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Forest management and the economics of carbon storage: the nonfinancial component

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ABSTRACT: Globally, forests fix and store significant amounts of carbon. This attribute aids in reducing the buildup of atmospheric CO_2. Forest management can increase biomass productivity on lands suitable for forest growth thereby enhancing the uptake of CO_2 by terrestrial ecosystems. Worldwide, however, only about 10% of the 3.6 billion ha of forests are currently under management, suggesting a considerable potential for expansion. Before national and international policy makers commit to increasing the level of forest management, they need information on the benefits and costs of forest management for this objective. Financial evaluations of forest management benefits and costs are not uncommon. But nonfinancial considerations are often not considered in such analyses, and they can change resulting conclusions. Using a series of 30 plantation regimes from around the world, this paper demonstrates the influence of including the nonfinancial cost (i.e. opportunity cost) of forest growing stock in selecting the most favorable opportunities for investments in carbon storage through forest management.

INTRODUCTION

Interest has grown internationally in the past decade for stepping up management of world forests. Interests stem from sustaining basic forest resources, reducing deforestation, restoring degraded lands, and protecting biodiversity. Current interest also stems from the potential of forest management to enhance global carbon fixation and storage within forest biomes (Dixon et al. 1991, Trexler 1991). Decisions to expand forest management throughout the world will hinge on many biological, social-political, and economic considerations.

This paper focuses on the economic considerations of forest management for carbon storage, and argues for the need to include nonfinancial benefits and costs. The nonfinancial components are often not considered in forest economic analysis (e.g. Sedjo 1983, Dixon et al. 1991, and the National Forest Management Plans for the U.S. South, USDA Forest Service 1985). The term nonfinancial is defined later, but examples of nonfinancial components of managed forests are biodiversity, aesthetics, and the opportunity cost of the growing stock. Using a series of plantation management regimes developed by Sedjo (1983), an economic analysis which includes growing stock costs is developed to illustrate these points.

Background

Biologically, the potential of forest management for carbon storage appears quite attractive. Global forests fix and store significant amounts of carbon because of their large biomass (62% of all terrestrial carbon is stored in forests; Waring & Schlesinger 1985) and vast size (one-third of the world's land area; WRI 1990). Forest management can enhance carbon fixing and storage of terrestrial ecosystems. Practices such as silvicultural tending of existing stands or establishing new forest plantations can increase biomass productivity on lands suitable for forest growth (Farnum et al. 1983, Zobel et al. 1987, Hughes 1991).

Worldwide, forests occupy 3.6 billion ha, yet only about 10% are currently under some form of active management (Mather 1990, Allan & Lanly 1991, WRI

1990, Laarman & Sedjo 1992). This suggests a potential to expand forest management in the world which could aid in mitigating the buildup of atmospheric CO_2 by terrestrial ecosystems. Winjum et al. (1992) estimated that expanding world forest management to over 600 million to 1200 million ha during the next 50 yr may be possible, and that such expansion could sequester 50 to 100 (metric) gigatons of carbon (Gt C). Using today's anthropogenic emission rates, 300 to 400 Gt of carbon will be released to the atmosphere in the same period (Schneider 1989). By comparison, therefore, expanding forest management would be a significant aid in mitigating against the increasing atmospheric CO_2 and the onset of global warming.

Socially and politically, momentum has grown in the world toward increasing forest management that facilitates, where appropriate, both conservation and sustainable development of forest resources. The 51 Forest Principles agreed upon by over 100 nations at the Earth Summit in Brazil during June 1992 had exactly such a target (Heiner 1992, UNCED 1992). Reaching consensus on the Principles is clearly a step toward increased social and political support for expanded global forest management.

