

# Measuring, Modeling and Mapping Ecosystem Services in the Eastern Arc Mountains of Tanzania

## Authors

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17

18 **Abstract**

19

20

21 In light of the significance that ecosystem service research is likely to play in linking  
22 conservation activities and human welfare, systematic approaches to measuring,  
23 modeling and mapping ecosystem services (and their value to society) are sorely needed.  
24 In this paper we outline one such approach, which we developed in order to understand

1 the links between the functioning of the ecosystems of Tanzania's Eastern Arc Mountains  
2 and their impact on human welfare at local, regional and global scales. The essence of  
3 our approach is the creation of a series of maps created using field based or remotely  
4 sourced data, data-driven models, and socio-economic scenarios coupled with rule-based  
5 assumptions. Here we describe the construction of this spatial information and how it  
6 can help to shed light on the complex relationships between ecological and social  
7 systems. There are obvious difficulties in operationalising this approach, but by  
8 highlighting those which we have encountered in our own case study work, we have also  
9 been able to suggest some routes to overcoming these impediments.

## 11 **Keywords**

14 Ecosystem services, economic valuation, Eastern Arc Mountains, Tanzania, carbon  
15 storage, biodiversity

## 18 **Introduction**

21 Current global concern regarding climate change, energy supply, food and water security  
22 and the loss of biodiversity, has made it clear that a scientifically robust, policy-oriented  
23 understanding of how these issues are interrelated will be essential for developing

1 effective solutions (Holdren 2008). The concept of ecosystem services is one construct  
2 for understanding how changes to our natural environment impact our welfare. How  
3 climate change will affect agricultural yields and water availability, how biofuel-crop  
4 expansion will affect biodiversity, and how growing human populations and economies  
5 will affect forest cover, are all examples of the important questions that fall under the  
6 rubric of ecosystem services research. In fact the use of the term ‘ecosystem services’ as  
7 a research framework, has become much more prominent in the academic literature over  
8 the past decade (Carpenter et al., 2006; Fisher et al., 2009), the publication of the  
9 Millennium Ecosystem Assessment (MA, 2005), and the newly formed Intergovernmental  
10 science-policy Platform on Biodiversity and Ecosystem Services (IPBES – see  
11 <http://ipbes.net>) has securely tied the importance of well-functioning ecosystems to  
12 sustainable human welfare.

13  
14 In light of the significance that ecosystem service research is likely to play in linking  
15 conservation activities and human welfare, systematic approaches to measuring,  
16 modeling and mapping ecosystem services (and their value to society) are urgently  
17 needed (Carpenter et al., 2006). In this paper we outline one such approach, which we  
18 developed in order understand the links between the functioning of the ecosystems of  
19 Tanzania’s Eastern Arc Mountains and their impact on human welfare at local, regional  
20 and global scales. The essence of our approach is the creation of a series of maps created  
21 using field based or remotely sourced data, data-driven models, and socio-economic  
22 scenarios coupled with rule-based assumptions. Here we describe the construction of this  
23 spatial information and how it can help to shed light on the complex relationships

1 between ecological and social systems. We highlight some of the difficulties of  
2 employing this approach, as well as some of the insights gained. While this project-  
3 Valuing the Arc (VtA) - is still a work in progress, we are able to illustrate some of the  
4 policy-ready outputs of such an approach.

5  
6 Below we describe the biological and socioeconomic importance of the Eastern Arc  
7 Mountains, the services they deliver, the sequence of steps in the mapping exercises, the  
8 importance of scenario-building, and a brief example of how to apply such an ecosystem  
9 services approach to linking conservation, human welfare and decision-making.

## 10 11 **Eastern Arc Mountains, Tanzania**

12  
13 The Eastern Arc Mountains of Tanzania (EAM) comprise 13 mountain blocks stretching  
14 the length of the country (Figure 1). The EAM is a globally important ecoregion  
15 (Burgess et al., 2004; Burgess et al., 2006), and constitutes a large part of one of the  
16 world's 34 hotspots of biological diversity (Mittermeier et al., 2004). It is home to  
17 around 550 endemic plants and more than 90 endemic vertebrates (see Burgess et al.,  
18 2007 for more in-depth information on biological importance of EAMs). In addition to  
19 this unique biodiversity, these mountains also provide a range of ecosystem services and  
20 related human benefits at local, regional and global scales - including timber and fuel  
21 wood; water for irrigation, domestic use and hydroelectricity; carbon storage; medicinal  
22 plants and other minor forest products; and nature-based tourism (Doggart and Burgess,  
23 2005).

[FIGURE 1 IN HERE]

At the same time this is an area of rapid land cover change, having lost 11% of its primary forests and 41% of its woodlands since 1975 (FBD, 2006). This conversion is driven by clearance for farmland, as well as increasing demand for timber and fuel wood. These pressures, subsistence and commercial, are rational in the short term, especially in a country where 44% of the population is food-insecure (UN, 2005) and over 90% of household energy comes from burning biomass (Sheya and Mushi, 2000), but they seem unlikely to provide a sustainable development strategy over the medium to long term. The uniqueness of the Eastern Arc's natural assets, and their significance for human welfare in Tanzania make this an important area for testing an ecosystem services approach and investigating the potential 'win-wins' and tradeoffs between conservation and human welfare.

