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Ecological Economics 33 (2000) 401–412

ECOLOGICAL ECONOMICS

www.elsevier.com/locate/ecolecon

SPECIAL SECTION: LAND USE OPTIONS IN DRY TROPICAL WOODLAND ECOSYSTEMS IN ZIMBABWE

Valuing ecological services in a savanna ecosystem: a case study from Zimbabwe

G. Kundhlande [a,*], W.L. Adamowicz [a], I. Mapaure [b]

[a] *Department of Rural Economy, University of Alberta, Edmonton, AB, T6G 2J4 Canada*
[b] *Department of Biological Sciences, University of Zimbabwe, Harare, Zimbabwe*

Abstract

Estimates of the value of carbon sequestration services provided by a savanna ecosystem and of the value of water for the supply of a number of environmental goods and services are developed in a Zimbabwean case study using an ecological–economic model that captures the interactions between ecological and economic processes. The estimated values of carbon sequestration, in both the woodlands of the Communal Area and the State Forest, are substantial, but slightly lower than the value of converting these lands to individually held agricultural land. This, and the lack of markets in which individuals can be compensated for maintaining some land under woodland as a store for carbon, creates strong incentives for households to convert woodlands to agriculture. There is a high value for additional water availability, associated with the supply of wild foods, firewood, crop production and carbon sequestration, suggesting that efforts towards conservation in this eco-region can have high economic returns. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Carbon sequestration; Marginal values; Water value; Ecological–economic modeling

1. Introduction

Ecosystems provide goods and services that contribute to human welfare, and provide an environment in which ecological processes take place (Costanza, 1991; Costanza et al., 1993). During the past decade, there has been growing concern about the deterioration of ecological systems, compromising their capacity to sustainably provide goods and services. The economics and ecological literature cites several reasons why the supply of these goods and services would be expected to decline. Many environmental goods are not exchanged in markets, and where markets exist they are often thin (inefficient), while environmental services such as carbon sequestration are public goods. Economic theory predicts that goods and services for which there are inefficient markets, or that are non-exclusive and non-rival in consumption, tend to be underrepresented in

* Corresponding author.

PII: S0921-8009(00)00149-X

management decisions, and as a result their supply will be sub-optimal. In the savanna region of Zimbabwe, the effect of these factors is to produce strong incentives for households to convert woodland areas (major sources of environmental goods and services) into agricultural land.

In the Communal Lands of Zimbabwe, households privately own their farms (although they don't own the land, whose ownership is vested in the state) and control the proceeds from farming. Livestock are grazed in communal woodlands, which are also a source fuelwood and wild foods (Campbell et al., 2000b; Grundy et al., 2000), and which provide numerous environmental services such as carbon sequestration and watershed protection. State Forests (land set aside by the state as 'forest' reserves) supply additional environmental resources and services when they are located adjacent to Communal Areas, and households are granted access (Grundy et al., 2000). Unlike agricultural output, the ownership of the environmental goods provided by woodlands in Communal Lands and State Forests can only be claimed through capture, while environment services are public externalities. Poorly defined ownership rights, and the externality and public goods characteristics provide an important explanation why environmental goods and services tend to be undervalued in resource management decisions.

This paper makes an attempt at estimating the value of environmental services provided by ecosystems. In particular, we attempt to estimate the economic value of carbon sequestration and water in the savanna ecosystem in northwestern Zimbabwe. Our reasons for focusing on these services are two-fold. (1) Although the ecological and economics literature assumes that these services are economically important, very little empirical evidence has been gathered to validate the claim, and in particular information for savanna ecosystems is scant. (2) Hydrological and carbon sequestration service values are potentially of great interest for domestic and international policies because they involve local and global externalities. Although carbon sequestration services do not have a direct and immediate productive effect for households in the rural areas in Zimbabwe, the loss of such a service may be linked to productivity losses in the long run.[1] Productivity losses will also be felt in other sectors of the economy through linkages with agriculture. Productivity changes may cause changes in relative prices in the domestic economy necessitating inter-sectoral factor substitutions, changes in household income and consumption patterns, as well as affect industries that process agricultural products. Although at present carbon sequestration does not have a productive role in the urban–industrial economy of most countries, this may change in the future, as international agreements on climate change may require all jurisdictions to implement measures aimed at reducing atmospheric concentrations of greenhouse gases.

