AN ABSTRACT OF THE THESIS OF

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Title: BIOMASS DYNAMICS OF DEAD DOUGLAS-FIR AND WESTERN HEMLOCK BOLES IN MID-ELEVATION FORESTS OF THE CASCADE RANGE

Abstract approved: ______________________________

Jerry F. Franklin

The rate and manner of biomass loss from decomposing Douglas-fir and western hemlock boles in mid-elevation forests of the central Cascade Range were measured. Bole bark and wood were considered separately. Loss of bole wood due to respiration was measured by change in bole wood density. Loss of bole wood due to fragmentation was measured by change in bole volume. Bole species, position (upright or prostrate), and diameter affected the rate of bole decomposition with regard to both fragmentation and respiration. Douglas-fir boles decomposed slower than western hemlock boles. For both species, upright boles decomposed faster than prostrate boles (k= 0.031 yr^{-1} versus 0.012 for Douglas-fir wood and k= 0.090 yr^{-1} versus 0.021 for western hemlock wood). Fragmentation proceeded at a faster rate than respiration for both prostrate and upright Douglas-fir boles.

Decomposing prostrate boles of western hemlock did not fragment. Upright western hemlock boles had substantial fragmentation losses. Seven to thirteen percent of the wood of an upright western hemlock bole was lost each year to fragmentation. The relationship between bole size and decomposition rate was complex. For upright boles, decomposition rates increased as bole diameter decreased. Prostrate boles showed no relationship between bole diameter and decomposition rate. Bark loss rates of prostrate boles were similar for both species ($k= 0.02\ yr^{-1}$). Upright boles lost their bark faster than prostrate boles ($k= 0.038\ yr^{-1}$ to 0.14). Bark was lost faster from small than large boles. The decomposition data for all boles were quite variable.

A computer simulation model was built to attempt to examine the question of how the quantity and type of wood and bark of dead boles would vary in a Douglas-fir/western hemlock forest as the stand developed. No age trends were apparent from the model output. The amount and type of dead bole wood fluctuated within a given range which was determined by the stochastic fluctuations in annual mortality.

Biomass Dynamics Of Dead Douglas-fir And Western Hemlock Boles In Mid-elevation Forests Of The Cascade Range

by

Robin Lee Lambert Graham

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BIOMASS DYNAMICS OF DEAD DOUGLAS-FIR AND WESTERN HEMLOCK BOLES IN MID-ELEVATION FORESTS OF THE CASCADE RANGE

INTRODUCTION

Ecosystem studies have traditionally ignored mortality of trees and subsequent decomposition of the bole wood and bark.[1] Tree mortality is erratic in both time and space, requiring either many years of data collection (decades) or very large sampling areas (tens of hectares) for accurate measurement, particularly in the case of long lived species. Consequently, only six studies of forest net primary production have included tree mortality, although it equaled or exceeded leaffall in five of those measured (Sollins 1981). Studies in wood decomposition have also been infrequent; dead boles do not lend themselves to litter bag studies and frequently take decades or centuries to decay. However, development of efficient whole-tree harvesting systems and increased utilization of woody residues for fuel have recently stimulated interest in the production, fate, and role of large woody debris in forest ecosystems (Grier 1978, Lang and Forman 1978, Larsen et al. 1978, Harvey et al. 1979a, Lang and Knight 1979, Cline et al. 1980, Lambert et al 1980, Graham and Cromack 1981, Sollins 1981).

Dynamics of large woody debris are particularly important in the forest ecosystems of the Pacific Northwest which typically contain a

1. A bole refers to the stem of a tree not including branches.

tremendous mass of dead bole wood (100 to 500 Mg/ha) (Franklin et al. 1981). A vast reservoir of organic carbon, these dead boles can carry the accumulated energy and nutrients of the ecosystem through catastrophic fires and volcanic eruptions that periodically destroy these forests (Hemstrom 1979). In the undisturbed forest, dead boles are habitat for much of the forest's fauna and flora, especially as nesting sites and seedbeds (Minore 1972, Maser et al. 1979). This lignin-rich mass may cover 20% of the forest floor and affects soil processes and development to an unknown but undoubtedly significant degree (Harvey et al. 1978, Harvey et al. 1979b, Jurgensen et al. 1979). The replacement of virgin Pacific Northwest forests by small stature managed stands with little woody debris, necessitates that we improve our understanding of the role of woody debris in these ecosystems.

My objective was to describe quantitatively the decomposition of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) and western hemlock (Tsuga heterophylla (Raf.) Sarg.) boles in mid-elevation forests of the central Cascade Range. These two species dominate the forest ecosystem, Douglas-fir in early and mid successional forest and western hemlock in late successional and climax forest. In addition, early descriptive studies by foresters in this region showed that Douglas-fir boles decay much more slowly than western hemlock boles (Boyce 1929, Englerth 1942). Consequently, the two species can be used to represent opposite ends on a continuum of decay susceptibility.

I differentiated between bole wood and bole bark and between upright boles (snags) and prostrate boles (logs) because bark is chemically dissimilar from wood (Lambert et al. 1980) and because snags and logs serve in unique capacities for wildlife (Maser et al. 1979, Thomas et al. 1979). Separation of these components was therefore necessary if the information on decomposition was to be useful for future nutrient cycling or wildlife studies.

Respiration losses were separated from fragmentation losses in measuring overall bole wood decomposition rates. Wood respiration is defined for this study as the loss of bole wood biomass due to respiration and leaching, which decreases wood density but does not alter bole wood volume. Wood fragmentation is the loss of wood biomass, due to abrasion or sloughing, which decreases the volume of the bole but does not alter wood density. These two components of bole decomposition were separated because 1) in previous work fragmentation rates were found to be greater than respiration rates (Lambert et al. 1980) and 2) the two components have vastly different implications for soil development and for organisms utilizing dead wood. Fragmentation transfers recalcitrant organic matter from the bole to the forest floor while respiration changes the quality of the wood that an organism utilizing the bole experiences. Studies of wood decomposition have seldom differentiated between these two means of bole decomposition or have only measured respiration. Respiration rates alone appear to drastically overestimate bole longevity in the ecosystem but they may not overestimate the ecosystem longevity of the organic carbon from the bole. The relative importance of respiration and fragmentation is discussed in more detail elsewhere (Hunt 1977, Lambert et al. 1980, Sollins et al. 1980, Sollins 1981).

This paper is divided into four sections, due to differing methodology for studies of snags and logs. These sections are: log decomposition; snag decomposition and breakage; frequency of tree mortality producing a fresh snag or an entire prostrate bole; and a general discussion of bole decomposition.

SECTION I. LOG DECOMPOSITION

Methods

Study site:

Seven old-growth stands were selected at the H.J.Andrews Experimental Forest in the Central Cascade Range near Blue River, Oregon (Fig. 1). In this region of the Cascades precipitation occurs mainly in the winter, and month-long summer droughts are common. Snowpack at H.J. Andrews is intermittent at elevations below 800 m, but persists at depths up to 500 cm from December to March at 1350 m (A. McKee, personal communication). The selected stands were characteristic of environmentally moderate western hemlock habitat types (Zobel et al. 1976), ranged from 490 to 990 m elevation, and had a north to northwest aspect excepting one stand with a southeast aspect. The mean January, July, and yearly soil and air temperatures in two stands at 480 and 880 m elevation are shown in Table 1 (Emmingham and Lundberg 1977).

Sample logs:

Sixty-five Douglas-fir and 35 western hemlock windthrown trees were selected for detailed study. Each dead tree had an exposed root system, a pit behind the upturned roots, and a prostrate, often complete bole. In addition each dead tree had either scarred an adjacent living tree in the process of falling or had a tree growing on it. Assuming that the windthrown tree died when it fell, its residence time on the forest floor as a dead bole could be determined exactly by the age of the scar, less precisely by the age of the

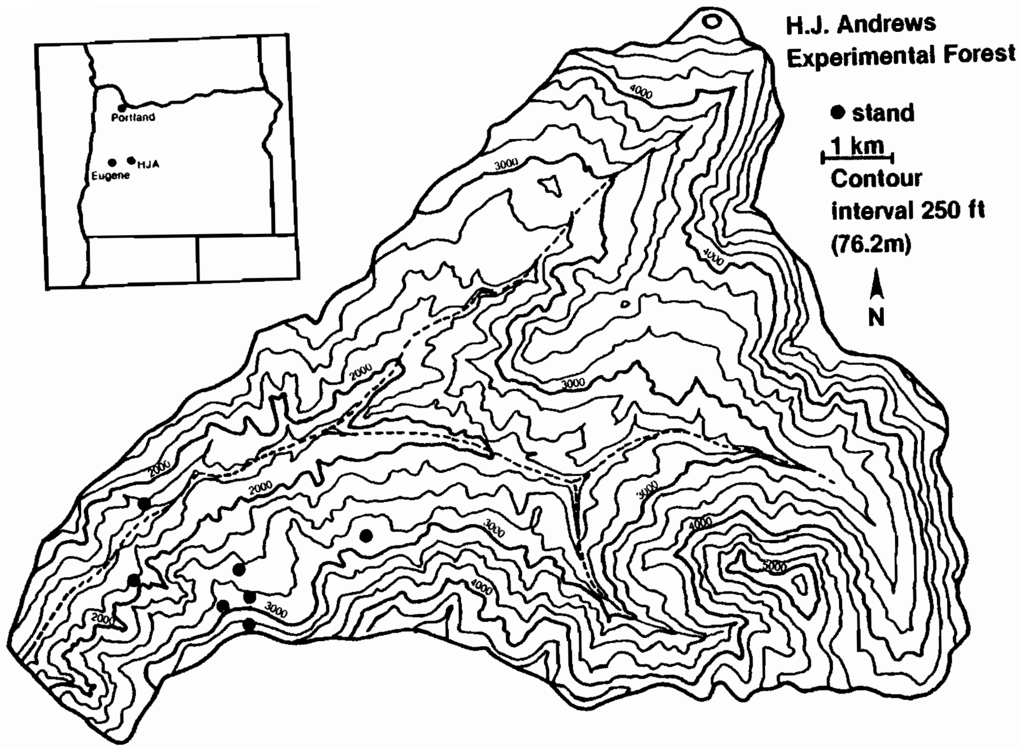

Fig. 1. Map of H.J. Andrews Experimental Forest near Blue River, Oregon showing location of stands used in the log study.

Table 1. Average temperatures in degrees °C of two log sampling sites at H. J. Andrews Experimental Forest, Oregon. Soil temperature is at 20 cm depth.

