ARTICLES

Do the indigenous forests affect the net CO_2 emission policy of New Zealand?

Graeme M.J. Hall[1] and David Y. Hollinger[2]

Abstract

Concern with rising greenhouse gas levels and climate change has led the New Zealand Government to sign international agreements to construct carbon budgets and control greenhouse gas emissions including CO_2. Government policy on CO_2 emissions assumes the indigenous forests are "carbon-neutral", neither gaining nor losing carbon. To test this hypothesis, data were pooled from surveys, done over the last 35 years, throughout South Island and Stewart Island indigenous forests. Tree diameter and height data from 5965 permanent plots (178 species) were used to estimate total carbon, and 1829 remeasured plots (134 species) were compared to estimate annual change. Total stem volume was estimated from diameter by species diameter/height equations, mean plot canopy height, and a parabolic volume equation. Volumes were converted to biomass using basic wood density.

Total carbon in the above-ground stems of the South Island and Stewart Island indigenous forests was estimated at 483.1 ± 2.99 million Mg (95% CI) over 3.25 million ha of forest with an annual net loss of 1.8 ± 1.5 million Mg C yr^{-1}. Changes are not uniform throughout the indigenous forests; loss of live-carbon is predominantly from the podocarp-broadleaved areas. Carbon losses appear to be greatest in areas impacted by large populations of introduced wild animals. The net-emission policy includes increasing new land planting of exotic forests to average 100,000 ha yr^{-1}. To offset estimated mean carbon losses from the South Island and Stewart Island indigenous forests the area of plantation forest (mean ~ 13 years old) would have to be increased by 29,000 to 36,000 ha yr^{-1}. Extending this result to all New Zealand's indigenous forests and assuming similar forest trends occur in the North Island, plantation area would have to be increased by 46,000 to 58,000 ha yr^{-1}. These preliminary results suggest the indigenous forests could impact strongly on Government policy.

Introduction

Levels of atmospheric greenhouse gases (GHG), dominated by CO_2, continue to rise. The Intergovernmental Panel on Climate Change (IPCC), a scientific group commissioned by the world's Governments, has concluded that the increases in CO_2 and other greenhouse gases have led to a "discernible human influence on global climate" (IPCC, 1955). This influence has taken the form of a 0.3-0.6 °C temperature rise since the late 19th century. The IPCC projects that temperatures will continue to increase by 1 to 3 °C by the year 2100, a rate of warming that would probably be greater than any seen in the last 10,000 years (IPCC, 1995). To coordinate a global response to such changes, proposals have been made for an international law of the atmosphere (Goreau 1990), and commitments have been made by many countries to control GHG emissions.

International Agreements

An Intergovernmental Panel on Climate Change programme aims to complete a global carbon budget from national terrestrial carbon inventories (Houghton *et al.*, 1992) in order to improve predictions of future climate change. By January 1992 several countries, including New Zealand, had submitted complete or partial inventories of national greenhouse gas emissions. In September 1993 New Zealand ratified the United Nations Framework Convention on Climate Change (FCCC) and is therefore legally committed to adopt measures to stabilise national CO_2 levels. New Zealand is also a signatory under the Montreal Process, a non-binding agreement by 10 non-European temperate countries with proposals to protect important values derived from forests (Ministry of Forestry 1995, Wijewardana 1995). In this agreement one of the seven major points is the need to preserve indigenous forests because of their importance in the global carbon cycle.

New Zealand Policy

To meet these international agreements, the Government has set a target to return the net national level of anthropogenic CO_2 emissions back to that of 1990 and stabilise them by the year 2000, with the ultimate objective of reducing them to 20% below the 1990 figures. The policy is controversial because it relies initially on increased forest planting to absorb carbon rather than first reducing total emissions. This is a different position from many other FCCC co-signatories and is opposed by environmental advocacy groups such as Greenpeace and the Royal New Zealand Forest and Bird Protection Society that would prefer to seek to first control fossil fuel emissions and stop any deforestation, and then plant more forests. In New Zealand, over 87% of national gross CO_2 anthropogenic emissions come from fuel combustion with an additional 9% from industrial processes (Ministry of Commerce 1994), so the Government may fear that cutting these sector-emissions could disrupt the national economy.

Without additional controls and with an average GDP growth of 2%, New Zealand's CO_2 emissions are forecast to rise by 17.8% from 1990 to 2000. With an average 3% GDP growth, emissions are forecast to rise by 21.6%. Most of this projected rise is due to the energy sector. Present government policy measures are designed to lower this growth rate 20% by slowing source emissions and 80% by a net reduction in CO_2 from increased plantings in exotic forest (Ministry for the Environment 1994). To achieve such a reduction, new land planting is expected to average 100,000 ha yr^{-1} until 2020, a figure that is well above past and recent planting levels. New planting dipped to less than 15,000 ha yr^{-1} in 1991 and has increased since then to over 60,000 ha yr^{-1} (Lane 1995).