### **Measuring, Modeling, Mapping**

Figure 2 shows a conceptual layout for the approach we have developed for the EAM project. It is shown as a series of mapped layers, but what is not shown is the underlying data collection and modeling aspects of the approach. Here we unpack each of the layers shown in figure 2 and discuss the data and modeling needs, some of the outcomes to date and some of the difficulties we have encountered.

[FIGURE 2 IN HERE]

### ***Inventory***

The first layer starts with an inventory. The ideal would be to gather all available spatially-explicit data on the biophysical and social systems of interest. Data could include landcover classes, information on climate and soils, demographic, infrastructural and institutional variables, knowledge of resource use, etc. This information provides a backdrop for the ecosystem services that might be of interest, but also is used in developing the models that underpin other layers that characterize ecosystem services (below). For example, knowledge of landcover, road layout and forest governance, might shed light on the use of forest for providing timber and might also underpin a predictive model of rates of extraction of non-timber forest products (NTFPs; Ahrends, 2005), and timber-based products (Ahrends et al., 2010). In VtA, this initial stage included workshops to update existing landcover maps, interviews of government, NGO and academic stakeholders, and using past research to identify the focal ecosystem services for the project. From stakeholder engagement and expert opinion gathered across three continents we determined that Valuing the Arc (VtA), given the resources available, should focus on five categories of services and benefits – carbon, water, timber and NTFPs, pollination and biodiversity. Each category contains a suite of services and benefits for which spatially explicit data was sought for the inventory layer (Table 1).

[TABLE 1 IN HERE]

1

2   Wherever possible these datasets were mapped to explore spatial interactions between  
3   datasets, highlight the social context of the biophysical data and identify places where  
4   further primary data collection is necessary or where modeling needs to fill in  
5   information gaps. For example, from the Tanzania Socio-Economic Database we were  
6   able to get population statistics at a coarse district level. From the Center for  
7   International Earth Science Information Network (CIESIN, 2005) we could get a  
8   modeled surface of the population of Tanzania on a 2.5 arc-minute grid. However, this  
9   layer showed people living within Nature Reserves, which we know from direct  
10   observations to be incorrect. Here, our inventory process identified a crucial layer of  
11   spatial information that needed improvement.

12

13   This step also helped to identify three focal river basins for fine-grained analysis and  
14   fieldwork: the Sigi Basin (draining the Usambara Mountains), the Ruvu Basin (draining  
15   the Uluguru Mountains) and the Kilombero Basin (draining the Udzungwa Mountains).  
16   The three basins were chosen because they are relatively well documented, have  
17   important ecosystem service flows to local and downstream users, and are the subject for  
18   ongoing policy processes. For example, the River Ruvu which drains the Uluguru  
19   mountains supplies the capital Dar es Salaam with a large proportion of its fresh water.  
20   Since the 1950s there has been a steady and significant decline in the baseflow of the  
21   river which is causing serious concerns for the maintenance of supply to the city (Doggart  
22   and Burgess, 2005). This decline has been linked to degradation in the forested areas of  
23   the catchment (FBD, 2006). In addition to these biophysical characteristics the Ruvu has



1 a range of governance structures in place with varying ownership and management  
2 combinations including some forests co-managed by local people through Participatory  
3 Forest Management agreements (Blomley et al., 2008). While much of the data collected  
4 at this stage focused on the entire EAM study region, more detailed datasets were  
5 collected for these three study basins in order to create realistic maps and robust models ,  
6 which will eventually be used to parameterize models for the whole of the EAM.

7  
8 The issue of water supply to downstream users from a forested area that has few  
9 resources available for its management, is also now being addressed through Payment for  
10 Environmental Services schemes (Fisher et al., 2010), which are delivering money from  
11 the city of Dar es Salaam to forest adjacent communities to improve their land  
12 management with respect to water regulation.

### 14 ***Service Production***

15  
16 The next layer involves understanding how, where and at what rate ecosystem services  
17 are produced on the landscape. This requires a biophysical understanding of ecosystem  
18 processes from theory through to measurement and modeling. At the most basic level,  
19 land cover maps can provide surface information about the types of services a landscape  
20 may provide (e.g. carbon sequestration, water supply, climate regulation). Process  
21 models and ground measurements can help to further identify, scale and quantify  
22 services.

