ACES: Abrupt Changes in Ecosystem Services and Wellbeing in Mozambican Woodlands

Summary

This project examines how woodland loss is changing ecosystem services and wellbeing of the rural poor in Mozambique. It will integrate this new information into land use policy and practice to alleviate rural poverty. Poor rural households depend vitally on ecosystem services derived from woodlands (Clarke *et al.* 1996). However, little is known about change: how the impacts of woodland loss and agricultural expansion affect rural wellbeing. Gradual land use change can cause abrupt or non-linear changes to ecosystem services and rural livelihoods (e.g. Rodrigues *et al.* 2009), but given the complexity of the system, the key ecological and social processes remain opaque (Campbell and Byron 1996). Better land use policy and practice require empirical evidence on the impacts of land use change on rural wellbeing (Dewees *et al.* 2008). ACES will deliver such evidence, within a framework designed for, and by, those involved in land use decisions. The project will do so through a novel combination of stakeholder participation in the construction of Bayesian belief networks, the collection and analysis of large-scale social-ecological data along gradients of land use change, leading to the creation of future scenarios through which impacts can be assessed. These methods allow the incorporation of different types of knowledge, a systems approach to complex realities, and the co-production of outputs to ensure maximal impact. Our approach will inform policy formulation and implementation that will directly influence the expansion of commercial agriculture, intensification of small-holder agriculture, rural development, and the likely trade-offs in management of woodlands for food, energy, timber, carbon and biodiversity. The project will employ four postdoctoral researchers from Mozambique and Zimbabwe who will work in close collaboration with researchers from Edinburgh, Exeter and Brazil, led by an interdisciplinary team from southern and northern institutions. A steering committee of experienced scientists and practitioners from Zimbabwe, Mozambique, Brazil and Europe will provide strategic guidance and international policy linkages. The project builds on decades of work at three sites in Mozambique, and long-standing involvement in pro-poor science-based land use policy in Mozambique. It leverages 6 other projects in Mozambique with a value of >£2.2M, and international projects >£30M. In particular, this project is closely linked to a £1.9M investment in pro-poor land use in our study area, allowing our research to have a direct impact, as well as attracting stakeholder interest and the development of communities of practice.

Introduction and science-policy rationale

Miombo and mopane woodlands support the livelihoods of 100s of millions of the world's poorest people (Campbell 1996b). They are dominant vegetation types in southern Africa (White 1983) and present a unique social-ecological system characterised by relatively high population densities, rapidly growing populations, shifting cultivation, a reliance on biomass for energy (Clarke *et al.* 1996) and complex ecological interactions involving an interplay of trees, grass and multiple disturbances including fire (Frost 1996; Ryan and Williams 2011). There are extremely tight linkages between social and ecological components of the system; rural households derive much of their wellbeing from the woodlands (Cavendish 2000; Shackleton *et al.* 2007) and associated agricultural systems, and the role of ecosystem services (ES) in mitigating poverty has been well documented (Dewees *et al.* 2008). However, demand for agricultural land and energy is driving rapid rates of deforestation and forest degradation, altering the ecosystem structure from which these services are derived (Ryan *et al.* 2012).

In addition to these internal dynamics, new external forces are altering the system. Historically, these woodlands have been of little use to commercial timber and farming interests (Dewees *et al.* 2008), being relatively infertile, prone to tsetse, and with sparse stocks of commercial timber. This is changing, with a new influx of capital and technology from the emerging economies of Brazil, Russia, India, China and South Africa (BRICS), and new linkages to commodity chains bringing increasing exposure to the global demand for land and protein (Lambin and Meyfroidt 2011). The expansion of commercial agriculture (InfraCo 2010; Nhantumbo and Salomao 2010; ABC 2012) and improving agricultural returns are seen as key routes to development (Jones and Tarp 2012) and are the first objective of Mozambique's Poverty Reduction Action Plan (PARP 2011), but the trade-offs in terms of altered ES and the wellbeing of the poorest are not yet understood.

The way in which individuals, households (hh) and communities in woodlands respond and adapt to changing ecosystem structure, function and services has not been well documented (Campbell 1996a). However, the available evidence shows that a range of adaptive responses allow hhs to sustain their wellbeing in the short term as woodland resources decline (Campbell *et al.* 2000a), including substituting some resources with external inputs such as fertiliser, changing consumption patterns, and making efficiencies (Remme *et al.* 1997). However the broader literature shows that not all groups can adapt in this way, and substituting out of natural resource dependence is particularly challenging for poor, remote and female-headed hhs (Little *et al.* 2001; Fisher 2004). There may exist concomitant processes whereby thresholds of ecosystem structure are exceeded and adaptation is constrained by limited access to non-natural capitals, precipitating poverty traps (Berkes and Folke 1998; Seixas *et al.* 2002). **Thus we hypothesise that there are abrupt changes in wellbeing as ecosystem services change with woodland loss.** The identification of any such thresholds of abrupt change is crucial to inform management of land use change to minimise poverty, especially given the absence of social safety nets (Dewees *et al.* 2008).

The challenge of developing and implementing effective land use policy is great, and the confluence of a declining woodland resource, growing populations, and new external pressures mean that it will not get easier. The multiple uses of woodlands, as well as their ecological complexity, mean they have historically not been managed to benefit the rural poor (Dewees *et al.* 2008), despite an agenda of management decentralisation. Overall there is little national policy, let alone practice, that acknowledges the importance of ES for wellbeing or which tries to manage the decline in ES as woodlands are converted or degraded. We will build on our track record of successfully influencing national land use policy in Mozambique (documented in Nhantumbo and Salomao 2010; Nhantumbo 2012; Sitoe *et al.* 2012). Through the co-production of a research framework, the generation of robust empirical data, the articulation of realistic future scenarios and the creation of communities of practice, this project will lead to **better pro-poor land use policy in the woodlands of Mozambique.**

Why Mozambique?

The focus of ACES is on Mozambique because it typifies the challenge of managing woodlands for the benefit of the rural poor. Furthermore, relatively good governance allows for critical, informed debate and policymaking, thus maximising our impact. Mozambique still has an extensive woodland resource (70% of the land cover; 55 M ha), albeit with high deforestation (0.2-1.7%/yr, Marzoli 2007) and degradation rates (2-3%/yr, Ryan *et al.* 2012). Mozambicans are predominantly agrarian, with ~14 M people cultivating ~5.5 M ha (PEDSA 2011). The country is extremely poor by any standard (184/187 in the UNDP 2001 human development index, 54% poverty incidence), particularly in rural areas, where for example, 64% of agricultural households are consumption poor and 87% are asset poor (Jones and Tarp 2012). Recent economic growth has been rapid, but poverty rates are not currently decreasing (PARP 2011). Inequality remains high (Gini Index 0.45) and social unrest is increasing (Jones and Tarp 2012). Agricultural intensification is seen as the route to rural development and decreasing poverty (PARP 2011), but has proved elusive. Currently there are around 400 large commercial farms producing sugar cane, sorghum, tobacco, cotton, tea, citrus and livestock, comprising only 5% of national agricultural production (PEDSA 2011). However, the potential is high and change imminent; the Ministry of Agriculture recently indicated the intention to allocate 5.8 M ha to grow soya in northern and central Mozambique under the ProSavana project (Clements & Mançano 2012).

