Kocha J., Koelkinga C., Priess J. A. (2010) Indirect land-use changes can overcome carbon savings from biofuels in Brazil. *Proceedings of the National Academy of Sciences,* **107**, 3388-3393.

Li R., Guan Q., Merchant J. (2012) A geospatial modeling framework for assessing biofuels related-related land-use and land-cover change. *Agriculture Ecosystems & Environment,* **161**, 17-26.

Lindborg R., Stenseke M., Cousins S. a. O., Bengtsson J., Berg Å., Gustafsson T., . . . Eriksson O. (2009) Investigating biodiversity trajectories using scenarios – Lessons from two contrasting agricultural landscapes. *Journal Of Environmental Management,* **91**, 499-508.

Liu C., Berry P. M., Dawson T. P., Pearson R. G. (2005) Selecting thresholds of occurrence in the prediction of species distributions. *Ecography,* **28**, 385-393.

Lynd L. R., Von Blottnitz H., Tait B., De Boer J., Pretorius I. S., Rumbold K., Van Zyl W. H. (2003) Converting plant biomass to fuels and commodity chemicals in South Africa : a third chapter? *South African Journal Of Science,* **99**, 499-507.

Margules C. R., Pressey R. L. (2000) Systematic conservation planning. *Nature,* **405**, 37-47.

Mucina L., Rutherford M. C. (2006) *The vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19,* Pretoria, South Africa., South African National Biodiversity Institute, .

Musango J. K., Amigun B., Brent A. C. (2010) Understanding the implication of investing in biodiesel production in South Africa: a system dynamics approach. *28th International conference of system dynamics society*, 25-29, http://www.systemdynamics.org/cgi-bin/sdsweb?P1198+1190.

Nelson E., Mendoza G., Regetz J., Polasky S., Tallis H., Cameron D. R., . . . Shaw M. R. (2009) Modelling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment,* **7**, 4-11.

O' Connor T. G., Kuyler P. (2009) Impact of land use on the biodiversity integrity of the moist sub-biome of the grassland biome, South Africa. *Journal Of Environmental Management,* **90**, 384-395.

O' Farrell P. J., Anderson P. M. L., Le Maitre D. C., Holmes P. M. (2012) Insights and opportunities offered by a rapid ecosystem service assessment in promoting a conservation agenda in an urban biodiversity hotspot. *Ecology and Society,* **17**, 27. http://dx.doi.org/10.5751/ES-04886-170327.

Pattison R. R., Mack R. N. (2008) Potential distribution of the invasive tree *Triadica sebifera* (Euphorbiaceae) in the United States: evaluating climex predictions with field trials. *Global Change Biology,* **14**, 813-826.

Pearson R. G. (2007) Species' Distribution Modeling for Conservation Educators and Practitioners. Synthesis. . American Museum of Natural History. Available at http://ncep.amnh.org.

Phillips S. J., Anderson R. P., Schapire R. E. (2006) Maximum entropy modeling of species geographic distributions. *Ecological Modelling,* **190**, 231-259.

Phillips S. J., Dudík M. (2008) Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography,* **31**, 161-175.

Raghu S., Anderson R. C., Daehler C. C., Davis A. S., Wiedenmann R. N., Simberloff D., Mack R. N. (2006) Adding biofuels to the invasive species fire? *Science,* **313**, 1742.

Reyers B. (2004) Incorporating anthropogenic threats into evaluations of regional biodiversity and prioritisation of conservation areas in the Limpopo Province, South Africa. *Biological Conservation,* **118**, 521-531.

Richardson D. M., Blanchard R. (2011) Learning from our mistakes: minimizing problems with invasive biofuel plants. *Current Opinion in Environmental Sustainability,* **3**, 36-42.

Righelato R., Spracklen D. V. (2007) Environment - Carbon mitigation by biofuels or by saving and restoring forests? *Science,* **317**, 902.

Romijn H. A. (2011) Land clearing and greenhouse gas emissions from Jatropha biofuels on African Miombo Woodlands. *Energy Policy,* **39**, 5751-5762.

Scherr S. J., Mcneely J. A. (2008) Biodiversity conservation and agricultural sustainability: towards a new paradigm of ‘ecoagriculture’ landscapes. *Philosophical Transactions of the Royal Society B: Biological Sciences,* **363**, 477-494.