1 As an example, in the EAM we have been measuring carbon storage at different  
2 elevations and within the vegetation of different land cover types, to develop a service  
3 production map of carbon storage. In addition a sub-set of plots has been monitored for 3  
4 years to assess rates of carbon sequestration. One of the difficulties here is the fact that  
5 we often measure phenomena where they are most obvious - in this case, measuring  
6 carbon in forests containing many large trees. At the inventory phase we realized that the  
7 majority of previous research quantifying the carbon density of vegetation in the EAM  
8 has taken place in the high carbon storage montane forests, with little work done in  
9 woodlands, degraded forests, crop mosaics or pure cropland. There is an equally difficult  
10 problem to overcome when building hydrological models of service production. Our  
11 early efforts to produce a map of “water production” suggested the relatively dry Selous  
12 area was important for water production. This error arose because a globally available  
13 rainfall surface was extrapolating rainfall across widely spaced meteorological and river  
14 gauges, with one gauge in a high rainfall area close to the mountains, and the next in the  
15 dry centre of the Selous. The reality, not captured by the models, was a much steeper  
16 rainfall decline within a few kilometers of the mountain. Here the task of generating a  
17 first-cut map led to a series of insights about our modeling process and identified the  
18 need for further data collection. While production maps are unique to individual services  
19 a simple overlay will indicate areas on the landscape where a bundle of services may be  
20 produced.

## 21 22 *Service Flow*

1 Next, the service production maps are combined with an understanding of how services  
2 spread through the landscape and information on land use and topography to estimate  
3 where services flow from their point of production. There are a variety of spatial  
4 relationships between where ecosystem services are produced and where the benefits of  
5 those services are enjoyed, and therefore individual flow maps could be needed for each  
6 service. Some services flow globally, others may only be experienced at their point of  
7 production, and some are constrained to flow in a particular direction (Figure 3). For  
8 example, a forest can only provide water regulation services to areas that are downstream  
9 of them. Mapping such flows requires the integration of biological processes (e.g. water  
10 uptake by plants) and physical processes (e.g., hydrological networks). One of the  
11 difficulties in this stage is that obtaining a fine-scale understanding of flows can require  
12 prohibitive amounts of data. For example, our timber production layer tells us where  
13 such a benefit is produced, and from extensive transect and disturbance data (see Table 1)  
14 we know how much ‘flows’ from our forests, but mapping exactly where the good  
15 ‘flows’ across the landscape requires extensive fieldwork and market surveys. From pilot  
16 surveys and published NGO reports, we are building a heuristic decision model to  
17 allocate these timber flows based on the typical uses of individual species and their unit  
18 cost. For example, species with a higher end use value are likely to travel further and to  
19 wealthier markets (e.g. larger cities). Since an ecosystem service is inherently an  
20 anthropocentric concept understanding these flows without linking them to actual  
21 beneficiaries only gives an example of ‘potential’ flows of services. Real flows  
22 materialize when beneficiaries are present.

23

[FIGURE 3 IN HERE]

### ***Beneficiaries***

In order to move from potential flows to realized flows of benefits we next need to have an understanding of where people are on the landscape and whether they utilize these flows. The concept of ecosystem services is human-focused and therefore only exists if there are human beneficiaries. If there are no human benefits (at any scale) then we are not talking about ecosystem services, but rather ecosystem processes or functioning. Therefore, connecting the flow of services to people who may consume them, i.e. translating potential service flows into benefits, is a necessary step.

Beneficiary layers are obtained from maps of service flows, land use, combined with data on the spatial distribution of people on the landscape and their use of land and resources. For example, in the average year 60% of all electricity produced in Tanzania comes from hydroelectric power from dammed EAM rivers (The Economic Survey, 2008). The beneficiaries for this (10% of the Tanzanian population) are located in the major cities, especially Dar es Salaam, but the production areas, and those areas important for making sure the rivers flow throughout the year are likely to be well upstream from the electrified urban areas. Additionally, about half of the electricity produced (in 2007) was used for commercial and industrial ends (The Economic Survey, 2008), offering a different suite of benefits compared to household electricity usage.

1 Again difficulties lie in accurately placing people on the landscape and accurately  
2 assessing their use of the service (and where necessary the timing of that use). For  
3 example, knowing how small-scale irrigators benefit from water regulation services  
4 requires fine-grained and expensive data collection across a wide range of social and  
5 ecological contexts, and mapping how households use water for domestic uses requires  
6 extensive household surveys. Once this data is obtained, both the service flow and the  
7 beneficiaries become mappable elements.

8  
9 Together the first four layers provide information about the flow of ecosystem services  
10 across a landscape to beneficiaries. In some cases translating service flows to  
11 beneficiaries will have to be an iterative process, since service provision can change  
12 across the landscape as a result of direct use. For example, removal of freshwater for  
13 irrigation in the upper Uluguru watershed of Tanzania will change the level of  
14 downstream service flow, leaving less for the downstream beneficiaries in Dar es Salaam,  
15 and therefore changing the service flow map via quantity available at different potential  
16 use points. A related key issue here is gaining an understanding of where services are  
17 mutually supportive and where there are tradeoffs amongst services. For example,  
18 charcoal and timber production may negatively affect water regulation in the basins,  
19 where as carbon storage may be positively correlated with water regulation services in a  
20 given catchment. It is likely that the models used to integrate across services will be  
21 pared-down versions of the individual service models.

