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Valuation of Carbon Stock and Carbon Sequestration in Ayer Hitam Forest Reserve, Puchong

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ABSTRACT

The study estimated the physical and monetary value of forest biomass and the existing stored carbon (C), and the rate of C sequestration by vegetation in Ayer Hitam Forest Reserve (AHFR), Puchong, Selangor. The estimates used direct measurement - based method by a sample survey of AHFR where both above-ground and below-ground C pools were considered. Allometric biomass equations were applied to estimate individual tree biomass per hectare. The total amount of forest biomass - above-ground and below-ground - ranged from 209 to 222 t ha^{1} and the corresponding quantity of C stock ranged from 104 to 111 t ha^{1}. The rate of change of the C stocks was between 4 and 6.5 t ha^{1} yr^{-1}. Such rate of C sequestration was relatively high, comparable with sequestration rate of fast-growing Mahagony (sweitenia macrophylla) plantation. Using a weighted average price of carbon ranging from USD4.00 t^{-1} to USD50 t^{-1}, the estimates of the value of C stock ranged from RM1,654 ha^{1} to RM20,800 ha^{1}. The corresponding value of AHFR as a carbon sink thus amounted to RM2.06-25.96 million. In terms of the dynamics, the estimates of the value of C sequestration ranged from RM 0.87 million to RM 1.45 million yr^{-1}. The information is very useful in estimating the total economic value of AHFR and other tropical forests in future.

INTRODUCTION

Global climate change is a fluctuation in the average global temperature, commonly known as "global warming". As more scientific information about global warming accumulates, climate change is emerging as perhaps the greatest environmental challenge of the twenty-first century, which leads to destruction of the earth's ecosystem. The phenomenon of rising global temperatures affects both weather and climate.

Major global threats such as hunger, poverty, water shortage, displacement of population, air pollution, soil degradation, desertification and deforestation all contribute to climate change that necessitates a comprehensive approach to a solution. Changes in climate will also impact economic well being. Since temperature and precipitation are direct inputs to agriculture production, many believe that the largest effects will be felt in this sector.

The forest has an important role in regulating climate change. Tropical forests are important sources and sinks of carbon (C). When forests are cleared or degraded they contribute about one-sixth of global carbon emissions. In contrast, they have the potential to absorb about one-tenth of global carbon emissions projected for the first half of this century into their biomass, soils and products and store them in perpetuity. Conserving tropical forests is an important step towards reducing CO_2 in the atmosphere as the forests maintain a balance between the biomass of the world's vegetation and the amount of carbon dioxide. However, there is limited information on the extent of carbon sequestered and stored by tropical forests. This paper focuses on and attempts to develop a reliable estimate of the C stocks and the rate of C sequestration in the secondary forest of Ayer Hitam Forest Reserve (AHFR), Malaysia. Another objective of the paper is to monetize the value of the forest for its ecosystem service in terms of its carbon stock and carbon sequestration.

MATERIALS AND METHOD

Physical Measure of Forest Biomass and C Stock

A previous study estimates the total forest biomass and C stock of Air Hitam Forest Reserve (AHFR) using large scale volume based assessment from inventory data (Kueh and Lim, 1999). In this study a field inventory was conducted to estimate the biomass and C stock and the rate of CO_2 sequestration. This is considered as direct measurement-based as opposed to volume-based estimates of forest biomass (Brown and Lugo, 1982). Major C pools measured were above-ground biomass, below-ground biomass and forest litter. For the above-ground measurement sampling consisted of measuring the diameter and height of each tree. Six, 10 x 100 m transects, were laid out in forest areas representing the range of forest conditions in the forest reserve. Complete enumeration of all trees (≥ 10 cm dbh) was conducted in each transect. For each tree, the following data were recorded: a) species name, dbh (stem diameter at 1.3 m above the ground); b) total height; and c) height of first branch. The volume, biomass and carbon content per tree and per hectare were calculated.

Biomass per tree was computed using biomass regression equations. To facilitate comparison of biomass calculations, the following equations were used (Brown *et al.*, 1989; Brown, 1997):

$$Y = 42.69 - 12.8\,D + 1.242\,D^2 \quad [1]$$

$$Y = \mathrm{Exp}\,\{- 2.134 + 2.530 \ln D\} \quad [2]$$

$$Y = \mathrm{Exp}\,\{-3.1141 + 0.9719 \ln D^2 * H\} \quad [3]$$

where: Y = biomass per tree (kg) and D = dbh (cm) and H = the total height (m). A carbon content of 50% of biomass was assumed. Equation 3 has a height variable incorporated in the estimate of tree biomass.