Schoeman J. L., Van Der Walt M., Monnik K. A., Thackrah J., Malherbe L. R. (2000) *Development and application of a land capability classification system for South Africa*, GW/A/2000/57.

Scholes R. J. (1998) *The South African 1:250000 maps of areas of homogenous grazing potential.,* Pretoria, Environment and Forestry Technology, CSIR.

Schweers W., Bai Z., Campbell E., Hennenberg K., Fritsche U., Mang H.-P., . . . Zhang N. (2011) Identification of potential areas for biomass production in China: Discussion of a recent approach and future challenges. *Biomass and Bioenergy,* **35**, 2268-2279.

Shackleton C. M., Willis C. B., Scholes R. J. (2001) Woodlands or wastelands: Examining the value of South Africa's woodlands. *Southern African Forestry Journal,* **192**, 65-72.

Simberloff D. (2008) Invasion Biologists and the Biofuels Boom: Cassandras or Colleagues? *Weed Science,* **56**, 867-872.

Slade R., Saunders R., Gross R., Bauen A. (2011) *Energy from biomass: the size of the global resource,* London, Imperial College Centre for Energy Policy and Technology and UK Energy Research Centre.

Smeets E., Faaij A., Lewandowski I. (2004) *A quickscan of global bio-energy potentials to 2050: An analysis of the regional availability of biomass resources for export in relation to the underlying factors,* Utrecht, Copernicus Institute - Department of Science, Technology and Society.

Smith P., Gregory P. J., Van Vuuren D., Obersteiner M., Havlík P., Rounsevell M., . . . Bellarby J. (2010) Competition for land. *Philosophical Transactions of the Royal Society B: Biological Sciences,* **365**, 2941-2957.

Stoms D. M., Davis F. W., Jenner M., W., Nogeire T. M., Kaffka S. R. (2011) Modeling wildlife and other trade-offs with biofuel crop production. *GCB Bioenergy,* **4**, 330-341.

Thompson G. D., Robertson M. P., Webber B. L., Richardson D. M., Le Roux J. J., Wilson J. R. U. (2011) Predicting the subspecific identity of invasive species using distribution models: *Acacia saligna* as an example. *Diversity And Distributions*, 1001-1014.

Tilman D., Socolow R., Foley J. A., Hill J., Larson E., Lynd L., . . . Williams R. (2009) Beneficial biofuels-The food, energy, and environment trilemma. *Science,* **325**, 270-271.

Tollefson J. (2011) How green is my future? *Nature,* **473**, 134.

Trabucco A., Achten W. M. J., Bowe C., Aerts R., Van Orshoven J., Norgrove L., Muys B. (2010) Global mapping of Jatropha curcas yield based on response of fitness to present and future climate. *GCB Bioenergy,* **2**, 139-151.

Van Vuuren D. P., Van Vliet J., Stehfest E. (2009) Future bio-energy potential under various natural constraints. *Energy Policy,* **37**, 4220-4230.

Vanderwal J., Shoo L. P., Graham C., Williams S. E. (2009) Selecting pseudo-absence data for presence-only distribution modeling: how far should you stray from what you know? *Ecological Modelling,* **220**, 589-594.

Von Maltitz G. P., Brent A. (2008) *Assessing the biofuel options for Southern Africa,* CSIR, Pretoria.

Warren D. L., Seifert S. N. (2011) Ecological niche modelling in Maxent: the importance of model complexity and the performance of model selection criteria. *Ecological Applications,* **21**, 335-342.

Webber B. L., Yates C. J., Le Maitre D. C., Scott J. K., Kriticos D. J., Ota N., . . . Midgley G. F. (2011) Modelling horses for novel climate courses: insights from projecting potential distributions of native and alien Australian acacias with correlative and mechanistic models. *Diversity And Distributions,* **17**, 978-1000.

Wessels K. J., Reyers B., Van Jaarsveld A. S. (2000) Incorporating land cover information into regional biodiversity assessments in South Africa. *Animal Conservation,* **3**, 67-79.

Wessels K. J., Reyers B., Van Jaarsveld A. S., Rutherford M. C. (2003) Identification of potential conflict areas between land transformation and biodiversity conservation in north-eastern South Africa. *Agriculture, Ecosystems & Environment,* **95**, 157-178.

Wicke B., Smeets E., Watson H., Faaij A. (2011) The current bioenergy production potential of semi-arid and arid regions in sub-Saharan Africa. *Biomass and Bioenergy,* **35**, 2773-2786.