## 22 23 ***Benefits***

1

2 After understanding where services are produced, how they flow and who benefits from  
3 their flow, the next layer needed is one that gives a magnitude to the importance of that  
4 benefit. This is what we consider a value layer. Probably the most common metric of  
5 value for ecosystem service research is monetary, but alternative evaluation layers may  
6 be constructed incorporating for example, indices of human vulnerability. For many  
7 services, the value of a given level of service provision will change across the landscape  
8 because of geographical variation in either biophysical supply or human demand. For  
9 instance, the value of clean water provision will be affected by how wealthy the  
10 beneficiaries are; what they use it for; and how scarce or abundant water is across a  
11 landscape. In the EAM our dataset for charcoal prices covering 63 locations shows that  
12 prices in Dar are up to twice as high as in other urban areas, and this is not simply a  
13 reflection of transportation costs (see Edge et al., 2009). Here price is only a proxy for  
14 value, but the data does show spatial variation in value. For other services the financial  
15 value will be constant across landscapes or even globally, as in a uniform global value for  
16 carbon storage (Strassburg et al., 2009). The latter does not suggest that the value of  
17 climate regulation is homogeneous across the landscape, just the market price as its value  
18 proxy per tonne of carbon stored.

19

20 A benefit from using monetary valuation across services is that it allows for  
21 commensurability in deriving “net” benefits and costs, by bringing each service assessed  
22 into a common metric. In Tanzania we are deriving our value layer through multiple  
23 methods. For example, we will evaluate the benefits of water provision for irrigation by

1 a production function approach - i.e. assessing the additional productivity and value  
2 added to net crop receipts by irrigation water. The values for timber, NTFPs and  
3 hydroelectric power services will also be imputed using market prices in a production  
4 function approach. Market and household surveys can be a direct way to get at these  
5 values, but one thing we have learned from our fieldwork was that our expectations of  
6 modeling several similar goods across such a large area were optimistic. For example,  
7 we are able to create a list of a few dozen distinct NTFPs. However, many of these are  
8 only collected in certain contexts, at certain locales, or under certain conditions (e.g.  
9 rainy season). In response to our findings from the market and household surveys we are  
10 therefore modeling only the most commonly collected NTFPs - poles, firewood,  
11 mushrooms, charcoal, thatch as well as trying to bundle some wild fruits and vegetables.  
12 These are products whose production we can attempt to model and to which we can also  
13 attribute values, as well as examine potential substitutes in the market place. Therefore  
14 we exclude medicinal herbs, honey, fibers for baskets, rope and fodder collection from  
15 our modeling.

16

17 The benefits of biodiversity conservation also present a complex valuation problem,  
18 including accounting for the differences between 'local' people and their value  
19 preferences and residents in international 'donor' countries (Horton et al., 2003; Hanley  
20 et al., 2003). In VtA our objective was to estimate the willingness to pay of UK (donor  
21 country) residents for conserving wildlife in the EAM, using a split sample survey design  
22 (Morse-Jones et al., 2010). A choice experiment method was used to present respondents  
23 with a series of questions describing the possible outcome for wildlife if current

development pressure trends continue and if conservation measures are implemented. In the choice experiment, respondents were asked to choose their most preferred option in each question. The options were described in terms of three attributes (1) the number of unique species saved; (2) the number of non-unique species saved and (3) the donation by the household to enable outcomes to be achieved. The levels for the donation were based on a literature review and pre-testing. By varying the attribute levels across the options and modeling how this affects choices we were able to estimate willingness to pay for total changes in wildlife conservation, as well as for changes in the individual attributes. The experiment suggested that UK residents were willing to pay on average £53 (2008 GBP) per household per annum for conservation efforts in the EAM (Morse-Jones et al., 2010).

### *Costs*

Benefit values are only one side of the coin. In order to make robust policy recommendations we need to have an understanding of both the benefits of a functioning ecological landscape as well as the costs of providing that landscape. The costs of conserving landscapes for ecosystem service provision include not just the direct management costs of interventions (such as salaries for park guards) but also the opportunity costs for local stakeholders (i.e. their net benefits foregone as a result of conservation), implementation and transaction costs of a conservation intervention, possible acquisition costs, and any damage costs that might be incurred (Naidoo et al., 2006) - in our case crop damage would most likely be caused by vervet monkeys,



1 baboons and bushpigs. In the EAM, the opportunity costs of conservation are found by  
2 examining the profitability of the foregone farming and fuel collection opportunities. For  
3 example, in some districts of the EAM up to 95% of the people are either employed in  
4 agriculture or are subsistence farmers, meaning that any further designation of restricted  
5 land use could directly affect opportunities for agricultural expansion. We have found  
6 that, on the district scale, the agricultural opportunity costs of conservation vary widely  
7 (NPV \$400/ha-\$8000/ha), and that by including the profit foregone from charcoal  
8 production (in the case of a woodland being converted first for charcoal and then  
9 agricultural use) the opportunity cost can increase by 12-167% (*b.fisher unpublished*  
10 *data*). An extensive field survey showed that variation in yield between farmers and  
11 across years makes it difficult to model opportunity costs at a fine scale using data from  
12 household surveys, which means these costs will likely be modeled at a coarser scale  
13 such as the ward level (i.e. several villages).