For sampling of under-storey vegetation (saplings and seedlings ≤ 10 cm dbh), five plots measuring 1 x 1 m were randomly laid out. All individual trees and woody species in each plot were harvested. Fresh weights of leaves, branches and stems of harvested trees and woody species were recorded in the field. Then these materials were taken to the laboratory for drying in the oven. Their oven-dry weights were recorded and the carbon contents of plant tissues were determined. Herbaceous vegetation was collected in five 2 x 2m plots randomly scattered in each transect. The fresh weights, oven-dry weights and C contents were determined. C stored in the litter layer on the forest floor was obtained by randomly laying out 0.5 x 0.5 m frame at five locations. Fresh weights, oven-dry weights and C contents were determined.

The field survey on C stocking in AHFR lasted three weeks. About 120 quadrants of 10 x 100 m were established in Compartments 12, 13, 14 and 15. Each quadrant was subdivided into 4 sub quadrants: 10 x 10 m, 2 x 2 m, 1 x 1 m, and 0.5 x 0.5 m. Trees were identified; the volumes, biomass and carbon contents per tree and per hectare were calculated.

The above-ground tree biomass measurements were taken twice: at the beginning and towards the end of the study to estimate C sequestration per year. It was assumed that litter biomass and soil organic C remained unchanged during the observation period.

Valuation of C Stock and C Sequestration

A review of the literature suggests that carbon can be valued from about USD5 to USD300 t^{1}. Richard and Stokes (1995), as quoted by Thompson *et al.* (1997) argued that the divergence arises because the marginal costs of CO_2 absorption through tree plantations are initially low, but then rise rapidly thereafter. The estimates of the marginal damage caused by aggravated greenhouse effect are not well known and the carbon value one chooses depends on the point on the marginal cost curve that is taken. Nordhaus (1991) arrived at a carbon value of about USD 20 t^{1} following his estimates of marginal benefit and marginal cost of abating CO_2 emissions; van Kooten *et al.* (1993) considered carbon values of USD20, USD50 and USD300. Thompson *et al.* (1997) adjudged a value of carbon of USD 50 t^{1} as reasonable after his review of carbon values used by Nordhaus and van Kooten.

Another source for carbon value is the price of carbon traded in the carbon market. The carbon market encompasses both the *generation of emission reductions* (*ERs*) through *project-based transactions* where a buyer purchases ERs from a project that produces measurable reductions in greenhouse gases (GHG), and *trading of GHG emissions allowances* allocated under existing (or upcoming) cap-and-trade regimes such as the European Emissions Trading Scheme (EU ETS).

The "cap-and-trade" approach, being used in the EU ETS, sets an overall cap or maximum amount of emissions per compliance period. Companies are given allowances which represent their targets or "caps" for a compliance period. At the end of the period they must surrender sufficient allowances to reconcile against their total emissions during the period, if this is below their caps then they have allowances to sell; if not, they must purchase allowances from companies which have exceeded their emissions reductions targets. Each allowance permits the holder to emit one tonne of CO_2.

Lecocq and Capoor (2005) reported that Verified Emission Reductions (VER) have traded between USD3.6 and USD5t^{-1} CO_2e between January 2004 and April 2005, with a weighted average price of USD4.23t^{-1} CO_2e. Certified Emission Reductions (CER), on the other hand, have traded between USD3 and USD7.15t^{-1} CO_2e over the same period of time, with a weighted average of USD5.63t^{-1} CO_2e.

On the other hand, the Katoomba group's Ecosystem Market Place (2004) reported that the trading activity and prices per tonne of carbon traded at the Chicago Climate Exchange (CCX) have been growing steadily. A total amount of 2,250,000 tCO_2e valued at about USD2 million was traded through the CCX during 2004. During that period, prices ranged from USD0.71 to USD2.06t^{-1} CO_2e, with most trading occurring around USD1t^{-1} and between USD1.63 and USD4.65t^{-1} CO_2e from January 2004 to December 2006 in the carbon market. These prices are much lower than those found in the regulated carbon markets, such as the EU ETS, NSW, and Kyoto, in part because the CCX is voluntary and also because of the large volume of inexpensive agricultural sequestration offsets being offered, which would not be permitted under the other schemes.

