Biofuels and biodiversity in South Africa

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The South African government, as part of its efforts to mitigate the effects of the ongoing energy crisis, has proposed that biofuels should form an important part of the country's energy supply. The contribution of liquid biofuels to the national fuel supply is expected to be at least 2% by 2013. The Biofuels Industrial Strategy of the Republic of South Africa of 2007 outlines key incentives for reaching this target and promoting the development of a sustainable biofuels industry. This paper discusses issues relating to this strategy as well as key drivers in biofuel processing with reference to potential impacts on South Africa's rich biological heritage.

Our understanding of many of the broader aspects of biofuels needs to be enhanced. We identify key areas where challenges exist, such as the link between technology, conversion processes and feedstock selection. The available and proposed processing technologies have important implications for land use and the use of different non-native plant species as desired feedstocks. South Africa has a long history of planting non-native plant species for commercial purposes, notably for commercial forestry. Valuable lessons can be drawn from this experience on mitigation against potential impacts by considering plausible scenarios and the appropriate management framework and policies. We conceptualise key issues embodied in the biofuels strategy, adapting a framework developed for assessing and quantifying impacts of invasive alien species. In so doing, we provide guidelines for minimising the potential impacts of biofuel projects on biodiversity.

Introduction

The uncertainty of long-term fossil fuel supplies, volatile fuel prices and increasing CO_2 emissions have generated much interest in alternative fuel sources, especially 'biofuels', which are defined as solid, liquid or gaseous fuels obtained from biological material.[1] The production of biofuels is being widely promoted as a renewable and environmentally friendly way of reducing the use of fossil fuels.[2] Biofuels have garnered much support and feature on political agendas in both developed and developing countries.[3] In the developed world, biofuels offer a potential means of reducing greenhouse gas emissions and increasing fuel security. In the developing world, besides the issue of fuel security, the main drivers behind the establishment of a biofuel industry are the need to facilitate rural and national development, provide jobs and improve trade balances. These factors are all influenced by the establishment of and demand from international markets that promise certain economic and fuel-security incentives, such as those in Europe.[4,5,6,7]

Much of the global debate on biofuels has focused on policy, economics, social issues (such as competition with food crops), and the potential of biofuels to reduce greenhouse gas emissions.[4,8] Apart from demonstrating an overall net energy gain relative to fossil fuels,[9] biofuels also need to be environmentally sustainable. Key areas highlighted by various life-cycle assessments for biofuels to achieve sustainability relate to feedstock options, land use and the available processing technologies.[1,10] Achieving environmental sustainability for biofuels is important for curbing the growing negative perception, especially when these negative perceptions could influence public acceptance of biofuels,[11] reducing demand, despite the increasing investment and development opportunities.[12]

South Africa is a world leader in conservation planning[13] and aims to protect its biodiversity through a range of conservation initiatives and interventions. The main threats to biodiversity in South Africa are habitat transformation (changes in land use) and a range of impacts resulting from invasive alien species, especially plants.[14] Fourteen per cent of the country's land surface area is already under some form of cultivation or afforestation[15] and this is expected to increase in the future.[16] Biofuel initiatives have the potential to add substantially to these existing threats to biodiversity in two main ways: (1) directly, through habitat conversion and (2) indirectly, through the creation of new pathways for the introduction and dissemination of potentially invasive species to areas set aside for biofuel. Increased pressure for land resources highlights the growing concern that the existing network of protected areas still does not conserve a representative sample of our biodiversity, or fully include key ecological processes,[14] considered important for providing communities with some degree of resilience to future climate change.