14  
15 Another difficulty we have faced with modeling costs is the availability of data regarding  
16 the management and implementation costs of conservation. In some contexts this type of  
17 information might be readily available, but in our EAM project it requires a concerted  
18 effort to collate data from online records, government reports in scattered locations, and  
19 interviews with government staff. The range of different governance types which are  
20 used to manage the landscape also make it difficult as understanding the costs needed to  
21 manage a central government administered Nature Reserve will require different data-  
22 acquisition strategies than, say, those bearing on the management of a village-based  
23 forest reserve.

1

2 Both the valuation and cost steps require interaction with the development of scenarios  
3 (see below) in order to construct some form of ‘marginal’ values. For example, the  
4 marginal benefits of any given ecosystem service and the costs for securing the delivery  
5 of that service are functions of the difference between two states of the world – perhaps  
6 the current state and one where conservation schemes are initiated. The development of  
7 scenarios and their integration with the modeling and mapping exercises is explained in  
8 more detail below.

9

#### 10 ***Mapping Winners and Losers***

11

12 The advantage of measuring costs and benefits in the same monetary units is that you can  
13 combine the benefits value layer and the cost layer into one map. The result is a map  
14 with clearly demarcated areas of net gains and net losses. For example, if a current forest  
15 reserve involves high locally-incurred costs (e.g., opportunity or damage costs etc.) and  
16 limited local benefits (e.g. through NTFP provision), but delivers significant benefits  
17 (such as water flow regulation) at low cost (e.g. limited management cost) to people  
18 living in Dar es Salaam, then the map may show net losses nearby and net gains further  
19 away. An aggregated non-spatial summary of total costs compared to total benefits would  
20 not reveal this spatial variation, and would therefore not indicate where cost-benefit  
21 differentials are the smallest. Yet understanding such asymmetries is evidently crucial  
22 for the design of equitable policy interventions. In the EAM, CARE and the World  
23 Wildlife Fund are facilitating project work on the Ruvu River that aims to link the

beneficiaries of the water flowing from the Uluguru Mountains (mainly in Dar es Salaam) to those living and managing the land in these mountains. The intention is to ensure that land-use practices in the mountains help maintain water quality and that major water users pay the communities for their efforts and for foregone opportunities of forest conversion (Fisher et al., 2010). Providing maps of where these benefits are being produced and the relative costs of producing them will aid in targeting specific sub-basins, but also indicate the magnitude of compensation required.

## **Scenario Building**

The above steps all involve modeling phenomena that are dynamic and will change under different possible futures. Exploring the possible consequences of such change is vital if an understanding of ecosystem services is to be useful to decision-makers. They need to know not just about the gross values of services delivered from a particular area but about the likely net differences in value (incorporating costs as well as benefits) arising from the decision confronting them (say, to sanction a forest to be converted or not). Understanding these values spatially can help to understand how to optimize a landscape for a given goal (e.g. net benefit return), aid in comparing alternative policy impacts, or highlight potential future changes driven by different potential futures.

Key drivers of resulting differences in service values include land use change, demographic shifts, changes in patterns of demand, technological innovations and climate change. To explore the impact of such changes on human welfare requires scenario

1 building. Typically, scenarios are presented as ‘storylines’ which are internally  
2 consistent and offer plausible future possibilities (Gallopín et al., 1997; Peterson et al.,  
3 2003; Raskin, 2005; MA, 2005). Rather than representing a specific prediction each  
4 scenario should be thought of as a description of a possible future which has plausibility  
5 given the knowledge and assumptions on which it is based. When done thoroughly  
6 scenarios can guide policies towards specific end goals such as increasing human welfare  
7 or equity (Turner, 2005). Scenario building has become an important part of multi-  
8 disciplinary research being widely used in land use planning (Xiang and Clarke, 2003;  
9 Verburg et al., 2006), climate change analysis (IPCC, 2007) and conservation planning  
10 (Osvaldo et al., 2000) and, increasingly, in ecosystem service assessments (Castella et al.,  
11 2005; MA, 2005; Walz et al., 2007).

12  
13 In relation to our mapping approach, future scenarios would change each of the layers in  
14 figure 2. For example, a future with an increase in road infrastructure would alter the  
15 base inventory layer (and any layers that in turn informed by it); whilst a future with  
16 more forest conservation would affect the production, flow, beneficiaries, benefits and  
17 costs layers, and therefore the resultant map of winners and losers.