The hydrological function of the dry savanna has a direct impact on productivity of the surrounding areas. The economic importance of woodlands and forests stems from the fact that vegetation cover may stabilise the local climate and maintain rainfall patterns (Botkin and Talbot, 1992; Myers, 1995), and may reduce water loss by acting as a windbreak and by providing soil cover. Furthermore, trees and shrubs in the water catchment zones may also help regulate stream flow (maintaining stream flow during the dry season), help improve water quality, prevent soil erosion and flooding, and affect the recharging of ground water reservoirs (Bruijnzeel, 1990; Huntoon, 1992). However, trees may also result in removal of water from the system through evapotranspiration — thus the specific vegetation may either enhance or detract from water availability.

In this analysis we are interested in the value of water as an ecological service. We recognise that the relationship between vegetation, land use and water availability for use in crops and production for human needs is a complex one. However, the value of water availability, de-coupled from the vegetation–hydrology complexities, is clearly

[1] There is a general agreement that global warming will lead to significant reductions in agricultural productivity in developing countries (see Nordhaus, 1991; Cline, 1992b), and that subsistence agricultural systems stand to suffer the most because of their inability to take advantage of the risk pooling opportunities offered by markets (Reily et al., 1993) and constraints on adaptation.

reflected in the benefits to crops and other goods and services generated for human use. The 'services' of water benefit both the rural and urban sectors, since rivers, streams, wells and boreholes are important sources of water for human consumption, and crop and livestock production. Also of importance is the effect of water in the production of other ecological goods (wild foods, timber, and firewood) and services (e.g. carbon sequestration). The value of water in the supply of the latter set of goods and services is seldom estimated, understandably so given the difficulties involved in measuring the value of goods that are not exchanged in markets and whose production functions are rarely estimated. It is, however, our contention that a comprehensive quantification of all values using the best available methods should be attempted and that such information can provide important insights for decision makers.

A substantial part of the benefits of carbon sequestration and watershed protection benefits are enjoyed by other countries as international externalities, or by other parts of Zimbabwe. For example, it is believed that a disproportionate amount of the cost from future global warming would be borne by coastal communities, which will be flooded as the sea level rises. The savannas of southern Africa form the watershed zones of major international rivers (and tributaries feeding these rivers), for example, the Zambezi river, which is a major sources of power, irrigation water and water for domestic consumption for a number of countries.

The rest of this paper is organised as follows. Section 2 discusses the conceptual framework for assigning economic value to environmental services. Section 3 discusses the methods used in the present study to estimate productivity losses and other economic damages that might result from human-induced changes in the ecosystem. The methods involve the use of woodland biomass-growth and agricultural production models, and a decision-making framework that allows the examination of changes in carbon storage values and agricultural income. The results, discussion and conclusions from the modeling exercise are presented in subsequent sections.

2. Valuing ecological services

Environmental policies provide an opportunity to account for costs and benefits of commodities and services that are normally not traded in the marketplace. A number of techniques have been developed in the environmental economics literature to impute the value of environmental resources (Freeman, 1993). Most of the methods attempt to estimate the 'willingness to pay' of individuals or firms for environmental goods and services. An estimate of the value of environmental goods and services can be found by determining the demand function, or derived demand function for the good or service. Since environmental goods and services are not exchanged in the marketplace, economists use the relationships between private goods (goods that are traded in the marketplace) and environmental goods and services in order to gain information about the demand for environmental goods and services. For example, if watershed protection leads to a \$20 increase in agricultural productivity, then the beneficiaries of this service should be willing to pay up to \$20 for it.

Approaches for measuring environmental values arising from changes to firm's inputs, includes the measurement of *damage functions* and *productivity changes*. Damage functions and productivity change measurements examine a physical relationship between the environment and private goods for which value can be measured in the marketplace. Under such conditions, as when an environmental impact leads to marginal changes in the supply/production of a good sold in competitive markets, the willingness to pay amounts can be estimated directly by the supply changes valued at the observed market prices. For example, in the case of agricultural production, if output prices and the prices of other inputs remain unchanged when the supply or quality of environmental resource inputs change, then the economic value of the change in the supply of the resource is measured as the difference between the profit after the change and before the change. If the firm's behavior (in terms of input use or other forms of management) changes as a result of the change in the environmental input, then these behavioral responses also need to be quantified. For example, if a change in the quality of an input (water) occurs and that results in a change from one crop to another, then this crop switching behavior should be captured by the economic assessment approach, and the value of the quality change will reflect the change in economic conditions. Freeman (1993) provides an overview of the value of environmental quality change arising from such cases.