Economic considerations

The economics of carbon storage through forest management are less clear (Swisher 1991, Trexler 1991). Implementation of policies to expand world forest management to mitigate increasing atmospheric CO_2 will require substantial resources (Van Kooten 1991, Rubin et al. 1992). Before such large-scale efforts are undertaken, policy makers will require an understanding of the potential goods and services produced, and for each good and/or service, the value of the benefits and costs in quantitative terms (Barlowe 1978). For forests, such quantification is not always straightforward, but to the extent that the value of forest benefits and costs can be quantified, management decision making is facilitated (Kramer et al. 1992).

FOCUSING THE ECONOMICS OF FOREST MANAGEMENT FOR C STORAGE

Complex economic evaluations are typically approached by the method of abstraction or partial analysis since accounting for every aspect is beyond present understanding (Duerr 1960). Forest economics is a case in point, particularly when valuing forest management for the purpose of carbon storage. Thus, some focusing steps are called for and are offered in this paper.

To begin, forests afford humans a broad array of direct and indirect needs. The direct needs are commonly called goods and services, and typical examples (adapted from Smith 1992) are:

Goods	Services
Fuelwood	Recreation
Pulpwood	Biological diversity
Sawlogs	Landscape diversity
Water	Soil conservation
Wildlife	Amenity functions
Botanical yields	Pollutant sequestration

More could be added to both lists. Here, carbon storage falls within the broader service of pollutant sequestration.

In the economic evaluation of alternative choices regarding forest use, the benefits are either direct or indirect depending on their role in and level of economic activity (Miller & Blair 1985). Indirect contributions from forests providing goods and services include such items as employment for local people and the development of social infrastructure (from a portion of the revenues). Examples of such social benefits are transportation, schools, and governing systems. Market-driven prices reflecting values have been established for some direct forest benefits. The indirect benefits have not commonly been valued by market prices, and therefore as one focusing measure, this paper concentrates only on the direct impacts of carbon storage.

The next step is to determine the values for the benefits and costs of the direct goods and services. Again, the values of forest benefits and costs have historically been quantified with market-driven dollar amounts paid for commercial goods that *flow from* the forest (Dawkins 1972, Kessler et al. 1992). In recent years, economists have recognized forest values beyond the flow of commercial goods. For example, the forest has an aesthetic or non-consumptive value to many individuals, and from the broader social standpoint, it is now seen that there is great forest value in storing carbon (Kramer et al. 1992). Thus the *stock in* the forest as a resource has recognized value in addition to the goods and services that are produced and flow from the stock. This value also represents an element of the cost of forest management and will be discussed in more detail below.

Basically, values arise from the choices made by individuals and by societies (Samuelson 1964, Trexler 1991). The objective is different according to whether choices are made by individuals or by decision makers in the public agencies of society. Individuals make choices to maximize wealth, generally their own or a special interest group (Hirshleifer 1970). Societies, on the other hand, function most equitably when making choices in such a way that at least one person is better off and no one is worse off so that the net social welfare is increased (Winch 1971).

These 3 components (who, what, and for how much) when placed in a simple matrix provide a framework for further focusing of the economic evaluation of forest management for carbon storage (Table 1). In this manner, 8 cells are created. To evaluate goods and services produced by a forest, it is necessary to first identify who the decision maker is for a particular output and whether it is a good or a service, i.e. cell 1, 2, 3 or 4. Second, a value is placed on the benefit (b) and the cost (c). Examples of these 8 cells are given in Table 1.

Table 1. Distribution of benefits and costs of forest management relating the decision makers to benefits and costs according to what forests provide

Decision makers (Who) and Values (How much)	Forest provisions (What) Goods (flows)	Services (stocks)
Individuals		
Benefits	1b	2b
Costs	1c	2c
Societies		
Benefits	3b	4b
Costs	3c	4c

Examples of the 8 cells are:

1b Revenue a landowner receives for harvested trees
1c Cost of forest establishment and tending until harvest
2b Wildlife habitat or visual amenities
2c Interest paid on the loan to invest in the forest, or opportunity cost to the individual
3b Biodiversity; carbon storage
3c Nonfinancial cost of growing the forest or opportunity cost to society
4b Recreation; water yield; soil conservation
4c The same as 3c

Goods provided by the forests may be evaluated by financial means in the presence of competitive markets, but dealing with the stock of the standing forest calls for a nonfinancial approach. By definition, financial benefits and costs are defined as monetary values that would be reflected in a standard financial budget or accounting statement. Nonfinancial or non-market benefits and costs are reflections of the desirability of goods and services associated with forests which are not actively traded in financial markets. Examples besides growing stock are biodiversity and aesthetic characteristics.