18  
19 For VtA, we developed two socio-economic scenarios with Tanzanian stakeholders in a  
20 series of participatory workshops (see Swetnam et al. 2010). Both scenarios relate to the  
21 year 2025 (Table 2). Matazamia Mazuri (MM) means ‘hopeful expectations’ in  
22 Kiswahili and represents a future where Tanzania fully meets its stated policy goals on  
23 poverty alleviation and natural resource management, but still reflects the reality of a

1 population growth and economic pressures. Kama Kawaida (KK) means ‘as usual’ in  
2 Kiswahili and corresponds to a business-as-usual scenario where a growing population  
3 combined with ongoing resource exploitation leads to continued environmental  
4 degradation and steady-to-declining family income.

5

6 [TABLE 2 IN HERE]

7

8 Our scenario-building process continued with more formal descriptions of how the  
9 storylines impact on different sectors (agriculture, water supply, tourism, forestry and  
10 population). The sectoral impacts were then translated down to ordinal-level impacts on  
11 specific human-environment interactions (e.g. “large increase in area under agriculture”).  
12 Finally, further discussion established a series of rules for translating these ordinal scores  
13 into changes in our mapped surfaces (Swetnam et al., 2010). So in the case of a large  
14 expansion in agriculture we needed a rule for establishing the location and magnitude of  
15 this expansion, and so considered that agriculture expands in areas abutting existing  
16 agricultural land until the threshold prescribed in the storyline is met (e.g 10% increase in  
17 agriculture). Once such mapped outputs have been generated they can then be used as  
18 revised inputs to the layers in figure 2, thereby generating descriptions of the plausible  
19 gains and losses that may be incurred by specific future courses of action.

20

21

22

23 **Illustrative Example of the Mapping Approach**

1

2 Here we provide a brief stylized example of how the mapping approach can help provide  
3 insights for policy and management decisions based on some preliminary results from our  
4 project. We focus on the carbon stored in two Forest Reserves, Shagayu and Image (both  
5 ~80km<sup>2</sup> in size), and examine the relative costs and benefits of the conversion of these  
6 forests by expanding subsistence agriculture.

7

8 [FIGURE 4 IN HERE]

9

10 Starting with the inventory layer, we map population around the reserve, the reserve  
11 boundaries, and land cover within and surrounding the reserves (Figure 4). The  
12 production layer considered here is simply the carbon stored in each landscape as in this  
13 example we are only concerned with a single ecosystem service (Shagayu: mean 325  
14 tC/ha; Image: mean 277 tC/ha). Likewise, for this initial test we generate our production  
15 layer simply using mean values from the literature of carbon storage in each land-use  
16 type, for each of four pools: above ground, below ground, soil and dead matter. The flow  
17 and beneficiary layers are unmapped as the benefits of carbon storage, i.e. climate  
18 regulation from this carbon not entering the atmosphere, are assumed to accrue globally  
19 regardless of where the carbon is stored (because CO<sub>2</sub> is a well-mixed gas in the  
20 atmosphere). The value layer could be derived using a range of existing monetary values  
21 for carbon: voluntary carbon markets (~\$5/tCO<sub>2eq</sub>), compliance markets such as the  
22 European Trading Scheme (~\$18/tCO<sub>2eq</sub>), and damage cost avoided estimates (~\$15-  
23 \$50/tCO<sub>2eq</sub>) (Tol, 2005) that are all readily available and defensible under differing

assumptions. For our example, however, we will forego appending a value to the carbon and discuss the important underlying issues further below.

For the cost layer we created an opportunity cost based on the net rents from the top five crops grown in the Lushoto and Kilolo districts where the reserves occur (Shagayu and Image, respectively) based on the average crop yield and regional market price (*NPVs 30 years  $r=10\%$* ). We also added the foregone benefits of charcoal production specific to the forests in these districts that are converted under our scenario. These costs are just an approximation of the opportunity costs at these forest reserves, because for one, they are based on district values. We also added management and implementation costs for managing a carbon-offset project for the projected converted areas (proxy for managing the forest reserves) (Borner and Wunder 2008). Specifically, the opportunity cost was calculated as:

$$O_x = \sum_i^I (y_{ix} a_{ix} p_i) - C + .34Gn + M$$

Where  $O_x$  is the opportunity cost of conservation in  $x$ .  $a_{ix}$  is the area planted with crop  $i$  in  $x$  (ha),  $y_{ix}$  is the yield of crop  $i$  in  $x$  in tonnes/ha (Tanzanian Agricultural Census 2003);  $P_i$  is the price of crop  $i$  from regional price data in USD/tonne (FAO's PriceStat database), and  $C$  is the cost of inputs including cost of seeds, transportation, land, labour and fertilizer (*b. fisher unpublished data; Tanzanian Agricultural Census 2003*).

1  $G$  is the aboveground biomass in a given hectare (in kg), and .34 represents a conversion  
2 of biomass to charcoal based on kiln efficiencies and published field work and  $n$  is the  
3 profit from charcoal production (\$/kg) (Malimbwi et al., 2007; Van Beukering et al.,  
4 2007).  $M$  is the proxy measure for management and implementation costs (Borner and  
5 Wunder, 2008).