	Air temperatures (°C)			Soil temperatures (°C)		
Elevation	Jan.	July	year	Jan.	July	year
440 m	1.8	20.4	10.4	2.8	14.8	8.6
880 m	1.3	18.1	9.3	1.9	13.3	7.9

nursling tree.[2] Decayed boles often act as nurse logs for western hemlock seedlings in these forests (Minore 1972). Information recorded for each windthrown bole was:

1) bole length (dm);
2) outside bark horizontal and vertical diameters (cm) at 1.3 m from base and top end ;
3) bark cover (%);
4) decay class (I to V for Douglas-fir and I to IV for western hemlock);
5) scar age (yr) or nursling tree age at breast height (1.3 m); and
6) height class and species of largest tree/seedling growing on bole.

The decay classification (Table 2) used was patterned on a system first developed for Douglas-fir by R. Fogel, M. Ogawa, and J.M. Trappe (unpublished) and subsequently modified by Triska and Cromack (1980), Graham and Cromack (1981), and Sollins(1981) for studies of wood decay in the Pacific Northwest. No decay class V western hemlock boles were sampled because western hemlock boles, due to the manner in which they rot, rarely form decay class V boles.

Wind-thrown boles were sampled, if possible, 2 m in from either end of the bole and at its midpoint. Cross sections of the bole 10 cm in thickness were cut with a chainsaw and taken for samples. If the bole diameter at the sampling point exceeded 30 cm, a wedge of a

2. "Nursling trees" are trees which germinated and grew on a dead bole. This bole in turn is referred to as a "nurse log".

Table 2. Decay classification for Douglas-fir and western hemlock logs.

Decay Class	bark cover	smallest branch size	sapwood condition	heartwood condition
I	100%	fine	clear/stained	clear
II	80-100%	medium/coarse	stained	<20% stained
III	40-80%	coarse/none	rotted/sloughing	>20% but <80% rotted
IV	<40%	stubs/none	sloughing/gone	>80% rotted/sloughing
V	0-10%	none	gone	red, cubical, sloughing

cylinder was cut for the sample. Care was taken, since the pattern of decay was often quite variable, to cut samples which appeared to be representative of the entire cross section and contained proportional amounts of sapwood, heartwood, and bark. In all, 162 Douglas-fir and 98 western hemlock samples were taken.

At each sampling point I recorded:

1. distance from base of the bole (dm);
2. diameter (cm) - horizontal and vertical, both inside and outside the bark (cm);
3. bark cover (%);
4. rot condition -solid, brown, white, or any combination of the three; and
5. decay class (I to V for Douglas-fir; I to IV for western hemlock).

After finishing the field measurements, I placed the samples in plastic bags and took them back to the laboratory for detailed measurements. In some cases where samples were too crumbly to withstand transportation I measured their volumes, excluding bark, in the field by recording the appropriate geometric shape and dimensions of the sample.

At the laboratory, I removed bark from wood. As in the field, volume of the wet wood sample was measured by approximating a geometric form. The bark and wood samples were dried at 60 C for 4 weeks to obtain dry mass. Wood density of samples was calculated as sample dry mass divided by wet volume. Wet volume was used so that field volume measurements could be directly converted to dry mass.

Log age (years since tree death) was assumed equal to the scar age if a scar was located or 50 yr + nursling age if no scar datum was available. Seedling/sapling data collected from logs which also had scar dates indicated that fallen boles were 50-yr-old before nursling trees growing on them were breast high.

Logs were assigned a dbh (diameter at breast height) value equal to outside bark diameter 1.3 m from root base. If bark was absent, dbh was calculated as the measured diameter plus twice the bark thickness of a live tree of similar diameter. Average bole wood density (S) of each log was calculated as the weighted (by diameter^2) mean of its individual wood sample densities (Eq. 1).

$$S = \frac{\sum(sd^2)}{\sum(d^2)} \qquad (1)$$

d = diameter(cm) of bole at sampling point
s = wood sample density (g/cm^3)

The original and current bole wood volumes were determined for each windthrown bole studied at the H.J. Andrews Experimental Forest. Present bole wood volumes were calculated using the Smalian formula for Douglas-fir and the sub-neiloid formula for western hemlock. Smalian formula assumes a paraboloid form (little tree taper) and sub-neiloid formula assumes the frustrum of a neiloid (substantial tree taper). Both formulas use inside bark basal diameter, inside bark top diameter, and bole length to determine bole wood volume. Inside bark diameters were calculated as the outside bark diameter, as measured on the bole, minus twice the bark thickness, as measured at the nearest sample point.

Original bole volumes were determined by calculating the wood mass of a live bole of the same dbh, using a regression equation based on dbh (Gholz et al. 1979). Mass was converted to volume by dividing by the fresh wood density of Douglas-fir (0.47 g/cm^3) or western hemlock (0.41 g/cm^3) (Brown et al. 1949). The percent of the original bole volume of the windthrown tree still remaining as a log was calculated as the present bole volume divided by the original bole volume times 100 and was used to determine the rate of volume loss. This value occasionally exceeded 100% because of the way original volume of a log was calculated. Comparisons of volumes predicted from the regression equation with the volumes calculated from the Smalian or sub-neiloid formulas for completely intact boles revealed that volume overestimates were not correlated with dbh of the bole. Since changes in volume was of interest rather than absolute percent, these overestimates were ignored.

Two measures of bark were used to calculate bark loss rates; percent bark cover and percent of the original bark mass still remaining on the bole. The latter was determined by taking the ratio of the sample bark mass to sample wood volume and dividing by the average of the same ratio for decay class I samples. This ratio should reflect the loss of bark provided that (1) there is no loss of wood volume before complete loss of bark, (2) the bark and wood sample from a sampling point were sampled proportionate to their volume of the bole, and (3) decay class I samples had lost no bark. I included this measure because total bark loss from a bole is a function of both cover loss (amount of bole surface which is void of bark) and gradual thinning or change in density of bark still on the bole.

Results

Decay group and log size distribution:

Datable small windthrows were difficult to find because small boles do not have the force when they fall to scar a live tree. As a result of this difficulty, the dbh distribution of windthrows was skewed towards larger values (Fig. 2). The distribution of bole diameters at the sampling points was broader and more even. Therefore, the sample diameters rather than the dbh of the windthrows were used to define five species-diameter groups (Table 3), hereafter referred to as "decay groups". The decay groups (large,medium, and small Douglas-fir and large and small western hemlock) were used to examine the effect of bole dimension on decay. Approximately the same number of samples belonged to each decay group. Whole boles were also assigned to decay groups on the basis of dbh, but almost all boles fell into the "large" catagory. Both sample and whole bole data were analyzed by decay group. Due to the low number of boles in the small dbh decay groups, the effect of bole dimension could not be assessed accurately with data which were available only on a whole bole basis.

Age versus decay class:

Western hemlock logs were much younger than Douglas-fir logs in the same decay class (Table 4). Mean age of a decay class decreased with decreasing diameter although this relation was not statistically significant (Table 5). For a given decay class, the mean age of

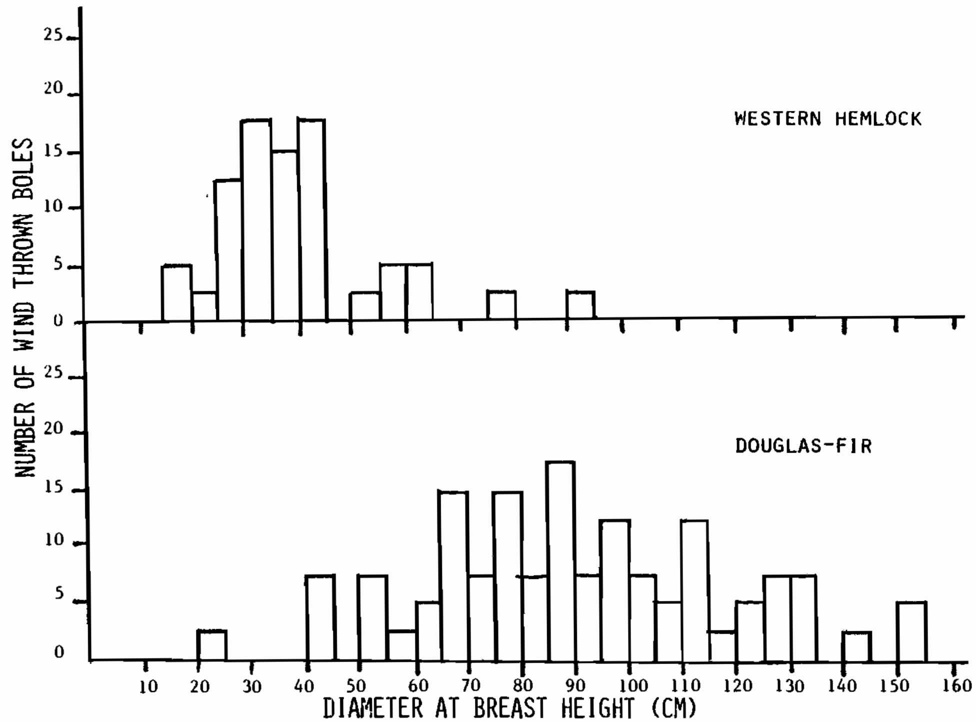

Fig. 2. Frequency distribution, in 5 cm intervals, of dbh (diameters at 1.3 m height) of sampled Douglas-fir and western hemlock windthrown boles.

Table 3. Range of diameter or dbh within decay groups. Log samples were classified by bole diameter at sampling point. Entire boles were classified by bole dbh.

Decay group	range of diameter or dbh
Large Douglas-fir	>65 cm
Medium Douglas-fir	>40 cm <65 cm
Small Douglas-fir	<40 cm
Large western hemlock	>25 cm
Small western hemlock	<25 cm

Table 4. Age in years of Douglas-fir and western hemlock windthrown boles by decay class. Standard error of the mean is given in parentheses. (See Table 3 for dbh range within decay groups.)

