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How Much Ancient Forest Should Society Retain? Carbon Uptake, Recreation and Other Values

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ABSTRACT

Non-marginal and marginal approaches for determining optimal preservation of ancient forests on BC's coast are compared. When marketable (e.g., timber, non-timber products) and non-marketable benefits (e.g., carbon fixing, amenity values) of preserving old growth and maturing forests are considered (where the opportunity cost of preserving such forests are the benefits of sustainable commercial forestry foregone), the non-marginal method recommends harvest of all remaining old growth. For the marginal approach, a deterministic optimal control model is solved to compute socially optimal stocks of old growth. In this case, the numerical results indicate that large-scale conversion of old-growth forests can be justified on economic grounds.

INTRODUCTION

The government of British Columbia (BC) in Canada owns more than 95% of the forestland in the Province. While these forests had been primarily managed for timber production, a series of initiatives were undertaken in the early 1990s to address environmental objectives, including the Protected Areas Strategy, Timber Supply Reviews, a Forest Practices Code, and a Forest land Reserve. One impact of these initiatives was to curtail commercial logging on the Coast, but they have also triggered conflicts regarding the preservation of old-growth timber (see Ells et al. 1997). Failure to determine unambiguously the economic surpluses involved in logging and preserving forests may have contributed to conflict. This research addresses the question of how much old-growth forest to protect against logging in order to maximise society's overall well being.

In a deterministic world with no uncertainty, environmental damage is measured by foregone benefits. When a native stand of mature timber is logged, the foregone benefits are given by the sum of total (direct and indirect) use value and total existence value in its use as wilderness. Use value includes the value of non–timber (or minor) forest products, and benefits from recreation, wildlife viewing and hunting.[1] Taking into account uncertainty may imply that option value and quasi-option value should be considered, adding extra costs to current logging.[2] In the context of old-growth management, Reed (1993) analyses uncertain timber and amenity values, while Conrad and Ludwig (1994) and Conrad (1997) provide empirical applications with uncertain amenity values. Conrad and Ludwig (1994), for example, show that a deterministic model would lead one to protect 24% (16%) of remaining old growth if the discount rate is 4% (6%). Introducing uncertainty into the model would increase the proportion of remaining old growth to protect to as much as 36% (21%). In these models, amenity values are left unspecified, except as a proportion of commercial timber value (0.01 in the numerical example of Conrad and Ludwig).

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[1]Recreation subsumes wildlife viewing and hunting, but a distinction is made here because of data availability. Recreation thus includes swimming, other water recreation, hiking, biking, motorized vehicle use (including off–road), camping, *etc*.

[2]Option value is associated with risk aversion, and is the amount people are willing to pay for an environmental amenity, over and above its current value, to maintain the option of having that asset available in the future. Quasi-option value, in contrast, is associated with irreversibility, and measures the benefits of greater flexibility as information improves over time (Graham-Tomasi 1995).

In this paper, we balance conflicting demands on forestlands in the coastal region of BC by computing socially optimal stocks of old-growth forests. We consider a variety of non-timber values and explicitly include carbon (C) storage and uptake benefits, which has been ignored in the earlier studies. The model we employ is reminiscent of Ehui and Hertel's (1989) model for the Ivory Coast, but, while they consider the trade off between sustainable forestry and agriculture, we focus on preservation of old growth that would otherwise be converted to second-growth plantation forest. A great deal of uncertainty surrounds various non-timber benefits, such as the forest's role in storing carbon or its value in biodiversity prospecting, so we employ sensitivity analysis to illustrate the broad range of potential solutions.

In the next section, we summarise the values associated with preservation and calculate the total costs and benefits of preserving "ancient" forests, concluding that, on the basis of average costs and benefits, it is in the best interests of society to harvest all old growth. Then, in section 3, we present a dynamic optimisation model and examine the opportunity costs of preservation and conversion (logging benefits, C-flux costs/benefits, changes in amenity values, etc.) *at the margin*. Numerical results are provided in section 4, and they suggest society should retain a substantial amount of ancient forest. Our conclusions ensue.

NON–TIMBER VALUES FOR BRITISH COLUMBIA: EVIDENCE

In this section, existing information about non–timber values for BC is examined and summarised, and total benefits of retaining old-growth forests are compared with the associated opportunity costs. The objective is to provide the best estimates currently at hand and reach a tentative conclusion about preservation of old growth.

Since little information is available about the benefits of "remaining flexible," we purposely err on the side of the environment. That is, because it is possible to delay logging to a future period, the environmental costs of logging are purposely overstated. However, the extent to which it is possible to overstate non–timber benefits of BC's forests must also be recognised. For example, one would certainly expect the value of biodiversity prospecting in BC's temperate rain forests to be less than that in tropical "hotspots." Likewise, the existence value of BC's forests should not exceed that of similar forests in the United States; the population of the US is simply much greater. Further, forestry operations in BC do not result in deforestation (conversion of land to other uses); rather, new forests replace the old, with the new forests contributing to many of the same non–timber values that are associated with the old. These limits or upper bounds to non–timber values must be observed if a serious accounting of potential non–timber values is to take place. With this caveat, we provide measures of non–timber values in four categories: (i) non–timber (or minor) forest products (NTFPs), (ii) recreation, hunting and wildlife viewing, (iii) nonuse amenities, and (iv) carbon fluxes. The sum of NTFPs and recreation values represent total use value.

Non–timber Forest Products

Minor forest products mainly include wild edible mushrooms, floral greenery, medicinal plant products, fruits and berries, herbs and edible plants. The most important activity, for which the most information is available in BC, is the picking of wild edible mushrooms. Other activities appear to be less important, although little is known about them. While the BC Ministry of Forests attempts to regulate (parts of) the non–timber forest products sector, it does not collect royalties—indeed, income taxes are generally not collected either. Thomas and Schumann (1993) provide a broad overview of NTFPs and their market potential.

At present, between 2,000 and 5,000 people harvest a total of 33 species of wild edible mushrooms across BC. The most important varieties are pine mushrooms, marketed primarily in Japan (where it is known as white matsutake), and chanterelles, morels and boletes, with the latter three sold mainly in Europe (France, Germany and Italy). As a result of government studies, the most is known about pine mushrooms.