The Indigenous Forests

An important question unable to be addressed when this

1 *Graeme Hall, Manaaki Whenua – Landcare Research, PO Box 69, Lincoln, New Zealand.*
2 *David Hollinger, US Forest Service, NE Forest Experiment Station, Durham, NH 03824 USA.*

government policy was formulated is whether the large stores of carbon locked up in the stems, roots, and soils of indigenous forests are stable or changing. These forests cover 6.2 million ha (~23%) of the total New Zealand land area of 27.1 m ha (Newsome 1987). In the absence of any firm data the net CO_2 emission policy assumes indigenous forests are neither losing nor gaining carbon (Ministry for the Environment 1994). Changes may come about because the total land forest area has changed or because the overall amount of vegetation (biomass) in the forest's stands has increased or decreased.

To determine whether stand biomass is changing we used a database of tree diameters obtained from past indigenous forest surveys of the South Island and Stewart Island. These surveys were carried out in lowland, montane, and sub-alpine forests. The sample plots are in a wide range of stands that vary in composition, structure, and age, and give extensive coverage of the indigenous forest area (Fig. 1.). This network of permanent plots was established and maintained by the New Zealand Forest Service for inventory and monitoring and has been used for observing structural and compositional change throughout the last 25 years. We used the data to estimate the total pool of live-stem forest carbon, and from the remeasured subset of plots to find how the carbon pool has changed over time.

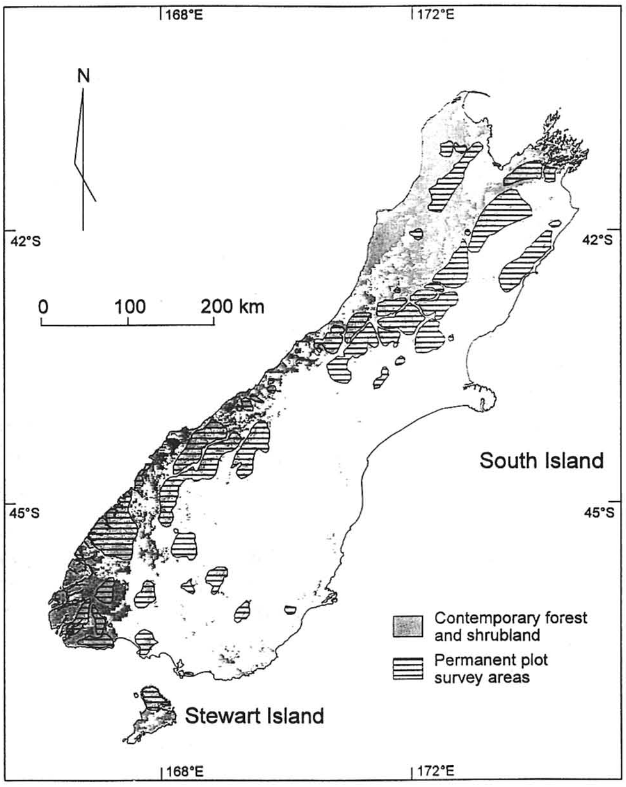

Fig. 1. Areas of vegetation surveyed in the South Island and Stewart Island of New Zealand overlaid on the contemporary indigenous forest and shrubland cover. Permanent plots are established throughout the survey areas and used to estimate total above-ground stem carbon in the indigenous forest.

Methods

For each of the permanent plots, we derived total tree live stem biomass per hectare from the individual tree diameters and plot height data by estimating total stem volumes of individual trees, converting volume to biomass using basic wood density, and summing over the plot. This approach differs from previous assessments that used data from a study of an individual stand to represent the mean biomass density of a nationwide forest type (Hollinger and Hunt 1992, Tate *et al.,* 1993). Plot data from multiple stands allow a measure of variation of the estimate to be calculated, and plot remeasurements enable changes (Mg ha^{-1} yr^{-1}) to be determined. Changes in carbon over time are presented as the average annual change calculated from the initial measurement (Harcombe *et al.*, 1995) with rates assumed to be constant over the census periods. We compared relevant plot-based biomass estimates against whole-stand harvest studies to assess the reliability of our method.

We have used established methods to reach an estimate of total live stem biomass. As is common in such studies, e.g. Harcombe *et al.* (1995), there are several possible sources of error (some of which may be self-cancelling) such as in field measurements of the original survey data and the height/diameter datasets, in the steps of estimating the stem heights, volumes, and biomass, and in the past biomass and volume study estimates we tested against.

Forest classes

To examine differences between forest types we separated the indigenous forests into eight major classes using the New Zealand-wide vegetation classification of Newsome (1987). No mixed forest and grassland or scrub types were used and forest boundaries were assumed constant over time. Total stem carbon in Mg ha^{-1} was obtained for each class by multiplying projected forest area by the mean biomass ha^{-1}. Biomass ha^{-1} was estimated from the data recorded from the plots located in each forest class.