Wiens J., Fargione J., Hill J. (2011) Biofuels and biodiversity. *Ecological Applications,* **21**, 1085-1095.

Wilcove D. S., Rothstein D., Dubow J., Phillips A., Losos E. (2000) Leading threats to biodiversity: what's imperiling U.S. species. In: *Precious Heritage: The Status of Biodiversity in the United States.* (ed Stein BA, Kutner, L.S., Adams, J.S) pp Page. Oxford, Oxford University Press.

Wilson K. A., Meijaard E., Drummond S., Grantham H. S., Boitani L., Catullo G., . . . Watts M. (2010) Conserving biodiversity in production landscapes. *Ecological Applications,* **20**, 1721-1732.

Wolmarans R., Robertson M. P., Van Rensburg B. J. (2010) Predicting invasive alien plant distributions: how geographical bias in occurrence records influences model performance. *Journal of Biogeography,* **37**, 1797-1810.

Table 1: The three spatial filters used to indicate provide Biodiversity conservation scenarios utilised in this analysis. All data was extracted from an online database (www.bgis.sanbi.org).

Biodiversity scenarios	Description of biodiversity layers
Protected Area	Protected Areas are indicative of the minimum data available for biodiversity conservation. These layers indicate areas that are excluded from land availability assessments. In this assessment informal protected areas (private nature reserves, game farms) are included here.
Important Biodiversity Areas	This scenario identifies areas of high biodiversity that occur outside of protected areas. Two biodiversity databases were used to compile this spatial filter, The National Protected Area Expansion Strategy (NPAES) and Critical Biodiversity Areas taken from the Eastern Cape Biodiversity Conservation Plan (ECBCP). These areas are not formally conserved, and have been identified to contain high biodiversity value.
Ecological corridors	Ecological corridors enhance the connectivity between important biodiversity areas and reduce vulnerability of intact patches in the landscape. These areas are known to contribute to the provision of ecosystem services.

Table 2: Summary statistics for nine biofuel species based on MaxEnt projections to the Eastern Cape. Suitability in millions of hectares (Mha) is indicated for four threshold values, namely: LPT (lowest minimum threshold), sensitivity at 95% and 90% of presence points and where sensitivity equals specificity.

				LPT		95%		90%		Equal sensitivity and specificity	
Fuel type	Species	AUC	Std dev.	Value	Area	Value	Area	Value	Area	Value	Area
Bioenergy	*Acacia mearnsii***	0.92	0.005	0.003	16.87	0.169	14.25	0.370	10.42	0.426	9.37
Ethanol	*Arundo donax***	0.91	0.006	0.004	16.87	0.092	16.87	0.224	16.76	0.374	14.97
Ethanol	*Beta vulgaris**	0.87	0.005	0.003	16.87	0.196	1.28	0.366	0.76	0.473	0.00
Biodiesel	*Camelina sativa*	0.90	0.005	0.009	16.87	0.102	1.64	0.219	0.13	0.423	0.00
Biodiesel	*Jatropha curcas***	0.78	0.034	0.005	15.96	0.103	4.71	0.162	3.45	0.343	1.64
Biodiesel	*Miscanthus sinensis*	0.90	0.018	0.014	14.33	0.100	0.69	0.185	0.16	0.257	0.02
Bioethanol	*Sorghum halepense***	0.80	0.004	0.010	16.87	0.159	16.86	0.277	14.72	0.481	1.00
Bioethanol	*Panicum virgatum*	0.81	0.007	0.013	16.70	0.147	1.92	0.311	0.01	0.480	0.00
Biodiesel	*Ricinus communis**	0.84	0.012	0.013	16.87	0.138	16.87	0.225	16.87	0.381	15.62

*present in South Africa

**declared an invasive alien plant in South Africa

Table 3: The total area and percentage of land use occupied within land capability classes (Arable, Marginal and Excluded) in the Eastern Cape.