A measure of value is required for either financial or nonfinancial evaluations. This is especially true for the array of benefits and costs associated with forest management (i.e. cells 1b through 4c of Table 1). In the case of financial analysis, these values are based on monetary prices established through market exchanges. For nonfinancial analyses, the values are also expressed as monetary prices which allow the summing of and comparison within and between alternatives.

Monetary prices established through market transactions may also represent social values (i.e. cells 3b, 3c, 4b, and 4c of Table 1). However, if markets are incomplete or non-competitive, market prices may not represent social values (Hirshleifer 1970). In the event of an absence of prices representing social value, numerical estimates of social value can be estimated and utilized as 'accounting' prices (Little & Mirrlees 1974). An example is the incorporation of environmental costs in the decision making for developing new electrical utilities (Palmer & Krupnich 1991). These accounting prices may deviate significantly from explicit prices under conditions of incomplete or noncompetitive markets, but they are intended to express social values that are ignored by existing markets (Sinden & Worrell 1979).

Recent work by Dixon et al. (1991) is an example of a financial assessment of the costs of forest management practices for the purpose of carbon fixation and storage. For example, considering just financial costs of implementing reforestation over a 50 yr period, the cost in 1990 US$ per metric ton of carbon sequestered was $8, $6, and $7 in the boreal, temperate, and tropical regions, respectively.

In addition to financial costs, the traditional and direct economic costs associated with forest management also include the cost of waiting for tree harvests. That is, there is a cost associated with establishing a plantation and waiting some period of time before harvest. This cost is classed as a nonfinancial cost and is the cost associated with the opportunities forgone by having money invested in the use of resources such as forest land and its growing stock until tree harvest, i.e. the opportunity cost of managing a forest for timber yields. Because forests are a form of biological or genetic production, where the producing unit is also the desired product or service, these costs are significant to forest management decisions (Duerr 1988). To illustrate, the plantation analysis below focuses on the significance of forest stock opportunity cost.

METHODS

For the analysis, the value of the growing stock is computed for 30 plantation regimens developed by Sedjo (1983). The resulting values allow a comparison of the carbon storage costs with: (1) financial costs alone; (2) plantation revenues included; and (3) net costs determined particularly (a) with and (b) without an element of nonfinancial costs considered.

Sedjo's representative plantations. Sedjo (1983) developed a model to simulate the productivity, costs, and revenues of a series of over 30 plantations of the world. The purpose was to compare the productive potential and monetary returns of forest plantations representative of major forested regions throughout the world. The simulations were based upon data for actual plantations as reported in the literature or obtained from credible experts associated with well-documented plantations. For this analysis, 30 of the simulated plantations were selected that represented 18 temperate and 12 tropical forest regions or nations of the world (Table 2). Plantation species were mostly of coniferous genera (*Pinus* and *Pseudotsuga*) though 2 hardwood examples are included (*Gmelina* and *Eucalyptus*). Both short-rotation pulpwood crops and longer-rotation sawlog crops with pulpwood thinnings were considered.

Cost of the forest stock. The amount of growing stock of a forest stand is commonly expressed as the stemwood volume of the commercially valuable trees at any given age. For example, a plantation of loblolly pine *Pinus taeda* in the southeastern United States is estimated to have 258 m^3 ha^{-1} of stemwood volume or growing stock at age 30, i.e. representative plantation no. 1 from Sedjo (1983) (Table 3, Fig. 1). At the time of final harvest, the volume of growing stock and its value are equal to the stand yield and its value. In this example, 258 m^3 ha^{-1} is the yield valued at a price of $18.94 per m^3 for loblolly pine at 30 yr (Table 3; all dollars in this paper are 1979 US$).