There is no denying the potentially positive benefits of biofuels to the South African economy,[9] but failure to consider all possible outcomes of biofuel production could have substantial unforeseen costs. There are currently no mandatory blending requirements for biofuels, but government initiatives are underway (see 'South African industrial biofuels strategy' and Box 1) to establish a biofuel industry to improve the country's fuel security and drive rural development objectives. Despite the rapid global expansion of biofuel plantations, little information is available on the potential ecosystem impacts of such land use.[6] Given South Africa's globally significant biodiversity, such information is critical for developing appropriate strategies to minimise impacts before any major production initiatives are launched. The emergence of the South African forestry, timber, pulp and paper industry also relied on the use of alien plants, many of which are now invasive, resulting in large-scale transformation of habitats, and multiple conflicts with other potential land uses such as conservation.[17] The history of forestry in South Africa is therefore informative when considering strategies for the use of biofuels.[18] Besides the many policy and legal frameworks that regulate the forestry industry, considerable research has also been undertaken on the impacts of forestry species on ecosystems. South Africa also has a long history of problems with invasive plant species, and of devising innovative approaches for managing such problems. Research insights from invasion biology should also be useful for predicting and preventing or reducing additional problems from invasive species that could result from the specific pathways created by new introductions and dissemination patterns that will be required to launch a biofuel industry in the country.[18]

This paper examines key issues relating to the potential for the sustainable production of biofuels in South Africa whilst minimising the impact of the region's biodiversity. Although we discuss the emerging liquid biofuel industry with reference to the Biofuels Industrial Strategy of the Republic of South Africa,[19] these lessons are applicable to other renewable energy initiatives that rely on biomass.[4,20] We discuss the role of existing and future technologies in relation to feedstock selection and associated ecological impacts. Measuring the impacts of biofuels is also addressed in relation to proposed frameworks for assessing the impact of invasive species. Finally, we highlight the role of industry as a mechanism for facilitating the introduction and dissemination of potentially invasive species, and identify ways of reducing impacts.

The South African industrial biofuels strategy

South Africa is the only southern African country that has a formal biofuels strategy: the Biofuels Industrial Strategy of the Republic of South Africa of 2007,[19,21] hereafter 'the strategy'. The Department of Minerals and Energy envisages biomass energy (liquid biofuels) contributing 35% to national targets for renewable energy production as set by The White Paper on Renewable Energy by 2013;[20] the remainder will be contributed by solar and wind projects. The strategy outlines mechanisms to undertake a 5-year pilot programme to supplement a cautionary initial biofuel target of 2% of liquid fuels, with a decision on whether to increase this proportion to be made at the end of the pilot phase.[19]

BOX 1: Biofuels in South Africa.

South Africa's history of using biomass as an energy source dates back to the 1920s when ethanol derived from sugar cane was mixed with petrol.[7] Between the 1970s and early 1990s South African involvement in the development of alternative fuel sources was largely in response to sanctions placed on the apartheid government.[4] As a consequence, South Africa developed the capacity to convert both coal and natural gas to petroleum using the Fischer–Tropsch process. Currently about 23% of liquid fuel used in South Africa is derived from coal, 5% from natural gas and 72% from imported crude oil.[71] From the perspective of greenhouse gas emissions, coal-derived liquid fuels are about twice as polluting as oil-derived fossil fuels. Research projects in this area were scaled down after the democratic elections in 1994, as improving services and opportunities for previously disadvantaged people were seen as more immediate needs.[4] There is currently renewed public and political interest in biomass energy and the agricultural practices through which biofuel can be produced are considered to have the potential to fulfil both social and energy mandates in many countries, including South Africa.[19] A challenge for the South African government is the considerable investment and infrastructure required to guarantee the continued supply of appropriate feedstocks, and the need for efficient biomass conversion techniques.[7] Globally, biofuel production is a relatively new industry and more research is needed on technologies, agricultural practices, and the potential environmental and social impacts. Initial growth of biofuel enterprises will depend on first-generation technologies. Recent technological advancements that allow for increased feedstock selection, e.g. hardwoods, agricultural and municipal wastes, are constrained by the non-viability of commercial applications because the conversion technologies of cellulosic biomass are still in development and may be commercially available within the next two decades.[1,4] Nevertheless, projected technological advancements could expand the options for feedstock species and create more efficient conversion processes for lowering CO_2 emissions.