A damage function provides physical information about how damage from, say, global warming is affected by carbon dioxide emission levels, and it relates damages to monetary values. The physical component of the damage function provides information about the amount of economic dislocation due to climate change caused by increased atmospheric concentration of carbon dioxide. Then, using data on the amount of carbon dioxide emitted from human activities and the costs of damage to coastal communities and ecosystems, increased use of energy for air conditioning, increased incidences of mortality due to heat stress and reductions in water supply, it is possible to estimate the value of carbon sequestration from the estimated damage function. Thus, the value of an activity that reduces atmospheric concentrations of carbon dioxide (e.g. the value of woodlands for carbon sequestration) may be measured as the amount of carbon sequestered times the cost of damages caused by an additional tonne of carbon dioxide released into the atmosphere. In this paper we rely on other studies for measures of the per unit value of 'damage'. These measures of damages (dollars per tonne of carbon emissions) can be used to assess the benefits of sequestering carbon, in that units of carbon sequestration reduce the damage effects. Thus, we do not measure the damages of climate change in this paper; we use other studies that have produced measures of the value of carbon emission reduction to assess the value of carbon sequestration.

3. Methods: ecological–economic model

An ecological–economic model was used to estimate the carbon sequestration and watershed benefits from protecting woodland areas. This approach allows us to model the reactions of ecosystems to natural and human-induced disturbances, and the effects of ecosystems on human well-being, thus enabling us to have a better understanding of the interactions between ecological and economic processes. The approach also allows us to incorporate feedback elements thus creating a dynamic system. This study is an attempt at an empirical application of the several largely conceptual studies that propose ecological–economic modeling (Russell, 1993; Bockstael et al., 1995). Initially we build a model specifically to investigate the value of carbon sequestration and water, with simplified resource extraction and growth functions; later our model was integrated into the larger model (Campbell et al., 2000a). The components of the integrated model are described in the following papers: the ecological system, Gambiza et al. (2000); patterns of use of forest products, Grundy et al. (2000); grazing, Campbell et al. (2000a); and crop production, Chivaura-Mususa et al. (2000). The model was constructed using STELLA (a computer simulation programme), and was used for two different woodland areas, the Mzola State Forest and the neighboring Communal Area. The latter is slightly less dense than the former because of greater harvesting.

3.1. Modeling carbon fluxes

Carbon flow is modeled by keeping track of the biomass (an organic storage for carbon) in living and dead trees, grasses and shrubs. Although below-ground biomass has been shown to be a critical component for net carbon storage (Pingoud et al., 1996), only above-ground biomass is considered here.

Total biomass, measured in tonnes per ha, is calculated for each year, both for the remaining stock and for the removals. Removals consist of four different end-use categories (commercial timber, poles, thatch grass and grazing) plus the losses due to fires and natural mortality. The remaining (on-stand) stock of biomass is defined as living trees, shrubs and grasses in the ecosystem after removals.

In the model, fire is a random variable since the size of the area affected by fires is likely to vary each year, and planned burning is not part of the management strategy for the woodlands. Rainfall, a factor affecting biomass growth in the stand and crop production, is also modeled as a normal random variable.

A key component of carbon valuation exercises is the definition of a baseline and assessment of carbon sequestration relative to this baseline. Since a fundamental concern in the region is the conversion of forest land into agricultural land or deforestation, we examine the stock of carbon in biomass and products, relative to a case where forest land is converted to agricultural land. Thus, in this approach we assume that the best alternative land use is agriculture, which will remove the majority of permanent biomass storage of carbon, and the ability to produce woodland products. The value of carbon sequestration arises from the fact that if the land is not used for carbon sequestration (and other forest products), it will be changed to agriculture. Thus, the value of carbon storage is really a value of avoiding deforestation and the emission of carbon to the atmosphere.[2] Thus, the valuation is relative to carbon that would be held in an agricultural system, should all the forest land be converted to crop land. The value of carbon in this system is assessed along the lines of Van Kooten et al. (1995) who suggest the use of a form of the 'debit/credit' valuation system. Essentially, in each year that carbon is maintained in the system the 'owner' receives a credit based on an annualised value for carbon storage. A credit is assumed if the land is maintained in forest and not converted to agriculture. These credits are calculated yearly, producing a stream of values in each time period over a planning horizon. Future additions to biomass are discounted thus the present value is small.