Land use classes	Arable Mha (%)	Marginal Mha (%)	Excluded Mha (%)	Total Mha (%)
Forestry	0.06 (51.9)	0.02 (18.4)	0.04 (29.6)	0.12 (0.74)
Cultivation	0.32 (47.1)	0.28 (40.6)	0.09 (12.4)	0.69 (4.09)
Other	0.40 (13.4)	0.66 (22.2)	1.91 (64.3)	2.97 (17.6)
Natural*	2.32 (17.7)	5.39 (41.2)	5.36 (41.1)	13.1 (77.6)
Total	3.10 (18.4)	6.35 (37.7)	7.40 (43.9)	16.86 (100)

* as indicated in the National Land Cover Database 2000

Table 4: The area and percentage overlap of Biodiversity scenarios with land capability classes (Arable, Marginal and Excluded) in the Eastern Cape. Areas with no recorded biodiversity value are also indicated.

Biodiversity Scenarios	Arable Mha (%)	Marginal Mha (%)	Excluded Mha (%)	Sum Mha (%)
Protected Areas	0.04 (4.0)	0.23 (24.8)	0.66 (71.2)	0.93 (5.5)
Important Biodiversity areas	0.51 (12.0)	1.13 (26.8)	2.59 (61.9)	4.23 (25.1)
Ecological corridors	1.02 (14.8)	2.22 (32.3)	3.65 (52.9)	6.89 (40.9)
Total	**1.56 (12.9)**	**3.59 (29.8)**	**6.90 (57.3)**	**12.05 (71.5)**
Non Biodiversity Areas	0.75 (15.6)	1.80 (37.4)	2.26 (46.9)	4.81 (28.6)
Total all	**2.32 (13.7)**	**5.39 (31.9)**	**9.16 (54.3)**	**16.86 (100)**

Table 5: The range in percentage overlap of model projections as applied to suitable areas within the Eastern Cape. Overlaps with biodiversity scenarios are also indicated for Protected Areas, Important Biodiversity Areas (IBA) and Ecological corridors (EC).

Area (Mha)		**Arable Area (Mha)**			**Total arable overlap**	**Marginal Area (Mha)**			**Total marginal overlap**	**No biodiversity overlap**
		PA (0.04)	**IBA** (0.51)	**EC** (1.02)	(1.56)	**PA** (0.23)	**IBA** (1.13)	**EC** (2.22)	(3.59)	(2.56)
Species	Threshold									
Acacia mearnsii	LPT*	95.7	96.5	99.0	98.1	95.7	97.1	99.0	98.2	99.3
	95	95.7	94.7	97.8	96.7	92.2	92.1	86.3	88.5	53.7
	90	94.1	90.5	84.9	86.9	51.6	72.0	54.0	59.5	84.5
	sens=spec**	86.7	88.2	82.4	84.4	38.1	62.7	46.2	50.9	45.7
Arundo donax	LPT	95.7	96.5	99.0	98.1	95.7	97.0	99.0	98.1	99.3
	95	95.7	96.5	99.0	98.1	95.7	97.0	99.0	98.1	98.6
	90	95.7	96.3	98.2	97.5	95.7	95.6	98.7	97.5	99.3
	sens=spec	95.1	92.4	93.2	93.0	93.3	87.0	88.8	88.5	87.4
Beta vulgaris	LPT	61.9	27.5	35.5	33.5	18.1	20.4	17.7	18.6	15.2
	95	61.9	27.5	35.5	33.5	18.1	20.4	17.7	18.6	1.2
	90	19.3	2.5	2.5	2.9	1.5	2.0	1.3	1.5	15.2
	sens=spec	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0
Camelina sativa	LPT	95.7	96.5	99.0	98.1	95.7	97.1	99.0	98.2	99.3
	95	61.9	27.5	35.5	33.5	18.1	20.4	17.7	18.6	0.2
	90	0.0	0.5	0.4	0.4	0.0	1.8	0.6	1.0	15.2
	sens=spec	95.1	92.4	93.2	93.0	93.3	87.0	88.8	88.5	87.4
Jatropha curcas	LPT	95.7	95.2	98.7	97.5	94.4	96.3	98.5	97.5	98.1
	95	67.7	39.1	51.7	48.0	54.0	30.8	30.4	32.0	17.0
	90	54.3	33.0	41.1	38.8	30.4	25.3	21.2	23.1	24.0
	sens=spec	38.4	18.5	22.4	21.5	10.9	14.9	8.5	10.7	7.5
Miscanthus sinensis	LPT	89.9	89.5	82.2	84.7	49.9	85.6	79.2	79.3	81.3
	95	15.9	7.7	2.7	4.7	4.1	8.1	2.4	4.3	0.2
	90	12.0	1.9	0.3	1.1	2.0	2.0	0.2	0.9	1.4
	sens=spec	0.0	0.3	0.0	0.1	0.0	0.5	0.0	0.1	0.2
Panicum virgatum	LPT	83.3	94.4	97.9	96.4	92.6	96.0	98.2	97.2	99.0
	95	8.6	12.3	10.4	11.0	2.4	10.7	23.8	18.3	0.0
	90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.1
	sens=spec	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ricinus communis	LPT	95.7	96.5	99.0	98.1	94.4	97.0	99.0	98.1	99.3
	95	95.7	96.5	99.0	98.1	94.4	97.0	99.0	98.1	99.3
	90	95.7	96.5	99.0	98.1	94.4	97.0	99.0	98.1	99.3
	sens=spec	95.1	94.9	96.0	95.6	92.8	87.3	92.9	91.1	89.1
Sorghum halepense	LPT	95.7	96.5	99.0	98.1	95.7	97.1	99.0	98.2	99.3
	95	95.7	96.5	99.0	98.1	95.7	97.1	99.0	98.2	99.3
	90	95.7	96.5	99.0	98.1	95.7	97.1	99.0	98.2	99.3
	sens=spec	14.5	2.7	3.2	3.3	1.4	3.8	5.8	4.9	6.5