The strategy aims to achieve economic and social development in rural areas via the agricultural development in the former homeland areas. Objectives include adding to the renewable energy pool and improvement of the country's fuel security.[22] The creation of jobs and improving the development imbalance between informal and small-scale farming areas and commercial farming areas are key components of the biofuel supply chain.[4] In order to achieve these socio-economic goals government support is being confined to regions that are likely to benefit most, such as former homeland areas in the Eastern Cape.[19] Incentives for locally based processing plants will rely on feedstocks being acquired via contractual agreements from small-scale farmers in the region.[22] This is intended to stimulate demand and incentivise farmers to optimise longer-term yields whilst increasing land productivity.[19]

Approved crops for bioethanol production are sugar cane and sugar beet, and for biodiesel are sunflower, canola and soya beans.[19,22] The suitability of these species has been mapped for South Africa according to both rain-fed and irrigated options, including information on grain sorghum for bioethanol.[23] The strategy recognises that food security should not be compromised; consequently, maize is currently excluded. The strategy also recognises potential problems of introducing dedicated energy crops. The Department of Agriculture has placed a moratorium on a potential energy crop, *Jatropha curcas* ('jatropha'; see Box 2), because of concerns regarding its potential invasiveness. Despite South Africa's standpoint on jatropha, South African neighbours have shown strong support for the use of this species in providing employment opportunities and meeting fuel security needs, by continually committing land to its cultivation.[21] If this strategy proves successful, it could generate similar growth in South Africa. Biofuel developments are still at an early phase and ongoing research to optimise feedstocks and processing techniques may well promote feedstocks not mentioned in the strategy. Current research aims to increase feedstock options by exploring potential impacts with special attention being directed towards jatropha.[24] Consequently, based on South Africa's biofuel feedstock selection, the production of existing crops needs to be scaled up considerably to meet the proposed minimum target of 2% (400 million litres per annum) biofuel penetration into the liquid fuels market.

Technology as a potential driver of impact

The demand for biofuels, like other commodities, is driven by the needs of human societies and is influenced by available processing technologies. These technologies will determine the success and the extent to which the biofuel industry will be developed in South Africa. Whilst the strategy aims to use biofuel expansion as a vehicle for social development, too little attention is given to the implications of current and future technologies on the environment. In the following section we discuss the role of technology in biofuel feedstock selection and the implications for the environment.

Feedstocks

Until now, production of liquid biofuels has focused mainly on surplus food and feed crops (hereafter edible crops) that rely on *first-generation* conversion pathways, using agricultural mechanisms to produce sugar, starch, or vegetable oil components for biofuel processing. As discussed above, the strategy has outlined a suite of crops reliant on first generation processing technologies to meet initial biofuel targets. Some edible crops have a low land-use efficiency; their use in commercial biofuel production is expected to be extremely demanding on land resources.[1] The current crop selection will need to be phased into a rotational crop system as many of the anticipated feedstocks are annual or short-term crops. Also, the use of edible crops for fuel purposes raises ethical and nutritional concerns as resources such as energy, water, fertilisers and land may be allocated to produce feedstock for fuels over the provision of food in poorer communities.[25] A key challenge will be to maximise existing agricultural output to produce a surplus for biofuel production, without affecting the pricing and availability of food.

Historically, increasing food demands have been met by initially increasing the area under cultivation and, more recently, through the development of new technologies (use of higher yield cultivars, pesticides and inorganic fertilisers) to increase yields.[15] Recent attempts to further increase plant productivity via genetic modification have in most cases failed to fulfil promised potential[26]; this is likely to be the case for biofuel crops. In South Africa, the Eastern Cape is characterised by areas of low agricultural production[15]; productivity in this region could be increased by investment and technological inputs. The introduction of novel farming practices to produce new crops like sugar beet, canola and sweet sorghum, to supplement the need for sugars and starches, needs further exploration in areas such as the Eastern Cape. Economic viability is recognised as the major barrier to the introduction of biofuels production[27] and many first-generation feedstocks require value to be derived from both the fuel produced and by converting wastes into useful by-products.[1,9] Successful utilisation of by-products includes valuable livestock feed (e.g. rapeseed cake and soybean meal), biomass fuels (straw, husks and bagasse) and materials for industrial use (such as glycerine).