Decay group	decay class	# of logs	mean age	age range
Large Douglas-fir logs	I	3	20 (13)	3 - 47
	II	10	19 (2)	7 - 27
	III	17	40 (3)	15 - 58
	IV	15	97 (11)	47 - 187
	V	10	169 (13)	126 - 261
Medium Douglas-fir logs	I	-	-	-
	II	2	13 (2)	11 - 16
	III	1	30	30
	IV	1	51	51
	V	5	169 (26)	157 - 187
Small Douglas-fir logs	I	-	-	-
	II	-	-	-
	III	1	12	12
	IV	-	-	-
	V	-	-	-
Large western hemlock logs	I	2	6 (3)	3 - 8
	II	15	13 (1)	7 - 20
	III	7	21 (2)	15 - 29
	IV	8	31 (3)	20 - 45
Small western hemlock logs	I	-	-	-
	II	1	14	14
	III	-	-	-
	IV	2	17 (11)	6 - 27
All Douglas-fir logs	I	3	20 (13)	3 - 47
	II	12	18 (2)	7 - 27
	III	19	38 (3)	15 - 58
	IV	16	95 (11)	47 - 187
	V	15	169 (9)	126 - 261
All western hemlock logs	I	2	6 (3)	3 - 4
	II	16	13 (1)	7 - 20
	III	7	21 (2)	15 - 29
	IV	10	28 (3)	20 - 45

Table 5. Age in years of Douglas-fir and western hemlock samples by decay class from windthrown boles. Standard error of the mean is given in parentheses. (See Table 3 for range of diameters in decay groups.)

Decay Group	decay class	# of samples	mean age	age range
Large	I	7	26 (6)	10 - 47
Douglas-fir	II	17	33 (4)	3 - 52
samples	III	16	50 (6)	16 -108
	IV	4	110 (24)	79 -187
	V	2	160 (0)	160
Medium	I	4	14 (5)	3 - 25
Douglas-fir	II	10	18 (2)	7 - 27
samples	III	22	54 (7)	16 -123
	IV	19	96 (11)	26 -174
	V	7	165 (8)	141 -193
Small	I	0		
Douglas-fir	II	10	16 (4)	3 - 47
samples	III	12	36 (5)	16 - 79
	IV	17	86 (15)	16 -261
	V	13	152 (12)	30 -197
Large	I	2	8 (0)	8
western hemlock	II	21	14 (2)	3 - 45
samples	III	16	22 (2)	10 - 45
	IV	11	28 (2)	20 - 39
Small	I	1	3 (0)	3
western hemlock	II	14	14 (2)	7 - 15
samples	III	20	13 (1)	6 - 18
	IV	10	26 (3)	20 - 31
All	I	11	21 (4)	3 - 47
Douglas-fir	II	37	25 (2)	3 - 52
samples	III	50	48 (4)	16 -108
	IV	42	93 (8)	16 -261
	V	22	157 (8)	30 -197
All	I	3	6 (2)	3 - 8
western hemlock	II	35	14 (2)	3 - 45
samples	III	36	17 (1)	6 - 45
	IV	24	27 (1)	20 - 39

entire Douglas-fir logs tended to be less than that of individual Douglas-fir samples.

Wood density versus decay class:

The mean wood density for samples of a given decay class and species was remarkably consistent across all decay groups (Table 6). Douglas-fir wood was denser than western hemlock wood for every decay class and particularly, for decay class IV. For Douglas-fir but not western hemlock, average wood density of entire boles was higher than average wood density of individual samples in a given decay class.

Respiration rates:

Respiration rates were determined through regression analysis using log age and wood density as independent and dependent variables respectively. A logarithmically transformed exponential decay model (Eq. 2) was used to determine the respiration rates (k) of each decay group (Table 7).

$$\ln(s) = b - k(t) \qquad (2)$$

s = wood density of sample or bole (g/cm^3)
t = age of sample or bole (yr)
k = respiration rate (yr^{-1})
b = constant

Graphs of bole wood density versus years since tree death showed no inflections in the decay curve (Fig. 3); respiration rates were apparently independent of bole age. Wood from western hemlock boles

Table 6. Density of Douglas-fir and western hemlock wood by log decay class based on wood sample densities and weighted average wood density of entire boles. Standard error of the mean is given in parentheses. (See Table 3 for range of diameters within decay groups.)

Decay group	Decay class	# of samples	# of logs	wood sample density (g/cm3)	bole wood density (g/cm3)
Large Douglas-fir	I	7	3	0.433 (0.018)	0.449 (0.040)
	II	17	10	0.335 (0.022)	0.350 (0.015)
	III	16	17	0.307 (0.024)	0.328 (0.013)
	IV	4	15	0.123 (0.011)	0.222 (0.025)
	V	2	10	0.154 (0.002)	0.145 (0.014)
Medium Douglas-fir	I	4	-	0.432 (0.021)	-
	II	10	2	0.345 (0.034)	0.445 (0.022)
	III	22	1	0.279 (0.020)	0.336
	IV	19	1	0.219 (0.025)	0.168
	V	7	5	0.132 (0.011)	0.183 (0.026)
Small Douglas-fir	I	-	-	-	-
	II	10	-	0.357 (0.019)	-
	III	12	1	0.283 (0.022)	0.358
	IV	17	-	0.188 (0.013)	-
	V	13	-	0.153 (0.015)	-
Large western hemlock	I	2	2	0.377 (0.033)	0.361 (0.013)
	II	21	15	0.292 (0.017)	0.286 (0.016)
	III	16	7	0.265 (0.019)	0.274 (0.025)
	IV	12	8	0.142 (0.011)	0.168 (0.013)
Small western hemlock	I	1	-	0.458	-
	II	14	1	0.286 (0.018)	0.299
	III	19	-	0.220 (0.011)	-
	IV	11	2	0.158 (0.012)	0.203 (0.043)
Douglas-fir	I	11	3	0.433 (0.013)	0.449 (0.040)
	II	37	12	0.344 (0.014)	0.366 (0.017)
	III	50	19	0.289 (0.013)	0.330 (0.012)
	IV	40	16	0.196 (0.014)	0.218 (0.024)
	V	22	15	0.146 (0.010)	0.157 (0.013)
western hemlock	I	3	2	0.404 (0.033)	0.361 (0.013)
	II	35	16	0.290 (0.012)	0.287 (0.015)
	III	35	7	0.241 (0.011)	0.274 (0.025)
	IV	23	10	0.150 (0.008)	0.175 (0.013)

Table 7. Respiration rates (k) as determined by the regression model of wood density versus age of windthrown bole using density of individual samples and the weighted average wood density of entire boles. (See Table 3 for diameter and dbh range of decay classes.)

	model based on individual samples			model based on entire boles		
Decay Group	# of samples	k (yr^{-1})	r^2	# of logs	k (yr^{-1})	r^2
Large Douglas-fir	46	0.0064	0.356	55	0.0062	0.682
Medium Douglas-fir	62	0.0055	0.432	9	0.0045	0.518
Small Douglas-fir	52	0.0043	0.428	1	-	-
Large western hemlock	50	0.0250	0.370	32	0.0244	0.513
Small western hemlock	45	0.0123	0.122	3	-	-
Douglas-fir	160	0.0053	0.421	65	0.0058	0.6503
western hemlock	96	0.0185	0.231	35	0.0211	0.3898

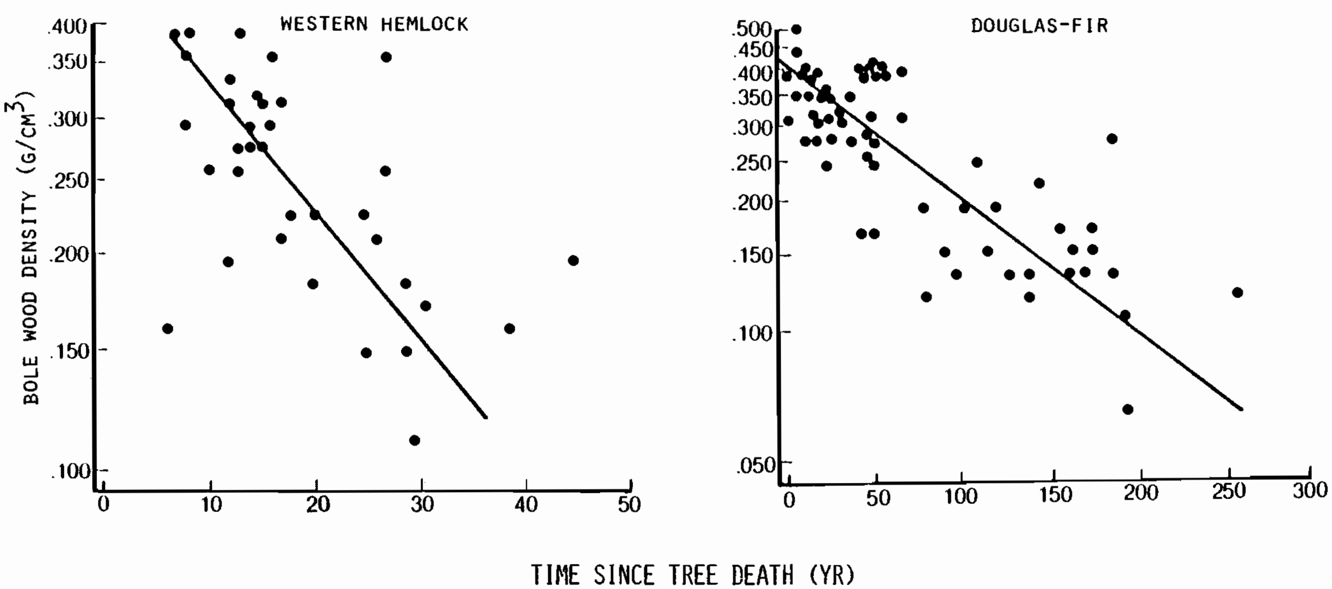

Fig. 3. Wood density of windthrown boles in relation to time since tree death. Regression line from which respiration rate was determined is shown.

of any dimension was respired significantly faster than Douglas-fir wood (Table 7). Respiration rates appeared to decrease with decreasing diameter but such differences were not statistically significant ($p > .05$) due to the large amount of unexplained variability in the data ($r^2 < .50$). Likewise there was no statistically significant difference in decay rates calculated from individual wood sample densities or the weighted average density of entire boles.

Log fragmentation:

On the basis of graphs of the percent of the original bole volume remaining versus age of the bole (Fig. 4), I ran 2 sets of regressions to determine fragmentation rates. I regressed the natural logarithm of the percent of original bole volume remaining against bole age first using all logs and then using only decay class IV and V logs because the graphs indicated that fragmentation did not begin until decay class IV. Because the volume data were collected on the entire boles not the individual samples, the data for the small dbh decay groups were too limited to analyse the effect of bole dimension on fragmentation.