Forest plot data

We used 5965 permanent forest plots from the National Indigenous Survey Vegetation database (NIVS; Forest Research Institute 1989), and of these, remeasured data were available for 1829 plots (~31%). Time between measurements varied from two to

Table 1. Indigenous forest cover classes with numbers of permanent forest plots in the South Island and Stewart Island of New Zealand. Forest classes and projected areas come from Newsome (1987) and the plot data from the National Indigenous Vegetation Survey database (NIVS; FRI 1989).

Forest Class	No. Plots Measured	No. Plots Remeasured	Projected Area (ha)
Beech Forest	2601	1251	1678 000
Beech-Broadleaved Forest	117	72	84 000
Broadleaved Forest	1166	162	108 000
Highland Podocarp-Broadleaved Beech Forest	234	46	172 000
Highland Podocarp-Broadleaved Forest	239	120	28 000
Lowland Podocarp-Broadleaved Forest	759	120	401 000
Lowland Podocarp-Broadleaved Beech Forest	802	58	742 000
Podocarp Forest	47	0	39 000
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	5965	1829	3252 000

25 years with many plots remeasured several times at two to 10 year intervals. Plots were present in all major forest classes with initial sampling densities ranging from 1.1 plots per 1000 ha in lowland podocarp broadleaved beech forest to 10.8 plots per 1000 ha in broadleaved forest (Table 1).

Plots were permanently marked in the field with defined areas or boundaries. Woody species on the plots were identified and stem diameters measured in mm as near to breast height (dbh) as possible. For consistency among surveys, only stem diameters >2.5 cm were used. This resulted in a dataset of over 361,000 stem measurements of 178 woody tree species for estimating total carbon, and over 143,000 stems of 134 species for estimating annual change.

Mean plot slope was used to convert ground area to projected area for the final live-stem biomass and carbon content figures in order to match the projected forest areas of Newsome (1987). The plots were located by map reference, overlaid onto the forest class maps, and assigned to forest cover-classes with GIS software (Terrasoft 1991).

Volume estimation

We used the parabolic volume formula of Whittaker and Woodwell (1968) to estimate total individual above-ground stem volume over bark because, for ecological purposes, it provides an effective approach to the estimation of volume and a reasonable basis for comparing forests (Whittaker 1966). The method requires measures of dbh and total height for individual trees.

Field workers recorded dbh and the mean height of the canopy over the plot ('canopy height'), but did not measure individual stem heights due to time and cost constraints. To estimate total stem height from dbh, we employed the parabolic equation of Ker and Smith (1955) constrained by the plot canopy height. This equation requires maximum dimensions for each species. We used the analysis package PC-DIAM (Hall 1994) to make distributions of all NIVS diameter data and set the diameter constant to the 95th percentile. Maximum species heights were obtained from the literature; Hinds and Reid (1957), Wardle (1966, 1967), Franklin (1968), Wardle (1969, 1971), Salmon (1980), Knowles and Beveridge (1982), Wardle (1984), Wardle (1991).

Biomass and carbon content

Biomass was derived from volume by basic wood density (oven dry weight/green volume). Basic density measurements were obtained for the major timber species from Entrican *et al.* (1951), Hinds and Reid (1957), Wardle (1984), Harris (1986), and Clifton (1990). For species that had air-dry (weight/volume at 12% moisture content) values, basic density was estimated by linear regression. For the remaining species, basic density was set to the mean of the measured values of the genus or to the mean of all measured values (~0.520). These density estimates do not allow for decay or defects in the stems, and do not allow for bark-density. Total carbon content was taken to be 50% of the total dry matter or biomass (Waring and Schlesinger 1985).

The methods for estimating tree height and total stem volume from individual diameter and plot canopy height are referred to as the parabolic model. To test the accuracy of the height method, we obtained independent measures of diameter and heights of individual stems from three forest types and compared measured versus estimated height for the species. Total stem stand volume estimated by the model was compared against published case-studies based on destructive sampling, and results of productivity studies that used either timber volume tables compiled by the New Zealand Forest Service (Duff 1952, Duff and Burstall 1965) or the volume equations of Ellis (1979). We conclude from Tables 2 and 3 that our methods (Appendix 1) provide an unbiased plot-based estimate of stem volume and hence of live forest biomass. Examples of height and volume comparisons include mountain beech, mixed red and silver beech, and mixed podocarp forest. These species dominate the majority of South Island forests.

Results

Carbon Estimates for the Indigenous Forest Classes

From the 5965 plots we estimate live stem carbon over 3.25 million ha of indigenous forest in the South Island and Stewart Island total 483.1 million Mg with 95% confidence intervals (CI) of ± 2.9 million Mg (Table 4), giving an average live stem biomass of 297.5 ± 5.9 Mg ha^{-1} over the whole area. Estimated changes in live stem carbon from all the 1829 remeasured plots over the sample periods indicate an imbalance in the standing stock of the forest with a net average loss of more than 0.38% yr^{-1} or -1.8 million Mg C yr^{-1} with 95% CI of ± 1.5 million Mg. Stratifying the indigenous forests into forest classes shows changes in carbon are not occurring uniformly with gains up to 2% yr^{-1} and losses of -4% yr^{-1} (Fig. 2). The northern and southern areas of forest in

Table 2. Estimates of individual tree heights compared against measured tree heights. Individual diameters and heights were recorded for species in three areas. Goodness-of-fit between measured and modelled heights is shown by mean heights and rank correlation coefficients (r).