The future of biofuels lies in the ability to commercialise advanced conversion technologies, such as the Fischer–Tropsch synthesis process, and biochemical pathways capable of converting lignocellulosic material to produce ethanol or liquid hydrocarbons.[1,25] These advanced processing methods, termed *second-generation* technologies, are currently in various stages of development and are expected to be commercially available in the next decade or two.[1] The role of such technologies will favour the production of perennial crops such as fast-growing trees (e.g. short-rotation woody crops) and grasses; and could use waste products generated from non-biofuel production systems (i.e. crop and forest residues).[6,25]

Ecological implications

The increased land requirements to produce biofuels in South Africa will have to be balanced within the emerging bioeconomy[28] as the demand for land to produce food, timber and fibre continues to increase.[6] As a result, potential conflict between areas of high biodiversity importance and biofuel production is likely to cause a larger impact in areas without formal protection status but which play important roles in regional and global biodiversity conservation.[14,26,29] Biodiversity impacts of transformation may extend beyond the land directly in question.[25] For example, biodiversity is indirectly affected when agricultural land is converted for biofuels production and new land elsewhere has to be brought into production to supplement the agricultural shortfall. These indirect effects could have profound impacts on the carbon balance of biofuels[1] and are difficult to calculate.

Agricultural landscapes around the world show a diversity of structures, functions and levels of productivity, and every type of landscape affects (positively or negatively) the ability of ecosystems to provide goods and services to varying degrees.[30,31] Importantly, the greater the difference in overall structure between the landscape (e.g. a biofuel plantation) and the original (natural) vegetation at a given site, the greater the likely overall impact on ecosystem functioning, services and biodiversity.[32] Impacts on biodiversity of biofuel cultivation will be strongly influenced by the location, cultivation practice and the choice of species (Figure 1).[33,34] Major structural changes in vegetation cover and biomass have been shown to affect the albedo, phenology, water use, micro-climates, fire hazard, habitat for other biota, and many other important features.[33,35] In areas where production is considered to be low, the intensification of agriculture through the addition of chemicals and effort could further affect biodiversity and result in trade-offs between existing ecosystem services. Water is also a limiting factor for development[36] and the redirection or increased demand may place further strain on dependent terrestrial and aquatic ecosystems.[37]

The current pursuit of biofuels following existing technologies is acknowledged as the 'first wave' and processes are likely to increase in efficiency as technology and strategies evolve.[38] As technology processes evolve we can expect the expansive nature of first-generation biofuels to diminish as the yield per unit area increases and feedstocks change. The resulting changes in production may lead to the abandonment of many first-generation or species-specific crops in favour of more efficient species or methods to produce alternative fuels. There are numerous benefits associated with future developments and the possibility of crop abandonment and existing production methods becoming redundant is a reality. Depending on the crop, this could provide favourable conditions to initiate invasions as numerous propagule-source foci will remain in contact with potentially invasible habitat.

Ecological impacts resulting from changes to the management of resources should also be considered. For example, both the agriculture and forestry sectors rely on waste materials/residues left *in situ* to contribute to nutrient-cycling processes that are important for maintaining soil quality and increasing the carbon organic matter returned to the soil.[39] Therefore using residues for biofuel may have varying effects within each industry and increase the risk of soil erosion and deplete soil organic matter, potentially requiring excessive use of fertilisers and herbicides to maintain crop yields.

It has been suggested that an increase in the productivity of underutilised or degraded land in South Africa could improve regional biodiversity through the adoption of sustainable agricultural practices. The reduction in overgrazing, reduced tillage and better management of land resources and agrochemicals could in fact work synergistically to promote biodiversity whilst increasing agricultural intensification. Biofuels may therefore have a restorative capability, increasing soil productivity and biodiversity within an agro-ecological system. The aim would be to synergise these developments to meet both ecological and social goals.[40]

Measuring the impact of biofuels

In order to understand the potential biodiversity implications of introducing and cultivating biofuel feedstocks in South Africa, one needs to consider the impact as the product of the extent, abundance and local-scale effect,[33] as summarised in the equation by Parker et al.[41]:

$$I = R \times A \times E. \qquad \text{[Eqn 1]}$$

Impact (I) is hereby described as the product of the (potential) geographical range of the introduced/invasive species (R), the (potential) abundance or density of the introduced or invasive species (A) and the effect of an individual species or the measurable impacts at the smallest spatial scale (E). Although originally proposed for quantifying the impact of invasive species,[35,41] this approach allows us to identify the individual and combined dimensions of areas of conflict between agricultural expansion and biodiversity conservation and also to classify production scenarios according to various scales of impact (Figure 1). This framework allows us to visualise the impact of biofuel feedstock plantings across different scales (such as field, landscape and regional).[33,42]