Aim and Objectives

ACES will contribute to poverty alleviation in Mozambique by co-producing new knowledge of the dynamic links between land use change, ES and the wellbeing of the rural poor, meeting the demand from policy makers and practitioners for ways to better manage Mozambique's woodlands (Dewees *et al.* 2008; Wiggins *et al.* 2012). To achieve this we will:

- Create a framework to analyse the key relationships between land use, ES and wellbeing that are of greatest relevance to the rural poor, civil society, private businesses and decision makers in Mozambique, using trusted conduits to engage key stakeholders: Work Package (WP) 1.
- Collect data and empirically analyse the key relationships between land use, ES and wellbeing at three sites representing the main land use intensification gradients in Mozambique (WP2 and 3), including one location of increased investment in agriculture by the BRICS.

- Formally test hypotheses about the relationships between land use, ES, and wellbeing. In particular we will examine whether land use intensification is likely to cause abrupt changes in ES provision and wellbeing (WP4).
- Create plausible future scenarios of land use in Mozambique. These scenarios will articulate ways in which rural poverty can be alleviated by the optimal management of landscapes to support ES and human wellbeing (WP5).
- Build communities of practice at multiple levels able to turn this new information into better land use policy and practice (Pathways to Impact).

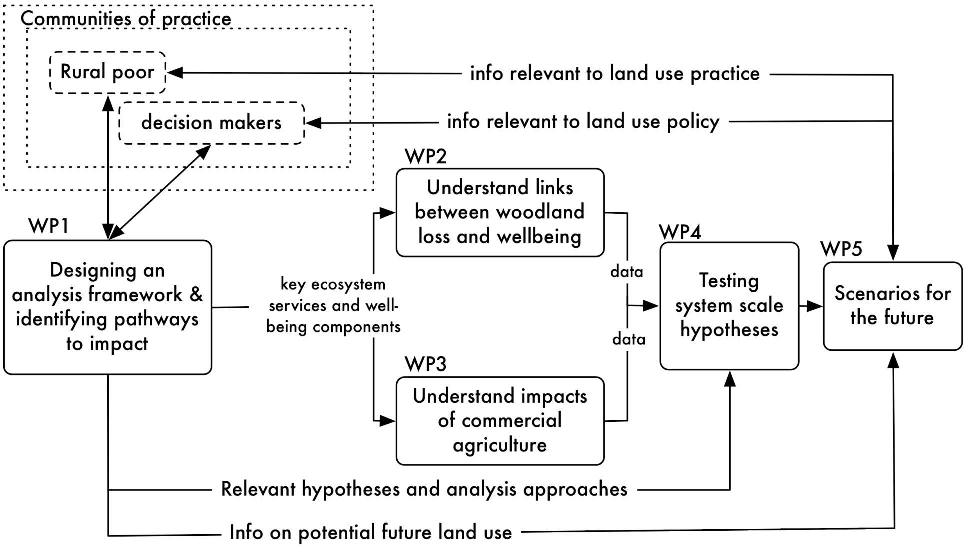


Figure 1. The structure of ACES. Boxes show work packages (WPs) and arrows indicate information flow

Methodological approach: overview

Defining the questions of interest to stakeholders, and which will lead to impact, is crucial. We are interested in a complex system with unclear boundaries. To allow tractable issues to be identified, we will engage stakeholders to identify how the system is perceived to operate, and to identify aspects of poverty and types of ES that are most pertinent. The use of a **Blueprint Protocol** for ecosystem assessment (Seppelt *et al.* 2011) and **Bayesian belief networks** (BBNs) will allow us to define the system to be studied in a way that engages stakeholders. This approach follows our work for the UK NEA (Haines-Young *et al.* 2011) and similar work in Mozambique (Lynam *et al.* 2004). Our data collection will be rooted in the basic notion that some aspects of rural wellbeing stem from ES, which are in turn the products of ecosystem structure and function. **We will operationalise our ESPA conceptual framework** (Fisher *et al.* submitted), which builds on a synthesis of relevant literature (Fisher *et al.* accepted) to identify key parameters for an empirical framework that we will apply to the social-ecological systems under study. By exploiting a **space-for-time substitution** we will gain insight into how wellbeing changes as land use intensifies. Past work demonstrates that ecosystem services are important contributors to wellbeing in miombo woodlands (Cavendish 2000), and that this importance varies between social groups and types of service, with the poorest disproportionately reliant on provisioning ecosystem services (Campbell 1996a; Clarke *et al.* 1996). Taking this as our departure point, we bring novelty by examining how this relationship changes with land use intensification and woodland loss, both by smallholders, and crucially, new globalised agricultural investments. We maintain an explicit focus on **how changes in ecosystem services are experienced by different groups in society, with a particular focus on the poorest.** Most studies to date have only characterised parts of the complex system (Campbell and Byron 1996), meaning **there is a need for large scale systematic data collection and analysis**. Because of the complexity of the system under study, there is also **a need for new analytical approaches**, that can incorporate different types of knowledge and uncertainty, and which acknowledge the presence of feedbacks and non-linear behaviour (Carpenter *et al.* 2009). We will use **structural equation modelling** to address this. Finally, by **creating scenarios** of future land use and rural wellbeing, we will be able to fuse the new process understanding and existing beliefs into simple tools to explore the impacts of future policy.

Data collection
Our sampling strategy in WP2&3 is based on sampling along gradients of land use intensity, effectively using spatial variation in land use intensity and associated impacts on ecosystem structure as a substitute for the temporal land use intensification dynamic. The utilisation of such space-for-time 'natural experiments' is the only ethical and practical approach to our questions, but does have limitations that we will address and adjust for (Rodrigues *et al.* 2009; Walker 2011). We will select study areas which have a gradient of land use from woodland to agriculture-dominated landscapes and where we can hold some aspects of the social-ecological system constant, by selecting regions with relatively homogenous biophysical conditions. We can then quantify relevant variations in the remaining aspects. A gradient of land use intensity will have strongly varying social dynamics, which are likely to co-vary with land use change intensity. For instance, access regimes change with changing resource abundance (Clarke *et al.* 1996), as do consumption preferences and the desire to modernise (Campbell 1996a; Campbell *et al.* 2000a). Cause and effect are often unclear in the presence of tight feedbacks, and our analytical approach is therefore aimed at revealing such linkages and understanding them, in both qualitative and quantitative terms. We have designed a methodology to capture data on the suite of social-ecological parameters that will allow both quantitative and qualitative examination of the relationships of interest (Tables 1-4). These parameters have been chosen based on a review of the literature (Clarke *et al.* 1996; Chidumayo 1997; Scoones 1998; Leach *et al.* 1999; Campbell *et al.* 2000b; Shackleton *et al.* 2007), but will be modified in light of WP1, which may identify other aspects of particular importance to stakeholders. A pilot study, at the start of the fieldwork phase will help us revise and refine the effectiveness of our methods.

Poverty groups and social differentiation
We will use participatory wealth ranking (Chambers 1994) as a means to stratify the sampled hhs, and to identify local indicators of wealth and wellbeing. This will enable us to analyse our data by relative wealth/wellbeing strata, giving us the opportunity to understand the situation of the poorest. It will also enable us to draw conclusions about whether better management of ES can contribute to poverty reduction (moving above a poverty line), as well as prevention (the maintenance of a minimum standard of living, which may be below the poverty line; distinction in Angelsen and Wunder 2003).

Systems Analysis
Our social-ecological data collection will largely be at the level of the hh, but will include focus groups and key informant interviews, particularly to finalise our requirements for quantitative socio-economic data. Our analysis will be at two levels: inter- and intra-village. Firstly, to understand the detailed interactions between land use and wellbeing, we will analyse data at hh and community focus group level (intra-village). Our research questions, activities and outputs are detailed under WP2 and 3. Secondly, to try and generalize our understanding and provide information at a system level we will undertake inter-village analysis along the gradients. The latter will be conducted by fusing a mixture of expert knowledge and statistical analysis based on structural equation modelling (SEM; aka path analysis, WP4). This broader generalised knowledge is vital to the construction of scenarios, which will be created to meet the needs of stakeholders at all levels (WP5), and represent our key pathway to impact.