*LPT: Lowest presence threshold

**sens=spec: Equal sensitivity and specificity

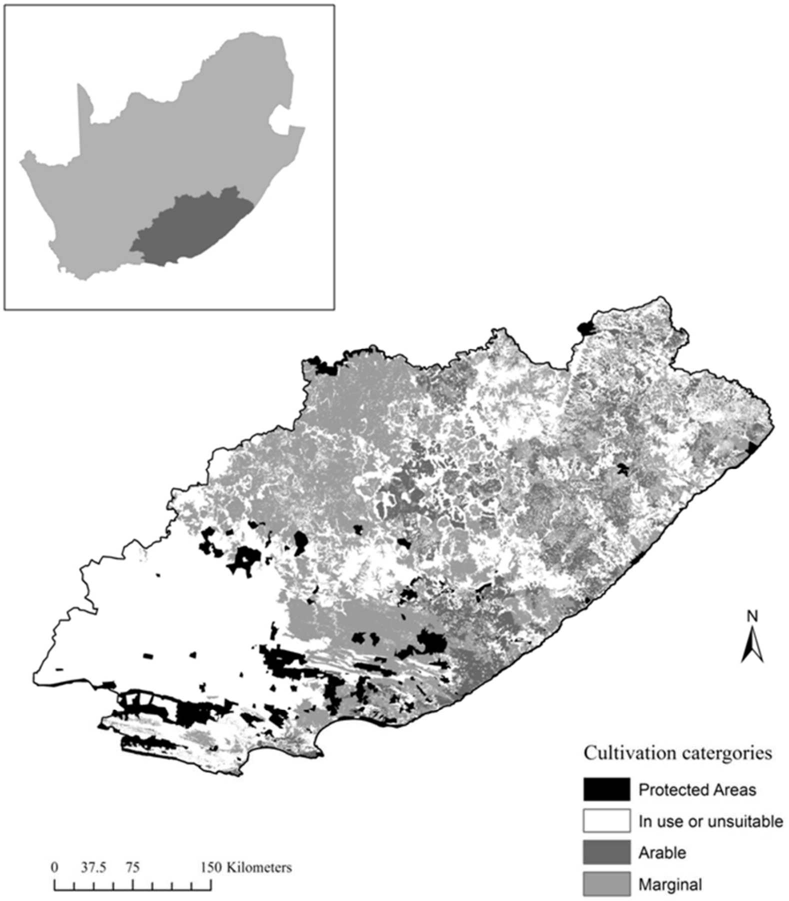
Fig.1 The location of the Eastern Cape province, South Africa (inset), indicating broad categories of cultivation potential. Protected Areas (black) indicate locations of the formal and informal conservation network, which are automatically excluded from land availability assessments.

Fig. 2 The methodological framework adopted for this analysis and the related databases.