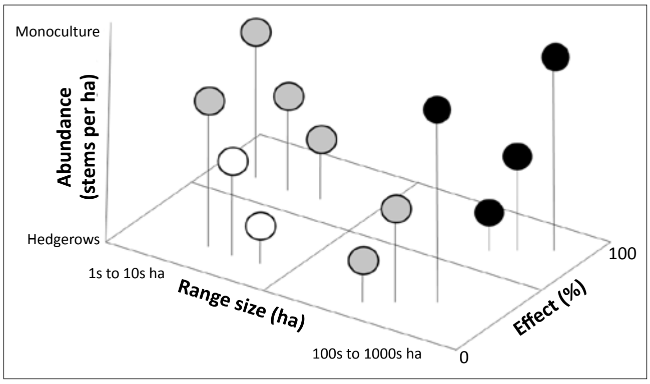

FIGURE 1: Applying the impact framework ($I = R \times A \times E$)[41] to a biofuel classification system. Impact (I) is defined as the product of the (potential) geographical range (R), the (potential) abundance or density (A) and the effect (E) of an individual species or the measurable impacts at the smallest spatial scale. A range of scenarios can be depicted, depending on the range, abundance and effect of biofuel species. Together these depict the overall biofuel footprint, the role of planting configurations and effects at the local scale. The diagram incorporates the role of small-scale growers and large-scale commercial plantations at various abundances (e.g. from hedgerows to larger scale monocultures). The diagram also allows for various types of feedstocks as depicted by the per capita (local-scale) impacts on the receiving environment. The shade of the circles depicts the overall impact (white = low, grey = medium and black = high).

BOX 2: *Jatropha curcas* – the solution for Africa?

Jatropha curcas (Figure 2), Euphorbiaceae, (hereafter jatropha) has been widely promoted as a drought-resistant non-edible perennial oil crop for producing biodiesel as it can grow in low–rainfall and otherwise marginal areas.[72,73] The oil content of the seed is about 30% – 35% and can be used as a fuel prior to trans-esterification to biodiesel. The seed oil is potentially suitable for rural village electrification as demonstrated in pilot projects in India and Mali. Jatropha has also been recommended for reclaiming marginal and degraded lands[73] because of its ability to improve soil quality and reduce erosion.[49] Jatropha plantations were expected to increase to 5 Mha in extent by 2010 but, although widely considered by most SADC countries as a viable biodiesel crop, there is a moratorium on planting in South Africa, mainly because of concerns about its invasive potential.[19] It is currently only grown in a few trial plantations and hedgerows in South Africa.[24] Yield claims for jatropha range between 0.4 t/ha per year and 12 t/ha per year, indicating that its undomesticated nature and limited physiological data[72] make crop productivity unpredictable. Whereas recent research has demonstrated that jatropha is unlikely to use more water than indigenous vegetation in the study area of KwaZulu-Natal,[24] these findings need to be scaled up to determine the impacts of plantations on watersheds.[74] Jatropha, like other agricultural crops, requires water and good soils to realise the large yields that initially raised the species to prominence as a biofuel crop. Notions of growing this still 'wild' plant in monoculture seem to be shifting towards using it in small-scale farming, which benefits the rural poor who use the oil to fuel stoves and lamps and diversify their income.[73]

Geographical range – the overall biofuel footprint

It is difficult to predict the likely geographical footprint of the biofuels industry for the whole of South Africa. However, the strategy outlines that government support is currently restricted to the rural areas of the Eastern Cape, mainly because of the need for social upliftment in that region,[22] with refineries planned for the towns of East London and Coega, near Port Elizabeth (http://www.asgisa-ec.co.za). The optimal size for different kinds of biomass-processing plants have yet to be determined but they are expected to depend upon the nature of biomass processed and the kind of conversion processes employed.[43] According to a recent study,[7] using about 10% of an available 3 million ha domain in the Eastern Cape should be sufficient to meet the 2% blending ratio based on average yields of sugar cane and