Pine mushrooms are found "… along the coast and interior mountain ranges of western North America from northern California to Alaska, … the eastern Maritimes and as far south as Tennessee, … and throughout the northern forested regions of Saskatchewan and Manitoba" (BC Ministry of Forests 1995, p.10). Clearly, pine mushrooms are associated with many forest types, although forests must be older than 50 years. About two–thirds of those engaged in mushroom picking are local residents who supplement their incomes, the remainder are professional or nomadic harvesters, who also travel to the Yukon, NWT, Saskatchewan, Oregon and California to pick mushrooms. The vast majority of mushrooms are marketed in Europe and Japan, but no annual crop statistics are available. A 1994 survey of mushroom companies found that, in 1993, almost C$3.9 million was paid to pine mushroom pickers for 125.3 tonnes of mushrooms (about $31 per kg).[3] In 1992, some 32,000 kg of morel mushrooms were harvested. Interestingly, 1993 was considered a poor year for pine mushrooms due to drought, while 1992 was considered a poor year for morels. However, given that there is no other information on mushroom harvest and values, it is impossible to determine whether these years were truly good or bad.

Compared to data for the US Pacific Northwest (PNW), the value of mushrooms to BC is either understated or BC forests are not as rich as those to the south. In 1992, mushroom companies in the US paid US$20.3 million to 10,400 pickers and the gross value of the industry as a whole (including processing) was estimated at US$41.1 million, with a net benefit of US$2.9 million. Using the ratio of gross sales for BC to gross sales for the PNW, and taking into account the exchange rate, one obtains an estimate of net benefits for BC of approximately C$0.6 million.[4] Dividing by a total area of mature timber for BC of 26.7 million hectares (see Table 2 below) gives an average net benefit of $0.02 per ha. Even if the industry is five times larger than this, the average net benefit is only $0.10 per ha. Lacking sufficient data to estimate marginal benefits of picking mushrooms, we assume they are constant.

Knowledge about other NTFPs is even sparser. Floral and greenery products are important, particularly at Christmas time. The government does exercise some control by requiring those cutting white pine boughs on Crown land, for example, to obtain a letter of authorisation. Permission prescribes harvesting procedures, schedules and designated area, but says nothing about quantity. Again no attempt is made to collect royalties. A 1991 US study estimated that floral and greenery products generated about US$128.5 million in sales at the wholesale level in 1989 (Schlosser et al. 1991; BC Ministry of Forests 1995). The study encompassed the US PNW and BC, but most of the industry appears to be located in the State of Washington. Salal (including salal tips) was the most valuable crop, accounting for 10.2% of total sales, with bear grass second at nearly 9.0%.

Schlosser et al. (1991) indicate that there were 2,670 full–time and 2,750 part–time harvesters, and that plant material cost the floral and greenery industry US$47.7 million. Using

[3]Of this amount, 110 tonnes was harvested in the Terrace–Nass Valley area and not on the Coast (BC Ministry of Forests 1995).

[4]This is determined as $[(3.9\times0.7)\div20.3)\times2.9] \div 0.7$, where C$=US$0.70. Unless otherwise indicated, values are in Canadian currency.

these authors' cost of labour and assuming that part–time workers spent only one–tenth as much time on this activity as full–time workers, the cost of labour amounts to US$44.2 million. This leaves a net surplus or economic rent of $US3.5 million spread across two states and one province. If BC generates one–third of these benefits (but recall that the largest share of the industry is in WA), then, upon adjusting for exchange rates, the benefits from harvest of floral and greenery amount to $1.65 million in BC. Since the focus of the above study was on areas west of the Cascade Mountains, dividing by 3.4 million ha of mature forest on the Coast (see Table 2 below) gives a value of almost $0.50 per ha.

There is no information about the value of BC forest–dependent plant and animal species as a potential source of medicinal and pharmaceutical products. Estimates by Simpson et al. (1996) suggest that the value of BC forests is likely much less than US$1 per hectare in biodiversity prospecting. Even in a hotspot such as western Ecuador, the potential biological value of forests is less than $25 per ha, while it is only $0.20 for a floristic province in California.

Finally, there are many other NTFPs that are available from BC forests, ranging from wild berries and fruit to products used to make crafts. Again, there is no information about harvest levels, the types of ecosystems that these products are found in, their occurrence in other jurisdictions, and the value of the products. Based on the above information, it is unlikely that the value of these products amounts to $0.10 ha^{-1}.

Many of the (modest) values associated with NTFPs are related to timber growth and, thus, are not incompatible with normal timber production (which includes harvesting). It is true that the capability of a site to grow (some types of) mushrooms might disappear for a period of up to 50 years after harvest, but mushrooms continue to be available on other sites and will return in the future. Floral greens will be available much sooner after a site is harvested. Hence, as long as commercial forestry is sustainable, which is the case in BC, the production of non–timber forest products will be sustainable.

Benefits from Recreation, including Hunting and Wildlife Viewing Benefits

The BC Ministry of Forests (1991) has estimated forest recreation use benefits, *plus* the value that recreationists attach to the future option of continuing to pursue these activities. These are provided by forest region in columns (4) and (5) of Table 1. Forest recreation use and wildlife viewing are valued at about $40 million per year, while preservation for purposes of future recreation and wildlife viewing (option demand) is valued at slightly more than $147 million per year. Thus, forest recreation is valued at $187.0 million annually. Annual forest recreation benefits by forest region are provided in column (4) of Table 2. Each hectare of forest is valued at about $11.80 in forest recreation, with the highest value ($34.00 per ha) occurring in the Vancouver forest region and the lowest value ($1.49 ha^{-1}) in the Prince Rupert forest region. Such an allocation assumes that all recreation value is attributed to mature forest area, which is clearly not the case. Thus, the values reported in Table 2 are high, but any other means of allocating benefits based on these data would result in much lower per ha values for recreation.

Table 1. Population of BC and Forest Recreation Use and Preservation Values by BC Forest Region, $1992

Region	(1) Total Population	(2) Adult Population	(3) Regional % of Adult Population	(4) Recreation Use Value ($mil/y)	(5) Recreation Preservation Value[a] ($mil/y)	(6) Nonuse Benefits [b] ($mil/y)
Vancouver	2,102,460	1,583,017	74.5%	4.54	111.13	339.22
Prince Rupert	83,048	53,602	2.5	4.97	4.49	11.49
Kamloops	328,398	239,572	11.3	10.03	11.23	51.34
Prince George	161,769	105,411	5.0	6.83	8.22	22.59
Nelson	148,195	104,840	4.9	8.15	9.40	22.47
Cariboo	59,495	39,376	1.8	5.11	2.87	8.44
TOTAL	**2,883,365**	**2,125,818**	**100.0**	**39.62**	**147.34**	**455.53**

Source: BC Ministry of Forests (1991, pp.15, 48–49, 51)
[a] Recreation preservation value includes preservation for purposes of future recreation and future wildlife viewing.
[b] Estimated as follows: household WTP for nonuse benefits is estimated at $300 per year. Divide adult population by 1.4 to get number of households and multiply by $300 (see text).