We are interested in biomass stocks and flows in this case because about 45% of biomass is comprised of carbon. Thus, gross carbon stored in vegetation (tonnes per ha) will be the stock of biomass in the woodland multiplied by 0.45 plus carbon storage in removals. However, the length of the time period for which carbon is removed from the atmosphere depends on the rate of mortality of trees and the different decay (emission) rates of the various categories of woodland products. Biomass decay and the release of carbon as CO_2 in each end-use category were assumed to occur at a constant rate until the end of the lifetime of the product. Poles were assumed to decay at a rate of 10% per year, and the same rate was assumed for products from commercial timber and natural mortality in the woodland stand. Grass was assumed to completely decay in 1 year, releasing all the carbon in it, and firewood and vegetation burned during fires was also assumed to decay 100% (although there could be significant amounts of carbon stored in charcoal representing a very stable store for carbon). Thus, net carbon stock (tonnes per ha) per period was calculated as:

$$C_{St} = 0.45\left(B_t + \sum_{\tau=0}^{t-1} 0.9^{\tau+1} P_{t-\tau} + \sum_{\tau=0}^{t-1} 0.9^{\tau+1} L_{t-\tau} - G_t - W_t\right) \quad (1)$$

where: C_{St} is the net carbon storage in year t, B_t is biomass stocks at the end of period t, P_t represents poles harvested, L_t represents commercial timber harvested, G_t represents grass removals, and W_t is the amount of firewood used in period t. Carbon stocks are tracked in each period relative to the base case, keeping account of the changes in living biomass as well as the accumulation (and depreciation) of woodlands products. Thus, poles and commercial timber harvested in previous periods is included in the carbon stock until it has fully depreciated. Fire is included in

[2] Note that this is in contrast to the studies that examine carbon sequestration in lands managed as forests. In lands managed for forestry, temperate forests in North America for example, the benefits of carbon sequestration would arise from increments above a baseline forest condition. These increments may arise from intensive forest management, fire suppression, or some other practice that increases yields and adds carbon above a baseline amount. In the savanna region the pressure is to limit deforestation, rather than forest management, thus agricultural use is employed as the baseline.

the model and removes biomass according to a randomly generated fire probability. Thus, the carbon stocks calculated are actually a form of expected carbon stock that will vary if the fire regime changes.

The net carbon stock stored in the form of biomass is assigned an economic value by multiplying the stock by the value of a tonne of carbon. We use an estimate of Z$250[3] for the value of carbon. This estimate is comparable to an estimate of US$20 suggested by Fankhauser (1993) as the 'central' value of damage for one tonne of carbon released into the atmosphere.[4] In order to calculate the net benefit of woodland preservation compared to the likely alternative use of the land, the carbon storage values are summed for all time periods and discounted to the present using a discount factor. In calculating the present value of carbon storage, we have assumed a 50-year planning horizon given the long lag before the greenhouse effects are realised. A discount rate of 5% per annum is used, which is comparable to the 2% rate recommended by Cline (1992a,b) for evaluating decisions with long-term environmental consequences.