The fragmentation rate (rate of volume loss) varied between species (Table 8). Douglas-fir showed no loss of original bole volume for the first 80 years of decay until it reached a decay class IV state. However, once a bole had reached that state there was a steady erosion of bole volume until by age 270 only 20% of the original bole volume remained. In contrast western hemlock boles showed no decrease

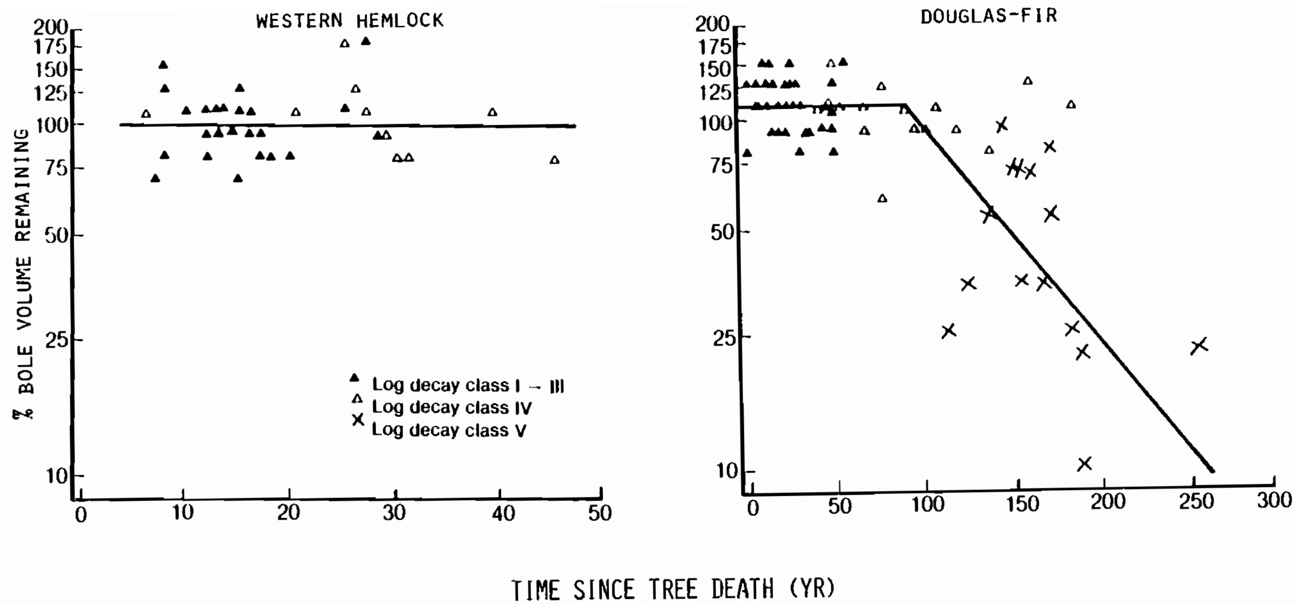

Fig. 4. Percent of original bole volume still remaining in relation to time since death of windthrown trees. Decay class I to III boles are shown as solid triangles; decay class IV boles as open triangles; and decay class V boles as crosses. Regresssion lines from which fragmentation rates were determined are shown.

Table 8. Fragmentation rates for Douglas-fir and western hemlock logs based on volume data from all windthrown boles and only decay class IV and V boles. (See Table 3 for range of dbh within decay groups.)

	Fragmentation rates based on data from all decay classes			decay classes IV and V		
Decay Group	rate (yr-1)	r^2	n	rate (yr-1)	r^2	n
All Douglas-fir	0.00630	.505	65	0.0082	.401	31
Large Douglas-fir	0.00640	.481	55	0.0082	.315	25
Medium Douglas-fir	0.00630	.630	10	-	-	-
All western hemlock	0.00059	.001	35	-	-	-

in volume with age, although individual bole values for the percent of the original bole volume which remained varied greatly at any age.

Bark loss:

Loss of bark from samples in each of the five decay groups appeared to follow an exponential curve, regardless of whether bark loss was based on change in percent of original bark mass still remaining on the sample or change in percent bark cover on sample (Figs. 5 and 6). To determine bark loss rates for each decay group, I regressed the natural logarithm of decay class averages for percent bark cover and percent of original bark mass still remaining against average decay class age for each decay group. Decay class averages were used rather than individual sample data because many of the sample bark values were zero and if transformed logarithmically, had a value of negative infinity. Both Douglas-fir and western hemlock showed increasing bark loss rates with decreasing diameter (Table 9). The species differed in that bark loss rate as determined by bark cover and bark loss rate as determined by percent of original bark mass still remaining were almost identical for Douglas-fir but not for hemlock.

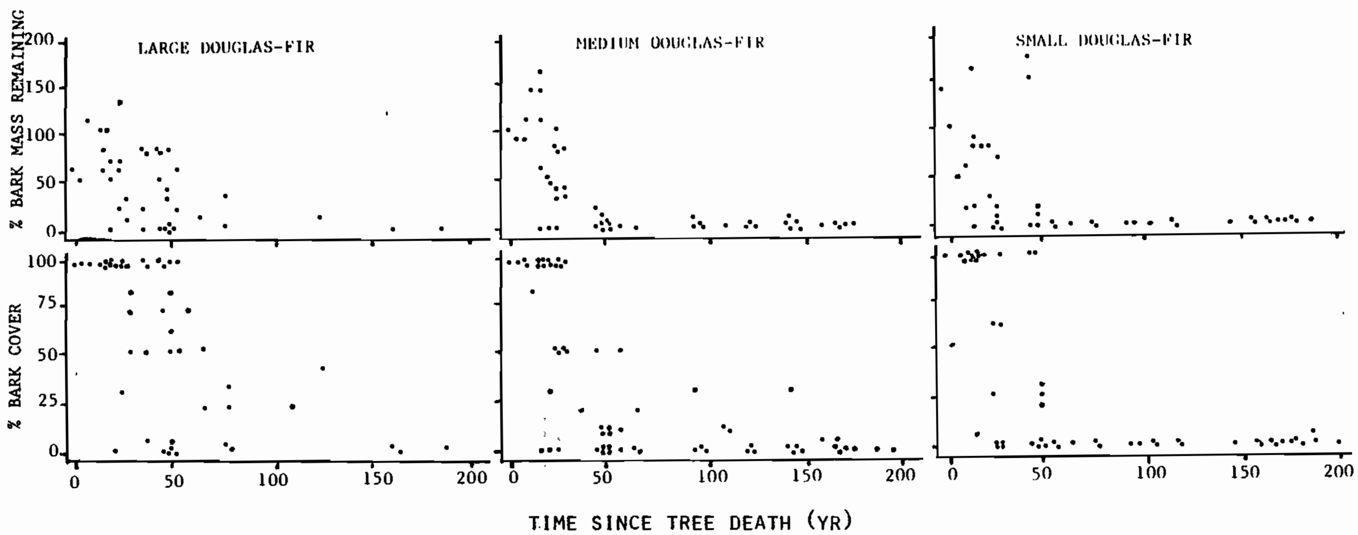

Fig. 5. Percent of the original bark cover and mass remaining on samples taken from windthrown Douglas-fir trees in relation time since tree death. Bole diameter at sampling point determined decay group (large, medium, or small). See Table 3 for more detail on decay groups.

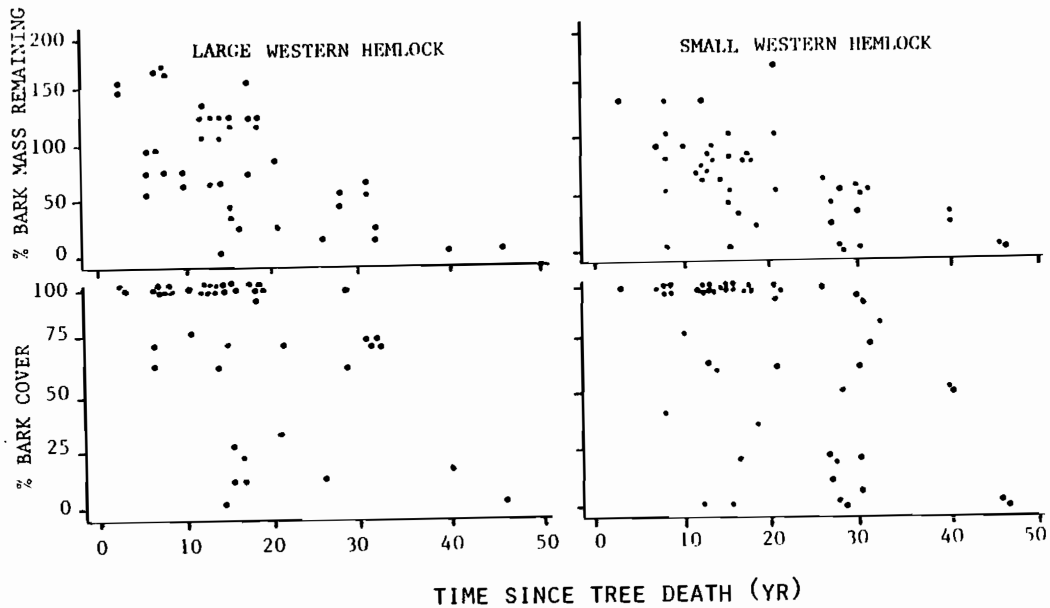

Fig. 6. Relation of the percent of the original bark cover and mass still remaining on samples taken from windthrown western hemlock trees and the number of years since tree death. Bole diameter at sampling point determined decay group (large or small). See Table 3 for more detail on decay groups.

Table 9. Bark loss rates for Douglas-fir and western hemlock as determined using percent of original bark mass remaining on bole and using percent bark cover. (See Table 3 for diameter range within decay groups.)

Decay Group	% bark mass remaining rate (yr^{-1})	r^2	% bark cover rate (yr^{-1})	r^2
Large Douglas-fir	0.020	.909	0.021	.986
Medium Douglas-fir	0.023	.908	0.018	.965
Small Douglas-fir	0.034	.981	0.039	.978
Large western hemlock	0.021	.746	0.019	.674
Small western hemlock	0.065	.930	0.026	.979

Discussion

All told, the data revealed a complex and sometimes contradictory picture of log decay as it related to time, size of bole, and species. Some of the variablity of the data was due to methodology. Therefore, before exploring the results, I will discuss some of the problems inherent in the measurements.

Error analysis:

Decay class- Changes in bole appearance with decay were continuous but decay classification was necessarily discrete; therefore, assignment of a bole to a decay class was subjective. In addition, a large variance associated with decay class values was expected because within a decay class there should have been an even rather than normal distribution of ages and densities, since a class represented a segment of a continuum rather than a discrete type.

Density- Density determinations were based on previous experience with wood samples (Lambert 1980, Lambert et al. 1980). I estimate errors using this method at ± 10% , if volume is measured in the field, ± 20%. Errors were also incurred by not knowing the original density of the sample before decay. In using a regression model of wood density against age to determine respiration rate, it was assumed that decayed boles with equivalent wood densities had lost the same proportion of their original wood to respiration. Because the density of fresh Douglas-fir wood can range between 0.30 g/cm^3

and 0.70 g/cm^3 on a dry weight basis (Kollmann and Cote 1968), equal density in decayed wood does not necessarily reflect equivalent wood losses. Due to the original spread of fresh wood densities, there should have been a spread of decayed wood densities at every log age, even if all the logs had been respired at exactly the same rate. This variability in original wood density must certainly be responsible for some of the variablity in the decay class means and decay regressions.