A more recent study that focuses solely on wildlife viewing suggests that the earlier values reported for recreation in BC may be a bit on the low side (Reid 1998). The direct and indirect benefits from wildlife viewing by region of BC are provided in Table 3. Total benefits amount to some $985.6 million annually. These values are based on the willingness of respondents to a 1996 “Wildlife Activities Survey” (Reid 1998) to increase actual spending on the activity.[5] Based on total area of mature timber in the province (26.7 million ha), the annual value of wildlife viewing is $36.92 ha^{-1}. With some exceptions, the regions reported in Table 3 do not correspond directly

[5]For indirect activities, an open–ended format (using a payment card) was used; for direct activities, a dichotomous choice format was used (see Reid 1998).

to the forest regions identified in Tables 1 and 2. However, by dividing the sum of wildlife viewing benefits for Vancouver Island plus the Lower Mainland by the area of mature forest in the Vancouver region, the annual value is \$206.79 ha^{-1} for the BC Coast. If only the values associated with direct viewing of wildlife (wildlife viewing is the purpose for taking the trip), then the annual benefits of wildlife viewing amount to \$29.67 ha^{-1}, or \$163.29 ha^{-1} on the Coast.

Table 2. Mature Forest Area, Recreation Expenditures by Area, by Forest Region, $1992

Region	(1) Mature Timber ('000s ha)[a]	(2) Recreation Use Value (\$ ha^{-1}yr-^{1})[b]	(3) Recreation Preservation Option Value (\$ ha^{-1} yr-^{1})[b,c]	(4) Total Recreation Benefits (\$ ha^{-1}yr $^{-1}$)[b]
Vancouver	3,402	1.34	32.67	34.00
Prince Rupert	6,367	0.78	0.71	1.49
Kamloops	2,373	4.23	4.73	8.96
Prince George	9,596	0.71	0.86	1.57
Nelson	1,390	5.86	6.76	12.62
Cariboo	3,565	1.44	0.81	2.25
Total (Average)	**26,693**	**(1.48)**	**(5.52)**	**(11.80)**
Interior (Average)	**23,693**	**(1.51)**	**(1.56)**	**(3.06)**

[a] Source: BC Ministry of Forests and Lands (1992, p.37)
[b] Source: Calculation
[c] This is the value of retaining the option to pursue recreational activities at some future date.

Table 3. Annual Direct and Indirect Economic Benefits of Wildlife Viewing in BC, 1996

Region	Adult Population (‘000s)	Indirect Activities: Total (\$ mil)	Indirect Activities: Annual per Adult	Direct Activities: Total (\$ mil)	Direct Activities: Annual per Adult
Vancouver Island	549.2	27.7	\$50.45	221.5	403.35
Lower Mainland	1,672.8	120.3	71.92	334.0	199.66
Thompson–Nicola	123.6	7.7	62.43	38.3	310.15
Kootenay	116.5	6.3	53.66	56.1	481.78
Cariboo	53.5	3.5	65.71	22.0	412.12
Skeena	70.4	6.9	98.71	32.1	456.30
Omineca–Peace	132.9	9.1	68.84	29.7	223.66
Okanagan	254.4	12.0	47.14	58.1	228.54
British Columbia	**2,973.2**	**193.6**	**65.11**	**792.0**	**266.38**

Source: Reid (1998)

There is little information about how wildlife viewing conflicts with, or is enhanced by, commercial logging operations. It is most likely that commercial timber production and viewing of wildlife are not compatible during logging operations and for a (short) period thereafter, but that logging does enhance this use value by providing access and by providing a greater diversity of landscapes in the longer run (see Budiansky 1995). Further, wildlife viewing is not confined to mature forest areas. Indeed, most wildlife viewing occurs in areas where wildlife are most abundant, such as bird or wildlife sanctuaries, clearings, along rivers (fish going to spawn), ocean settings (viewing whales and other mammals), and so forth. Therefore, the value associated with mature forest areas is likely much smaller than indicated above, particularly on the Coast where opportunities for viewing birds, fish and sea mammals are greatest. A not unreasonable estimate of the value of forestland for the purpose of wildlife viewing on the BC Coast is to take one–fourth of the above value. Hence, wildlife viewing is assumed to be worth $51.70 per hectare of mature forest.

More recent information is also available about the benefits of hunting (Reid 1997). In 1995, BC residents spent $73.9 million hunting. Expenditures themselves are not a measure of benefit or well being. Rather, it is the surplus associated with hunting that is the appropriate measure of benefit, and this turns out to exceed expenditures by more than $2 million (Table 4). In this case, the economic surplus or benefit is determined as respondents' maximum willingness to incur increased daily hunting costs before they would stop the activity (see Reid 1997).

It is important to note that the economic values per harvested animals are quite high, ranging from $1,084 for mountain goat to $7,722 for grizzly bear. This suggests that, where the number of individuals of a species is high, it may be economically worthwhile to permit greater harvest levels. Further, as the owner of the resource, the government may also be able to extract more of the rent associated with hunting. Before this is possible, however, it is necessary to conduct a proper bioeconomic analysis of each species, including identification of growth rates and minimum viable populations. As hunting is not incompatible with commercial forest operations in many instances, and indeed logging may increase access for hunters while providing open spaces for the species generally hunted, it is difficult to argue in favour of reduced logging on the basis of this use.