However, a fully regulated series of plantations that would produce this level of yield and value on an annual basis would have to comprise 31 ha. This provides 1 ha of each age-class year plus 1 ha for the 0 age-class available for reforestation annually. The growing stock volume of the 31 ha forest would equal

Table 2. Representative plantation regimes used for analysis in this paper and their rotation ages (Sedjo 1983)

Region/Species	Regime			
	Pulpwood		Integrated, with standard-quality sawtimber	
	Plantation no.	Rotation age (yr)	Plantation no.	Rotation age (yr)
North America				
U.S. South				
Pinus taeda, average-yield site	1	30	2	35
Pinus taeda, high-yield site	3	30	4	35
Pacific Northwest				
Pseudotsuga menziesii, average-yield site	5	40	6	50
Pseudotsuga menziesii, high-yield site	7	30	8	40
South America				
Brazil, Amazonia				
Pinus caribaea	9	12	10	16
Gmelina spp.	11	19	12	12
Brazil, central				
Eucalyptus spp.	13	19	14	19
Brazil, southern				
Pinus taeda	15	12	16	20
Chile				
Pinus radiata	17	25	18	32
Oceania				
Australia				
Pinus radiata	19	29	20	35
New Zealand				
Pinus radiata	21	18	22	27
Africa				
South Africa				
Pinus patula	23	15	24	26
Gambia-Senegal				
Gmelina spp.	25	30	26	40
Eucalyptus spp.	27	21	28	30
Asia				
Borneo				
Pinus caribaea	29	15	30	20

Table 3. Representative Plantation 1 in southern USA: *Pinus taeda* on an average-yield site managed as a pulpwood regime with 2 commercial thinnings and harvest at age 30 yr. Associated costs, stumpage prices and yield are as presented by Sedjo (1983)

Year	Practice	Cost ($ ha^{-1})	Stumpage price ($ m^{-3} ha^{-1})	Yield (m^3 ha^{-1})
0	Site preparation	180.75		
0	Planting	83.42		
0–30	Stand protection (per year)	2.00		
4	Hardwood control	69.52		
10	Controlled burning	11.63		
17	Pulpwood commercial thinning		14.94	49.31
22	Pulpwood commercial thinning		14.94	49.31
30	Pulpwood harvest		18.94	258.05

the sum of the growing stock on each of the hectares that make up the forest or 3982 m^3 with a value of $63615 (Tables 4B & 5).

The nonfinancial opportunity costs are again the implicit costs representing the opportunities forgone by the use of assets for a given purpose (Samuelson 1964) and are an important consideration. In this example, the opportunity cost is the cost of using the 3982 m^3 of growing stock valued at $63615 to produce 258 m^3 of pulpwood each year instead of liquidating the plantation to generate $63615 in revenue. Opportunity costs for stocks of nondepreciable capital, like forest growing stock, are usually estimated as a rent for the use of productive assets. The rent is based on a discount rate, expressed as a percent, which is the price of deferred consumption. In this study, the annual rate used was 5 %, a real rate of interest commonly used in forest economic analysis which is net of inflation and risk (Davis & Johnson 1987). That is, 5 % of the growing stock value, $63615, is $3181 (Table 5). This amount is estimated as the annual opportunity cost (nonfinancial) of using the growing stock to produce pulpwood for a year (adapted from Duerr 1988).