Study sites
We will work at three study sites, each with a gradient from relatively undisturbed woodland to intensively cultivated areas. These have been provisionally selected on the basis of known gradients of land use change (Ribeiro *et al.* 2008a; Ribeiro *et al.* 2008b; Cumbane 2010; Joshi and Ryan 2012; Ryan *et al.* 2012) selecting areas with similar soils and woodland vegetation and avoiding gradients which include markedly divergent land use history in the colonial period. Study site location will be refined by WP1.

- North (Tete Province, WP2). This miombo site runs from the Nacala development corridor to the buffer zone of the Niassa Reserve. ProSavana will be implemented in this region. Ribeiro's work here since 2005 provides community facilitators and existing partnerships.
- Centre (Sofala and Manica, WP2&3). This area has a longer history of commercial agriculture and major plans for the expansion (InfraCo 2010). We have a track record of working with commercial firms in the area (Nhantumbo and Salomao 2010). UEM (Sitoe) and UoEd (Ryan) have several study sites in this areas giving access to district administrators and local

collaborators. Project partner MICAIA is active in this area working with both smallholders and commercial firms.

- South (Gaza, WP2). This is a gradient of mopane woodland, dominated by the extraction of charcoal for supply to Maputo (Cumbane 2010). Bandeira (UEM) and LUPA (project partner) have strong links to communities and government here.

Work Package 1. Designing a framework for analysis

Leads: Nhantumbo (IIED) & Patenaude (UoEd). Resource: 2 post docs, 1 at UEM (3 years), 1 at UoEd (2.5 years), split with WP5

A Blueprint Protocol (Seppelt *et al.* 2012) will serve as the backbone analytical tool to underpin data collection, testing the system scale hypotheses and scenario construction. Given the need for: (1) a broad, multi-dimensional understanding of poverty (Hulme *et al.* 2001) and its converse, wellbeing; (2) a necessary focus on only a subset of ES of importance for poverty alleviation; and (3) the engagement of a wide range of stakeholders, close collaboration with partners in the development of the protocol is fundamental. Collaboration in the design, production and delivery of research is critical to secure stakeholder engagement and to produce credible outputs (Cash *et al.* 2003). After an initial preliminary selection of suitable stakeholders (see Box 1), further stakeholder mapping will help minimise the risk of marginalising underrepresented actors (Prell *et al.* 2009).

To formalise the conceptual understandings of our stakeholders, we will use Bayesian Belief Network techniques (BBNs; see Box 2). BBNs are an ideal tool for modelling the causes and effects of different drivers of change, management impacts and other factors and are also adept at representing uncertainty in social-ecological systems. We will use them both to (1) formalise our Blueprint Protocol (WP1) by representing current land use/ES/wellbeing linkages at local, regional and national scale (Smith *et al.* 2011), and (2) to allow the stakeholders to construct quantitative future scenarios (WP5). BBNs have been used widely by our team for exploring the impacts of land cover change under different scenarios (e.g. in the UK NEA, Haines-Young *et al.* 2011) and by others in the context of community-led decision-making in African woodlands (Bacon *et al.* 2002; Lynam *et al.* 2004). They provide a graphical method of displaying the relationships between variables - crucial to aid stakeholder participation. Variable linkages are represented by conditional probability tables, which are parameterised by elicitation involving experts and local stakeholders or from data. The strength of BBNs lie in the transparent way of dealing with complexity, as well as their capacity to deal with a combination of expert opinion, empirical data and missing data. To ensure close integration between WP1&5, the same staff will undertake the stakeholder engagement for both WP1&5 and activities will be conducted with the same groups, sometimes at the same meetings.

Activities: A1.1 Initial stakeholder group consultations and workshops

Through our networks, partners, and past work, we will identify from whom to elicit expert and local knowledge and identify the key ~20 participants at each stakeholder workshop. Ease of travel is a major constraint for some stakeholders, so 3 workshops will be held in rural areas (at each study site; hereafter local scale), 3 in the provincial capitals (regional) and 1 in Maputo (national). This process will build on the successful national REDD consultation process facilitated by IIED (Nhantumbo 2012). Our project partners will help facilitate these meetings, which will be run by the UEM and UoEd post docs and the IIED Impact Fellow, guided by the UEM staff who have long experience of working in each area (Ribeiro, Bandeira, Sitoe). The national meeting will be guided by Nhantumbo and Sitoe who have worked at a national policy level for decades. All meetings will use Ketso for creative engagement (Tippett *et al.* 2011).

Box 1. Preliminary and abbreviated list of stakeholders

- Community groups and national NGOs: ORAM, CTV, Forum Terra, Forum de Florestas
- Private sector: CTA – Confederation of Private sector Companies – they have groups divided by investment sector including Agriculture, tourism, forestry, energy; FEMA – Forum of private sector companies for Environment; commercial agricultural enterprises in Beira corridor identified by AgDecCo.
- Government (national): **Ministries of: Coordination of Environmental Affairs** – National Directorates of Environmental Management, Land Use Planning; **Agriculture** – National Directorates of Agrarian Services, Lands and Forests, Agrarian Economy; **Tourism** – National Directorate for Conservation Areas; **Finance**; **State Administration** –National Directorate for Rural Development
- Government (Regional and Provincial): Gabinete do plano de Zambeze; Beira Agriculture Corridor; Provincial Directorates of Environment, Energy, Planning and Development, Agriculture
- Researchers: Instituto de Investigação Agrária de Moçambique (IIAM); Centre for Sustainable Development (Chimoio)
- International policy groups and NGOs: CIFOR, ICRAF, WWF-Mz, CARE

A1.2. Construct preliminary BBNs and iterate with stakeholders
Information elicited from the stakeholders will be used to construct draft BBN models using Netica software, detailing the important factors relating wellbeing and land use at the three different scales. The social-ecological processes under investigation in the region will be reviewed and then allocated to variables under different categories. The validity of relationships in the BBNs will then be checked and the states of each node defined. At this point an accurate model of the stakeholders' *perceptions* will be constructed which will then be used to highlight agreements and disagreements between groups and scales via a second round of the 7 workshops, to be completed by 2014. The main areas of agreement and conflict in terms of objectives, interventions and other factors will be presented and discussed.

A1.3 Complete stakeholder BBNs
The research team will create a 'master' BBN diagram combining the local, regional and national-scale BBNs and will add potential management interventions drawn from all scales and expert knowledge. Including all the objectives and interventions from the stakeholders is crucial. This final BBN should provide a modelled synthesis of the overall current state and drivers of land use change for each gradient and at the three scales. This is delivered to WP5 for construction of scenarios and quantitative output.

A1.4 Finalise the Blueprint protocol
Based on the outputs from the stakeholder meetings, formalised in the master BBN, WP1 will coordinate our final definition of the system under study, bridging the interests of stakeholders with the constraints of project implementation. This will be agreed by all WPs in time for fieldwork planning in early 2014.

Outputs: O1.1 A Blueprint protocol for the project. This will provide detailed model descriptions of the social-ecological systems, represented by BBNs. This includes: definitions of the spatial and temporal scales considered on each gradient and for the national scenarios; boundaries of the systems; environmental attributes of interest; a list of the ecosystem functions and services considered important for poverty alleviation and which are affected by land use intensification. It will identify the flows (sources and sinks) of ES within the system and across boundaries, and the beneficiaries and losers from ES; as well as the main actors and governance structures. Relevant meanings of wellbeing and poverty will be defined and indicators agreed. The draft list of parameters to be measured will be finalised (Tables 1-4). This will allow the project staff a unique overview of the current state of land use in Mozambique, and specifically at our sites.