Table 4. Annual Expenditures and Economic Benefits of Resident Hunting in BC, 1995

	Expenditures by Hunters	Economic Benefits to Hunters	Estimated	Economic Value per

Species Hunted	Average Daily	Total ($mil)	Average Daily	Total ($ mil)	Number Harvested	Animal Harvested[b]
Cougar	$84.20	0.742	$89.50	0.788	287	$2,748.60
Black bear	58.20	5.561	40.00	3.825	2,940	1,301.10
Grizzly bear	108.70	1.324	105.30	1.282	166	7,722.40
Mountain sheep	96.50	2.245	83.20	1.938	335	5,783.60
Mountain goat	103.10	1.174	60.10	0.684	631	1,084.60
Elk	50.10	7.820	51.60	8.051	2,237	3,598.90
Caribou	126.50	1.161	70.70	0.649	190	3,413.80
Moose	48.00	15.463	49.10	15.823	9,396	1,684.00
Mule deer	41.40	22.852	45.20	24.918	22,637	1,100.70
White–tailed deer	35.40	10.794	44.90	13.700	10,698	1,280.60
Small game	10.40	1.432	7.80	1.067	n.a.	n.a.
Upland birds	7.40	2.639	7.80	2.814	n.a.	n.a.
Waterfowl	12.90	0.637	8.00	0.397	n.a.	n.a.
Total(Average) [a]	**(49.80)**	**73.863**		**75.935**		

[a] Column totals may not add due to rounding.
[b] Calculation.
Source: Reid (1997)

Hunting values are spread rather evenly across BC (Reid 1997), so one can allocate values simply by dividing total economic benefit ($75.9 million) by total area. If mature timber area is employed (Table 2), we obtain a value of forestland in hunting of \$2.84 ha^{-1}. Again this is an overestimate in the same way as argued above.

The more recent information on wildlife viewing and hunting can be used to update estimates for total recreation value. For the BC Coast, data from Reid (1998) are used to estimate the value of wildlife viewing at \$51.70 ha^{-1}. Data from Reid (1997) suggest that hunting contributes \$2.84 ha^{-1} for all of BC. Together, wildlife viewing and hunting contribute \$54.54 ha^{-1} to recreation value on the BC Coast. This constitutes some 24.5% of total recreation value (van Kooten 1995, p.706). However, not all recreation is incompatible with logging. Certainly, motoring and boating are not and may even benefit from roads developed as a result of logging.[6] The same is partly true of the activities fishing, camping/swimming, and hiking/skiing. For the latter categories and using data from van Kooten (1995), we attribute one–half of the hiking/skiing values and one–third of fishing and swimming/camping benefits to mature forest. In

[6]Then the net benefit from logging should be increased to take into account the enhanced recreation values it brings about. The same is true where logging actually enhances wildlife viewing benefits, particularly of large game animals. Further, the economics literature suggests that, in contrast to the widely held view that there are only negative nonuse benefits associated with forest development (logging), there may in fact be some positive externalities associated with development of wilderness (see Castle, Berrens and Adams 1994; Drake 1992).

that case, the total value of mature forest on the BC Coast in recreation turns out to be \$105.51 ha^{-1}.

Nonuse Benefits

It is likely that the greatest opportunity cost associated with commercial timber operations on the BC Coast is the potential loss in nonuse benefits, or existence value. Using contingent valuation methods (CVM), US researchers calculated that households were willing to pay between \$50 (Rubin et al. 1991) and \$275 (Hagen et al. 1992) annually to preserve wilderness for northern spotted owl. For BC, Vold et al. (1994) found that households were, on average, willing to pay \$136 per year to double the amount of wilderness in the province from 5% to 10%, and that they would be willing to pay \$168 per year to triple the amount of wilderness to 15%. In order to err on the side of the environment, we assume households value wilderness at \$300 annually. If households consist of 1.4 adults on average, it is possible to calculate the total nonuse benefits by forest region; total annual nonuse benefits are \$455.5 million for all of BC and \$339.2 million for the BC Coast. These results are reported in column (6) of Table 1. Using mature forest area (Table 2), these values translate into average nonuse values of \$17.07 ha^{-1} of mature forestland for all BC and \$99.71 ha^{-1} for the BC Coast.

Obviously, people not residing in BC may also derive utility from preserving old-growth forests in the Province. Since BC is currently not compensated for this positive externality, it will probably not include it in its deliberations concerning optimal stock size. However, as a sensitivity analysis we have included an analysis of "global optimal stock size" in section 4 by assuming non-residents would be willing to pay an amount equal to the WTP of residents—nonuse benefits are doubled.

Benefits of Carbon Sequestration in Forest Ecosystems

Forests play an important role as a carbon sink, with release of C and its uptake important considerations in determining optimal stocks of old growth.[7] According to the Kyoto Protocol of December 1997, in meeting their emission targets for 2008–2012, countries are debited for C released as a result of deforestation, but credited for C sequestered as a result of reforestation and

[7]See Sedjo, Sampson and Wisniewski (1997) for a review of C fluxes in forest ecosystems.

afforestation. Reforestation that occurs after clear cutting also leads to a credit, while harvesting does not result in a debit (Canadian Forest Service 1998).[8] As a result, we consider both the situations where cutting trees results in a debit and where it does not.

It is not clear whether logging and subsequent replanting (as opposed to land use *change*) will reduce the total annual C flux. For some ancient forests, it may take several hundred years to restore the ecosystem's C balance to where it was before logging occurred, but it is not clear that a net amount of C is released. This depends on the extent to which C gets stored in forest products and assumptions concerning the rate of decay of those products (see van Kooten et al. 1993; van Kooten et al. 1995; Sedjo et al. 1995; Sedjo et al. 1997). Inclusion of a forest's C uptake benefits might provide grounds for cutting trees sooner and more frequently than is currently the case in BC.

For tree species found on BC's Coast, wood contains an average 182.4 kg of C per m^3 (van Kooten et al. 1993, p.247). Assuming reasonable carbon shadow prices of \$20 and \$50 per tonne (t), and a high value of \$100 t^{-1} C, the value of C released or sequestered is \$3.65 m^{-3}, \$9.12 m^{-3} and \$18.24 m^{-3}, respectively. Assume that mature forest on the Coast has a mean standing inventory of commercial timber of 500 m^3 ha^{-1} (see below). Further, assume that proportion ρ ($0 \leq \rho \leq 1$) of the C gets stored in products that decay (release C) at a rate δ (say 2%) per year. Then, it is easy to show that the amount of C released at time of harvest is:

$$\left[\frac{\delta\rho}{1+r-\delta} + (1-\rho)\right] C, \qquad [1]$$

where r is the discount rate (which could be zero) and C is the amount of carbon stored in the trees on the site that is harvested (182.4 kg per m^3). Multiplying by the shadow price of C gives the contribution to climate-related damage caused by harvesting old growth forests and changing land use (i.e., deforestation). An indication of the climate-related damages from deforestation (harvesting old growth and converting the land to another use) is provided in Table 5 for various values of the parameters in [1] and shadow prices of C. The results are not very sensitive to

[8]At least this is how Canada interprets the Kyoto Protocol on forestry, although it will probably several years before there is international agreement on how the terms reforestation, afforestation and deforestation will be interpreted for the purposes of the Protocol. According to a common Canadian definition of reforestation, a country will receive credit for planting after harvesting. This creates an imbalance, because the inclusion of harvesting would have meant a significant debit for Canada given that only post–1990 activities are being considered, and Canada invested heavily in reforestation prior to 1990.

discount rates between 4% and 10%, and are also not highly sensitive to changes in the decay rate between 0.02 and 0.10. Clearly, only if carbon is stored in wood products (ρ>0) do climate-related damages vary with the discount rate.