3.2. Modeling the value of water

While ecosystems are important for providing a wide range of hydrological services, water supplies are important in influencing the supply of products (wild foods, firewood, timber and poles) and services (e.g. carbon sequestration) by the ecosystem. Water availability also influences crop production. One of the objectives of the present study is to estimate the value of water in this region. We examine the marginal value of water by assessing the impact of water availability changes on various output that have relatively well-defined market values. This essentially follows the approach outlined by Freeman (Chapter 9). Environmental service (water) is treated as a component of the production process, and changes in this aspect are assessed by examining the response of the producer (household) through the model of crops and woodland products. An estimate of the 'total' marginal value of water[5] in the ecosystem is obtained by summing the value of water in the production of the various goods and services obtained from the ecosystem (assuming that the production of one good or service is independent of the other). A sophisticated model of household behavior would identify the potential for crop switching as water availability changes (e.g. Adamowicz and Horbulyk, 1996). However, given the relatively modest changes in water availability and limited technological options available, the lack of 'crop-switching' in this study may be regarded as only slightly affecting the results. A model of Ricardian rent arising from change in water availability, much like the analysis presented by Mendelsohn et al. (1994) that examines climate change, would accurately reflect behavioral changes by the households (firms) in response to changing climatic conditions.

The value of water in crop production is estimated with the use of a crop production model. Crop production is represented as a simple Cobb–Douglas production function whose arguments are labor and water (rainfall). Other inputs are not considered as they are not very significant in the form of agriculture practiced in the region and their inclusion would likely not significantly affect the relationships of interest.

The marginal value of water is examined by introducing 'small' variations in the mean rainfall variable and determining the impact of rainfall on the value of goods and services (specifically the

[3] At the time of the study the market exchange rate between the Zimbabwean dollar (Z$) and the US dollar was US$1 = Z$10.

[4] Recent studies suggest that carbon values may range from US$0.50 per tonne to US$50 per tonne where the higher values are expected in the future as global warming impacts are experienced. However, recent trades for carbon offsets have been priced at the lower end of this scale.

[5] In each case we calculate marginal values associated with incremental changes in water availability. We then sum these marginal values over the selected products being examined. If the production functions are inter-related, then this simple summation assumes a strict relationship between the production functions. Thus, we essentially assume that the production functions are independent. Note that we do not calculate a "total" value for water, since most output in this region would cease without water.

marginal value of water in crop, wild foods and grass production and in carbon sequestration). This approach captures the marginal value of water via mean annual rainfall through production functions for market goods (crops) and through the implicit production process for non-market goods (carbon sequestration). The range examined is ±200 mm of annual rainfall around the mean annual rainfall of 650 mm per year. It should be noted that the method used in this study does not provide the total value of water in these ecosystems, which is infinitely large. Rather, the approach examines marginal values. Furthermore, the calculations are not intended to be interpreted as the value of changing rainfall levels as it is generally impossible to affect mean rainfall. Rather, these calculations outline the value of developing water conserving strategies (or avoiding water-using strategies) that result in water service levels approximated by these equivalent changes in mean rainfall levels. The mean rainfall level is employed since it is a significant driver of the model components for this eco-region. Finally, the changes in water availability may have negligible effects. However, over the long time horizon these effects may be more additive. Thus it is important to calculate how water availability over time is capitalised into ecological services.

In the crop production model, the total value of agricultural output (mainly maize) is obtained by multiplying the output by the market price for a tonne of maize in 1997, and changes in productivity are calculated as the difference between the value of output at the different levels of water availability. The capitalised value of agricultural production is calculated by applying a discount rate of 5% over a period of 50 years.

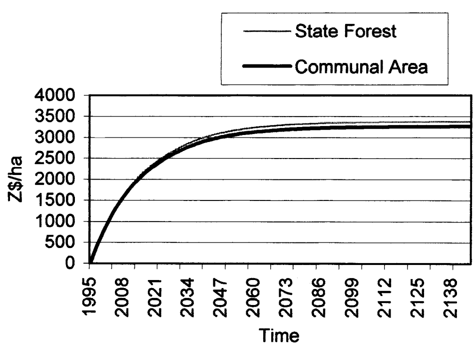

Fig. 1. Present value of carbon sequestration in State Forest and Communal Area (Z$ per ha)

4. Results

4.1. Carbon sequestration value

The present value for carbon sequestration (per ha) rises rapidly from the initial period (1995) until approximately 2050 (Fig. 1). After this point the fact that carbon benefits are discounted heavily, plus the fact that the growth of the biomass (less storage of carbon in products) is small relative to the discount rate, results in a slowing in carbon values. The present value in either the State Forest or the Communal Area is slightly more than Z$3200 per ha and the level of Z$3000 per ha is reached after approximately 50 years. The present value of carbon benefits illustrates that guaranteeing to leave these lands in woodland for a time period of 50 years would realise a benefit of approximately Z$3000.