O1.2 A master BBN of local, regional and national understandings of land use change and rural wellbeing. This will form the basis for the scenario development in WP5 and the integration of the new knowledge from WP2-4.

O1.3 A policy brief summarising the actors and current understanding of land use change in Mozambique, highlighting agreements and discrepancies between groups and scales. This will be aimed at national actors to allow them a better understanding of other groups' perceptions, central to a deliberative process, and will begin the process of engaging our communities of practice (See Pathways to Impact).

WP2. The links between woodland conversion & degradation and wellbeing

Leads: Ribeiro (UEM), Ryan (UoEd). Key resources: 2 post docs x 3 years, 1 at UEM, one at UoEd [Nicholas Berry]

This WP will quantify ecosystem structure, function, services and wellbeing along three gradients. The aim is to understand the empirical relationships between these, and to determine which factors mediate the use of ES. This will allow us to quantify the aspects of the ecosystem that most strongly influence wellbeing along the gradients. The gradients have been selected to include areas where smallholder agricultural expansion and woodland degradation are occurring (Ribeiro *et al.* 2008a; Cumbane 2010; Joshi and Ryan 2012), but where commercial agriculture is not yet present. Based on a standardised protocol developed through WP1 and detailed in Tables 1-3, we will collect data describing the state of the social-ecological system in a sample of 30 villages along each gradient (stratified by land use intensity from larger scale maps, then randomly sampled based on village names). Through qualitative data collection we will also characterise the current trends and issues particularly pertinent for the poorest, allowing us to focus the quantitative analysis.

Research questions
Q2.1 How do changes to ecosystem structure along land use intensification gradients affect the key supporting services on village land (NPP, nutrient cycling and diversity)?

Q2.2 What factors determine household use of, and dependence on, provisioning, regulating and cultural ecosystem services?

Q2.3 As woodland resources decline along the gradient, how do households adapt to the reduced provision of some services? What constrains these adaptive responses?

Q2.4 How does changing ecosystem service availability affect the wellbeing of different groups of people, particularly in terms of poverty status and gender?

Activities: A2.1 Assessment of ecosystem structure and supporting services
For the sample villages along each gradient we will characterise the ecosystem structure and supporting services of the area that village members have rights to use. This will be done using participatory land use mapping to determine spatial patterns of land use, merged with high resolution optical and radar satellite data (Hessel et al. 2009). These maps will be combined with hh reported and modelled crop yields, forest inventories and faunal assessments (details in Table 1). In addition we will characterise the functional diversity of the landscape at both land cover patch scale (from remote sensing) and floristic diversity (α-diversity from plots and transects). Diversity will be analysed in terms of functional attributes (Diaz *et al.* 2011) that relate to the *use* of species and land cover types, by creating a checklist of uses based on the large existing literature (Thobega *et al.* in press) and focus group discussions. We will analyse the diversity of fauna using both functional use criteria and known indicator species (Tinley 1977). This will allow both a land use classification, and estimates of productivity of agricultural and woodland areas, in units that relate to human use (e.g. t/yr of fuelwood available, number of building poles, maize yield, availability of edible birds). The soil fertility status of the village land will also be analysed based on soil sampling in fields and along transects. We have developed geostatistical techniques to allow efficient sampling of these landscapes (Woollen *et al.* 2012).

A2.2 Determining the factors that affect the use of ecosystem services
Through focus groups and randomly sampled hh surveys (stratified by poverty group), we will characterise the use of ES at the hh level, examining how people experience the presence and absence of services. We will focus on the ES use measurements detailed in Table 1, but will adapt this based on the findings from WP1, and at a village level, to reflect the reality on the ground. Once we have understood use, we can understand household characteristics that determine use and dependence. This will involve differences between services: regulating services differ qualitatively from provisioning as access to provisioning services is easy to control the use of, whereas it is harder to restrict access to regulating services (Fisher *et al.* submitted). Changes in cultural services are likely to be associated with spiritual and ritual practices and aspects of social cohesion. By using a mixture of qualitative and quantitative approaches, we will be able to suggest models of the determinants of resource use (Table 2) and test these models (i.e. hypotheses) using multi-level structural equation modelling (see WP4 for details). This will reveal the importance of the factors we *can* quantify, and through the inclusion of unmeasured latent variables (Asah 2008), the limitations of the explanatory power of these factors.

A2.3 Analysis of adaptive responses to woodland decline
The space-for-time substitution along the land use intensification gradients allows us to understand, quantitatively, changed ecosystem service usage with woodland loss. We will also seek to understand through qualitative investigation the trajectories and adaptive responses of particular communities which have experienced rapid or recent changes in ecosystem services. The following adaptive responses are documented in the woodland literature (Clarke *et al.* 1996): changes to gender roles, transport modes, commercialisation, substitution, decreased use, more restrictive use rights, greater reliance on private land (Campbell 1996a). We will assess these in our sampling strategy and data collection, but we also expect others (e.g. migration) to be discovered more inductively in our pilot surveys and focus groups.

A2.4 Analysis of the distributional impacts of land use change
We will investigate changing ES and societal responses through a lens of social differentiation. What evidence exists suggests that such changes are experienced very differently depending on for instance, existing wealth/wellbeing and gender (Daw *et al.* 2011; Fisher *et al.* accepted). This

requires a socially stratified sample, which will be obtained using participatory wealth/wellbeing ranking. This will give the ability to disaggregate the dataset by wealth/wellbeing.

Outputs: O2.1. A paper describing how ecosystem structure and function changes along the gradients, reporting both the changes to ecosystem functions and those of specific importance for human use. Given the novel level of replication and the extensive nature of the characterisation, we expect this paper to be suitable for *Global Change Biology*.

O2.2 A modelled description of the determinants of hh ES use, structured by qualitative analysis of focus groups and assessed quantitatively using SEM. This would be suitable for publication in *Global Environmental Change* or *Environmental Conservation*. In the process of this activity, we will empirically adapt our ESPA conceptual framework (Fisher et al, in review). A methodological paper will focus on how socio-economic factors in Table 2 can be empirically assessed to understand ESPA issues. This would be suitable for publication in *Ecosystem Services*.

O2.3 A quantitative and qualitative investigation of adaptive responses to changes in provisioning, regulating and cultural ES. The particular novelty would be in documenting for the first time perceptions of, and adaptation to, changed availability of these services along land use intensification gradients in woodlands. This paper will test for the presence of adaptive responses using SEM models, structured by focus group discussions. This would be suitable for publication in *Global Environmental Change*.

O2.4 A quantitative examination of the impacts of changing ES use on the wellbeing of hh along the gradients, analysed by poverty groups and gender. We will adapt this into our 2nd policy brief and video aimed at those involved in forest management and conservation and the promotion of improvements to smallholder agriculture, and publish this in e.g. *World Development.*

D2.1. A spatially explicit data set characterising the ecosystem structure, function and services of each village for use by WP4. Maps and summary data will be left with each village's leadership.

D2.2. A structured database of the data collected, to be curated and made public by the end of the project. This will allow for reuse and thus longitudinal ecological and social studies.