Survey Area	Species	No. Stems sampled	Height (m) mean	Height (m) std.dev.	Est. Height(m) mean	r
Harper-Avoca (Harcombe *et al.* 1995)	*Nothofagus solandri* var. *cliffortioides*	753	14.9	5.1	14.1	.80
Station Creek (Stewart and Burrows 1994)	*Nothofagus fusca*	183	18.4	9.3	17.0	.94
	Nothofagus menziesii	1014	9.7	5.5	10.5	.91
Southland coast-Stewart Is. (Burrows *unpubl. data*)	*Dacrydium cupressinum*	370	24.6	5.2	24.8	.65
	Metrosideros umbellata	71	17.1	3.6	16.9	.83
	Nothofagus menziesii	56	24.3	3.8	24.5	.39
	Nothofagus solandri var. *cliffortioides*	28	20.3	3.4	19.7	.50
	Podocarpus hallii	56	18.3	4.0	21.4	.51
	Prumnopitys ferruginea	149	19.7	3.9	21.8	.63
	Weinmannia racemosa	108	16.8	2.8	17.8	.60

the South island appear to be mostly stable or gaining carbon, with losses predominantly occurring in central Westland, Stewart Island, and around the south-eastern and south-western areas of the South Island (Fig. 3).

Pure beech (*Nothofagus*) forest covers over 50% of the total forest area and contains about 45% of the forest carbon (219.7 ± 3.1 million Mg, Table 4). Annual carbon losses and gains within the pure beech forest are in an approximate equilibrium. The remeasured data suggest a small mean annual net gain of 0.067 million Mg C yr^{-1} or ~0.03% yr^{-1} with 95% CI for this beech class ranging from -0.40 million Mg C yr^{-1} to 0.54 million Mg C yr^{-1}.

Podocarp and broadleaved forest classes at higher altitudes or in classes where beech is not a major component appear to be losing carbon. The podocarp-broadleaved forest in the low elevation type contains 126.9 ± 4.0 million Mg. It occurs widely throughout Westland and Stewart Island (401,000 ha) and is losing carbon at a mean rate of 1.2 ± 0.7 million Mg C yr^{-1} or around 3.0 Mg of carbon ha^{-1}. This loss is almost 2.0% yr^{-1} of the total stem live carbon stock. The high elevation podocarp-broadleaved forest covers a much smaller area (28,000 ha) with a carbon storage of 8.1 ± 0.4 million Mg and a possible loss of carbon at 0.16 ± 0.17 million Mg C yr^{-1} or around 5.9 Mg C ha^{-1} (-4.1% yr^{-1}). The broadleaved forests on the mid-slopes of the central Westland ranges (108,000 ha) where beech is absent (34.9 ± 0.9

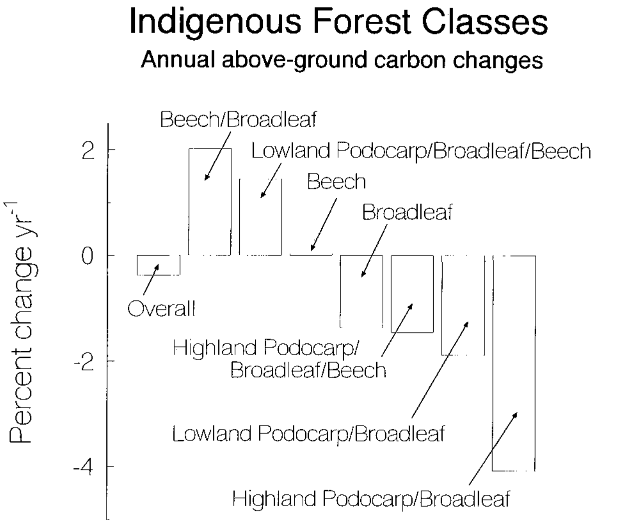


Fig. 2. Annual estimated percentage changes in above-ground carbon in the indigenous forest classes. Changes range from 2.0% yr^{-1} for the beech-broadleaved forests to -4.1% yr^{-1} for the highland podocarp-broadleaved forests. The change over all forests is a loss of -0.38% yr^{-1}.

Table 3. A comparison of total stem volumes obtained from stand biomass and production trials against estimated volumes by the parabolic model using plot data recorded in the same or nearby areas. Volumes are given in m^3 ha^{-1}.