Age- Ages of the individual decay class V samples were among the least accurate data. Half of the decay class V boles had charcoal. As the ages of all decay class V logs were determined by coring and aging trees growing on them and none of these trees had fire scars, the windthrown boles with charcoal must have burned before the nursling trees started growing. Although 50 yr were added to the cored tree's age at dbh to estimate the down bole's age, the reasoning for adding 50 yr was based upon data from unburned boles. An age comparison of trees growing on class V boles revealed that saplings on burned boles were 30 yr younger than those on unburned boles. Since burned boles were just as decayed as unburned boles, either burned boles had decayed more quickly or seedling establishment had taken longer.

Wind-thrown bole volume- Errors were incurred in estimating both original and current bole volume. Using regression equations based on dbh to predict a bole's original volume gives an approximate value, as boles of the same dbh can have quite different volumes depending on the tree height and taper. In addition, if any sapwood or heartwood had been lost, the measured dbh of a bole underestimated the original dbh and the calculated original volume underestimated the real volume.

Choice of a volume formula (which assumes a certain type of bole taper) greatly influenced calculated present volume. I chose the Smalian formula for Douglas-fir because for intact, unbroken boles it gave values approximately (± 10%) the same as were calculated from the regression equation. I chose the sub-neiloid formula for western hemlock on the recommendation of other workers (Wiley et al. 1978). Also, the volumes calculated for intact boles using the sub-neiloid formula correlated much better with the volumes generated by a regression equation for the same boles than did volumes calculated using the Smalian formula.

Drying boles may shrink (Grier 1978) causing losses in volume but not mass. Shrinkage without actual mass loss will cause overestimation of fragmentation rates. In addition, respiration rates will be underestimated because wood density increases with shrinkage. Since volume losses were not observed in the early decay classes where shrinkage might have been expected, shrinkage losses probably did not affect the fragmentation rates to any significant degree.

<u>Precent of original bark mass still remaining</u>- The ratio of bark mass to wood volume is a function of bole diameter; more so for Douglas-fir than western hemlock (Gholz et al. 1979). This error was partially compensated for by the separation of diameter classes in the decay groups. Variability observed in the regression models of percent bark mass remaining against log age may also have been due to

variability in the original ratios of bark mass to wood volume, even among boles of the same diameter. Imperfect sampling of bark and wood may have introduced errors too; chain saw cutting is imprecise even for a skilled sawyer.

General discussion:

Size class differences- No clear relationship between bole dbh or sample diameter and respiration rate was apparent from my data. Arranged by decay class, the data suggested that respiration rate was negatively correlated with bole size because the average age of the individual decay classes decreased with decreasing diameter while average wood density remained the same. However, the hypothesis that decay proceeds more slowly as the surface area to volume ratio decreases (increasing diameter), as others have suggested (Lang and Knight 1979, Lambert 1980, Franklin et al. 1981, Means et al. 1981) and the decay class data would imply, was contradicted by the regressions of wood density versus age. The decay group respiration rates or "k" values (sensu Olson 1963) showed increasing respiration rates with increasing diameter, although the differences were not statistically different ($p > .2$). I ran the regressions eliminating class V samples on the chance that the less reliable age and density values of the decay class V samples might be causing these trends. Removing the class V samples resulted in significantly poorer fits to the models and exaggerated the very trend I had hoped it would eliminate.

Respiration rates of two size classes of Sitka spruce (*Picea sitchensis* (Bong) Carr.) and western hemlock logs on the western coast of the Olympic Peninsula showed decreasing respiration rates with increasing diameter, although the differences between the rates were not statistically significant for either species (Lambert 1980). At the time the lack of significance was attributed to inadequate sample sizes (n=16 and 19 for the two spruce classes and n=18 and 10 for the two western hemlock classes) (Lambert 1980). The data presented here were just as equivocal despite the much larger sample sizes (n=46, 63, and 52 for Douglas-fir size classes and n=50 and 45 for western hemlock). My present hypothesis is that insect activity in these logs is sufficient to increase the surface area vulnerable to fungal attack such that large boles can be respired at the same rate as small ones. Work in progress by my colleagues at Oregon State University should provide a resolution.

Respiration rate- Bole wood respiration as measured by wood density loss was extremely variable. As in previous studies (Grier 1978, Lambert et al. 1980, Graham and Cromack 1981, Means et al. 1981), time since death accounted for only 40 to 60% of the variation in wood density of decaying logs of a given species. A comparison of respiration rates found for Douglas-fir and western hemlock in this study and in others revealed that my rates were similar to those found by other researchers. Respiration rates found for Douglas-fir logs at a slightly higher elevation at H.J.Andrews were 0.0063 yr^{-1} using the scar technique for aging but measuring volume by water displacement (Means et al. 1981). Means also found an exponential decay model (as used in this study) preferable to a linear, asymptotic, or summation exponential decay model for explaining wood density loss.

Grier (1978) reported a lower decay rate (0.0118 yr^{-1}) for western hemlock logs on the coast of Oregon. The respiration rate of western hemlock logs on the coast of the Olympic Peninsula (Lambert 1980) was again less than this study's rate for western hemlock logs of the Cascade Range (0.0124 versus 0.0250 yr^{-1})). A slower wood decay rate in the Coast than Cascade Range was also noted by Wright and Harvey (1967) in their study on rot in beetle-killed Douglas-fir trees. They attributed the slower rate of decay in the Coast Range to the cooler, wetter summers there.

Fragmentation rates- Fragmentation has been found to cause more significant wood losses than respiration in the limited number of bole decay studies that have included both components of decay. Fragmentation (as measured by the difference in total mass loss and wood density loss) accounted for 60% of the overall bole decay rate of balsam fir (*Abies balsamea* (L.) Mill.) in subalpine forests in New England, while respiration (as calculated by loss in wood density) accounted for only 40% of the observed decay rate (Lambert et al. 1980). Sollins (1981) divided annual bole mortality by amount of dead wood present and assumed a steady state condition to estimate a biomass decay rate of 0.028 $^{-1}$ for both standing and down boles in an old growth western hemlock/Douglas-fir forest in southwestern Washington. He suggested that high fragmentation rates produced overall bole decay rates three times greater than the recorded respiration rate for Douglas-fir (Means et al. 1981), the major species in his forest.

Fallen Douglas-fir boles apparently reached decay class IV before fragmentation began. Once they had reached that state however, they fragmented more rapidly than they respired. Fragmentation rates presented here are undoubtably underestimates because the percent of the original bole volume still remaining of class IV and V logs was overestimated. Fragmentation of Douglas-fir boles commenced with decay class IV because by that stage the wood had lost half of its density and was easily broken. Why then, didn't the western hemlock wood also fragment when it reached decay class IV? The answer lay in examining bark loss patterns. Large western hemlock logs lost their bark at about the same rate as Douglas-fir but western hemlock bole wood decayed much more quickly than Douglas-fir bole wood. In fact, bark loss rates in western hemlock were lower than wood respiration rates. Consequently, a western hemlock log still had protective bark when the wood had reached the stage at which it could be readily fragmented. Extremely rotted western hemlock boles were commonly found with completely intact bark. Douglas-fir logs in contrast, had lost most of their bark by the time wood fragmentation began. Western hemlock bark held together and gradually sloughed off from the outer surface while Douglas fir bark, which was thicker and heavier, tended to fall off in chunks exposing the bole wood. Allison et al. (1961) found that Douglas-fir bark was respired only slightly faster than Douglas-fir wood when both were ground and mixed with soil. This suggests that the higher rate of bark loss than wood respiration in Douglas-fir was due to fragmentation of bark from the log rather than respiration of bark.

Douglas-fir and western hemlock logs also differ in the kind of rots which develop in their wood (Buchanon 1940). Decaying Douglas-fir logs are dominated by brown rots. Such rots produce hard, cubical, easily fragmented wood which breaks across grain. Decaying western hemlock is dominated by white rot, which produces a soft, spongy wood that is difficult to fragment. In addition, white rotted wood, which has degraded, thin cell walls, will easily compress under pressure while brown rotted wood, which has intact cell walls rich in lignin, will fall apart. Class IV western hemlock logs, which had very porous wood (.15 g/cm^3), would easily be flattened under a heavy snowpack. Soon after, covered by litter, these boles would "disappear" from the forest floor. This difference in rot types might explain why the decaying western hemlock logs retained their original volume and why class V western hemlock logs were impossible to find. It also suggests profound differences in the nutrient cycles and microfauna of boles of these two species. Certainly a species which took 300 yr to decay and produced a lignin-rich residue would function differently in soil development and as wildlife habitat than a species which rotted away in 50 yr leaving little or no residue.

SECTION II. SNAG DECOMPOSITION

Snag decomposition differs from log decomposition in that decomposition of snags occurs through not only fragmentation and respiration but also "breakage" of the bole. Like fragmentation, breakage reduces the volume of a snag; however, breakage of a snag creates remnant log or logs from the upright bole while fragmentation does not. Breakage, an episodic event, can occur only from the top of the snag while fragmentation, a continuous process, can occur anywhere along the bole.

To determine rates for these three processes, a chronosequence of snags analogous to the chronosequence of windthrown boles used for the log study was needed. Upright dead boles do not leave scars which record their death as do windthrown boles; generally a snag can be aged only if someone recorded the date of its death. In the Pacific Northwest, several ongoing, long-term studies of conifer growth provide records of tree mortality. I chose snags from three of these studies for measuring fragmentation rates and breakage. Snags in these stands were not used to determine snag wood respiration rates because such determinations require sampling the bole wood which necessitates falling the snags. To avoid destroying datable snags which are a rare resource, I chose two of the log study sites at H.J. Andrews Experimental Forest for sampling snags destructively. I used the information on age and appearance gathered from the chronosequence data to then age the H.J. Andrews snags.