Table 1. An indicative list of the land use and ES parameters to be measured in each village along the gradients. Asterisks indicate services which are not well understood at present, or where the mismatch of spatio-temporal scales make the link to local land use unclear. In these cases we are dependent on WP1 to elicit parameters of relevance. Services have been categorised according to MEA (2005) with the inclusion of dis-services (Dunn 2010)

Parameter	Description	Method
Land use intensity indicators		
Current level of degradation	Composite indicator to capture multiple aspects of degradation: - woodland biomass: difference from edaphic/climatic limit, - woodland area and patchiness - floristic diversity	Biomass will be assessed through radar remote sensing (Ryan *et al.* 2012) and groundtruthed against plot data, which provides floristic detail. Potential biomass will be assessed following Frost (1996)
Intensity of large scale commercial agriculture	Area under commercial agriculture, crop type and time since establishment	Expert classification of high resolution optical/NIR images, to construct time series of land cover and the expansion of commercial agriculture from 2000
Supporting services		
Agricultural and woodland net primary productivity	NPP of agriculture and woodland - describes the autochthonous inputs to the ecosystem	Modelled following Ryan & Williams (2011) for trees, Frost (1996) for grass, CENTURY (Ardo and Olsson 2003) for crops - extending the work of Berry & Ryan (2012)
Soil fertility	Soil organic C, N and available P indicate the productivity of the land area, especially in terms of agriculture.	Soil sampling in fields (Ghee *et al.* 2010) and in woodlands following Woollen et al (2012) P following Quesada *et al.* (2009). Org C analysed wrt to texture.
Functional and species diversity of woodland & agricultural trees	The diversity of tree species underpins various provisioning services, and also the ability for substitution	Plots and transects following (Ribeiro *et al.* 2008a). Functional and use diversity (Thobega *et al.* in press)
Abundance and diversity of birds, land snails, grazers and predators	Underpins provision of non-plant protein	Following Tinley (1977), adapted for rapid assessment on small plots
Provisioning services		
Crop yields	Annual yields of major crops, based on farmer assessment	Household (hh) surveys upscaled with participatory land use map
Extent of NTFP harvest	Collection of honey, medicines etc	Hh surveys, survey of collectors and producers, Including methods to improve accuracy of self-reporting of illegal practices (St. John *et al.* 2010)
Production / use of charcoal, fuel wood, poles	Harvesting of woody biomass for use or sale	
Domesticated & wild animal use		
Inputs of org matter	Collection of dung and litter	
Regulating services*		
Erosion control, pest outbreak control, mediation of floods	Understand importance of ecosystems for regulation of soils, pests and natural disasters.	hh survey & focus groups, district records of deaths and disease outbreaks. Key informant interviews with district health, agric & wildlife officials.

Cultural services*		
Levels of tourism, areas of sacred woodland, presence of traditional healers	Self reported indicators of various cultural services, identified by focus group	hh survey and focus groups
Dis-services		
Malaria	Estimate of incidence rates and days lost to sickness.	hh survey and focus groups, key informants (health workers, district agricultural official), public health statistics.
Tsetse fly		
Other ecosystem-related health hazards		
Crop pests	Loss rates, frequency of outbreaks	
Human- animal conflict	Impacts on health, fear, death	

Table 2. Household or village level factors that mediate the use of ecosystem services. These represent the empirical adaptation of our ESPA framework. These will be assessed using focus groups, hh surveys (Angelsen *et al.* 2011), participatory land use mapping in combination with GIS analysis (Hessel et al. 2009), and interviews with key informants. Where factors confound simple quantification, we will develop ordinal measures.

Market presence/activity	The presence of local markets will critically affect extraction and use of ES, most obviously provisioning (commodities). Thus we will measure village level market access, by recording geographical distance (or travel time) to trading centres and other markets.
Proximity to different kinds of ES	Proximity to ES will influence their use; we will understand proximity through participatory land use mapping. This will be recorded for each hh.
Endowments	Endowments are conventionally understood at the hh level: "the rights and resources actors have" (Leach *et al.* 1999). This can involve natural endowments (covered above in terms of proximity), and legal or customary endowments, associated with property rights (Schlager and Ostrom, 1992) and other means of access (Ribot and Peluso, 2003).
Entitlements	Also understood at the hh level or differentially within the hh, entitlements are the means to use a resource: "legitimate effective command over alternative commodity bundles" (Leach *et al.* 1999; Sikor and Nguyen 2007)
Capitals	Households have human, financial, physical (includes technology), and social capital (we exclude natural capital as covered in Table 1 via ES) (Scoones 1998)
Preferences	The preferences of people govern ES availability via management/selection of particular species, hence govern the character of the ecosystem and also which ES hhs use.
Adaptive capacity	Hhs are likely to adapt their livelihood strategies to changed access to ES. Such adaptations will be explored qualitatively to guide model construction (see A2.2). The climate adaptation literature suggests that adaptive capacity relates to entitlements, capitals etc (Adger and Kelly 1999).

Table 3. Poverty indicators to be measured to assess rural wellbeing. Informed by the Mozambique National Poverty Assessment (MPD-DNEAP 2010)

Consumption poverty indicators	Household information on consumption and purchases. Cost of Basic Needs approach.
Food consumption	Food poverty index, expressed as cost per person per day to meet a regionally-specific minimum calorific requirement when consuming a food bundle comprised of goods that the poor in the region actually consume (MPD-DNEAP, 2010; 82). Will not be used in peri-urban areas where index is unreliable (van den Boom 2011).
Non-food consumption	Cost of non-food basic goods consumed over a given period (e.g. soap, clothes). Includes purchases, home-produced items and received gifts.
Non-monetary poverty indicators	Access to/ownership of private and public goods and services. Assets are robust indicators, reflecting longer processes of material accumulation compared to fluctuating short-term consumption. Access to education /health central to poverty assessment, e.g. Human Development Index
Housing quality	e.g. materials of roof, floor, walls.
Ownership of consumer durables	e.g. bicycle, motorbike, TV, mobile phone, bed. Robust as (sometimes) can be observed rather than reported.
Access to education	% hh currently enrolled in educational programme; education level of hh members
Access to health services	Time taken to walk to nearest primary health facility; quality of facility (ordinally ranked).
Access to clean water	Access to potable source, and use of water treatments
Anthropometric indicators	To understand chronic and acute malnutrition. Central to poverty assessment in food-stressed regions.
Weight, Height, Age	Measured on children <5 years. Together these indicators give basis of assessment of wasting/stunting/underweight. Require direct measurement by trained staff.

WP3. Understanding the impacts of commercial agriculture

Leads: Artur (UEM), Fisher (UoEx), Ometto (INPE). Resource: 3yr postdoc at UEM, 3yr postdoc at UoEx, 1.5yr postdoc at INPE

Commodity chain analysis will be combined with hh survey data to understand how rural wellbeing changes as commercial agriculture expands. The commodity chain will be analysed for commercial agricultural crops that are rapidly expanding (identified by WP1), e.g. sugar cane, jatropha, and soya. We select cases in our central site (in the Beria corridor, but distinct from WP2) with commercial installations aged at least 3 years, such that effects are tangible. Expansion of large-scale plantations capitalised by the BRICS is a novel driver in Mozambique (Jones and Tarp 2012), but we will also examine outgrowing schemes because these potentially involve more broadly distributed benefits (Benfica *et al.* 2002), and create multifunctional landscapes rather than monoculture, therefore having different effects upon ES. We can therefore compare various modes of commercial agriculture, in particular looking to experiences of these crops in Brazil. A purposive sample of hh and community focus groups, using the methods in Table 1-4, along gradients of commercial agriculture will allow examination of impacts, in terms of ES availability for rural people (Tables 1-3), and what we term here 'non-environmental impacts'. We anticipate these non-environmental impacts to be predominantly associated with wage labour, commercial outgrowing opportunities and displacement from land. Our empirical analysis is driven by the hypothesis that the poorest stand to lose access to ES and gain little in terms of benefits unless they can access wage labour/outgrowing opportunities. Designed alongside WP2, this work package allows comparison between household wellbeing implications of commercial and smallholder agriculture, contributing evidence to the current debate about how to intensify agriculture in the region.