Study Area	Species	Stand Volume	Estimated Volume mean	std.dev.
Harper-Avoca (Harcombe *et al.* 1995)	*Nothofagus solandri* var. *cliffortioides*	394	392	110
Big Bush, Nelson (Benecke and Evans 1987)	*Nothofagus truncata*	490	486	176
South Westland	*Dacrydium cupressinum*			
Okarito (Griffith 1980)		451	416	234
Ianthe (Franklin 1973)		474 & 451	471	242
Station Creek,Maruia Valley (Bryan *et al.* 1975)	*N.fusca*/*N.menziesii*	660-875	804	n/a

Table 4. Total-stem dry weights in the Newsome (1987) indigenous forest classes of the South Island and Stewart Island of New Zealand ordered by total forest carbon. Change in plot biomass is calculated by subtracting the initial estimate from the final. Annual change is obtained by dividing biomass change by the length of the period between measurements (in years to the nearest month).

Forest Class	Estimated dry weight plot mean (Mg ha^{-1})	95%CI	forest total (million Mg C)	Estimated annual change plot difference mean (Mg ha^{-1} yr^{-1})	95%CI
Beech Forest	261.9	6.3	219.7	0.08	0.56
Lowland Podocarp-Broadleaved Beech Forest	361.0	17.7	133.9	5.25	2.76
Lowland Podocarp-Broadleaved Forest	316.4	20.1	63.4	-5.99	3.31
Highland Podocarp-Broadleaved Beech Forest	282.6	20.4	24.3	-4.14	4.69
Broadleaved Forest	322.9	17.3	17.4	-4.43	2.00
Beech-Broadleaved Forest	306.3	30.9	12.9	6.18	2.84
Podocarp Forest	386.0	61.5	7.5	n/a	n/a
Highland Podocarp-Broadleaved Forest	288.5	31.1	4.0	-11.77	12.28
All Forest	297.5	5.9	483.1	-1.13	0.94

million Mg C) show a loss of 0.23 ± 0.10 million Mg C yr^{-1} (95% CI), or 2.2 Mg yr^{-1} of carbon ha^{-1} representing an annual decrease of 1.4%. In the small pure podocarp forest type (39,000 ha) in the coastal areas of Westland, carbon stocks are estimated at 7.5 ± 1.2 million (95% CI) Mg C. Lack of remeasured plots prevent annual change being estimated.

The highland podocarp-broadleaved-beech forest (172,000 ha) is the only class with a beech component that shows a possible loss as indicated by a mean outflow of 0.36 ± 0.40 million Mg C yr^{-1} (-1.5% yr^{-1}) or 2.1 Mg of carbon ha^{-1}. The corresponding lowland type occurs below the altitudinal limit of the dominant podocarp *Dacrydium cupressinum* in the north-west and south-western regions of the South Island and covers the second largest area (742,000 ha). It contains an estimated 27.7% of the total indigenous forest carbon with a total of 133.9 ± 8.9 million Mg C. The low resampling intensity (Table 1) in this type prevents a reliable estimate of change other than the data indicating a possible gain in carbon of 1.5% yr^{-1}. Beech-broadleaved forest shows a mean percentage gain in carbon of 2.0% yr^{-1} or 0.26 ± 0.12 million Mg C yr^{-1}.

Discussion and Conclusion

There remain sources of variation in our estimates that require more investigation but we consider a valuable first step has been taken from field survey data to quantify the carbon stored in the live stems of the indigenous forests and to give an indication of change. To calibrate our model we found few detailed biomass studies had been done in these indigenous forests. Although live stem carbon is a primary factor, research is also needed to refine estimates of carbon and carbon change in other major components of the forest ecosystems such as in the soils, roots, litter, and dead wood.

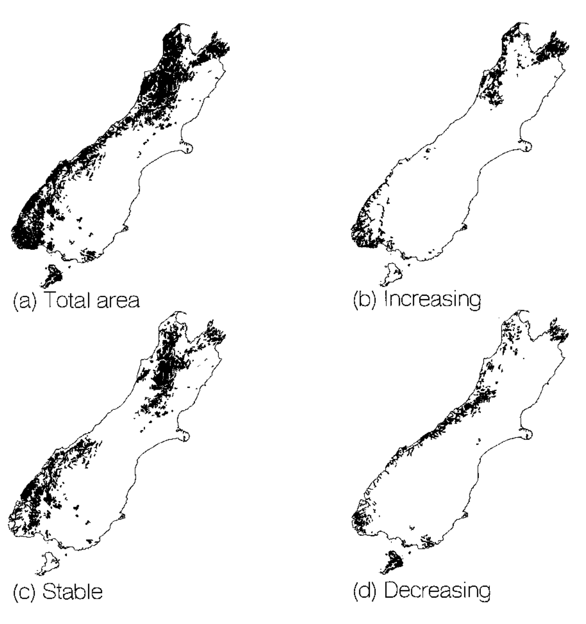


Fig. 3. (a) Forest areas of the South Island and Stewart Island.
(b) Forest class areas gaining carbon > 0.6% yr^{-1} (lowland podocarp-broadleaved-beech and beech-broadleaved forest).
(c) Stable areas ± 0.5% yr^{-1} (pure beech).
(d) Areas losing carbon < -0.6 yr^{-1} (lowland and highland podocarp-broadleaved, highland podocarp-broadleaved-beech, and pure broadleaved forest).