6  
7 When we add up the costs of conserving the forest reserves (countering the conversion  
8 scenario) we get values of \$10.6 million (\$2200/ha) and \$5.6 million (\$1660/ha) for the  
9 Shagayu and Image reserves respectively. In the conversion scenario, from our modeling,  
10 we know that the Shagayu and Image Forest Reserves lose 1.4 and .9 million tonnes of  
11 carbon respectively. Here rather than applying a value to each tonne of carbon we can  
12 simply calculate the necessary price of carbon in order to offset the opportunity and  
13 management costs of maintaining the two forest reserves, based on this stylized example.  
14 The breakeven carbon price for the Shagayu Reserve is \$2.06/tCO<sub>2</sub>, meaning that a  
15 carbon price set at that level could compensate the costs incurred in continuing to  
16 conserve that landscape. Similarly, the breakeven carbon price for the Image Forest  
17 Reserve is \$1.70/tCO<sub>2</sub> (see table 3). The knock-on policy question is whether these  
18 carbon payments can be realized.

19  
20 This example looks at just one benefit (carbon storage), two costs (opportunity and  
21 management costs) and one scenario. A more comprehensive assessment of the  
22 conversion costs and benefits of these two forest reserves would incorporate a fuller  
23 suite of ecosystem services including water regulation, pollination, and other NTFPs.



1 Additional costs not accounted for here include soil depletion, damage costs, and some  
2 measurement relating to how conversion or conservation might affect market prices of  
3 agricultural and timber products. However, even this simple example illustrates our  
4 approach, and provides insight on the partial costs and benefits of conservation v.  
5 conversion. The example also points out the spatial aspect of production, costs and  
6 benefits as they differ greatly between the forest reserves. Further, these reserves were  
7 selected because they are similar in size, but set in contrasting locations. The Shagayu  
8 occurs in the heavily populated Usambara Mountains, while the Image is located in the  
9 sparsely populated Udzungwa Mountains. This distinction is critical if we were not  
10 concerned simply with the value of carbon, but rather with how many people would be  
11 impacted by foreclosing their option to convert forest into agriculture. In this case the  
12 stakeholders who benefit from carbon storage are largely global, while those paying the  
13 greatest share of the costs are local. Table 3 shows that there are an estimated 35793  
14 people living within 5 km of the Shagayu Reserve, but less than 700 people within 5 km  
15 of the Image Reserve. If the Tanzania Government, or a carbon buying institution, had to  
16 decide which forest to conserve they could be faced with a choice of foreclosing the  
17 opportunities of some percentage of 35 thousand people or some percentage of the 700  
18 people. The latter might be more plausible politically and potentially more easily  
19 compensated. Alternatively, they could see these population disparities as pressures and  
20 an argument that by protecting the Shagayu they are demonstrating additional carbon  
21 saved in the face of a greater conversion threat.

22

23

[TABLE 3 IN HERE]

1

2 The simple example of our approach allows us to consider multiple policy or  
3 management options in the face of a changing landscape, but in the future will enable  
4 such decision-making on an analysis of several services, multiple costs and a suite of  
5 scenarios, delivering an added depth of information to the decision-making process.

6

7

8

## 9 **Conclusion**

10

11 In the past few years we have learned much about how ecosystem service research can  
12 best inform decision-making. Key lessons include the importance of integrating cost  
13 data, in addition to benefit data (Ando et al., 1998; Naidoo et al., 2006); making spatially-  
14 explicit assessments at both ecologically and policy-relevant scales (Chan et al., 2006;  
15 Rouget et al., 2006); and employing contrasting scenarios that are meaningful to  
16 decision-makers (Balmford et al., 2008). Our approach described here incorporates these  
17 insights and delivers policy-relevant information in an easily accessible way. There are  
18 obvious difficulties in undertaking this approach, but by highlighting those which we  
19 have encountered in our own case study work, we have also been able to suggest some  
20 routes to overcoming these impediments.

21

22 Our approach was designed to address the impacts of different policy options on  
23 ecosystem services and their role in providing human well-being. It is intimately

1 concerned with equity issues, in that a key output is a map of the relative winners and  
2 losers of various different future scenarios and policies. We also see it as a general  
3 approach, which can be applied at various scales and with varied levels of input detail.  
4 Of course there remain several key challenges within our project and the larger  
5 ecosystem service research agenda like: How do we incorporate the importance to  
6 human welfare of those services which conventional economic valuation fails to  
7 meaningfully express? What are the transaction costs of applying such a research  
8 program? How can such an approach be undertaken in contexts where data and funding  
9 are limited and institutions weak? How do we understand service flows and values that  
10 change spatially and temporally over short time scales, e.g. seasonal variations,  
11 migrations, fluctuating stocks? How can we incorporate ecosystem services and their  
12 valuation into climate change models that include representations of the land surface  
13 (Doherty et al., 2010)? This set of questions represents only a fraction of those that  
14 remain for more robust ecosystem service analysis. While these challenges may seem  
15 significant, the importance of delivering accurate and timely information on the role well-  
16 functioning ecosystems play in human welfare will continue to grow.