It is interesting to note that the carbon value is slightly lower than the calculated agricultural value as estimated by the Gwaai Working Group (1997). Annual rental rates for agricultural land in the Communal Area are about Z$600 per ha, which at a 5% discount rate become a capitalised value of Z$12 000. However, if private discount rates are assumed higher, on the order of 10% per year, these annual rental rates imply a capitalised value of Z$6000 per ha. When compared to the land values implied by the crops sector of the integrated ecological economic model (Campbell et al., 2000a), the carbon values and the crop values are quite close. Implied land values in the integrated model, assuming a 5% discount rate and using the average crop return over the period, are approximately Z$4000 per ha.

Fig. 2 displays the annual stocks of carbon converted into monetary equivalents for each year that the forest condition is maintained. Both the State Forest and the Communal Area have similar annual contributions to carbon sequestration, until the later years in the time series. Near the end

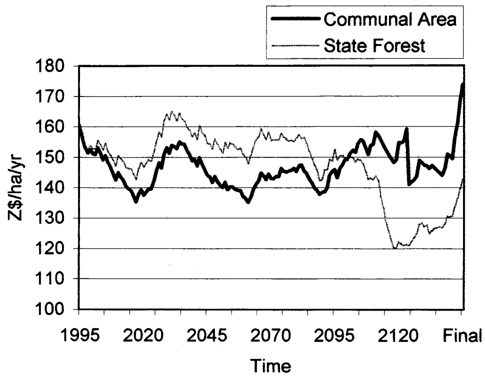

Fig. 2. Annual carbon sequestration value in State Forest and Communal Area (Z$ per ha per year)

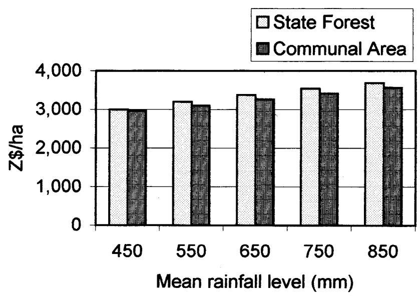

Fig. 3. Carbon sequestration net present values (Z$ per ha) in different rainfall regimes in State Forest and Communal Area.

of the analysis period, annual contributions of State Forest diminish relative to the contribution from Communal Area. This may be due to increased use of State Forest for firewood harvesting (which removes carbon from the system). Interestingly, even with expansion of population and increased use of woodland resources, the carbon sequestration rates remain relatively constant throughout the period.

Carbon values are essentially public goods values. They cannot be realised unless some form of market mechanism is created to compensate local people for the storage of carbon in their woodlands. However, even if such benefits generated for the global public were paid for (at the values estimated above), these values are somewhat smaller than the value associated with converting the woodland to agricultural production. The capture of benefits by local people is more direct in the case of conversion to agriculture and the benefits, as revealed by the crops section of the integrated model, are much higher. Thus, pressures for increased conversion of suitable woodland to agricultural land is expected to continue, even if carbon benefits can be paid to local people. Of course, there are many other values associated with the woodlands that may reverse this pressure.

4.2. Marginal value of water resources

The impact of additional water availability on carbon values, crop values, fuelwood and wild foods is examined.[6] The present value of carbon sequestration changes by as much as Z$1.75 per ha per mm of rainfall. This implies that the value of additional water capitalised in carbon stocks can raise the carbon sequestration value significantly. The water availability equivalent of 100 mm of additional rainfall will generate a Z$150 increase in the carbon sequestration value of woodlands (Fig. 3). Furthermore, this marginal value is only slightly lower for communal woodlands than it is for the State Forest. The marginal values per ha per year (not present values) are approximately Z$ 0.12 per mm with a range of Z$0.10–0.14.

The marginal value of water availability in the crops sector is even more significant than in the carbon sector. Using average crop net revenues over the entire time period, the marginal value per mm of rainfall equivalent is calculated and presented in Fig. 4. The marginal value is presented here as the change in net crop returns per ha per year with respect to a change in rainfall, given initial conditions of very low rainfall (500 mm per year), low rainfall (600 mm per year), medium rainfall (700 mm per year) and high rainfall (800 mm per year). The results show that the marginal value of water is highest in the dry initial condi-

[6] This is only a subset of productive activities that are affected by water availability and it does not include the impact on human health and productivity of livestock. These are significant omissions, but the data to assess these impacts were not available. Thus, these marginal values must be considered conservative measures of the marginal values of water.