Costs of carbon stored. The next step in determining costs of storing carbon is to divide costs and revenues in Table 5 by 31 ha to obtain *average* per-hectare values (Table 6). This allows comparisons

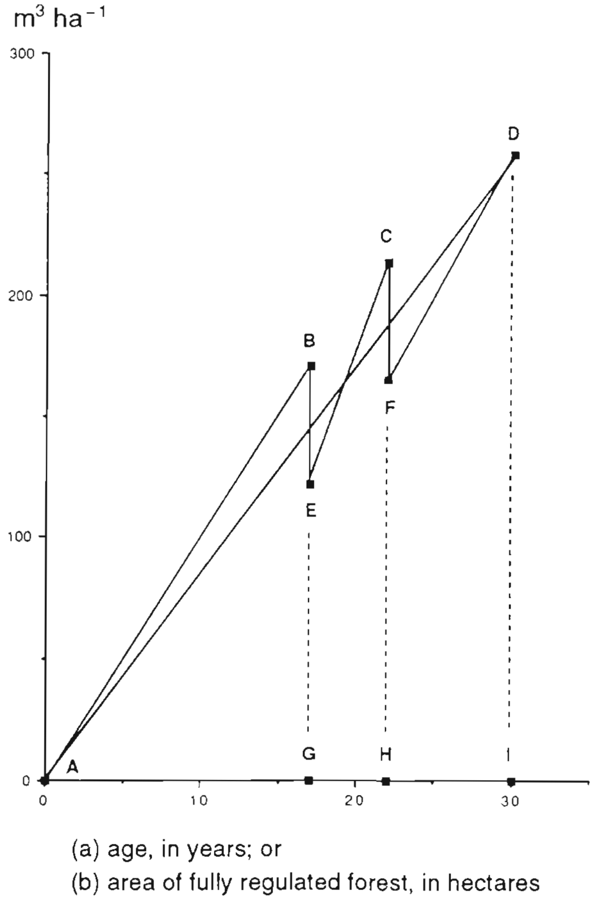

Fig. 1. Graphic illustration of the pulpwood regime for representative Plantation 1 (Table 3). The graphic serves 2 roles for this analysis depending upon the label for the horizontal axis: (a) time (yr) or (b) area (ha). The same procedure was used for all 30 representative plantations in Table 2. Fig. 1a shows simplified per-hectare growth curves and wood yields for Plantation 1. From Table 3, the final harvest yields 258 m^3 ha^{-1} at 30 yr. Therefore, the line AD is a simplified plantation growth curve (though in reality, such forest growth curves are usually 'S' shaped). Lines BE and CF represent the 49 m^3 ha^{-1} yields for the commercial thinnings at 17 and 22 yr, respectively. For simplicity, it was assumed that half of each yield occurred at points above and below line AD. In this manner, the overall growth curve for the plantation is represented by AB-BE-EC-CF-FD with a total plantation yield of 356 m^3 ha^{-1} (49 + 49 + 258 m^3 ha^{-1} as in Table 4A). Fig. 1b places Plantation 1 in the context of a 31 ha fully regulated forest. The forest has 1 ha for each age class in the 30 yr rotation plus 1 recently harvested hectare (at 0 on the horizontal axis) ready for reforestation annually. The growing stock was computed for 3 plantation periods plus the total as follows (also see Table 4B):

(i) before the first commercial thinning (area ABG on the graph) = 1452 m^3;
(ii) between the 2 thinnings (area ECHG) = 839 m^3;
(iii) between the second thinning and final harvest at the 30 yr rotation age (area FDIH) = 1691 m^3;
(iv) total (area bounded by lines AB, BE, EC, CF, FD, DI, and IA = 1452 + 839 + 1691 m^3) = 3982 m^3

Table 4. Growing stock, yields, and dollar values for representative Plantation 1 (Table 3)

A. Per hectare

Plantation age[a] (yr)	Growing stock[b] Before thinning (m^3)	After thinning (m^3)	Yield[a] (m^3)	Growing stock price[a] ($\$ m^{-3}$)	Value[c] (yield in $)
0					
17	171	122	49	15	735
22	214	165	49	15	735
30	258		258	19	4902
Total			356		6372