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Table 1: Results of scoping studies on available data to map and value key ecosystem series in the Eastern Arc Mountains of Tanzania.

Category	Services and Benefits	Current Data
Carbon	Carbon storage, Carbon sequestration, Climate regulation	Forest plots <sup>1</sup> (n= 2,300), inventory for 6 forest blocks <sup>2</sup> ; 580km of forest disturbance transects <sup>1</sup>
Timber / Non Timber Forest Products	Timber, Building materials (poles, thatch), Bushmeat, Medicinal plants, Roots, Honey	As above for carbon with additional information from household surveys in > 120 villages
Water	Water flow for households, irrigation and hydropower, Flow regulation	Rainfall monthly means, river gauge data
Pollination	Forest species pollination, Agricultural pollination	Crop presence for mountain blocks, pollinator species presence
Biodiversity	Genetic storage, Existence values	Vertebrate and vascular plant species lists for all mountain blocks and most forest reserves, regional inventories of birds, reptiles, amphibians and mammals
All		Land cover, administrative and census data, infrastructure (roads, railways), soils, geology, climate data

1 = Compendium from the last 10 – 15 years  
2 = from Sokoine University, Morogoro, Tanzania.

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Table 2: A comparison of the key socio-economic drivers embedded in the two scenarios used in the land cover modelling: Matazamia Mazuri ('hopeful expectations') and Kama Kawaida ("business-as- usual")

Descriptor	Matazamia Mazuri (2025)	Kama Kawaida (2025)
<i>GDP growth</i>	6%	5%
<i>GDP per capita</i>	\$1500	\$1100
<i>Growth sectors</i>	Tourism, Mining and Agriculture	Agriculture (area not productivity)
<i>Population growth</i>	2%	3%
<i>Population by 2025</i>	55 million	60 million
<i>Population with access to electricity</i>	40%	20%
<i>Energy sources</i>	Gas, coal, Hydro-electric Power Biomass (firewood and charcoal) main source for cooking but demand falling through technology interventions (stoves / waste residue fuels)	Gas, some coal and HEP. Biomass remains the main energy source.
<i>Agricultural sector</i>	Remains largest employer and largest component of GDP. Marketing, processing and improved transportation increases productivity. Some expansion of irrigated agriculture. Livestock production increases.	Remains largest employer and largest component of GDP. Productivity remains low with irrigated agriculture rare. Small-scale farming dominates with much work still done by hand and hoe.
<i>% area under medium-large-scale farming</i>	Doubles to 30%	Remains at 15%
<i>Global financing</i>	International payments for Carbon (through REDD) and PES schemes grow.	Payment schemes fail to be implemented in any significant manner.
<i>Protected Areas</i>	Increasingly well monitored and managed. Encroachment and illegal timber harvesting is arrested. Integrated catchment management is improving.	Little capacity for monitoring and management. Encroachment and illegal timber harvesting continues in reserves. Small-scale mining increases in the mountains.

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Table 3: Costs and Benefits of conversion of forest to agriculture in the Shagayu and Image Forest Reserves.

Forest Reserve	Estimate of stored carbon (mil. tonnes)	Carbon lost if forest is replaced by agriculture (mil. tonnes CO <sub>2e</sub> )	Opportunity cost of conservation (charcoal and agriculture)	Management and implementation costs of conservation	Necessary carbon price to offset costs*	Number of people living within 5km
Shagayu	2.6	5.1	\$ 10.3 million	\$233 thous.	\$2.06/tCO <sub>2</sub>	35793
Image	2.5	3.3	\$5.67 million	\$162 thous.	\$1.70/tCO <sub>2</sub>	637

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\*Reported in \$/tCO<sub>2</sub> where 1 tCO<sub>2</sub> = 1/3.667 tC

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**Figure 1.** Eastern Tanzania showing the Eastern Arc Mountain chain. While the focal ecosystem service production areas are outlined in black, the beneficiaries stem from local to global.

**Figure 2.** Series of sequential mapping exercises for assessing ecosystem services across a landscape.

**Figure 3.** Possible spatial relationships between service production units (P) and service benefit units (B). In panel 1, both the service provision and benefit occur at the same location (e.g. soil formation, provision of raw materials). In panel 2 the service is provided omni-directionally and benefits the surrounding landscape. This delivery can happen at local scales such as for pollination or pest control (dashed line) upto the global scale such as in carbon sequestration (solid line). Panel 3 demonstrates services that have specific directional benefits. For example, uphill forested areas provide water regulation services to both local (dashed line) and regional (solid line) (based on Fisher et al., 2009)

**Figure 4.** Changes in carbon storage for the Shagayu and Image reserves when moving from montane forests to agricultural land (left). Forest reserve boundaries and village locations within a 5km buffer (right)

# Measuring, modeling and mapping ecosystem services in the Eastern Arc Mountains of Tanzania

Fisher, Brendan

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