Table 4. Parameters to be measured to indicate the 'non-environmental' impacts of commercial agriculture

Commercial agricultural impacts (these will also be refined through scoping in WP1)	
Access to wage labour	Whether hh livelihoods include wage labour
Distance from commercial agricultural plantation	Important as 1) ecosystem services impacts 2) availability of wage labour and 3) outgrowing opportunities, commonly vary with distance
Cash crops and outgrowing strategies	Whether hh livelihoods include proceeds from cash crops or outgrowing schemes associated with commercial agriculture
Displacement associated with LU change	Understanding livelihood history in relation to displacement resulting from commercial agriculture/other LU change
Presence of remittances	Understanding contribution of remittances (internal/external to Mozambique) to livelihood

Research questions

Q3.1 What is the nature of the commodity chain for new types of commercial agriculture? How much value accrues at each stage? What goods and embedded ecosystem services are exported and to where?

Q3.2. What are the non-environmental impacts of commercial agriculture for rural wellbeing?

Q3.3. What impacts does commercial agriculture have on the ES important to rural wellbeing?

Q3.4. How does commercial agricultural intensification impact the poorest in rural communities in the Beira Corridor?

Activities: A3.1 Commodity chain analysis

We will synthesise a commodity chain analysis tool from Ribot (1998) and Bolwig et al (2008) to map the chain of 3 commercial agricultural products, through production, processing, exchange, transport, distribution, sale and export. Our empirical analysis will examine economic value accruing at each stage, and qualitative examination of the mechanisms by which access to benefits is maintained and controlled (c.f. Ribot 1998). Our core interests lie at either end of the commodity chain: exports, and opportunities for the rural poor in production and processing (see A3.2). At the top end of the chain we will examine the export of ES in terms of value, destination, and ES embedded in the goods of the chain (such as water (Allan, 2011), nutrients and greenhouse gas emissions. The embedded ES will be quantified by the INPE researcher based on Ometto's work on embodied GHG emissions (see track record). Value and destination data are available (in aggregate) from the Ministry of Agriculture and we have a track record of obtaining such data from commercial firms (Nhantumbo and Solomao, 2011). Expert knowledge of farming practices (at Instituto de Investigação Agrária de Moçambique, with whom Nhantumbo and Metzger have worked before (Asante *et al.* 2009), and at UEM, Artur) will inform our examination of ES embedded in the commodity chain. Our project partner MICAIA has close links to several commercial enterprises.

A3.2 & 3.3 Analysis of non-environmental and ecosystem service impacts

We anticipate the effects of commercial agriculture will be spatially uneven and unequally socially distributed. We anticipate major benefits in wage labour associated with plantations, and associated micro-economic effects. Despite Mozambique having relatively progressive arrangements for community consent for land transfer (Vermeulen and Cotula 2010), we may need to investigate the displacement of people and changed access to common property resources, and hence ES, through privatisation. In addition, there are likely to be ES implications resulting from the water demands, or changed nutrient cycling of plantations. The availability of wage labour, and other impacts are likely to be highly spatially variable (e.g. near the plantation gate), and socially differentiated (e.g. by gender/education). Early scoping with focus groups and participatory land use mapping will inform a purposive sampling strategy incorporating hhs experiencing the range of impacts. Sampling will also account for seasonal variation in commercial agriculture. Following finalisation of the sampling strategy, a hh survey will be conducted following Tables 1-4.

A3.4 Assessment of ecosystem service availability for the poorest members of rural communities

All investigations of household wellbeing will be through a lens of social differentiation (Daw *et al.* 2011) and our sample will be socially stratified by wealth/wellbeing through participatory wealth ranking. Disaggregation of data will allow examination of experiences of the poorest.

Outputs: O3.1. A journal article mapping the commodity chain of new commercial agriculture modes in central Mozambique. The highly topical nature of the BRICS's influence on African ES means this could be published in *Global Environmental Change*. A further paper in e.g. *Ecological Economics* will report methodological innovations in studying the commodity chain in terms of embedded ES.

O3.2, O3.3 A paper examining the impacts on local people, particularly the poorest, of commercial agricultural expansion in Mozambique, quantifying implications for hh wellbeing. Submission to e.g. *Environment and Development Economics*.

O3.4 Policy brief analysing the trade-offs in terms of ES use and wellbeing involved in the development of commercial agriculture, and the export of ES. This will include the differences between different commercial systems and scenarios of future land use based on WP 5. This is aimed at those making investment decisions and conducting advocacy around commercial agriculture in Mozambique, Brazil and internationally.

D3.1. A dataset of quantitative and qualitative data pertaining to the commodity chain of 3 commercial crops. This forms the basis of scenario and trade-off analysis between domestic use and export in WP 5.

D3.2. D3.3. and D3.4. A spatially explicit and socially disaggregated dataset resulting from the household survey. This dataset will be directly comparable in terms of indices with that of WP2 and will be made public to allow reuse and thus longitudinal ecological and social studies.

WP4. Testing system scale hypotheses of abrupt change

Leads: Grundy (UoZim), Ryan (UoEd). Resources: 2 post docs, 1x 1.5 yrs at UoZim, one shared with WP2 at UoEd [Berry]

WP4 will deliver an analysis of the empirical data from WP2 and 3, structured by the framework created by WP1. This analysis will draw out the generalities of the land use-wellbeing link and allow national scale conclusions. The analysis will primarily be statistical, initially using simple curve fitting and model building to look at broad patterns across and between the three land use intensification gradients of WP2. We will investigate both the statistics of the land use intensification-wellbeing link and the pathways by which they may be related. By combining these outputs with our qualitative datasets and the Bayesian Belief Network created by WP1, we will be able to construct and then test simple models of the links between ecosystem structure, function, services and wellbeing. The broad conclusions of this work are needed as input to the discussion and creation of scenarios in WP5, and also to produce policy relevant conclusions for the woodland nations of Africa. Thus there is a focus on producing generalised knowledge suitable for short, high impact papers and concise policy briefs.

Research Questions

Q4.1 Are there abrupt changes in wellbeing metrics along land use intensification gradients?

Q4.2 Are the processes by which households and communities respond to the loss of woodlands generalizable? If so, which processes link land use intensification and wellbeing?

Q4.3 Given future scenarios of woodland degradation and agricultural expansion, what are the likely national scale impacts on ES? What particular implications does this entail for the poorest?

Activities: A4.1 Breakpoint analysis and non-linear curve fitting

Q 4.1 will be addressed by statistical analysis of the data from WP2. This will be based initially on straightforward nonlinear curve fitting and breakpoint analysis using village-level land use intensity measures as the predictor and community level wellbeing indicators as the response variable. More sophisticated analysis using non-linear mixed effect models (Pinheiro *et al.* 2007) will allow us to test for differences among the three gradients, and among poverty groups.