B. For 31 ha fully regulated forest

Plantation period (yr)	Growing stock Volume[d] (m^3)	Values[e] ($)
0–17	1452	21 700
18–22	839	12 530
23–30	1691	29 385
Total	3982	63 615

[a]Data from Table 3
[b]Volumes from Fig. 1
[c]Values = Yield × Growing stock price, e.g. $49\ m^3 \times \$15\ m^{-3} = \$735$
[d]In Fig. 1b: $1452\ m^3$ = volume represented by area ABG
$839\ m^3$ = volume represented by area ECHG
$1691\ m^3$ = volume represented by area FDIH
[e]Value = Growing stock price from Table 4A times the volume; e.g. $1452\ m^3 \times \$15\ m^{-3} \approx \$21\,700$

between forest of different sizes, though in reality the average hectare in a fully regulated forest does not exist. Stemwood volume can be converted to metric tons of carbon per hectare (t C ha^{-1}) using formulas explained by Dixon et al. (1991). These yields in t C ha^{-1} were divided into 6 types of per-hectare costs: (1) financial costs; (2) growing stock costs; (3) gross costs (the sum of 1 and 2); (4) revenues; and (5) 2 net costs, (a) with growing stock (the sum of 3 and 4) and (b) without growing stock (the sum of 1 and 4). Results produce costs in $ t^{-1} C. In these 6 ways, values in $ t^{-1} C were computed for each of Sedjo's 30 simulated plantations.

Table 5. For Plantation 1, a summary of calculated values for volumes, costs, growing stock value, carbon stored, and revenues developed from data for a 31 ha fully regulated forest, given in Tables 3 & 4. Similar values were calculated for 30 representative plantations from Sedjo (1983)

Item	Units m^3	$	t C
Growing stock			
Volume	3982		
Value		63 615	
Carbon stored			1497
Annual growth			
Volume	356[a]		
Value		6372	
Carbon stored			134
Costs ($\$ yr^{-1}$)			
Financial			
Site preparation		181	
Planting		83	
Stand protection ($\$2\ ha^{-1}$)		62	
Hardwood control		70	
Controlled burn		12	
Sub-total		408	
Nonfinancial			
Growing stock		3181[b]	
Total annual costs		3589	
Annual revenues		6372	

[a]Annual growth = annual yield in a fully regulated forest
[b]Nonfinancial growing stock costs equal 5% of growing stock value

Table 6. Per-hectare data calculated for representative Plantation 1 from Table 5

Item	Units $m^3\ ha^{-1}$	$\$ ha^{-1}$	$t\ C\ ha^{-1}$
Growing stock			
Volume	128		
Value		2052	
Carbon			48
Annual yield[a]			
Volume	12		
Value		205	
Carbon			4
Costs		$\$ ha^{-1} yr^{-1}$	$\$ t^{-1} C$[b]
Financial		13	~3.00
Nonfinancial: growing stock		103	~25.75
Sub-total		116	~28.75
Revenues		205	−51.25
Net revenue		89	−22.50

[a]Totals from Table 5 divided by 31 ha
[b]$\$ t^{-1} C = \$ ha^{-1} yr^{-1}$ divided by $4\ t\ C\ ha^{-1} yr^{-1}$ (carbon stored annually)

RESULTS

Among the 6 cost calculations, results vary as to which region (temperate versus tropical) or which plantation regime (pulpwood versus integrated) is the more attractive investment regarding carbon storage by reforestation. The differences, where significant, illustrate how nonfinancial, as well as financial, components of economic analyses are important to evaluating the cost of carbon storage through forest management. Differences between regions and regimes were tested for statistical significance by the non-parametric Wilcoxon 2-sample test using 0.05 as the level of probability for acceptance of significant differences between median values (Devore & Peck 1986).