Methods

Snag chronosequence study sites:

Black Rock- The Black Rock snags are located in George T. Gerlinger State Experimental Forest (T8S R7W) on the eastern flank of the Coastal Range at 290 m elevation, near the town of Falls River, Oregon. The climate is mild; minimum January and July temperatures are 2.0 and 12.9°C. Precipitation is 200 cm and occurs mainly as winter rain (Berg personal communication). Sixty year old pure Douglas-fir stands occupy the site class II area as a result of natural seeding in after logging early in this century. Some remnant, highly decayed stumps from the original old-growth forest are still evident. The area is the site of a long-term thinning experiment (Berg 1970). As part of the project, diameters at breast height of live trees were marked and measured in thirty-six 0.4 ha plots. All thinned and unthinned plots were annually assessed for growth and mortality. In two unthinned control plots, I surveyed all trees which were recorded as having died since the beginning of the study 29 years ago. All the dead trees, which were on gentle, brush-free slopes, were easily identified by their marking or location.

Mt. Hood- The Mt. Hood snags are located in a stand (T3S R7E) at 580 m,elevation on an east facing 60% slope near Zig Zag, Oregon in the Mt. Hood National Forest. The climate is more severe than at Black Rock with mean January and July temperatures of 0.5 and 15.0°C. Precipitation occurs mostly as snow and winter rains and averages 250cm/yr(Sollins 1981). The 96-yr-old pure Douglas-fir stand developed on the site class IV+ land after a wildfire.

Three 0.4 ha plots were established in this stand by W.H. Meyer of the U.S. Forest Service in 1930 (Williamson 1963) as part of a regionwide growth and mortality study. All live trees were tagged and measured for diameter at breast height. The stand was remeasured in 1934, 1939, 1945, 1952, 1965, 1971, and 1980. I surveyed two plots for tagged trees which the original field records noted as having died between remeasurements.

Wind River: The Wind River snags are located in the T.T.Munger Research Natural Area (T4N R7E) on the Wind River Experimental Forest in the Gifford Pinchot National Forest near Stevenson, Washington. Elevation ranges from 340 m to 610 m over gently undulating terrain. Annual precipitation is 228 cm occurring mostly as winter rain or snow and the mean annual temperature is 8.9°C (King 1961). The site class III^- or IV^+ area is occupied by an old-growth stand composed primarily of Douglas-fir and goodly amounts of western hemlock, Pacific silver fir (Abies amabilis (Dougl.) Forbes), western red cedar (Thuja plicata Donn.), western white pine (Pinus monticola Dougl.), and grand fir (Abies grandis Lindl.). The forest experienced a major bark beetle outbreak in 1949 which killed many Douglas-fir trees.

In 1947 W. Stein, W. Bullard, and R. Steele of the U.S. Forest Service established a series of fifty-seven 0.08 ha circular plots in which all live trees were tagged and measured for diameter at breast height. These plots were remeasured for growth and mortality in 1953, 1959, 1965, 1971, and 1977. I surveyed all plots for tagged trees which were noted as having died between mortality checks during the 33 yr period.

Field Methods:

Fragmentation and breakage- At each site the following information was recorded for all standing dead trees (snags) whose approximate date of death was known from field notes:

1. dbh (cm);
2. height (dm);
3. bark cover (%);
4. crown condition- complete, <1/2 gone, >1/2 gone, or all gone;
5. smallest branch size- fine, medium, coarse, or none; and
6. snag decay class.

In addition, at Wind River and Black Rock, the ground around each snag was searched for identifiable fallen remnants of the original tree bole. If remnant logs greater than 0.5 m in length and of cylindrical form were present, the following information was noted:

1. end diameters (cm)- inside and outside bark;
2. length (dm);
3. bark coverage (%); and
4. log decay class.

A decay classification with three decay classes was developed for snags (Table 10). Only three snag decay classes were chosen because the log decay classification with five decay classes had proven unwieldy on some occasions and required many samples to differentiate classes. The snag classification is applicable to western hemlock and Douglas-fir; it would not be appropriate for species which tend to lose bark and form a shell of hardened sapwood as do many pines.

Respiration- Forty-two Douglas-fir and 37 western hemlock snags were selected for felling and detailed sampling at two log study sites

Table 10. Description of snag decay classes and condition of remnant logs generated from snag. Crown condition refers to the amount of crown still present.

Snag decay class	crown condition	branch size	bark cover	decay class of remnant logs from snag
I	all to <1/2	fine	100%	I or II
II	all to <1/2	medium	80 to 100%	II or III
III	>1/2	coarse	<80%	III to V

which were at 880 and 910 m elevation in the H.J. Andrews Experimental Forest. The selected snags covered the range of snag decay classes within each of the five decay groups (large, medium, and small Douglas-fir, large and small western hemlock; see Table 3 for range of dbh); none had originated from a fire.

Before falling, information like that taken at the chronosequence sites was recorded for each snag. The snags were felled on two consecutive weekends in July of 1980 during the middle of a four wk drought. Felled snags were sampled in the same way as the windthrown boles except that larger samples were taken. Bole diameter, both inside and outside bark, and percent bark cover of the snag were measured at each sampling point. The samples were placed in plastic bags, stored in a cool place, and returned within a week to the laboratory at Corvallis, Oregon. Bark was removed from the samples and outlines of the samples were then traced on newsprint. Samples were weighed wet and the following information recorded:

1. species;
2. diameter (cm);
3. average thickness of sample based on five measurements (cm);
4. sapwood (%) solid or with white or brown rot;
5. sapwood color;
6. sapwood texture- hard, firm, or soft;
7. heartwood (%) solid or with white or brown rot;
8. heartwood color;
9. heartwood texture- hard, firm, or soft;
10. insect activity- surface area affected (%) and;
11. type of insect activity.

Samples were then dried for 4 weeks at 60°C and reweighed.

Calculations:

Snag volume- The Smalian formula was used to calculate snag volumes of Douglas-fir and the sub-neiloid formula was used for western hemlock. The fraction of the bole diameter that was wood (B) was determined using percent bark cover of the snag and assuming a bark thickness of 12 cm for Douglas-fir and 8 cm for western hemlock on 100 cm dbh boles (Eqs.3 and 7). Bole diameter inside the bark was calculated by multiplying the diameter outside bark by this fraction. The diameter of the bole at the top of a snag (d_t) was calculated assuming a taper of 1 cm per meter of heighth for Douglas-fir and 2 cm/m for western hemlock (Eqs. 4, 5 and 8, 9). The equations for determining diameters inside bark and top diameter were developed by Dr. Joe Means at the U.S. Forest Service Forestry Sciences Laboratory in Corvallis, Oregon.

Terms

d_t = outside bark diameter (cm) at top of snag
d_b = outside bark diameter (cm) at breast height of snag
C = percent bark cover on snag
H = height (m)
B = fraction of bole diameter that is wood
V = volume (m^3) of snag bole wood

Sequence of equations for determining wood volume of Douglas-fir snags

$$B = (100 - 12C/100)/100 \quad (3)$$

$$d_t = d_b - (H - 1.37)/1.0 \quad (4)$$

$$d_t' = \max(d_t, 0) \quad (5)$$

$$V = \pi H B^2 (d_t^{2\prime} + d_b^2)/80000. \quad (6)$$

Equations for determining wood volume of western hemlock snags

$$B = (100 - 8\ C/100)/100 \qquad (7)$$

$$d_t = d_b - (H - 1.37)/0.5 \qquad (8)$$

$$d_t' = \max(d_t,\ 0) \qquad (9)$$

$$V = \pi H B^2 (d_t' + d_b)^2 / 160000. \qquad (10)$$

Volume of the remnant logs and original bole volume of the tree were calculated exactly as in the log study. If a remnant log diameter was available for a dead tree, it was substituted for the top diameter.

Snag bole volume, remnant log volume, and the total remaining bole volume of the original dead tree (summation of the snag and log volumes) were divided by original bole volume of the dead tree to make all trees comparable. All volumes were without bark. Dead trees which still had a complete stem were assigned respectively values of 100%, 0% and 100% for the snag, log, and total remaining bole volumes. All snags were presumed to have died at the midpoint of the interval prior to being recorded as dead in a mortality check.

Snag wood density- Wood volume of the snag samples was calculated by taking the average depth of the sample and multiplying it by the area of the sample face. Mass of the cutout tracing of the sample was coverted to area by multiplying paper mass by a standard ratio of area to mass determined from the mass of six 100 cm^2 paper samples. Wood density of the sample was then calculated as dry mass of the sample divided by sample volume. Like bole wood density (average wood density of the entire windthrown bole) in the log study, snag wood density (average wood density of the entire snag bole) was calculated by weighting the wood density of the individual samples by the square of diameter of the bole at the sampling points and taking the weighted average of the samples from a given snag.

Moisture: Sample wood moisture was calculated as the difference in wet and dry wood mass divided by dry mass. Snag wood moisture (average wood moisture of snag bole) was calculated in the same way as snag wood density.

Results

Snag age:

Large boles took longer than small boles to become decay class II or III snags. Thirty years after death none of the large Douglas-fir boles even approached a snag decay class III state while 24 yr after death some of the small Douglas-fir boles had completely disintegrated (Table 11). The assumed age range of the snag classes (Table 11), based on the age distribution of the sampled snags within a decay class, was used to determine the average number of years a snag belonged to a given decay class- the "duration" of a decay class. As the data encompassed a maximum of 50 yr of mortality data, some of the decay classes for the larger diameter trees were not represented in the data set. For such classes the assumed age range was based on snag data from the Coast Range of Oregon (Cline 1978) and on examinations of old fire created snags whose approximate age is known.

Snag fragmentation and breakage:

Breakage and fragmentation of the original dead bole, as reflected by the increase in volume of remnant logs and by the decreasing volume of total bole (snag+remnant) respectively, were highly erratic. Trends in fragmentation and breakage amenable to regression analysis were not present in any of the data sets of the five decay groups (Table 12 and Figs. 7-12). I will therefore, give a descriptive interpretation of snag breakage and fragmentation based on the volume

Table 11. Average age, age range, and decay class of remnant logs of sampled snags with assumed age range and number of years within a decay class (duration of decay class interval). Values were determined from a composite of snag data from all three chronosequence sites. Standard error of the mean is given in parentheses. (See Table 3 for dbh range of decay groups.)