A4.2 Structural Equation Modelling of structure-function-services-wellbeing linkages

We will use structural equation modelling (SEM) to identify the linkages between ecosystem structure and wellbeing, if any. SEM is commonly used for linking structure and function of ecosystems (Sutton-Grier *et al.* 2010), and this has been extended to social aspects of ecosystems (Asah 2008). We have used it for novel analysis of woodland ecosystems (Lehmann *et al.* in review). It is useful because it allows confirmatory and exploratory modeling, meaning we can test the linkages proposed by WP1, and explore the existence of others. SEM allows the same variable to be predictor and response, meaning complex, but controllable, webs of causality can be created. Furthermore it allows the use of latent variables which are un-measurable (e.g. wellbeing), but about which other measurable variables hold information (the indicators in Table 3). The use of SEM will allow us to test which factors most strongly determine wellbeing along our gradients, and which factors mediate any connections. By identifying the strong linkages we will be able to understand where the system is most likely to change rapidly under new drivers. To avoid producing underdetermined intractable SEMs, we will identify relatively simple conceptual models through WP 1.

A4.3 Upscaling of the impacts of expansion of commercial agriculture

WP2 and WP3 are structured to understand, at local scales, the implications of woodland loss/degradation and expansion of commercial agriculture on wellbeing. Our scenarios and pathways to impact are structured at regional and national scales. Hence there is a need to upscale our findings. Specifically, this will enable us to (1) combine our detailed understanding of woodland loss and wellbeing (WP2) with national spatial data about forest change (Marzoli 2007); (2) predict how aggregate rural wellbeing will change at regional scale, for different poverty groups, in relation to proposed and possible scenarios of land extent under commercial agriculture. For these efforts, we propose to create a spatial database using population predictions (from INE; www.ine.gov.mz), agricultural surveys (MinAg 2011), agricultural concessions locations (from DNTF, which we hold already), planned infrastructure investments and district development plans (which are public and available online). As our indicators (see Tables 1-3), are chosen to be compatible with national datasets (MPD-DNEAP 2010) the upscaling can be one through direct relation of our detailed understanding to national scale census and forecast data.

Outputs and outcomes

O4.1 A short, high-profile paper documenting the empirical relationship between land use intensity (degradation and smallholder agriculture) and (a) ecosystem service provision and (b) rural wellbeing. This paper will be adapted into a policy brief and video for the national and international forest policy community. This would be novel in that it would provide empirical support for hypotheses of abrupt impacts on human wellbeing resulting from gradual changes in land use, and would be aimed at a vey high impact journal, following similar papers of this nature (Rodrigues *et al.* 2009).

O4.2 A more in-depth analysis of the linkages between land use intensification and wellbeing, examining the determining factors in the relationship through SEM and exploring causality through qualitative analysis of focus group discussions.

O4.3 Maps, at a provincial and national scale, of proposed new agricultural expansion and associated estimates of rural wellbeing. These would be published by IIED as a policy report on commercial agriculture in woodlands, in Portuguese and English. The spatial data will be made public and integrated into future scenarios by WP5.

WP5: Scenarios of the future

Leads: Sitoe (UEM), Metzger (UoEd). Resources: post doc at UEM, post doc at UoEd [Paterson], both shared with WP1

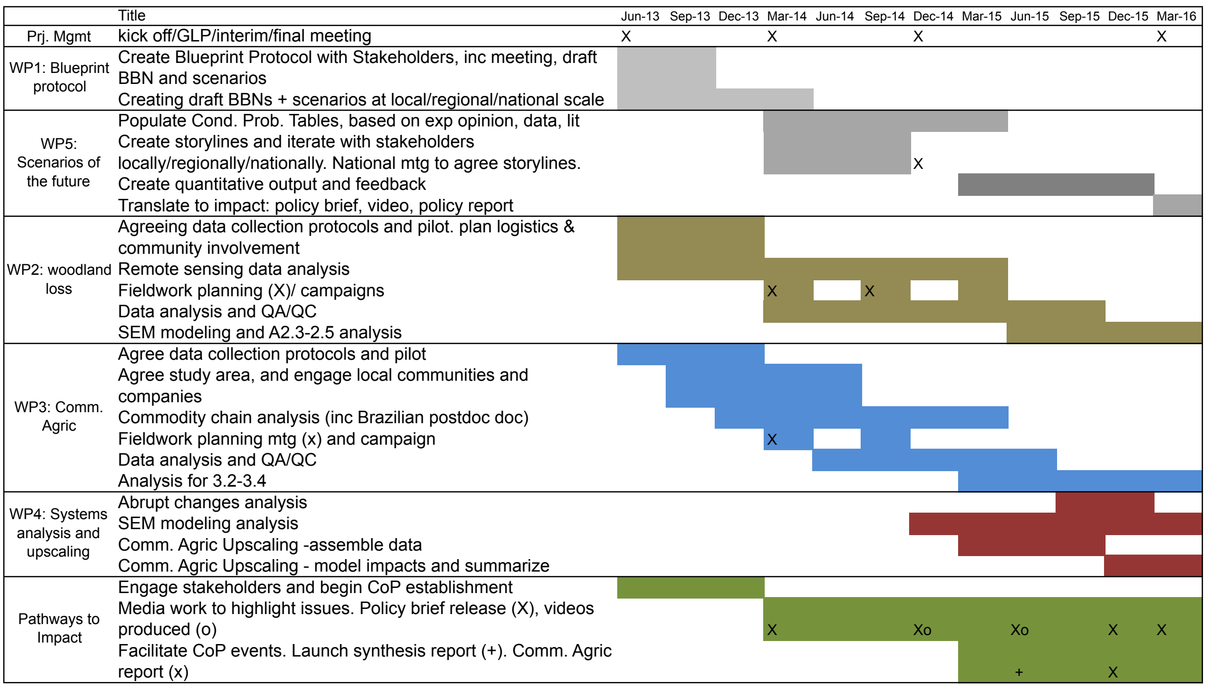
Exploring the possibilities of future land use change in Mozambique is a critical aspect of ACES. We propose to use scenarios to develop narratives of how the future *may* develop. Such scenarios provide an excellent participatory tool and constitute a key component of ACES impact strategy. For ecosystems in constant flux and with trajectories that are difficult to foresee, scenarios can illustrate and explore a diverse range of outcomes. They enable the integration of ecological and socio-economic elements (e.g., the empirical evidence and analyses conducted in WP2&3) and our previous work shows that scenarios provide stakeholders with versatile decision tools for land use management, something that predictive models struggle to achieve (Rounsevell and Metzger 2010). As such, they are ideally suited to help stakeholders elicit cause-and-effect linkages as well as to appreciate the scale and complexity of land use-wellbeing issues (Bennett *et al.* 2003). The scenarios will be created following input from our stakeholder groups to agree storylines, followed by quantitative and spatial modelling based on the BBNs, following Paterson's ground breaking work in the UK NEA (Haines-Young *et al.* 2011). Scenarios will reflect the project's scientific advances and will incorporate internally-consistent storylines of, *inter alia,* woodland loss/degradation, commercial agricultural expansion, forest management for carbon, national poverty alleviation, economic growth and climate change, building on our previous work on climate change impacts in Mozambique (Asante *et al.* 2009). As such, the scenarios will provide critical insights into the robustness of current and planned policy (e.g., the National Agriculture Development Programme). The Impact Fellow will then use the scenarios to illustrate potential land use futures and their impacts on rural wellbeing, and to empower our communities of practice to promote and implement pro-poor policy. In particular our associated TREDD project will be able to incorporate the results of these scenarios as it implements £1.97 M-worth of projects designed to alleviate poverty by improving land use.

Activities and outputs: A5.1 Draft scenarios based on initial stakeholder consultation
Both rounds of stakeholder workshops in WP1 will have a segment devoted to developing scenarios of future land use change. WP5 will then draft an initial set of scenarios outlining different plausible futures for land use in Mozambique. We will then populate the conditional probability tables of the BBNs using the results of WP4 and a literature review, as well as through expert opinion. This will provide the basis for quantitative output in terms of parameters of interest to the stakeholders for each scenario. Areas of high uncertainty can be discussed with the stakeholders and parameterized appropriately.