Carbon changes in the Indigenous Forests

Canopy breakdown and forest dieback cause the greatest change in live carbon. Over 90% of the estimated stem biomass on the indigenous forest plots is in large trees. When they die, live biomass on the site drops and carbon is transferred to coarse woody debris, litter layers, soils, and the atmosphere. A forest can gain or lose live-carbon depending on the population dynamics of its constituent stands. The broad areas within a Newsome (1987) forest class include forests that differ in composition, age structure, and animal history.

Forest dieback is complex and occurs in beech and podocarp/broadleaved forests independently of introduced animals (Fig. 4a). In many forests dieback has been attributed to a mix of actors such as drought, insect damage, snow break, wind, flooding, and earthquake damage (Wardle 1984). Major breakdowns of the forest canopy have also been documented and ascribed to the additional effects of introduced wild animals (Fig. 4b, Batcheler 1983, Rose *et al.*, 1992). Within forests sustaining high animal populations dieback has been related to: animal density, distance from liberation points, control history, composition and structure of the forest, substrate, climate, and forest disturbance history (Veblen and Stewart 1982, Stewart and Rose 1988, Payton 1988, Rose *et al.*, 1992).

There are some correspondences between large-scale studies of introduced wild animal impacts and estimated changes in carbon from the plot data. Forest classes without beech have estimated annual declines in live stem carbon that range from -1.4% to -4.1% yr^{-1}, while those with beech tend to be stable or show net gains of up to 2% yr^{-1} (Fig. 3). The pattern of these quantitative results is similar to the qualitative trends described in an early study of the forests in the Grey River headwaters. Wardle (1974) found the areas most susceptible to damage by ungulates, especially red deer (*Cervus elaphus*), were predominantly mixed podocarp and broadleaved forest, and those most vulnerable to possum (*Trichosurus vulpecula*) damage were kamahi-dominated associations. Beech-dominated forests were least susceptible to the impacts of both ungulates and possum.

Rose *et al.* (1992) used aerial photographs to study canopy dieback in the Westland southern rata-kamahi (*Metrosideros umbellata-Weinmannia racemosa*) forests above 500 m altitude and east of the Alpine Fault. These forests predominantly belong to the higher-altitude podocarp-broadleaved and podocarp-broadleaved-beech classes, and the pure broadleaved class. Dieback patterns reported by Rose *et al.* (1992) that showed possum invasion going towards the headwaters of major catchments agree with estimated declines in carbon in the highland podocarp-broadleaved and podocarp-broadleaved-beech forest classes (Fig. 2).

The future of forests with high densities of canopy species palatable to possums is not clear. These forests may adjust to possum impacts by an eventual change in species composition to less palatable dominants such as the beech species, or possibly revert back to scrub or tussock grassland with a corresponding long-term loss of carbon. In both scenarios an initial drop in live-carbon storage is indicated with a later recovery if beech or other non-palatable species come to dominate. The near complete disappearance of a former canopy has resulted in shifts to forest types dominated by species not preferred by possum in two of the earliest affected catchments, Kokatahi (Fig. 4a) and Fox (Rose *et al.*, 1992). This suggests that on top of forest dieback due to factors such as weather, earthquake, or insects, the imposition of introduced wild animals into the indigenous forest ecosystems may have created an additional source of dieback that has tipped changes in live-carbon towards the negative.