Unlike project-based assets, allowances are homogeneous assets, and purchase contracts for allowances are fairly homogenous as well. As a result, the spread of prices for Europe allowance (EUA) at any given point in time is small. EUAs traded between €7 and €9 in 2004, but their prices have increased substantially in recent months, to reach more than €17 in March and April 2005.

The economic valuation of AHFR in terms of its C stock and C sequestration will use several carbon values of USD 50t^{-1}, the weighted average prices of USD4.23/tCO_2 e, USD5.63/tCO_2e and €17 t^{-1}. These currencies were converted to local currency using appropriate exchange rates.

RESULTS AND DISCUSSION

The inventory of AHFR was conducted in May 2004 and was repeated in the subsequent year to learn the dynamics of the forest biomass and the rate of C sequestration. The distribution of tree

TABLE 1
Species distribution in AHFR

No.	Species	No. of trees (May 2004)	No. of trees (June 2005)
1	*Anisoptera*	6	6
2	*Calophyllum sp.*	6	6
3	*Canarium*	10	10
4	*Dipterocarpus*	53	53
5	*Elaeocarpus*	12	12
6	*Endospermum*	10	12
7	*Hopea*	21	22
8	*Knema*	15	15
9	*Palaquium gutta*	22	24
10	*Santiria*	12	12
11	*Shorea acuminate*	12	12
12	*Shorea macroptera*	22	20
13	*Other Shorea*	10	10
14	*Syzygium*	58	57
15	*Terminalia*	12	12
16	*Other species*	246	245
	Total	527	528

species in AHFR is presented in Table 1. The results show that a variety of tree species are found in AHFR, the majority being the lesser-known timber species. A total of 575 tree were sampled. Some of the more common commercial timber species found were the *Dipterocarpus* (10%), *Syzygium* (11%), and the *Shorea* species (8%). The composition of species was so diverse that about 250 trees recorded do not belong to species listed in the Table. They were categorized as other species and they made up almost 50% of the population.

The diameter distribution of tree species is shown in Table 2. About 80% of trees in AHFR were under 30 cm diameter where the majority belong to the lowest diameter class (10-20 cm) followed by trees in the 21-30 cm diameter class (about 21%). During the follow-up survey about 2% of trees in the initial sample had died. On the other hand, about 2.4% of trees were new members in the lowest diameter class (inbreeding). The diameter remained constant for about 14% of the trees but the trees grew taller. In general the change in the diameter was in the range of 0.1to 3.0 cm yr^{-1} and in the height, 0.1 to 4.1 cm yr^{-1}.

Above-ground Biomass

Biomass stocks accounted in this analysis were above-ground tree biomass (leaves, branches and trunks) per hectare. Given the information on the dbh and the total height measurements, total biomass of trees 10 cm dbh and above was estimated using allometric equations (equations 1, 2, and 3) shown previously. Two of the equations (1 and 2) use only diameter variable, the third equation incorporates the information on tree height to estimate tree biomass.

The total above-ground biomass value (TAGB), calculated by means of the three regression equations are shown in Table 3. The TAGB of AHFR range from196 t ha^{-1} to 209 t ha^{-1} in the initial year and from 201 to 215 t ha^{-1} in the following year. The results were comparable with biomass estimates in logged hill and disturbed hill forests in Peninsular Malaysia (Brown, 1997). The table shows that equation 3 consistently generated TAGB values midway between the highest and lowest values generated by equation 1 and 2 respectively. According to Brown *et al.* (1989), results from equation 3 that considers both diameter (D) and height (H) yield preferably better estimates since the biomass equation has additional information incorporated by the knowledge of H. Moreover, considering that about 80% of trees in AHFR were below 30 cm diameter, the rotation age when growth in diameter and height is rapid, excluding height information in biomass computation will miscalculate the value significantly. The use of allometric equation as in equation 3 was possible since the inventory of AHFR used direct measurement-based method that recorded both the diameter and height of the tree. In contrast, a large-scale volume-based assessment of biomass that usually lacks H information (usually due to time and cost constraints) may generate poorer estimates of forest biomass.