A5.2 Finalise scenarios and develop quantitative output
A third round of the 7 stakeholders workshops at all scales will present the initial scenarios and refine them. These will build up from the local level to culminate in a final national workshop where key actors approve the final set of scenarios to be produced. A final draft of the scenarios will then be created and shared with the stakeholders. The qualitative storylines of the scenarios will be used to develop quantitative, map-based outputs to aid an understanding of the effects of different land use pathways in Mozambique. The BBN output will be linked to the spatial data from O4.3 to map future changes in land cover, ecosystem services and wellbeing (Kuhnert *et al.* 2010; Swetnam *et al.* 2011; Haines-Young *et al.* 2011)

A5.3 Translate quantitative output into stakeholder information
The final element of the project is to ensure the storylines and quantitative outputs are shared with the stakeholders through suitable visual and oral means and promoted within key policy-maker circles by our communities of practice. WP5 will work closely with the Impact Fellow to provide spatial data and other output in appropriate formats. A series of events organised by our communities of practice will present the scenarios to stakeholders by accessible means. The Pathway to Impact summarises the main methods by which our communities of practice will wield influence: scenarios are crucial to this process as they are excellent communication tools for highlighting and engaging with the consequences of policy choice (Rounsevell *et al.* 2012).

Research plan



Collaborations, partnerships and co-funding

Co-funded projects. This project is closely integrated with 7 other projects in Mozambique, the UK, and internationally, leveraging >£2.3M. (1) *Testing REDD+ in the Beira corridor*, £1.97M; funder, Norwegian Embassy; lead, Nhantumbo; Co-Is Macqueen, Sitoe, Ribeiro, Ryan; project partners include MICAIA (see below) and GoM departments. TREDD will test how investments in land management via local govt., community groups and the private sector can improve rural wellbeing, including new forms of agricultural intensification. The results from ACES directly speak to the challenges TREDD is trying to meet. It provides us with a direct way of translating our research findings into pro-poor land use, and the scale of investment means we will have strong engagement with land use actors from the start of ACES. The direct link to demonstrator projects will provide working examples of pro-poor land use that can be scaled up at the end of ACES. Our Impact Fellow will work closely with TREDD staff and both will be managed by IIED. (2) The Mozambique national research fund supports Sitoe and Ribeiro to improve land cover and biomass estimates in the Beira corridor ($94k). This will provide detailed up-to-date land cover maps in the central region allowing us to identify commercial agriculture and appropriate sites for WP3 and facilitating project planning. (3) At our site in Tete, Ribeiro and Bandeira's project ($65k, Gates Foundation) on fire management and ES provides us with a logistical base and trained field staff available as assistants. (4) At our site in Gaza, Bandeira's $60k project from the same funders on land use and livelihoods provides similar leverage. (5&6) Two projects led by Ryan (UK Technology Strategy Board, £115k), provide the capacity and data to deliver radar-derived woodland biomass maps and remotely sensed indices of degradation for the three study sites for the ACES start date. The raw data will be supplied via existing European Space Agency-approved projects. (7) On the international stage, Ometto's €100k grant on embodied GHG emissions in traded products (INPE/IIASA) provides access to key trade data and methods for estimating embodied GHGs vital to WP3.

Links to international ES science: Four major EU FP7 projects provide €35M leverage into the international ecosystem services science agenda. *Operational Potential of Ecosystem Research Applications* (2012-2017; €15M) led by our team members Rounsevell, Metzger and Patenaude, links ACES to networks of scientists and practitioners allowing us to learn from and influence the state of the art. *Visions of Land Use Transitions in Europe*. (2011-15; €7M) on which Metzger leads the development of scenario and impact tools, gives us deep connections to best practice and new innovations in linking land science and policy. *Operationalisation of Natural Capital & Ecosystem Services: From Concepts to Real-World Applications* (2012-16, €9M),Co-I Pinho, is leading the development of spatial mapping of ecosystem services applicable to WP4 & 5. Ometto and Meir's AMAZALERT project (2011-2014; €4.7M) brings linkages to govt. ministries and agricultural researchers (Embrapa) in Brazil.

Project partners: The MICAIA foundation and LUPA both have long experience of working with community groups in our study areas on several aspects of rural development, including agricultural intensification. They provide a trusted link to local communities, a pool of trained technical staff who can be contracted for fieldwork assistance and the hire of reliable vehicles at cost price. They have supported our fieldwork over the last 5 years. In the North, Ribeiro's close links with the reserve management provides similar links. Through our project partner CTV (Centro Terra Viva) we have strong links to a range of CSOs working on land use, community development and pro-poor land use policy. Their Global Forests Partnership (World Bank funded) links to a broad network of policy advocates and practitioners. Through GFP, and other, IIED-run learning groups in the region, we have access to nearly all international groups advocating for pro-poor forest management, and long experience of facilitation and resource provision that make an impact.

Collaborations. Our team is already embedded in the Mozambique science-policy community. Through past projects we have worked with all the stakeholders listed in Box 1, most recently when IIED and UEM facilitated the national REDD+ process, which, via the S-S REDD project, involved INPE and UoEd. UEM have worked with CIFOR and the World Bank to produce science-policy reports on African woodlands. See track record for full details.

We have two **proposed activities** that will further leverage ACES. A proposal to the São Paulo Research Foundation (led by Ometto & Pinho) will examine how changing land use policy in Brazil is influencing land use in Mozambique, through quantitative analysis of trade patterns and case studies of individual actors. A recently established educational link between UoZim and UoEd means that we will recruit PhD and MSc students to work on land use-wellbeing linkages in Zimbabwe, allowing ACES research to be translated to the Zimbabwean situation, and providing strong cross-fertilisation between ACES and the long history of innovative woodland research emanating from UoZim.

Project management

A detailed management plan has been prepared for the project during its design. The roles and responsibilities of each team member are detailed in the CVs appended to this document. The PI (Patenaude) will be responsible for overall management and intellectual leadership of the project. She successfully delivered the ESPA framework project that underpins this proposal, and developed the collaboration between UoEd and INPE. As this project requires interdisciplinary breadth and depth, a deputy PI with complementary expertise to that of the PI has been assigned (Ryan). He will coordinate fieldwork and elements of the empirical analyses. Ryan builds on 7 years of work in Mozambique and three projects collaborating with UEM and IIED since 2005. As the PI and deputy are co-located, they will meet each week to ensure tight integration. Jointly, Patenaude and Ryan will be responsible for ensuring delivery of the project's outcomes. The structure of the project is designed to allow both cross-generational and S-S-N learning. The former is achieved through the Advisory Committee (AC). The AC comprises senior scientists and practitioners (Olsson, Sitoe, Grundy, Ometto, Rounsevell, Meir and Macqueen) and will provide intellectual mentoring and peer-review to WP leaders. Jointly, the AC and WP leaders will have the responsibility to agree timelines of deliverables and formally assess progress at 3 monthly intervals. Meanwhile, S-S-N knowledge exchange will be achieved via active partnerships where each WP is co-led and implemented by cooperating Southern and Northern post docs. All post docs will be funded to attend an international conference to allow further career development. The PI is responsible for WP co-ordination and will receive monthly reports from WP leaders. WP leaders are responsible for managing the post docs in each WP. The pathways to impact work will be managed by IIED and guided by Olsson, reporting to the PI. Inter-WP management will be by weekly or fortnightly conference calls (greater frequency at early stages to ensure team building and clarity on the necessary work).

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