Table 5. Climate-related Damages from Harvesting Old Growth on BC's Coast, per ha[a]

Shadow price of C ($/t)	ρ=0	ρ=0.60 δ=0.02 r=0	ρ=0.60 δ=0.02 r=0.04	ρ=0.60 δ=0.10 r=0	ρ=0.60 δ=0.10 r=0.04
Deforestation (permanent land use change)					
$20	$1,830	$ 760	$ 750	$ 850	$ 840
$50	4,580	1,910	1,880	2,130	2,120
$100	9,080	3,830	3,750	4,250	4,230
Deforestation followed by replanting					
$20	$1,230	$160	$150	$ 250	$ 240
$50	3,080	410	380	630	620
$100	6,080	830	750	1,250	1,230

[a] Assuming 500 m^3 per ha and 0.1824 t of C per m^3

Following Kyoto requirements, we employ the mean annual increment (MAI) for determining the benefits from carbon uptake.[9] Assume that second-growth stands regenerate naturally, achieve a standing volume of about 500 m^3 at age 80, and then are harvested; MAI is about 6.5 m^3 ha^{-1}. For trees growing on recently harvested old-growth sites, storage of C in wood products occurs far in the future. For ease of calculation, assume that all of the carbon is either stored after 80 years or that the wood is burned (replacing a C-equivalent amount of fossil fuels).[10] Then annual C uptake amounts to nearly 1.2 t ha^{-1}, with this amount sequestered each year indefinitely into the future. The respective shadow values of the annual C uptake are $24, $60 and $120 for C prices of $20, $50 and $100 per tonne. Using a discount rate of 4%, the respective carbon shadow benefits from plantation forests are $600, $1,500 and $3,000 ha^{-1}. According to Kyoto, these are the only climate-related values to consider when mature forests are harvested and replaced by second growth.

If old-growth forests are converted to plantation forests then the damage from changing

[9] C uptake is a function of forest age. If C flux benefits (or costs) are taken into account, the rotation age should be extended beyond the Faustmann rotation age, but not to the sustainable yield age (van Kooten, Binkley and Delcourt 1995).

[10] The "discounted" C released at time of harvest plus the C released from decay of products over the time period after harvest needs to be subtracted from the current period MAI. However, the needed correction is small and the MAI presented in the text is likely lower than one can be achieved in industrial plantations.

the forest's C balance is given by the difference between the release from harvesting old growth and the uptake from new plantations. These are the correct damages avoided if old growth is not harvested, and are also given in Table 5.

Conclusion Based on Average Costs and Benefits

A summary of estimated annual non–timber benefits for the BC Coast is provided in Table 6. These indicate that, if carbon storage benefits are ignored, the total non–timber value of mature forests amounts to no more than \$210 ha^{-1} yr^{-1}, or some \$5,250 ha^{-1} when discounted at a real rate of 4%. If C fluxes are included, the values will change dramatically, adding at most \$6,080 ha^{-1} but more realistically no more than \$1,000 ha^{-1} to the benefits of retaining old growth. These average values need to be compared with the average value of cutting the mature forest.

For the 5–year period 1990–1994, Grafton et al. (1998) estimate that the average annual rent to logging in all of BC was \$1,609.56 million. Assuming an annual harvest of 70 million m^3, this implies an average rent of \$22.99 per m^3. Timber on the Coast is generally substantially more valuable than that in the Interior. We employ an average rent estimate of \$30 m^{-3} for old-growth timber on the Coast and a value of \$23 m^{-3} for second growth that has regenerated naturally and is harvested at 80 years of age.[11] From Table 7, the average benefit from logging old growth is \$15,000 ha^{-1}, which is the same value employed by Conrad and Ludwig (1994). This compares with an average non–timber value of \$6,250 ha^{-1} (\$5,250 in non-carbon benefits plus \$1,000 in C benefits), and an overall maximum non-timber value of \$11,330 (if unrealistically high C benefits of \$6,080 ha^{-1} are used). Clearly, this analysis suggests that it would be socially optimal to harvest all the forest on the BC Coast. However, this conclusion is based on average values, and not marginal values. For this purpose, we develop marginal functions and resort to a dynamic optimal control model in the next section.

Table 6: Estimated Value of Non–Timber Benefits on the BC Coast (\$ per ha of Mature Forest)

Item	Annual Benefit per Hectare

[11]Actual rent will vary by species, size of logs and so on. The information for such a detailed analysis is not available, nor is it necessary for the purposes of this paper. In calculating the value of old–growth timber, we use weights on different species (see Appendix).

Non–Timber Forest Products	$**1.70**
– mushrooms	0.10
– floral and greenery	0.50
– biodiversity prospecting	<1.00
– other	0.10
Recreation	**105.51**
– wildlife viewing	51.70
– hunting	2.84
– fishing	10.93
– camping & swimming	14.84
– hiking & skiing	25.20
Nonuse	**99.71**
TOTAL (excluding carbon)	**206.92**
Annualised Carbon Uptake[a]	
– Harvest plus plantation	
– discounting future C[b]	6.00, 15.20, 30.00
– not discounting future C[c]	6.40, 16.40, 33.20
– Plantation only (Kyoto)	(24, 60, 120)

[a] Values refer to three shadow prices of C: $20, $50 and $100 per tonne.
[b] 4% discount rate, ρ=0.60, δ=0.02
[c] ρ=0.60, δ=0.02
Source: Calculation

Table 7. Total Forest Area, Area exceeding 120 Years, Stocking Levels at Various Ages, and Expected Returns for Old Growth and Naturally-Regenerated Stands Harvested at 80 Years Age