Impacts on the Net Emission Policy

Carbon storage trends in the indigenous forests could require the

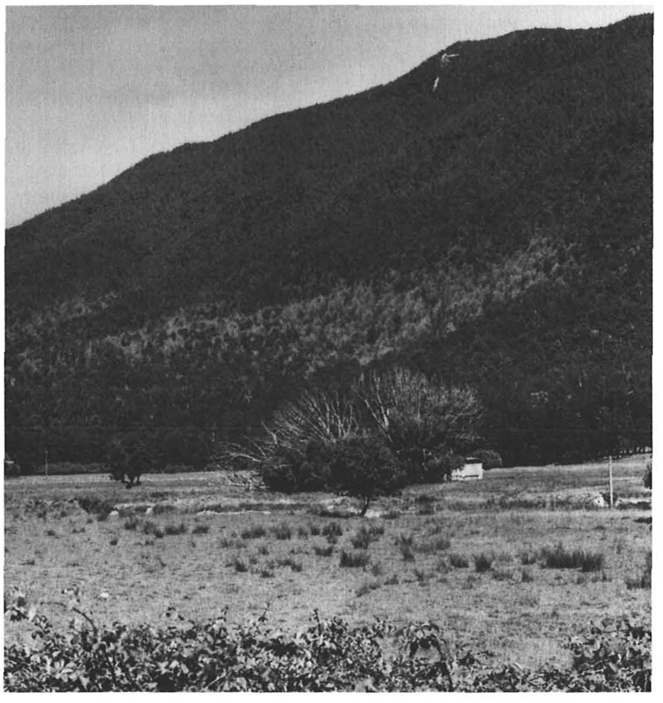
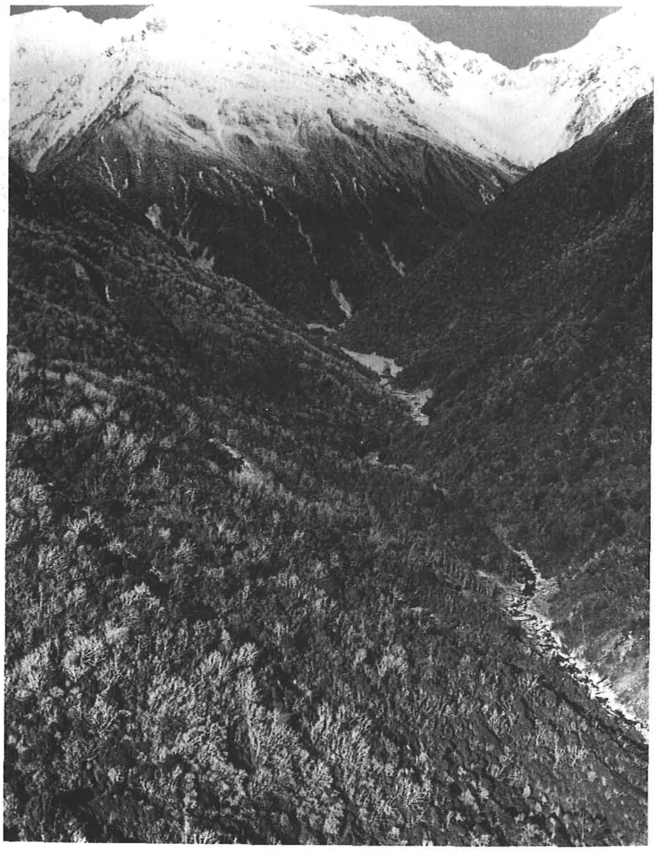


Fig. 4 (a) Canopy breakdown in beech (*Nothofagus*) forest from scale insect (*Inglisia fagi*) attack in Maruia valley. The light patch on the hillside is defoliated tree canopy. A survey of forest around the Maruia river found almost 5000 ha with more than 60% foliage loss (Hosking and Kershaw 1985). Photograph by H. Hemming 1981.



(b) Possum (*Trichosurus vulpecula*) browse impacts on mature stands of *Metrosideros umbellata* (Rata) in the Kokatahi catchment in highland podocarp-broadleaved forest. Major modifications to the forest canopy occurred in the 1940s and standing dead canopy trees covered the hillside in 1959. Photograph by J.H. Johns A.R.P.S. 1959.

Government to modify its net CO_2 emission policy. There is a risk in assuming that these forests are in equilibrium when a small annual per cent loss of 0.38% yr^{-1} could cancel out much of the intended carbon absorption effects from planting large extra areas in production forest. The indigenous forest survey data overall suggest the forests may be losing live carbon, particularly in the podocarp-broadleaved areas.

Mean total stem biomass, including non-merchantable stemwood and stem bark, for the exotic plantation forest estate is approximately ~91.0 Mg ha^{-1} or ~45 Mg C ha^{-1} assuming an average age of 13 years (Tate *et al.*, 1993, Maclaren and Wakelin 1991). In exotic forests, depending on site and management, Maclaren (1994) estimates total carbon (including both above- and below-ground C) ranges from 100 to 125 Mg ha^{-1} (49-62 Mg C ha^{-1} stem biomass). To balance the estimated annual loss in live total stem carbon of 1.8 million Mg C yr^{-1} from the South Island and Stewart Island indigenous forests would thus require an annual increase of 29,000 to 36,000 ha of average age (~13-year-old) plantation forest.

The eight Newsome (1987) indigenous forest classes, including the North Island, cover 5.12 million ha of New Zealand. Assuming the pattern of carbon changes in the North Island indigenous forests is similar to those described here, an extra 46,000 to 58,000 ha yr^{-1} of average-age exotic forest would be necessary to balance possible losses. These are preliminary results and offsetting factors may be found, perhaps in areas supporting regenerating forest-scrub or by tree spread to the forest-grassland types. However, the government net-emission policy, in so far as it includes the indigenous forests, may struggle to meet the FCCC agreed CO_2 targets by the year 2000 and thereafter.

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Appendix 1

Testing the Parabolic Model

Accuracy of individual tree-height estimates

Tree height estimates, and comparisons with measured data are shown in Table 2. In general, our method gave a close estimate to measured tree height. In the Southland coastal forest and Stewart Island forest, the mature podocarps *Prumnopitys ferruginea* (mean dbh 43.2 cm) and *Podocarpus hallii* (mean dbh 43.0 cm) were overestimated on average by 2.1m and 3.1m. We accepted these estimates, however, because they are within one standard deviation of the measured mean (Table 2), and because of general observations that in these southern areas the stature of these species is less than in Westland and further north (Hinds and Reid 1957).