The study of Kueh and Lim (1999) on biomass density in AHFR showed variations in the density due to species diversity and state of recovery of some forest compartments after

TABLE 2
Diameter class distribution of tree species in AHFR

No.	Diameter range (cm)	No. of trees (May 2004)	No. of trees (June 2005)
1	10.00- 19.99	299	292
2	20.00- 29.99	111	115
3	30.00- 39.99	49	50
4	40.00- 49.99	34	35
5	50.00- 59.99	19	21
6	60.00- 69.99	7	7
7	70.00- 79.99	4	4
8	80.00- 89.99	2	2
9	> 90	2	2
	Total	527	528

TABLE 3
Total above-ground biomass in AHFR

	May 2004			June 2005		
	Eq1	Eq2	Eq3	Eq1	Eq2	Eq3
Biomass (t ha-1)	209.30	195.61	197.64	215.32	201.46	208.24
C stock (t ha-1)	104.66	97.82	98.83	107.67	100.92	104.12
Total AHFR biomass (t)				268,753	251,930	259,900
Total AHFR C stock (t)				134,376	125,965	129,950
Change in biomass (t ha-1 yr-1)				9.13	8.91	12.65
Change in C stock (t ha-1 yr-1)				4.57	4.46	6.33
Total C sequestration (t yr-1)				5,700	5,561	7,895

Note: Equation (Eq)1 = $Y = 42.69 - 12.8\ D + 1.242\ D^2$
Equation (Eq)2= $Y = \mathrm{Exp}\ \{-2.134 + 2.530 \ln D\}$;
Equation (Eq)3 =$Y = \mathrm{Exp}\ \{-3.1141 + 0.9719 \ln D^2 {*}H\}$

disturbance. From species and diameter distribution in this study (Tables 1 and 2) it was observed that the forest stands were in the early stages of succession and were recovering from previous disturbances.

Given the results of the estimate, on average, the total above-ground biomass for the entire forest reserve of 1,248 ha ranged from 250,000 to 270,000t. Accordingly, the C stock in the AHFR ranges from 100 to108 t ha^{-1}, and from 125,000 to134,000t of carbon for the entire forest reserve.

In terms of the dynamics of the biomass and C stock in AHFR, the study showed that the rate of change of TAGB ranged from 9 to13 t ha^{-1} yr^{-1} and the C stocks, from 4 to 6.5 t ha^{-1} yr^{-1} (Table 4). The rate of C sequestration was rather high, comparable with the sequestration rate of fast-growing Mahagony plantation of 3.28 t ha^{-1} yr^{-1}. Generally, forest tree plantations have an average sequestration rate of 10.01 t C ha^{-1} yr^{-1} (Lasco *et al.* 2000). Hence based on the estimate of biomass accumulation, the C sequestration for the entire 1,248 ha of AHFR amounts to 5,500 - 7,900 t yr^{-1}.

The graphical analysis of the relationship of TAGB (kg), and dbh (cm) from the three regression equations are shown in *Figs. 1a* and 1b, *Fig. 1a* for all trees > 10 cm dbh while *Fig.1b* for all trees >10 cm < 20 cm dbh.

Below-ground Biomass

Biomass for other parts of the tree (fallen leaves, twigs, branches and seeds) was categorized under the below-ground biomass pool. The soil pool was not included in the assessment because of the destructive nature of data collection. The total below-ground biomass was made up of forest litter and herbaceous and woody plants; each category was further categorized into biomass types - leaves, branches, stems and other forest debris such as composed living matters.

The below-ground biomass estimates are presented in Table 4. Out of the total below-ground biomass of over 7,000 kg ha^{-1}, about 92% was forest litter amounting to 6561.69 kg ha^{-1} (6.56 t ha^{-1}). Considering that 50% of biomass is carbon, in terms of C stock, the belowground estimate amounted to about 3.60t ha^{-1}. Excluding the soil pool in the assessment tends to underestimate the total amount of C stock in this category.

Table 5 presents the total biomass and C stock - above-ground and below-ground - in AHFR according to allometric equations 1, 2 and 3. The total forest biomass ranged from 208 to 223 t ha^{-1}, the corresponding amount of C stock ranged between 104 and 112 t ha^{-1}. Considering the three equations and both types of biomass and C stock, it was estimated that the total C stock for AHFR was between 130,400 and 138,832t.