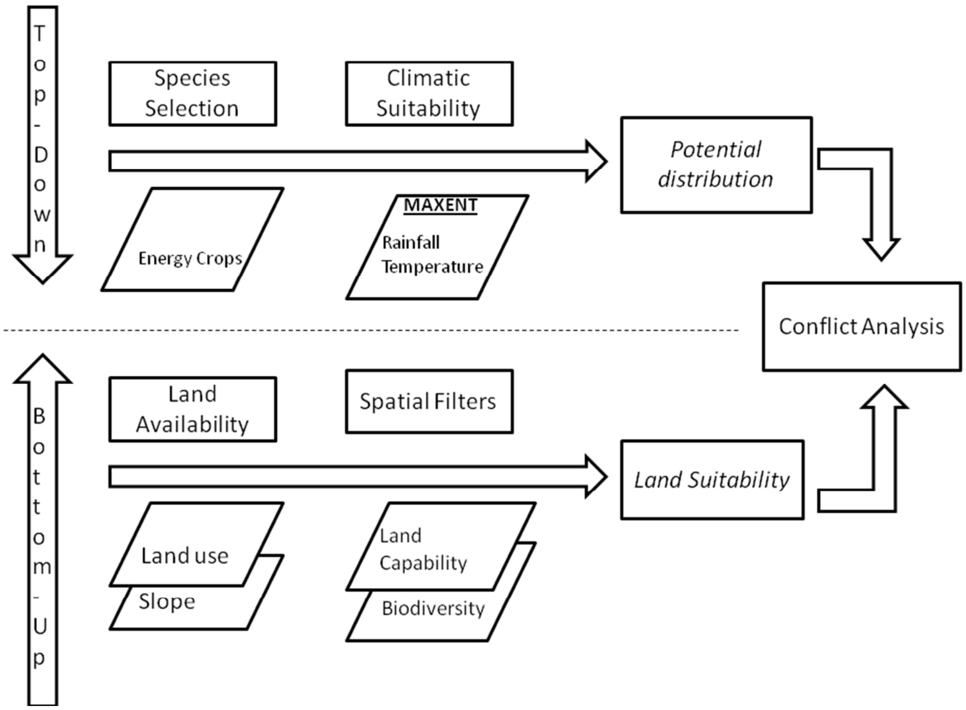
Fig. 3 Suitability estimates for nine potential biofuel species modelled for the Eastern Cape province using the species distribution model MaxEnt.

Fig.4 The affect of threshold choice on the predicted area (in millions of hectares) of nine biofuel species.

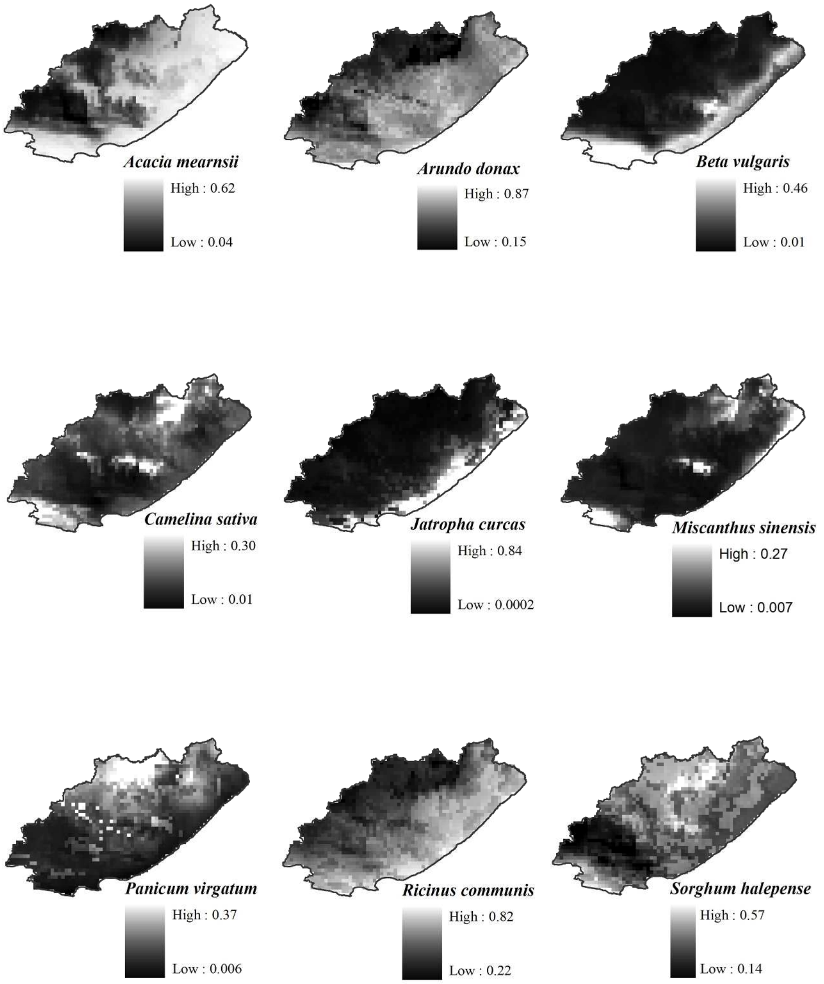
Fig. 5 Maps indicating increased vulnerability as biodiversity scenarios are introduced to land availability assessment for both optimal (a-c) and marginal (d-f) areas.