Species/ Site quality	Total Area ('000s ha)	Area of age 120+ years ('000s ha)	Stock at 80 years[a] (m^3/ha)	Net Annualized Rent for Second Growth[b] ($/ha)	Stock at 100 years[a] (m^3/ha)	Net Rent at Clear Fell[c] ($/ha)
Douglas fir						
– poor	290.8	111.5	221	242.57	319	10,572
– medium	395.7	60.3	445	488.44	619	20,427
– good	105.5	9.2	729	800.17	984	32,472
Cedar						
– poor	443.1	421.7	140	195.58	261	10,962
– medium	236.7	205.9	317	442.84	552	23,184
– good	26.4	16	626	874.51	993	41,706
Hemlock						
– poor	701.4	557.1	187	186.60	303	9,090
– medium	1,030.2	607.5	417	416.10	578	17,340
– good	228.3	67.7	723	721.44	907	27,210
Balsam						
– poor	189.4	147.6	190	189.59	336	10,080
– medium	147	115.7	394	393.15	611	18,330
– good	20.1	10.2	584	582.74	837	25,110
Spruce						
– poor	18.9	10.6	327	391.55	396	14,256
– medium	78.3	39.9	561	671.75	652	23,472
– good	43.4	23.3	928	1,111.19	1,061	38,196
Total (Av.)	3,955.2	2,404.2	(302)	(329.98)	(452)	(14,995)

[a] For stands that regenerate naturally

[b] Using $23 per m^3 as a base, but multiplying this by 1.1 for Douglas fir, 1.4 for cedar and 1.2 for spruce to reflect higher values for these species. A discount rate of 4% is used and age at harvest is 80 years. Additional rotations are not taken into account.

[c] Calculated at time of harvest using volume at 100 years and $30 per m^3 as a base, but multiplying this by 1.1 for Douglas fir, 1.4 for cedar and 1.2 for spruce to reflect higher values for these species.

Source: Thompson et al. (1992) and calculation

A MODEL FOR DETERMINING OPTIMAL STOCKS OF OLD-GROWTH FOREST

There are 51.8 million ha of productive forestland in BC (of which 45.8 million ha are publicly owned) and 13.9 million ha of unproductive forestland (BC Ministry of Environment, Lands and Parks 1996). Of productive forestland, 29.6 million ha (57.1%) is classified as mature, which is a slightly larger area than the area of mature timber provided in Table 2. However, we use the values in Table 2 because they are broken down by region, concluding that there are 3.0 million ha of mature timber on the Coast.

We employ a dynamic optimisation model to give some notion about optimal holdings of old–growth forests. The question is: Given information on non–timber benefits, how much old–growth forest should society keep in order to maximise the discounted flow of present and all future net benefits. The objective function for the optimal control model is as follows:

$$\max W = \int_0^{\infty} \pi(t)\, e^{-rt}\, dt\,, \qquad [2]$$

where

$$\pi = B[G(t)] + \int_0^{G_0-G} \left[F(z) + p_c\, C(z)\right] dz + \left[\tau(G) - p_c\, \gamma(G)\right] D(t). \qquad [3]$$

Here $\pi(t)$ is economic benefits; $B(G)$ are non–timber benefits (i.e., the sum of benefits from NTFP exploitation, old–growth related recreational benefits and the nonuse values associated with the conservation of old growth) as a function of the stock of old–growth forest remaining at time t, G(t); G_0 represents the initial stock of old–growth forest (assumed to be 3.0 million ha on the BC Coast), so that $G_0–G$ is land devoted to secondary forest production; p_c is the shadow price of carbon; $\tau(G) - p_c\, \gamma(G)$ represents the marginal benefit or cost (price) of logging old growth as a function of the old growth remaining at the time t; and r is the social rate of discount, assumed to be 4% (Heaps and Pratt 1989). The term $\int_0^{G_0-G} \left[F(z) + p_c\, C(z)\right] dz$ describes the total benefits for the $G_0–G$ hectares of old growth converted to plantation forests, and consists of commercial timber benefits (first term) and the shadow value of carbon uptake benefits (second term). The function $\tau(G)$ represents declining commercial timber benefits from harvesting old growth as a function of remaining old growth, while $p_c\, \gamma(G)$ is the accompanying shadow cost of C released to the atmosphere. The required functions are discussed below.

The dynamic (subject to) constraint is

$$\dot{G}(t) = -D(t), \qquad [4]$$

where the dot over the variable G indicates a time derivative and $D(t)$ is the area of old growth harvested at time t.

Maximisation takes place subject to the equation of motion provided in equation [4]. The current value Hamiltonian (suppressing time notation) is defined as: H = $\pi - \lambda D$, where λ is the co–state variable. Assuming an interior solution, the necessary conditions for an optimum solution are:

$$\frac{\partial H}{\partial D} = 0 \Rightarrow \tau(G) - p_c\, \gamma(G) = \lambda \quad [5]$$

$$\dot{\lambda} = r\lambda - \frac{\partial H}{\partial G} \Rightarrow \quad [6]$$

$$\dot{\lambda} = r\lambda - \left[B'(G) - F(G_0 - G) - p_c\, C(G_0 - G)\right] + \left[\tau'(G) - p_c\, \gamma'(G)\right] D(t).$$

The interpretation of [5] is that the rate of conversion of old growth should be chosen so that the marginal net benefit (commercial benefit minus carbon cost) of current conversion, τ, is equal to the opportunity cost of harvesting the old–growth stock in the future, λ, which is the user cost. Equation [6] provides a standard intertemporal non–arbitrage condition (Clark 1990).

The steady state occurs when the co–state multiplier and the area in old–growth forest are constant ($\dot{\lambda} = \dot{G} = 0$), so no further conversion from old growth to plantation forest takes place (D=0). The equation that describes the optimal forest stock in the steady state is:

$$\tau(G^*) - p_c\, \gamma(G^*) + \frac{F(G_0 - G^*) + p_c C(G_0 - G^*)}{r} = \frac{B'(G^*)}{r}. \quad [7]$$

Equation [7] says that, in equilibrium, the marginal present value of benefits of retaining old growth must be equal to the sum of immediate benefits of old–growth forest conversion and the present value of subsequent forest plantation production at the margin. Included in benefits are the shadow costs and benefits of C uptake and release. The difficulty in solving [7] lies with determining the five functions $F(G_0–G)$, $C(G_0–G)$, $\tau(G)$, $\gamma(G)$ and $B(G)$.

Marginal Commercial Timber and Climate-related Costs and Benefits

We distinguish two types of benefits from plantation forests: commercial timber benefits and C-uptake benefits. We assume constant timber rents of \$23 m^{-3} (BC harvests of old growth do not affect world lumber prices), but marginal site value falls because of declining site quality. Likewise, the shadow price of C is assumed constant (although we employ sensitivity analysis about this price), but the amount of carbon sequestered in second growth declines as more old growth is converted to second growth because growth is lower on poorer sites. Both the commercial timber value and benefits of C uptake are given annually because they accrue over time after a mature forest is cut.