Accuracy of Volume estimates
Beech/Podocarp community
The study of Beets (1980) allowed volumes estimated by the parabolic model to be directly compared against those obtained from harvesting. Volumes in a species-rich mature beech/podocarp forest were calculated by Beets (1980) for two catchments previously surveyed by 20 randomly-located diameter-data plots.

In the larger catchment of Beets (1980) study (catchment 7, 12 plots), the vegetation had a high number of tree species with canopy height ranging from 20m to 36m, and was dominated by *N. truncata* in association with the podocarps *Prumnopitys ferruginea, Dacrydium cupressinum*, and *Podocarpus hallii* over a sub-canopy mainly composed of *W. racemosa*. From the plot data, the parabolic model estimated total stem volume of the five major species as 440 ± 178.4 m^3 ha^{-1} (standard deviation) compared to 448 ± 151.3 m^3 ha^{-1} (standard deviation) compared to 448 ± 151.3 m^3 ha^{-1} from Beets (1980). The two methods showed no significant difference in plot volume ($p>0.9$, Mann-Whitney). In the other catchment (catchment 8a, eight plots) the dominant canopy species *N. fusca* replaced *N. truncata* over the *W. racemosa* dominated sub-canopy. The parabolic model estimated stem volume for the six major species as 328.7 ± 211.2 m^3 ha^{-1} compared to 347.8 ± 200.6 m^3 ha^{-1} for Beets (1980). There was no significant difference in plot volume between the methods ($p>0.7$, Mann-Whitney).

Other stand volume studies
We compared stem volumes from stand studies in several beech and podocarp forests against those estimated by the parabolic model. Plot data from the study sites was used if available; otherwise we selected plots located near to the sample stands with similar species composition and structure from the NIVS database. Reported volumes from the production trials of Franklin (1973), Bryan *et al.* (1975), and Griffiths (1980) were compared after converting merchantable timber volume under bark to total stem volume by applying Beets (1980) percentage factors.

From associated plot data the parabolic model generated volumes ha^{-1} that were close to those of the stand biomass studies (Table 3). Estimated mean volume of the 250 *N. solandri* var. *cliffortioides* (mountain beech) plots was within 2 m^3 ha^{-1} or 0.5% of the assessment by Harcombe *et al.* (1995) using the same data ($r=0.90$, $p<0.0001$), and resulted in similar values to earlier studies (Nordmeyer 1980, Benecke and Nordmeyer 1982, Wardle 1984). The estimate for *Dacrydium cupressinum* from Okarito forest plots differed by 1-5% and by 9% from the Franklin (1973) and Griffiths (1980) values. The high variation was due to the wide range of size classes and densities of the species in the 33 plots. In the mixed beech *N. fusca/N. menziesii* forest of Maruia valley the plot data of Stewart and Rose (1990) located in old growth forest gave an estimate within the range reported by Bryan *et al.* (1975) from production trials.

COMING EVENTS

April 1997

New Zealand Forest Research Institute 50th Jubilee Celebrations and Conference. "Forestry Research to Meet Future World Needs: the Mid-Point in our Century of Change" – Rotorua, New Zealand. April 1 – April 4. Robyn Scherer, NZFRI Ltd, Private Bag, Rotorua, Fax (07) 347 9380.

ANZIF Conference of the Institute of Foresters of Australia and the Institute of Foresters of New Zealand "Preparing for the 21st Century" – Canberra. April 21-April 23. ANZIF Conference Secretariat, MCi International Pty Ltd, P.O. Box 7404, 479 St Kilda Road, Melbourne, Victoria 3004, Australia. mcigroup@ozemail,com.au.

May 1997

15th Commonwealth Forestry Conference – Forestry in a Changing Political Environment: Challenges for the 21st Century – Victoria Falls, Zimbabwe. May 12-May 17. The Secretary General, The 15th Commonwealth Forestry Conference, Forestry Commission, P.O. Box HG 139, Highlands, Harare, Zimbabwe.

First International Tropical Wood Conference (New Tropical Timber Crops: Challenges in Processing and Utilisation) – Pan Pacific Hotel, Kuala Lumpur, Malaysia. May 13-May 16. Secretariat, The First International Tropical Wood Conference, Faculty of Forestry, UPM, 43400 Serdang, Selangor D.E., Malaysia.

October 1997

XI World Forestry Congress – Antalya, Turkey. Oct. 13-Oct. 22. Mr L.S. Botero, Associate Secretary-General, XI World Forestry Congress, FAO, Forestry Department, Via delle Terme di Caracalla, 00100 Rome, Italy. luis.botero@fao.org.

November 1997

IUFRO Division 2 Meeting on *Pinus radiata* Breeding and Genetic Resources – Rotorua, New Zealand. Nov. 17 – Nov. 19. Dr Peter Ades, School of Agriculture and Forestry, University of Melbourne, Parkville, Victoria 3052, Australia. peter.ades.agfo@muwayf.unimelb.edu.au