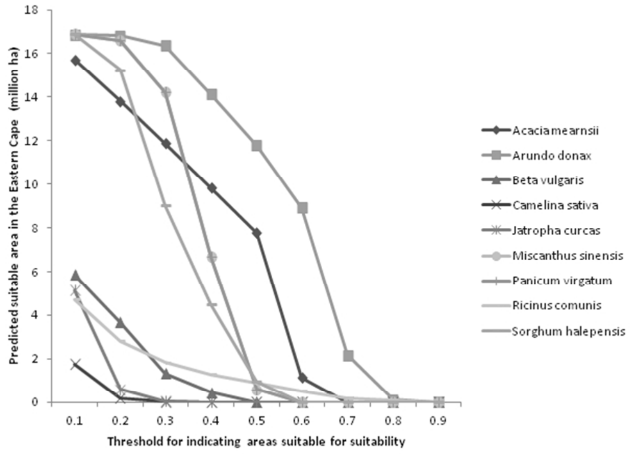
The location of the Eastern Cape province, South Africa (inset), indicating broad categories of cultivation potential. Protected Areas (black) indicate locations of the formal and informal conservation network, which are automatically excluded from land availability assessments.



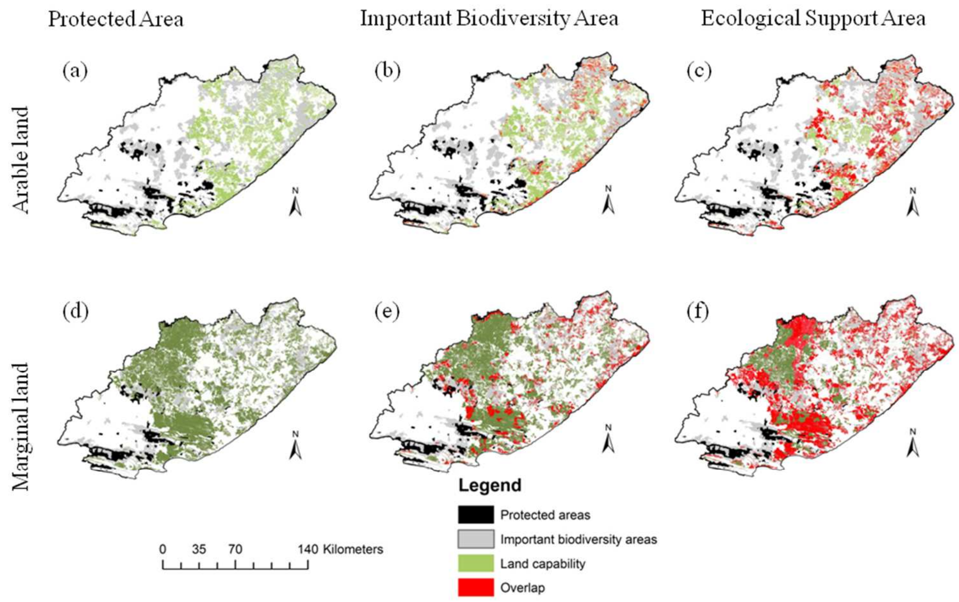
The methodological framework adopted for this analysis and the related databases.



Suitability estimates for nine potential biofuel species modelled for the Eastern Cape province using the species distribution model MaxEnt.
296x419mm (300 x 300 DPI)



The affect of threshold choice on the predicted area (in millions of hectares) of nine biofuel species.



5 Maps indicating increased vulnerability as biodiversity scenarios are introduced to land availability assessment for both optimal (a-c) and marginal (d-f) areas.