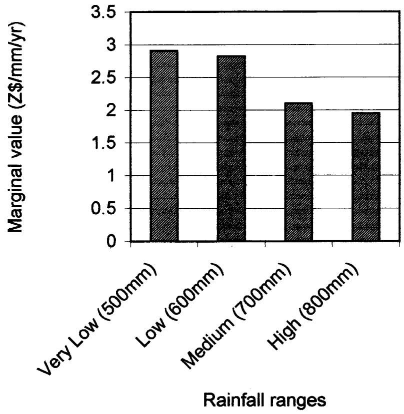

Fig. 4. Marginal value for water for crop production (Z$ per mm per ha per year) in different rainfall regimes. Crop production assumed to be similar in the State Forest and Communal Area.

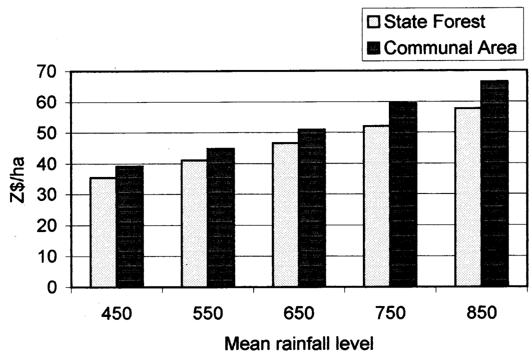

Fig. 5. Average value of fuelwood in different rainfall regimes in State Forest and Communal Area (Z$ per ha per year)

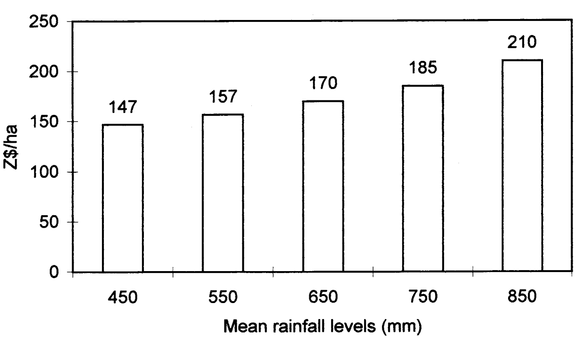

Fig. 6. Average value of wild foods in different rainfall regimes in State Forest and Communal Area (Z$ per ha per year)

tions (very low and low rainfall periods) and is approximately Z$3 per mm. The value diminishes at higher initial conditions, but remains approximately Z$2 even in the high rainfall conditions. A 100 mm increase in water availability will increase net crop revenue by as much as Z$300, which is a significant proportion of average annual crop value (above Z$1500 per year). Clearly the marginal value of water in agriculture is very significant.

The impact of water on fuelwood values is presented in Fig. 5. Firewood values increase as water availability increases, but the marginal values (per mm rainfall equivalent) are quite small relative to those for agriculture. On average, the marginal value of water is between Z$0.05 and 0.08 per mm per year. These marginal values are larger in the Communal Area, reflecting their importance for fuelwood collection.

The marginal value of water in wild food use is presented in Fig. 6. Wild foods values range from about Z$150 to over 200 per ha per year. However, the marginal values associated with water range from Z$0.12 to 0.20 per mm per ha per year. While these are somewhat higher than the marginal values associated with firewood, they are still considerably lower than the crop values. It is noteworthy, however, that the marginal values associated with food products are quite high, relative to the values for fuelwood and for carbon.

Given the annual average marginal values associated with water availability increases, it is possible to develop an estimate of the average capitalised value of increases in water in woodlands. Adding the values for carbon sequestration, firewood and wild foods, the capitalised marginal value of water (assuming a 5% discount rate) ranges from Z$5.40 to 8.40 per mm per ha.[7] However, this is significantly less than the capitalised value associated with crops that are mostly over Z$40.00 per mm per ha.

[7] Once again, recognising that additivity is based on an assumption of independent production processes.