Financial costs. The financial cost of producing a ton of carbon by reforestation in Sedjo's 30 simulated situations ranges from about $1 to $10 (Table 7). Temperate region plantations store carbon by this financial criterion at significantly less cost than for those in the tropical region. Median values are: temperate, $4 t^{-1} C; and tropical, $7 t^{-1} C (Table 8). By the Wilcoxon test, the temperate median is significantly different from the tropical median. No significant differences were evident between plantation regimes, i.e. the pulpwood versus integrated.

Growing stock costs. The cost of maintaining plantation growing stock relative to a ton of carbon stored in the 30 plantations ranged from $4 to $81 (Table 7). Least costs were associated with the tropical plantations. Median values are: tropical, $9 t^{-1} C; and temperate, $21 t^{-1} C (Table 8). The 2 medians are significantly different from each other, but the difference between plantation regimes was not significant.

Gross costs. Gross costs per ton of carbon stored range from $9 to $84 t^{-1} C. Systems which have the lowest gross costs per ton of carbon are predominantly those in the tropics and those with integrated crops. Mean values are: by regions – tropics, $14 t^{-1} C; and temperate, $24 t^{-1} C; by crop type – integrated, $18 t^{-1} C; and pulpwood, $22 t^{-1} C. Between regions and plantation regimes, the medians are significantly different.

Revenues. Revenues from timber and pulpwood harvests are handled as negative costs. Median values are: temperate, –$51 t^{-1} C; and tropical, –$38 t^{-1} C (Table 8). These medians are significantly different. The tropical revenues per ton of carbon are significantly different than those of the temperate region. Regarding plantation management, revenues per ton of carbon stored are significantly greater for integrated regimes than those for integrated pulpwood. The medians were, respectively, –$56 t^{-1} C versus –$42 t^{-1} C (Table 8).

Net costs. When calculating net costs, distinct and important differences appear depending upon whether or not nonfinancial costs are included. That is, the net costs of storing carbon considering only financial costs range from about –$74 to –$20 t^{-1} C (i.e. where plantation revenues are greater than costs and so are given as negative costs in Table 7). With growing stock costs accounted for, median values range from –$45 to –$5 t^{-1} C for 28 of the 30 plantations in the analysis, but for 2 plantations, 5 and 6 in Table 2, the revenues did not exceed the costs. Their cost are, therefore, +4 and +21 t^{-1} C respectively (Table 7). Plantations 5 and 6 represent Douglas fir *Pseudotsuga menziesii* growing on sites of average quality in the Pacific Northwest, USA. Together, they have the longest rotation ages (40 and 50 yr, respectively), volumes, and values of growing stock among all 30 plantations in the analysis.

More importantly, however, significant differences between the regional medians in $ t^{-1} C for temperate

Table 7. Calculated costs for a ton of carbon stored for representative Plantation 1 and the range of median values for 30 plantations from the temperature and tropical regions of the world (Table 2). To illustrate the importance of considering the growing stock opportunity costs, net costs (no.5) are shown with and without this cost included

Cost items No.	Calculations	Representative Plantation 1 ($ t^{-1} C)	Range of medians for 30 plantations ($ t^{-1} C)
1.	Financial	3.00	1.25 to 10.25
2.	Growing stock	25.75	4.00 to 80.75
3.	Gross (1 + 2)	28.75	9.00 to 84.00
4.	Revenue (negative costs)	–51.25	–25.00 to –75.75
5.	Net costs		
a.	Without growing stock (1 + 4)	–48.25	–73.75 to –20.00
b.	With growing stock (3 + 4)	–22.50	–45.00 to +21.00

[a]Two plantations (numbers 5 and 6 in Table 2) among the 30 under consideration did not have enough revenues to pay for the financial and nonfinancial costs included in the analysis. Thus their costs per ton of carbon sequestered were +$5 and +$21, respectively; the other 28 plantations all profitably had negative net costs ranging from –$45 to –$4