Source: Photographs taken by (a) K. Setzkorn, (b) R. Blanchard, (c) K. Setzkorn

FIGURE 2: *Jatropha curcas* is a perennial oil crop that is planted across much of southern Africa and used to produce biodiesel: (a) a young jatropha plantation in Mozambique indicating the spacing and extent of various planting schemes, (b) a 4-year-old trial plantation of 2-m-tall jatropha plants in Pietermaritzburg and (c) jatropha fruits which contain the seed nuts that are harvested for their oils (location unknown).

jatropha (currently banned from further planting in South Africa but nonetheless frequently used in projections). Importantly, these land-use estimates ignore growing biomass for the export market (e.g. www.Phytoenergy.org) driven by considerable demand from overseas markets for biodiesel and biomass production in developing countries such as South Africa.[1,12] They also fail to consider the role that private landholders could play in increasing the area of land under biofuel production. A review of all stakeholder involvement and commitments is needed to determine likely trajectories for biofuel cultivation; and would pave the way for informative scenarios regarding land-use requirements.

Abundance – the role of planting configurations

A much debated topic is the manner in which biofuel crops should or could be cultivated.[7,25] Firstly, the cultivation system relates to issues of scale and the size of the area to be planted. The implementation of large-scale plantations or numerous small-scale rural outgrowing schemes is influenced by the need to deliver a large and reliable supply of new agricultural feedstock to nearby refineries.[43] The strategy is pushing for small growers as the main producers, yet larger monocultures appear to be the most viable option. The choice of feedstock will also affect the nature of planting.[44] For example, sugar cane is often planted in monocultures, often over large areas; sugar beet and canola can be used as a rotational crop; jatropha (or other perennial trees and shrubs) can be planted as hedges in agroforestry systems or in monocultures.[45,46] These decisions may be influenced by the landowners themselves, their willingness to buy into biofuel schemes, and the different approaches to land management, such as the land-sparing versus various wildlife-friendly farming approaches.[47]

Such decisions will affect landscape heterogeneity. For example, large-scale plantings may act to create a more uniform landscape compared to small-scale schemes that may create more diverse landscapes, but increase fragmentation and the overall extent of biofuel cropping.[33] In most instances, land will have to be released from its current land use[26] with potentially important influences on the structure of farms at the lowest level of organisation. The potential for socio-economic benefits from small-scale farming will form a crucial part for government subsidies, as stated in the strategy. Previous experience has yielded mixed results for small-scale ventures in the Eastern Cape. To ensure social and environmental sustainability for such ventures to succeed, it is now recognised that adequate support, technical mentorship and community buy-in are crucial.[15]

Effects of individual species – effects at the local scale

The effect of biofuel crops on ecosystems and biodiversity depends to a large extent on functional attributes and the management requirements of the species. The per capita impact is a function of the plant's ability (native or introduced) to utilise or add resources, promote or suppress disturbance regimes and alter existing ecological processes (e.g. nutrient cycling and gene flow).[34,35]

Quantitative studies have yet to be carried out to determine the potential effects of specific biofuel species[26,48] and it is uncertain to what extent, if any, these species are capable of altering the physical habitat of the receiving environment. Whilst it is encouraging that certain species may have the capacity to improve degraded areas by improving soil quality and reducing erosion via the input of organic materials, for example jatropha,[49] it is concerning that many plants can radically change biogeochemical processes in new environments. For example, in nutrient-poor fynbos soils the increase in nitrogen by nitrogen-fixing woody alien legumes greatly reduces the ability of native species to recolonise the same habitat after clearing of stands of the aliens.[50]

The effect of a biofuel crop can also be attributed to the management regime of that particular crop. Where possible, impacts should be limited to the area undergoing cropping, thereby minimising disturbances beyond the cultivated area. Possible ways of minimising effects of individual species include: 1) avoiding gene flow to wild relatives in nearby populations, 2) preventing invasion by the crop into other habitats, 3) avoiding degradation of sensitive habitats and species within local landscapes, 4) not increasing the risk of loss of primary habitat and 5) minimising pollution of water, air and land resources.[33,51]