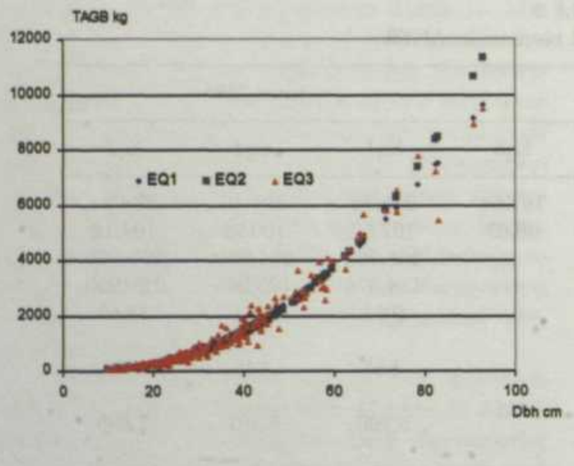

Fig. 1a: Scatterplot for all tree > 10 cm dbh

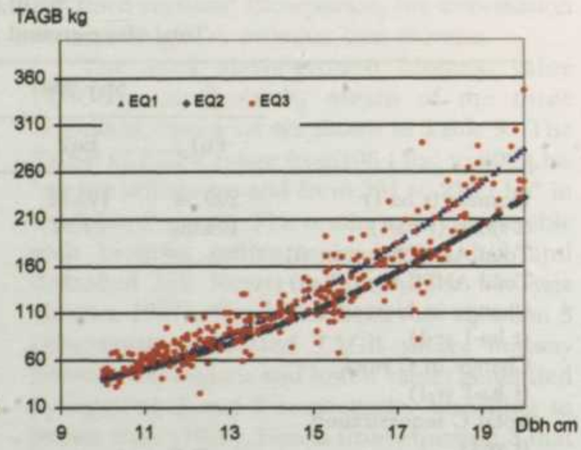

Fig. 1b: Scatterplot for all tree > 10 cm < 20 cm dbh

TABLE 4
Below-ground biomass estimate of AHFR

Sample size	Category	Unit	Biomass Type	Biomass	C stock
0.5 X 0.5 m	Forest litter	kg ha^{-1}	Leaves	1,384.89	692.45
			Branches	1,235.20	617.60
			Other	3,941.60	1,970.80
1.0 X 1.0 m	Herbaceous	kg ha^{-1}	Leaves	129.36	64.68
			Stem	323.25	161.62
2.0 X 2.0 m	Woody plants	kg ha^{-1}	Leaves	23.09	11.54
			Stem	97.38	48.69
			Branches	11.41	5.07
Total		kg ha^{-1}		7,147.19	3,573.09
Total		t ha^{-1}		7.15	3.57

TABLE 5
Total biomass and C stock in AHFR

Allometric equation	Biomass (t ha^{-1})		Total biomass (t ha^{-1})	C stock (t ha^{-1})	Total C stock AHFR (t)
	Above-ground	Below-ground			
Eq 1	215.32	7.15	222	111	138,831
Eq 2	201.46	7.15	209	104	130,407
Eq 3	208.24	7.15	215	108	134,401

Given the quantity of physical C stock, the economic value of carbon could be estimated by assigning its monetary value as outlined previously. The weighted average prices of carbon value used were USD50t^{-1}, USD4.23 t^{-1}, USD5.63 t^{-1} and €17 t^{-1}.

Table 6 provides the carbon values in various currencies, the exchange rates of the currencies as at June 2005, and the total values in local currency of C stock in AHFR according to the three equations.

The estimates show that the values of C stock ranged from MR1,653 ha^{-1} to MR 20,797 ha^{-1}. The corresponding values of AHFR as a carbon sink amounted to MR 2.06 million and MR 25.96 million. In terms of the dynamics, the estimates of the value of C sequestration ranged between MR 0.088 million and MR 1.48 million yr^{-1}.

TABLE 6
Economic value of C stock in AHFR

	Carbon value (per tonne)*			
	USD$4.23	USD$5.63	USD$50.00	17.00
MR per tonne	15.82	21.05	186.95	80.66
Value of C stock	MR ha-1			
Eq 1	1,760	2,342	20,797	8,973
Eq 2	1,653	2,200	19,535	8,429
Eq 3	1,704	2,267	20,134	8,687
Total Value of C stock in AHFR		MR		
Eq 1	2,196,306	2,922,766	25,955,063	11,198,763
Eq 2	2,063,039	2,745,418	24,380,164	10,519,246
Eq 3	2,126,217	2,829,494	25,126,783	10,841,387
Value of C sequestration			RM yr-1	
Eq 1	90,174	120,000	1,065,637	459,788
Eq 2	87,975	117,074	1,039,650	448,575
Eq 3	124,899	166,211	1,476,001	636,846