The same is not true when mature stands are harvested. There is a one-time commercial timber benefit at the time of harvest, although it varies by site. We assume that the most valuable sites are harvested first, followed by sites of increasingly lower quality as measured by species and standing volume. Clear cutting results in the release of carbon to the atmosphere and this is a debit. The climate-related damage from logging a mature forest equals the C contained in the commercial harvest volume multiplied by shadow price of C, and then adjusted for storage in wood products and subsequent decay using relation [1].

Data for estimating the above relations are found in Table 7. For plantation forests, a plot of the expected marginal net returns (at an assumed age of 80 years) and area converted from old to second growth is provided in Figure 1. Also provided in Figure 1 is a plot between expected standing timber volume at age 80 years and land converted to plantation forest. These plots suggest that exponential functions should be employed. Likewise, we employ exponential functions for the benefits of harvesting old growth as a function of remaining old growth, and standing volume as a function of old growth. Four exponential functions are estimated using the data in Table 7. The estimated parameters are all statistically significant at the 0.01 level or better, as are the goodness of fit statistics. How they are used in the model is indicated below.

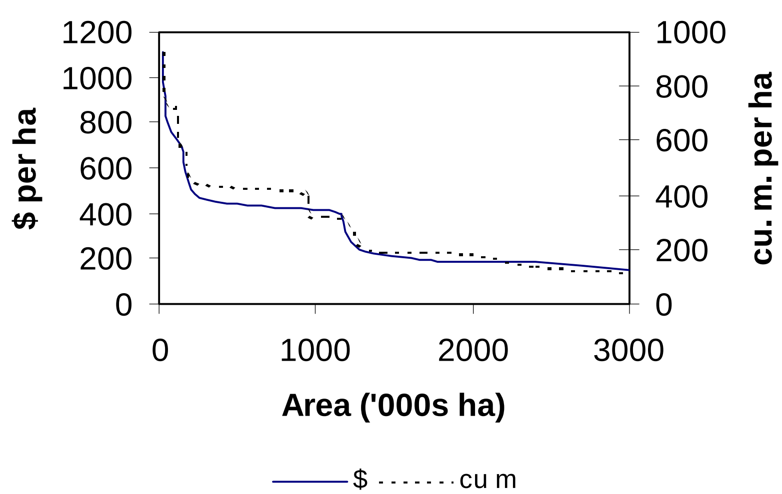

Figure 1. Marginal Expected Volume and Marginal Benefits of Second Growth
as a Function of Area in Second Growth.

The required functions for the model are as follows. The marginal benefit from logging old growth at time t is a function of how many quality sites (G) remain:

$$\tau(\mathrm{G}) = 7{,}451.495 \exp(0.000000586 \times \mathrm{G}). \quad [8]$$

The marginal climate-related cost of releasing carbon is given by:

$$\gamma(\mathrm{G}) = 0.1824 \times \left[\frac{\delta\rho}{1+r-\delta} + (1-\rho)\right] \times 138.437 \exp(0.000000644 \times \mathrm{G}), \quad [9]$$

where 0.1824 converts commercial timber volume into carbon, while the term taken from equation [1] takes into account storage (and subsequent decay) of C in wood products.

Old growth area is converted to plantation or second-growth forest, with the annualised marginal benefits from logging second growth given by:

$$F(G_0-G) = \frac{(1+r)^T}{(1+r)^T - 1} \times r \times \{765.92 \times \exp[-0.00000069 \times (G_0-G)]\}, \quad [10]$$

where (G_0-G) is the amount of land taken out of old growth and allowed to regenerate naturally into the next forest to be harvested.[12] The first term on the right-hand-side of [10] takes into account the benefits of future harvests (and differs slightly from the normal formula because the estimated benefit function is already in present value terms), while multiplication by r annualises returns. As above, we assume T=80 and r=0.04. The annual (marginal) C-uptake associated with second growth is given by:

$$C(G_0-G) = 0.1824 \times \frac{1}{T} \times 691.695 \times \exp[-0.00000072 \times (G_0-G)]. \quad [11]$$

Equations [8] through [11] are in terms of hectares, not thousands of ha.

Finally, it is necessary to determine the marginal non–timber benefits associated with retaining land in old growth. These benefits are over and above the benefits associated with the old growth already protected as parks, ecological reserves, wilderness areas, and so on. In Table 1, the value of an average ha of mature Coastal forest is given as $206.92 (Table 6). Multiplying by 3 million ha (the area of mature timber on the Coast) gives a total annual value of $620.8 million. We assume that this is the total willingness to pay (WTP), or total benefit, for non–timber products and amenities. Without additional information, it is simply assumed that the marginal function is linear as shown in Figure 2, where $B'(G)$ represents the marginal benefit as a function

[12]Natural regeneration yields greater net returns than artificial regeneration (e.g., Thompson *et al*. 1993).

of remaining old growth (*G*).[13] The total non–timber benefits are given by the area under the marginal benefit function, $B'(G)$.

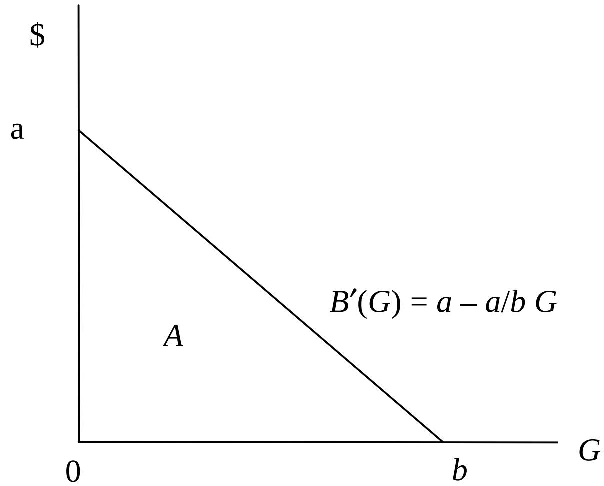

Figure 2. Marginal Willingness to Pay for Protection of Wilderness

Neither *a* nor *b* is known; only the area under the curve is known and fixed (equal to $620.8 million). However, once *a* is known, *b* is also known because $b = 2A/a$, where *A* is the area under the curve. Parameter *a* is the amount households are willing to pay to protect the next ha of old growth, over and above that already set aside. The amount individuals are WTP for each additional ha of preserved old growth declines as more and more mature timber is prevented from being harvested. Sensitivity analysis about the intercept is used to determine the optimal level of old growth to maintain. Of course, the higher the value of *a*, the steeper the slope of the marginal preservation function.