Industry as a pathway for the introduction and dissemination of invasive alien plant species

Non-native plant species are widely used for commercial forestry, agro-forestry, agriculture and horticulture in

South Africa[17] and economically important, wide-scale plantings have had considerable impacts on biodiversity and ecosystem services.[17,52] Escapes from plantations (e.g. wattles, pines and eucalypts) have become important invasive species in adjacent landscapes.[51] Many of the problems we face today caused by invasive trees are the result of plantings incentivised by government schemes focusing on short-term economic or social incentives.[53] It is estimated that 10 million ha of South Africa has been invaded to some degree and if condensed to adjust the cover to 100%, then this amounts to 1.7 million ha, which is greater than the extent of commercial forestry which totalled 1.5 million in 1996/1997.[54]

Despite the contribution of alien trees and shrubs to economies and livelihoods, there are many unexpected consequences and subsequent costs, both environmental and economic, which often outweigh the benefits of introduction.[36,51] Nevertheless the potential economic gains may be too great to prevent the widespread introduction of alien species for biofuel purposes.[5] The reasons for choosing alien plants over indigenous species for commercial forestry have been discussed previously.[51] The criteria for biofuel feedstock selection are similar, that is species: 1) need to grow fast with minimum tending, 2) are easy to manage, 3) produce large quantities of seeds/biomass and 4) are marketable and profitable.[55]

Many of the dedicated energy crops will be non-native to the region of planting and will probably be introduced multiple times as new varieties are developed for improved yield or resistance to pests and diseases (with propagules probably originating from different regions), further compounding the risk of future invasion.[56] Feedstocks that are *known* to be invasive and which are *guaranteed* to cause problems in this regard if used for biofuel production in South Africa include perennial grasses (e.g. *Arundo donax*, *Miscanthus* spp. and *Sorghum halepense*) and trees (e.g. *Millettia pinnata* and species of *Acacia*, *Eucalyptus* and *Populus*). There is a serious risk of private investors looking to profit from overseas demand for biomass, which could see these and many new plant species being widely propagated before effective legislation and planning guidelines are in place.

Existing measures for control

International regulatory bodies such as the Forest Stewardship Council (FSC) and environmental management systems such as the International Standards Organisation 14001 and various other self-regulatory bodies (e.g. the Biodiversity and Wine Initiative; www.bwi.co.za) have made it possible to mainstream biodiversity issues into the everyday management of South African plantations and other commercial agricultural operations.[53,57] These regulatory bodies enable farmers and foresters to consider a wider range of ecological impacts than those mentioned solely in legislation. For example, South Africa has the ninth largest FSC-certified area in the world and the largest area of certified exotic plantations.[57] Despite the economic contribution and environmental accolades, plantation forestry has been accused of impacting negatively on biodiversity and water resources, and contributing significantly to the current invasive species problem.[51,56] The Roundtable on Sustainable Biofuels (RSB: http://cgse.epfl.ch/page65660.html) presents a similar environmental management system for the biofuels industry and is currently undergoing testing of the existing criteria considered essential for mitigating impacts on biodiversity.[58]

The spatial scale of the potential biofuel industry (the massive area under cultivation that would be needed to make the venture viable) could be the single biggest threat to biodiversity and national-level priorities could affect regional and local-level commitments to biodiversity plans. A major aim for ensuring sustainable biofuel production, whilst keeping impacts to biodiversity at a minimum, should be to follow appropriate site-selection criteria and to embrace recent developments and advances in land-use planning. Whereas the use of suitability mapping (combining species requirements with soil and climate variables) was previously considered sufficient for planning in enterprises such as forestry, current approaches to conservation and natural resource management require operational, social and environmental factors to be considered to ensure the attainment of sustainable and defendable practices.[59] In the South African context this means balancing development goals with conservation concerns whilst maintaining large investor interest and opportunities. The importance of available mapping data in determining potential conflict and 'no go' areas (which recognise the importance of maintaining ecosystem function and connectivity) is crucial in this regard.