Note: Exchange rate (as at June 2005)
1 US @ MR 3.68
1 Euro@ MR 4.67
* 1 tonne = 0.9842 ton

CONCLUSION

AHFR is a secondary forest that had been logged since the 1930s. The survey conducted in 2004 and repeated a year later suggested that the forest is generally at the early stage of succession and is recovering from earlier disturbances. Considering species composition in AHFR, the disturbed forest is categorized as a commercially poor forest. Hence the appropriate land use of the forest reserve is not for commercial timber production unless interventions such as replanting or enrichment plantings of commercial species are carried out. While AHFR could be ruled out as being a productive forest, it seems more appropriate to be managed for its protective services. If conserved, AHFR will continue to provide ecosystem services, one of which is as a C sink.

The study indicates that conservation of AHFR will safeguard between 130,000 t and 139,000 t forest C stock while allowing the forest to sequester C at the rate of 5500 to 7,900 t yr^{-1} in total. The rate of C sequestration is relatively high because AHFR is at the stage of rapid growth as the stands are relatively young. The assessment of the rate of C sequestration was constrained by the duration of the study. Ideally, to increase the accuracy of the results, biomass change should be observed for a number of years.

In terms of the economics, the value of AHFR as a C sink was worth between RM2 million and RM26 million, with annual incremental value varying between RM0.87 million and RM1.45 million yr^{-1}, depending on the unit price of C.

An important implication of these findings is that apart from C sink, conservation of the AHFR will protect other ecosystem services. The goal of forest management for production forests to a large extent is mutually exclusive of other protective goals. Conservation of AHFR for C sink provides joint benefit with other ecosystem services that include watershed services, wildlife sanctuary, medicinal and herbal reserves, recreational services, research and educational purposes, and for indigenous forest dwellers.

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REFERENCES

BROWN, S. (1997). Estimating biomass and biomass change of tropical forest: A *primer.* Forestry paper 134, FAO. Rome.

BROWN, S. and LUGO, A.E. (1982). The storage and production of organic matter in tropical forests and their role in the global carbon cycle. *Biotropica, 14,* 161-187.

BROWN, S., GILLESPIE, A.J.R. and LUGO, A.E. (1989). Biomass estimation methods for tropical forests with applications to Forest Inventory Data. *Forest Science, 4,* 881-902.

KATOOMBA GROUP. (2004). Carbon market backgrounder: Chicago climate change. http://www.ecosystemmarketplace.com/pages/marketwatch.backgrounder.php

KUEH, J. H. and LIM, M. T. (1999). An estimate of forest biomass in Ayer Hitam Forest Reserve. *Pertanika J. Trop. Agric. Sci., 22,* 117-123.

LASCO, R. D., LALES, J.S., ARUEVO, M.T., GUILLERMO, I. Q., JESUS, A.C., MEDRANO, R., BAJAR, O.F. and MENDOZA, C.V. (2000). Carbon dioxide storage and sequestration in the Leyte Geothermal reservation, Phillipines. *Proceeedings World Geothermal Congress 2000* (p. 639-644). May 28-June 10, Kyushu-Tohuku Japan.

LECOCQ, F. and CAPOOR, K. (2005). State and trends of the carbon market 2005. International Emission Trading Association.

NORDHAUS, W.D. (1991). The cost of slowing climate change: A survey. *The Energy Journal, 12,* 37-36.

RICHARDS, K.R. and STOKES, C. (1995). *Regional Studies of Carbon Sequestration: Review and Critique.* Forest Sciences in Press.

THOMPSON, W.A., PEARSE, P.H., VAN KOOTEN, G.C. and VERTINSKY, I. (1997). Rehabilitating the backlog of unstocked forest lands in British Columbia: a preliminary simulation analysis of alternatives strategies. In P.N Nemetz. Vancounver (Eds.), *Emerging issues in forest policy.* UBC Press.

VAN KOOTEN, G.C., THOMPSON, W.A. and VERTINSKY, I. (1993). Economics of reforestration in British Columbia when benefits of CO_2 reduction are taken into account. In W.L. Adamowicz, W. White and W.E. Philips (Eds.), *Forestry and the environment: Economic perspectives.* Wallingford, UK: C.A.B International.