Decay group	decay class	n	Mean age	sampled age range	assumed age range	decay class duration (yr)	log decay class of remnant
Large	I	7	14 (4)	2 - 30	0 - 20	20	2.0
Douglas-fir	II	21	21 (2)	6 - 30	20 - 60*	40	2.7 (0.1)
	III	-	-	-	60*-120*	60	4.0
Medium	I	2	18 (6)	12 - 24	0 - 15	15	-
Douglas-fir	II	4	22 (1)	18 - 24	15 - 40*	25	4.0
	III	-	-	-	40*- 80*	40	
Small	I	35	5 (1)	0 - 12	0 - 8	8	-
Douglas-fir	II	58	13 (1)	5 - 21	8 - 18	10	2.5 (0.1)
	III	46	19 (1)	12 - 24	18 - 40	22	3.2 (0.1)
Large	I	2	2 (0)	2	0 - 5	5	-
western	II	12	12 (1)	6 - 24	5 - 18	13	3.0 (0.3)
hemlock	III	13	23 (2)	12 - 30	18 - 40	22	3.5 (0.3)
Small	I	1	6	6	0 - 5	5	-
western	II	4	18 (2)	12 - 24	5 - 15	10	2.7 (0.3)
hemlock	III	5	19 (1)	18 - 24	15 - 30	15	3.5 (0.3)

* based on Cline (1978)

Table 12. For Wind River and Black Rock snags in the five decay groups, average percent of original bole volume which is (1) still upright, (2) a remnant log, and (3) still remaining ie. not fragmented. Average percent of original bole volume still upright for Mt. Hood snags. Standard error of mean is given in parentheses. (See Table 3 for dbh range within decay groups.)

Decay Group	Decay Class	n	percent of original bole volume upright	remnant log	remaining*
Large	I	7	90 (6)	4 (5)	94 (5)
Douglas-fir	II	21	65 (5)	17 (3)	83 (3)
	III	-	-	-	-
Medium	I	2	100 (0)	0 (0)	100 (0)
Douglas-fir	II	4	76 (4)	1 (1)	77 (4)
	III	-	-	-	-
Small	I	35	95 (3)	2 (2)	98 (1)
Douglas-fir	II	58	61 (4)	23 (4)	84 (3)
	III	46	19 (2)	50 (5)	69 (4)
Large	I	2	100 (0)	0 (0)	100 (0)
western	II	12	52 (8)	26 (9)	78 (6)
hemlock	III	13	25 (8)	46 (12)	71 (9)
Small	I	1	100	0	100
western	II	4	36 (22)	37 (22)	73 (15)
hemlock	III	5	20 (10)	38 (16)	58 (10)
Small	I	22	99 (1)	na	na
Douglas-fir	II	88	62 (3)	na	na
(Mt. Hood)	III	63	33 (3)	na	na

*sum of %upright and %remnant log, represents unfragmented portion of bole data and then show how, on the basis of my interpretation, I calculated specific rates for breakage and fragmentation.

Small Douglas-Fir- The complete range of snag decay (from entirely intact to totally disintegrated boles) was present in the data set of 139 snags from Black Rock. It clearly showed the variability of volume change with snag decomposition (Fig. 7). The set of 140 of the same size snags from Mt. Hood also showed a scattered distribution of volume values at any snag age (Fig. 8). Trends for increasing fragmentation and breakage with age were apparent in the Black Rock data set which had decreasing upright and total (snag +remnant log) bole volumes and increasing remnant log volumes with snag age. The same trends, reflected by decreasing upright bole volume with snag age, were less obvious but still evident in the Mt. Hood data set. (Six to ten year intervals between mortality checks at this site obscured the data trends.) The proportion of snags which had broken to create remnant logs gradually increased with time, but the proportion of the bole volume which had fallen remained random.

In summary, small Douglas-fir boles appeared to break only once and at almost any height 5 to 20 yr after death. The volumes of the remnant varied tremendously but averaged 50% of the original bole volume. After breakage the remaining snag fragmented in place, until 40 yr after its death it was often gone from the forest floor.

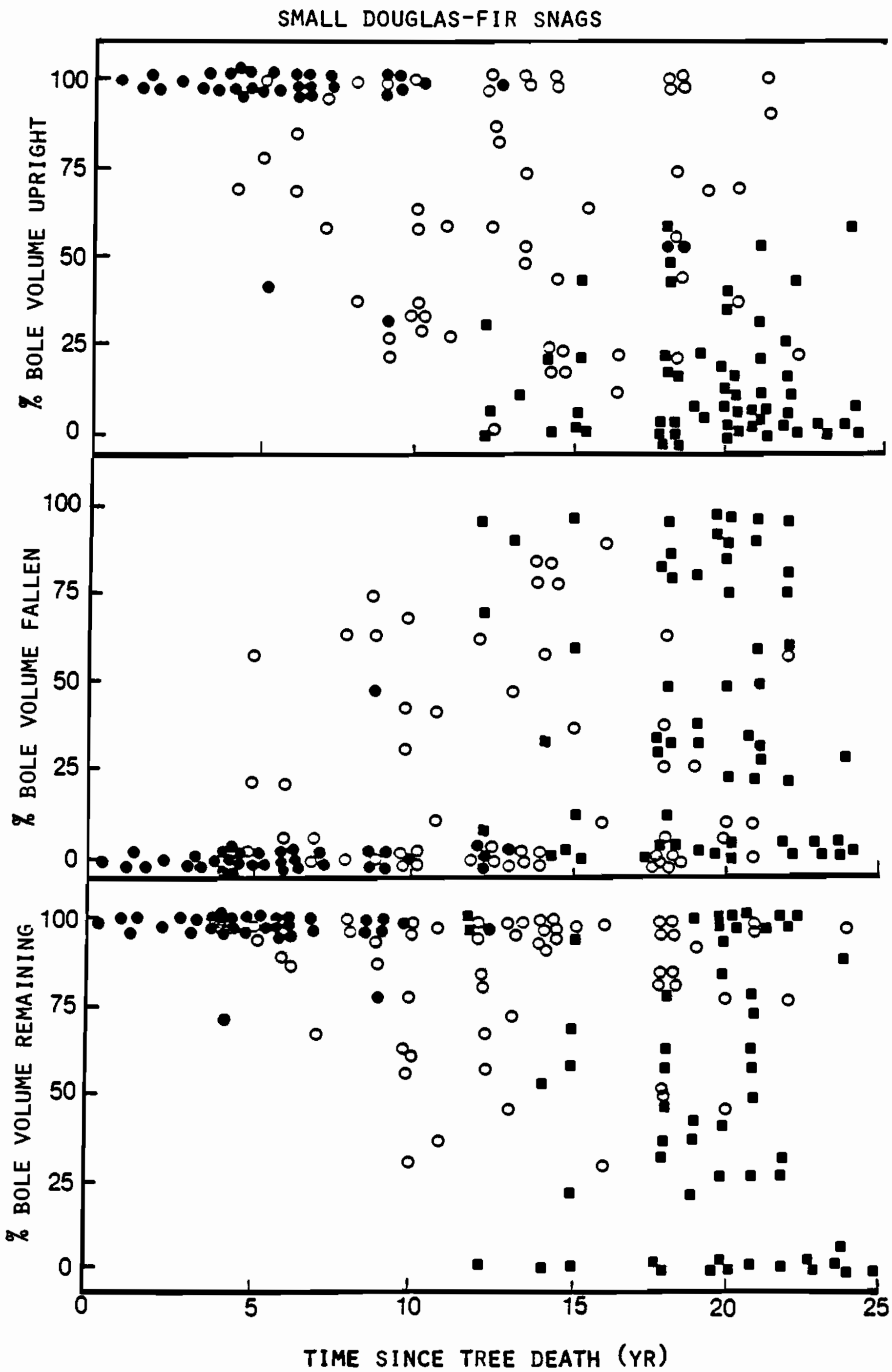

Fig. 7. Fragmentation and breakage of small Douglas-fir snags from Black Rock. Percent of the original bole volume of dead trees which is 1. still upright (top graph); 2. fallen to become a remnant log (middle graph); and 3. not fragmented (lower graph) is plotted against years since tree death. Remnant log volume and upright bole volume were added together to determine the percent of the original bole volume that was still remaining (ie. not fragmented). Decay class I snags are represented by closed circles, class II by open circles, and class III by closed squares.

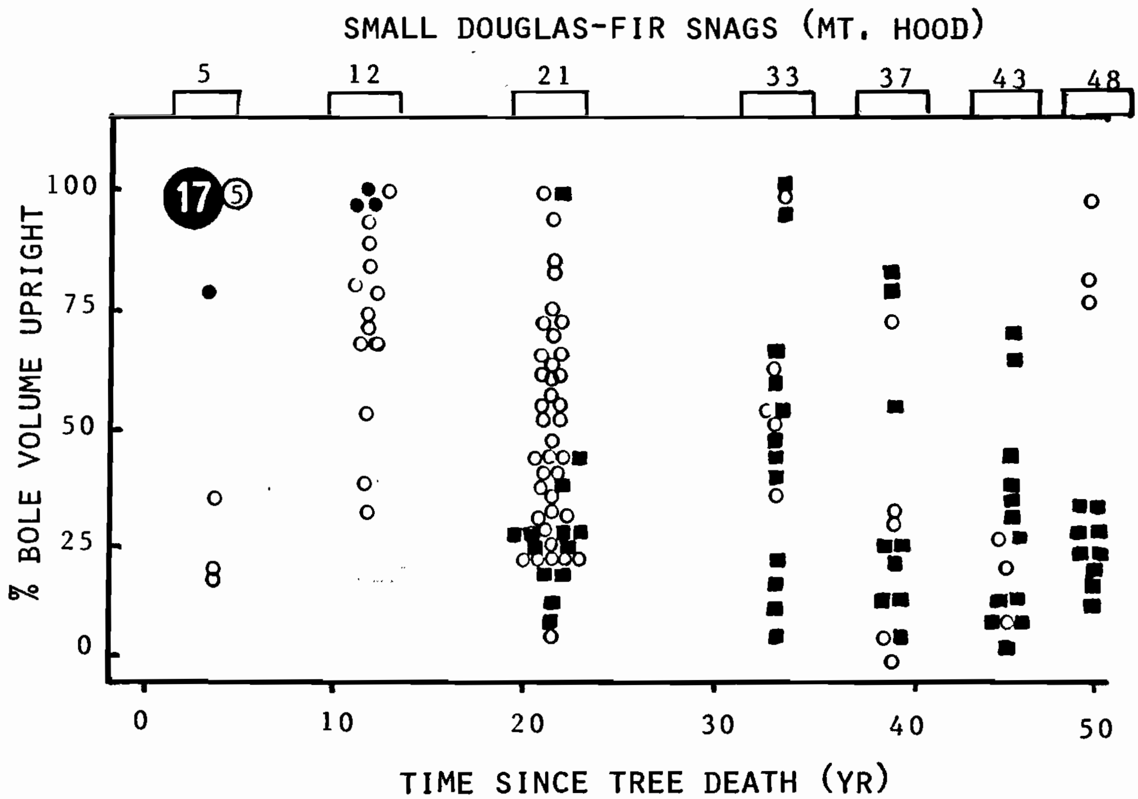

Fig. 8. Fragmentation and breakage of small Douglas-fir snags from Mt. Hood. Only upright volume of snags was measured and mortality checks were infrequent. See caption to Fig. 9 for further explanation of axes and symbols. Data points are clustered at certain years (top graph) because all trees dying between mortality measurements were given the same date of death.