Forestry has undergone a significant attitude change to land use, with ecologically sustainable management practices governing many of the forestry sectors.[60,61,62] For example, it is now illegal to extend plantations into riparian and wetland areas, which are important habitats for growing poplars. Previous unregulated actions have influenced existing policy to protect natural systems and minimise degradation. However, the threat of development continues to drive land-use changes in vulnerable and managed ecosystems.[63,64] According to Richardson et al.[17] South African legislation regulating invasive alien organisms could, until recently, only be used indirectly to tackle key strategic issues, because the focus of national control has been on the protection and conservation of natural and agricultural resources (e.g. Conservation of Agricultural Resources Act (CARA); National Water Act). The promulgation of the amendments to the National Environmental Management: *Biodiversity Act* (*Act 10 of 2004*) will provide a more focused and direct approach for dealing with potential impacts to biodiversity and invasive species; it is anticipated that the emerging regulations relating to alien species will be directly applicable to biofuel production.[65]

Given the extent of current problems and the measures put in place to control existing invasive alien species,[66] South Africa can ill afford to allow the widespread dissemination of additional species which have a high risk of becoming invasive. To this end, the identification of emerging invaders[67] and the establishment of an Early Detection Rapid Response Programme are testament to the importance attached to reducing future threats (www.sanbi.org).

However it should be recognised that legislation alone will not be enough to prevent the introduction of harmful species. Building relationships with key stakeholders is crucial for reducing the use of potentially invasive plants and for reducing negative impacts. Tools, such as global datasets and weed risk-assessment protocols, are available for screening high-risk species.[18,68] However, our ability to conduct risk assessments are affected by the multitude of interactions that can occur before negative impacts are recognised. They are, nonetheless, useful for flagging potential hazards based on the biology of a species, ecology, climatic requirements, history and biogeography in relation to the target region.[55] These challenges could be exacerbated by climate change as alterations to species distribution patterns could see new areas being invaded, as well as new species becoming invasive.[35] Furthermore, the calculation of the risks involved becomes more challenging as the interactions between alien and native biota become increasingly difficult to predict.[69]

Proactive means of minimising biodiversity impacts will be addressed by the development of policy, programmes and guidelines that are able to address the conservation of biodiversity in managed and unmanaged areas.[18,63,64,70] Suggestions include: 1) limiting land use to biodiversity-friendly alternatives where reserve expansion is not possible, 2) identifying protected habitats and species and giving them priority in conservation interventions, 3) providing adequate guidelines and incentives to promote sustainable agriculture, including demarcating marginal land not suitable for agriculture, 4) implementing effective farm design to reduce fragmentation and propagule dispersal and 5) promoting environmental standards and approved guidelines within the industry.

Finding a balance

The delay in implementing South Africa's biofuels strategy gives us an opportunity to carefully consider the full range of potential impacts posed by this emerging industry, and to plan accordingly. The impacts and threats posed by this industry can be markedly exacerbated or reduced by the various technological aspects of biofuel production. The selection of feedstock options, the intensity of planting, and the eventual geographic distribution and configuration of plantings across South Africa are crucial factors that will influence the impact of the industry on biodiversity. As technology and plant breeding advance we could see multiple new species or varieties of species emerging as potential biofuel feedstocks. Therefore, a framework is needed to evaluate the risks, costs and benefits of existing and future feedstocks. By considering possible development scenarios we are better placed to move beyond reactive responses towards the integration of sound guidelines, policies and legislation to ensure sustainability and accountability from the outset. It is also important that short-term incentives to promote the biofuels industry do not ignore the possibility that changing technologies could result in crop abandonment or downscaling in the near future.

Despite this call for a cautionary approach, the urgent and escalating need for rural upliftment and poverty alleviation may tip the balance in favour of increasing development mechanisms such as biofuels expansion, reducing environmental concerns to a lower level. Globally, the biofuels industry is expected to undergo rapid growth and South Africa should be well positioned to accommodate investments in this area. Policy should anticipate future developments and encourage projects that can contribute positively to rural development, whilst also reducing greenhouse gas emissions and preventing biodiversity loss. The issues are extremely complex and we need innovative collaborations between disciplines and the transfer of lessons learnt from similar industries.

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