NUMERICAL RESULTS

Using result [7], it is possible to calculate the optimal amount of old growth to preserve on the Coast for various assumptions about the marginal benefit function, $B'(G)$. The results are presented in Table 8. Consider first the case where we are interested only in the well being of BC residents, but C release (from harvest of old growth) and uptake (by second growth forests) are taken into account. Keeping total non-timber and non-carbon benefits fixed at $620.8 million

[13]The assumption of linear downward sloping non-timber benefits is not necessarily consistent with, for example, hunting values, which are spread rather evenly across BC. In any event, these numbers are dominated by the non-use values, for which the assumption of declining value at the margin is more apt (see Vold *et al*. 1994).

annually, the amount of the 3 million ha of ancient forest to retain is sensitive to assumptions about the ordinate intercept (steepness) of the marginal benefit function. For high values of the intercept *a*, the marginal benefit function is very steep and little of the remaining ancient forest would be protected (some 4% or less). If *a* is small, the marginal benefit function for retaining old growth is flat and lies almost everywhere below the marginal opportunity cost function; again very little old growth would be protected. For values of *a* between 300 and 5,000, and ignoring C release and uptake (p_c=0), the optimal amount of old growth society would retain is nearly 700,000 ha, or 23% of what remains.

Table 8. Optimal Ancient Forest to Preserve on the BC Coast, Various Scenarios and Shadow Prices for Carbon (‘000s ha)

Price of	Vertical Axis Intercept for Non-Timber Benefit Function (Value of “a”)								
carbon	300	500	1,000	2,000	3,000	4,000	5,000	10,000	50,000
Maximum benefits for BC residents (including C uptake and release)									
$0	0	486.5	681.8	495.4	362.3	282.7	231.1	120.1	24.7
$20	10.4	500.8	688.3	497.2	363.1	283.1	231.4	120.2	24.7
$50	39.2	522.6	698.2	499.9	364.2	283.8	231.8	120.3	24.7
$100	88.5	559.8	714.8	504.4	366.2	284.8	232.5	120.4	24.7
Maximum benefits for BC residents under Kyoto rules for C uptake									
$0	0	486.5	681.8	495.4	362.3	282.7	231.1	120.1	24.7
$20	0	474.8	676.2	493.9	361.4	282.4	230.9	120.1	24.7
$50	0	457.5	668.0	491.6	360.7	281.9	230.6	120.0	24.7
$100	0	429.4	654.5	487.9	359.2	281.0	230.1	119.9	24.7
Maximum benefits for BC residents plus non-residents									
$0	0	734.1	1,475.0	1,604.6	1,356.8	1,119.4	938.4	502.9	104.2
$20	13.4	756.6	1,493.0	1,614.4	1,361.0	1,122.0	940.0	503.2	104.2
$50	50.4	791.1	1,520.5	1,629.1	1,369.0	1,126.0	942.4	503.7	104.2
$100	114.2	850.2	1,567.7	1,654.2	1,381.4	1,132.7	946.4	504.5	104.2

If carbon release and uptake are taken into account, society would want to increase its protection of old growth by between 7,000 and 33,000 ha, depending on the shadow price of C. Taking into account the role of C increases old growth protection by some 1% to 5%. However, if the Kyoto rules for counting carbon are implemented, then less ancient forest should be preserved. Compared to the case where release of C is counted as a debit, the Kyoto rule suggests that 12,100 ha of additional old-growth forest should be converted to second growth if pc =

\$20 t^{-1}, 30,200 ha for a shadow price of C of \$50, and 60,300 ha for a shadow price of \$100. The Kyoto rule suggests reducing the amount of ancient forest to be retained by some 2% to 9%.[14]

Finally, consider the case where non-BC residents are interested in preservation of temperate rain forests on the BC Coast. Assume that households in the US, Europe, the rest of Canada and elsewhere would be willing to pay \$10 annually to protect old growth in BC. There are some 200 million households in these regions, so this increases the total nonuse value of the ancient forests by \$2 billion annually. Then it is optimal to increase protection of old-growth forests to 53.5% of the 3 million ha that remain. By taking into account climate-related benefits, an additional 50,000 ha should be protected, increasing overall protection to 55.1% of the remaining ancient forest. However, it is unlikely that the BC government would ever be compensated for the positive externalities that old-growth, temperate rain forests provide residents outside BC. There is a greater chance that, if compensation for protecting forest ecosystems was ever to be paid, it would be directed towards tropical forests.

CONCLUSIONS

How much ancient rain forest should British Columbians optimally protect? From an economics point of view, the answer depends greatly on the assumptions that are made concerning marginal costs and benefits of retaining old growth. We have demonstrated that, simply because old-growth ecosystems have large non-timber values and because they store large amounts of carbon, this is no guarantee that they should be protected. Indeed, on the basis of total (average) values, commercial timber values would swamp other values and one would conclude that all of the remaining three million hectares of ancient coastal forest should be logged. It is only when one examines costs and benefits at the margin that an argument can be made to preserve large tracts of coastal forest.

Under optimistic assumptions about non-timber values and marginal costs and benefits, it can be argued that near one-quarter of BC's remaining ancient rain forest should be preserved indefinitely. Indeed, if such forests have value to residents outside BC and if they are willing to

[14]The results with respect to carbon are not very sensitive to values of ρ and δ.

compensate BC for not logging its forests, then it could be in BC's best interest to protect more than one-half of the forests.

Including climate-related damages (benefits) from carbon released by logging old growth (C uptake by new forests), increases the optimal amount of old growth to protect by upwards of 5% over what it might be otherwise. However, if the Kyoto rule for counting C benefits is followed (only count reforestation benefits, but not debits associated with logging unless logging leads to permanent land conversion), then more land should be converted to second growth than would be the case if C fluxes were not taken into account.

Finally, the results of this analysis assume that good quality sites of old growth are converted (logged) first, followed by sites of increasingly poorer quality. Clearly, environmental groups would be against this. However, without additional data on the marginal changes in non-timber benefits, and how these are associated with changes in site quality, it is not possible to make definitive conclusions about optimal preservation of ancient forests. While there economists have come a long way in valuing nonmarket values, much theoretical and empirical work remains to be done before enough information is available to provide a strong economic answer to the question posed above.

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