5. Discussion and implications

The value of the subset of ecological services presented here illustrate the importance of the ecosystem functions in the savanna eco-region. However, while the carbon sequestration benefits are significant, they are not as large as the private benefits associated with conversion of woodlands to agriculture. Even if markets for carbon sequestration developed, the incentives will be strongly in favor of agricultural conversion.

An interesting issue that arises from this analysis is the consideration of the management of the State Forest with respect to the carbon sequestration benefits that can be obtained. A simulation was performed in which the settlers in the State Forest were relocated away from the woodland, and collection of wood material from the woodland was stopped. The implications in terms of carbon sequestration are interesting. The present value of carbon sequestration is approximately Z$20.00 per ha higher for both the Communal Area woodlands and the State Forest after exclusion. However, this is less than 1% of the total carbon value for these regions. Thus excluding the people from the State Forest has almost no effect on carbon sequestration values. This is in some ways not a surprising result. While exclusion of people from the State Forest will protect the woodland from removal of certain products, and maintain carbon values, the fact that removals are often in terms of slowly decaying wood products (e.g. construction wood) means that expulsion removes this store of carbon from the system. Similarly, increased pressure on the communal woodland may result from expulsion, but some of this impact is also buffered by the use of product as a carbon sink. At least in terms of the ecological service value of carbon sequestration, sustainable use of the woodland appears to be a strategy that is at least as good as expulsion of woodland dwellers. The sustainable use scenario assumes no major immigration into the forest, as conversion of the woodland to agricultural land will be at the detriment of carbon storage.

Although the values of carbon may seem impressive, the problem is that benefits of carbon are public values. They accrue both locally and globally. Carbon has to compete with other woodland benefits — timber and arable land — which are individually captured. Since much of the environmental damage due to greenhouse gas emissions results because of 'external diseconomies' and the benefits from reduced warming exhibit public goods characteristics, public policies are required to reduce global warming. Identifying the technological and behavioral changes required for CO_2 reductions is one thing, and choosing policies that will ensure adoption of the changes is another. Here we concern ourselves with some of the domestic policies that governments may formulate. Policies such as the creation and maintenance of forest and woodland reserves can increase the natural world's capacity to absorb greenhouse gases. However, economic analysis and empirical research is required to evaluate the effectiveness of the various strategies that are available to society. Typically such analyses involve comparing the costs and benefits of different courses of action. This will mean decisions will have to be made based on a broader set of criteria, not just on market criteria of demand for timber, agricultural products and the need to export timber products in order to generate foreign currency. These criteria are based on market transactions, and thus fail to fully account for the numerous functions and values that are not captured through market transactions. Forest use decisions that ignore those benefits that are not normally exchanged in markets introduce distortions in resource allocation, often with detrimental environmental consequences. In order to improve efficiency of resource allocation, researchers need to develop appropriate mechanisms for assigning economic value to non-marketed woodland goods and services, and improved valuation of those exchanged in thin (inefficient) markets.

The high value for additional water availability, especially in the crop production sector, suggests that there are high economic returns to water conservation activities in this eco-region. The benefits from water conservation have the attraction that they can be easily captured by households living in proximity of the eco-region. The higher marginal value of water in crop production in the initial conditions of very low rainfall suggests that undertaking water conservation activities will benefit households in the most arid zones of the savanna the most. These households are often the poorest.

6. Conclusion

An integrated ecological–economic model is used to estimate the value of carbon sequestration services and the value of water in the savanna eco-region of Zimbabwe. The study shows that the economic value of ecological services — carbon sequestration and water supply — is significant. However, for the woodlands in both the State Forest and Communal Area, these benefits are not as large as the private benefits associated with the use of the land for agriculture, making conversion of woodland an attractive option for individual farmers.

State Forests are relatively well protected against agricultural encroachment, leaving the use of the woodlands as a source of timber and non-timber products as the major point of conflict between the state and communities bordering the woodlands. The results of this study show that sustainable woodland management strategies that include allowing collection of woodland products by local communities does not seriously compromise the ecological service value of the woodland, at least not as far as carbon sequestration value is concerned.

Acknowledgements

The programme Agroforestry: Southern Africa, funded by the Canadian International Development Agency, provided support for this work.

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