Table 8. Comparisons among regions and regimes for the calculated costs for a ton of carbon stored among the 30 representative plantations (Table 2). Median values were calculated for each subsample of size n. Paired medians were tested for significance (significant differences among pairs of medians were screened by the Wilcoxon 2-sample test, that is, on the horizontal rows of data, medians between temperate vs tropical regions and regimes of pulpwood vs integrated crops are significantly different at the 0.05 level of probability where the letters a and b are noted; where no letter appears the medians are not significantly different)

Cost items		Medians ($\$ t^{-1}$ C)			
No.	Calculations	Regions		Regimes	
		Temperate	Tropical	Pulpwood	Integrated
1.	Financial	4 a	7 b	5	5
2.	Growing stock	21 a	9 b	18	14
3.	Gross (~1 + 2)	24 a	14 b	22	18
4.	Revenues (negative costs)	−51 a	−38 b	−42 a	−56 b
5.	Net costs				
a.	Without growing stock (~1 + 4)	−48 a	−32 b	−36 a	−49 b
b.	With growing stock (~3 + 4)	−22	−24	−20 a	−32 b
Sample size (n)		18	12	16	16

and tropical plantations vary strikingly depending upon whether growing stock costs are included. *Without* growing stock costs, the medians *are* significantly different with temperate plantations storing carbon at net costs of −$48 t^{-1} C versus −$32 t^{-1} C for tropical plantations. *With* growing stock costs considered, the medians *are not* significantly different at −$22 t^{-1} C and −$24 t^{-1} C, respectively. Medians for plantation regimes were significantly different in both instances with the integrated regimes being consistently more profitable for carbon storage than those for pulpwood (Table 8).

DISCUSSION AND CONCLUSIONS

The absolute values for costs found in this analysis are not as important as the observation that conclusions change as the economic analysis becomes more complete. Working down through Table 8 illustrates the point. If only the financial costs of the 30 plantation options were considered, the temperate plantations would appear more desirable from the standpoint of cost per ton of carbon than those in the tropics, i.e. $4 versus $7, and the plantation regime chosen makes little difference.

Continuing, growing stock costs would be less for tropical than for temperate plantations ($9 t^{-1} C versus $21 t^{-1} C), and again, no significant difference for regimes. The same trend is true for gross costs in Table 8. This result may be driven by the shorter rotation lengths along with reduced growing stock and growing stock values for forest crops in the tropics. For short rotations, stock costs are less since the monetary resources held as growing stock are less.

Looking at revenues, the median cost per ton of carbon stored would favor temperate over tropical plantations (−$51 versus −$38) and integrated regimes (−$56) over pulpwood (−$42). Integrated plantations with longer rotations, from this analysis, would appear to store carbon at less cost per ton of carbon.

Finally, as noted under 'Results', if only financial costs are added to the negative costs of revenues to determine a net cost per ton of carbon, the temperate plantations again appear more favorable than the tropical plantations, i.e. −$48 t^{-1} C versus −$32 t^{-1} C (Table 8). However, if net costs are calculated with the nonfinancial stock costs accounted for, then the difference between temperate and tropical plantations are non-significant, i.e. −$22 t^{-1} C compared to −$24 t^{-1} C. Thus conclusions do change as more components of the benefits and costs of forest management are valued and added to the economic analysis.

Other costs that still need to be considered include such items as land, crop maintenance, protection, and monitoring. Regarding benefits, the analysis did utilize the direct revenues realized from the harvest of tree crops for pulpwood or sawlogs. But other direct benefits providing revenue such as water yield and recreation, and indirect benefits such as jobs and contributions to social infrastructure, must still be added. As with the addition of opportunity costs for forest stock shown above, decisions about forest management would likely change as other components are included in the analyses for the costs of storing carbon through forest management. And ultimately, as pointed out by Kramer et al. (1992), social and political concerns may eventually be deciding considerations. However, economic evaluations of forest management that incorporate more of the benefits and costs associated with carbon storage, though partial in outcome, contribute to the response to economic questions which are integral to social and political concerns.

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