Medium Douglas-fir- Data were inadequate for an accurate assessment of snag volume loss (Fig.9) but they suggested the following scenario which was intermediate between large and small Douglas-fir. There was little or no breakage during snag decay class I. Forty years after death one or two breaks had occurred which put about 40% of the original bole volume of the snag on the ground as remnant logs of log decay class III. Thereafter the remaining upright bole disintegrated in place as a class III snag disappearing after 80 yr.

Large Douglas-fir- The following description of large Douglas-fir snag decay came from combining the Wind River data for the first 30 yr of decay (Fig. 10) with data from Cline (1978) for the remaining 90 yr. Large Douglas-fir snags lost an average of 10% of their bole volume to top breakage in the first 20 yr in decay class I. Over the next 40 yr in decay class II, the snags lost another 50% of their volume due to breakage but very little due to to fragmentation. By year 60 the snag was in decay class III and had begun to fragment more rapidly. The class III snags fragmented for 60 yr until at age 120 yr all that remained of the original bole was a mound or short stump of brown rotted wood.

Small western hemlock- These trees decayed quickly but in a highly variable fashion (Fig. 11). Like small Douglas-fir they did not break as decay class I snags. They broke only once during snag decay class II to produce a remnant log of log decay class III which averaged 40%

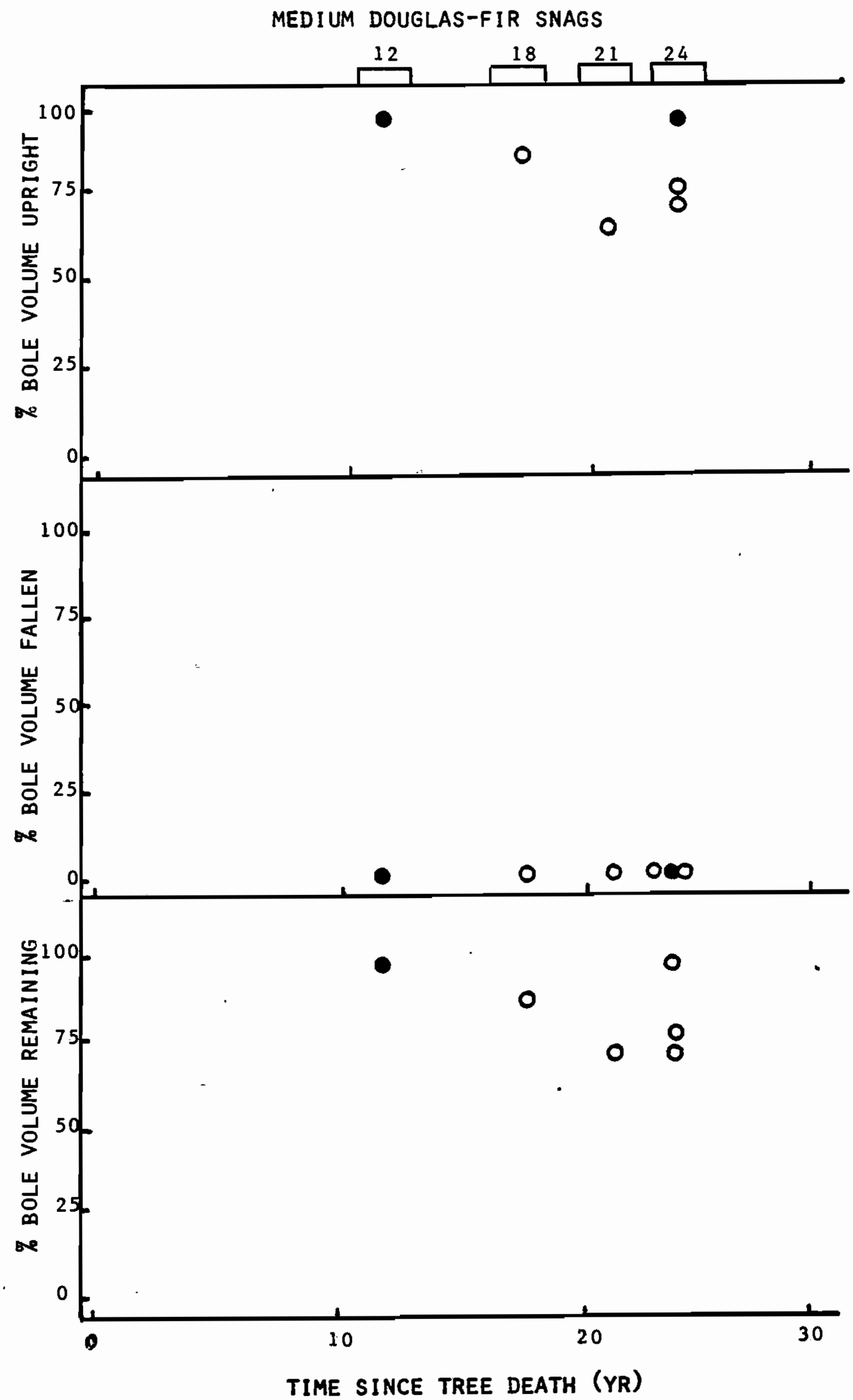

Fig. 9. Fragmentation and breakage of medium Douglas-fir snags from Wind River and Mt. Hood. See caption to Fig. 9 for explanation of axes and symbols. Data points are clustered at certain years (top graph) because all trees dying between mortality measurements were given the same date of death.

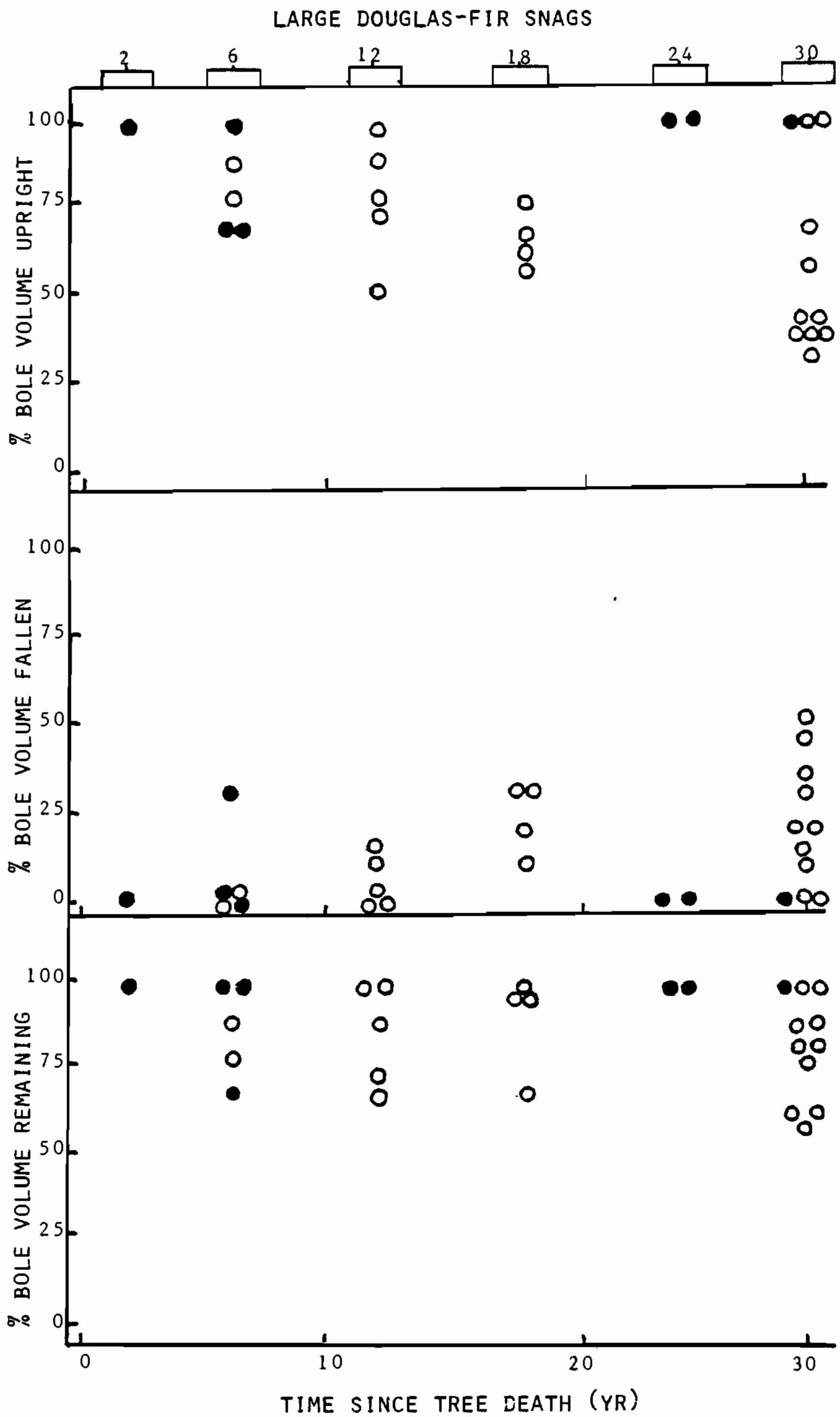

Fig. 10. Fragmentation and breakage of large Douglas-fir snags from Wind River. See caption to Fig. 9 for explanation of axes and symbols. Data points are clustered at certain years (top graph) because all trees dying between mortality measurements were given the same date of death.

of the original bole volume. They often dried out and then broke at the base where it was moist and fungi had rotted the wood. Once the boles had snapped, the remaining snag fragmented rapidly until 24 yr after death 50% of the original bole volume was gone and only 10% of it remained as a snag.

Large western hemlock- Large western hemlock boles disintegrated in much the same fashion as large Douglas-fir boles but faster (Fig.12). Because upright dead western hemlock boles passed through snag decay class I so quickly (5 yr), there was little breakage until snag decay class II. By the end of snag decay class II, 18 yr after death, 50% of the original bole volume was a remnant log of log decay class III and about 25% had fragmented away. By year 30 only 15% of the original bole was still standing.

Snag fragmentation rates and breakage- In order to compare log and snag decomposition it was necessary to calculate a rate for snag fragmentation comparable to that for log fragmentation. As noted before, the snag data, unlike the log study data, did not allow a simple regression analysis of percent of original bole volume remaining against years since tree death. It was therefore, necessary to devise another system for calculating these rates which would reflect the available information(Figs. 7 to 12 and Table 12).

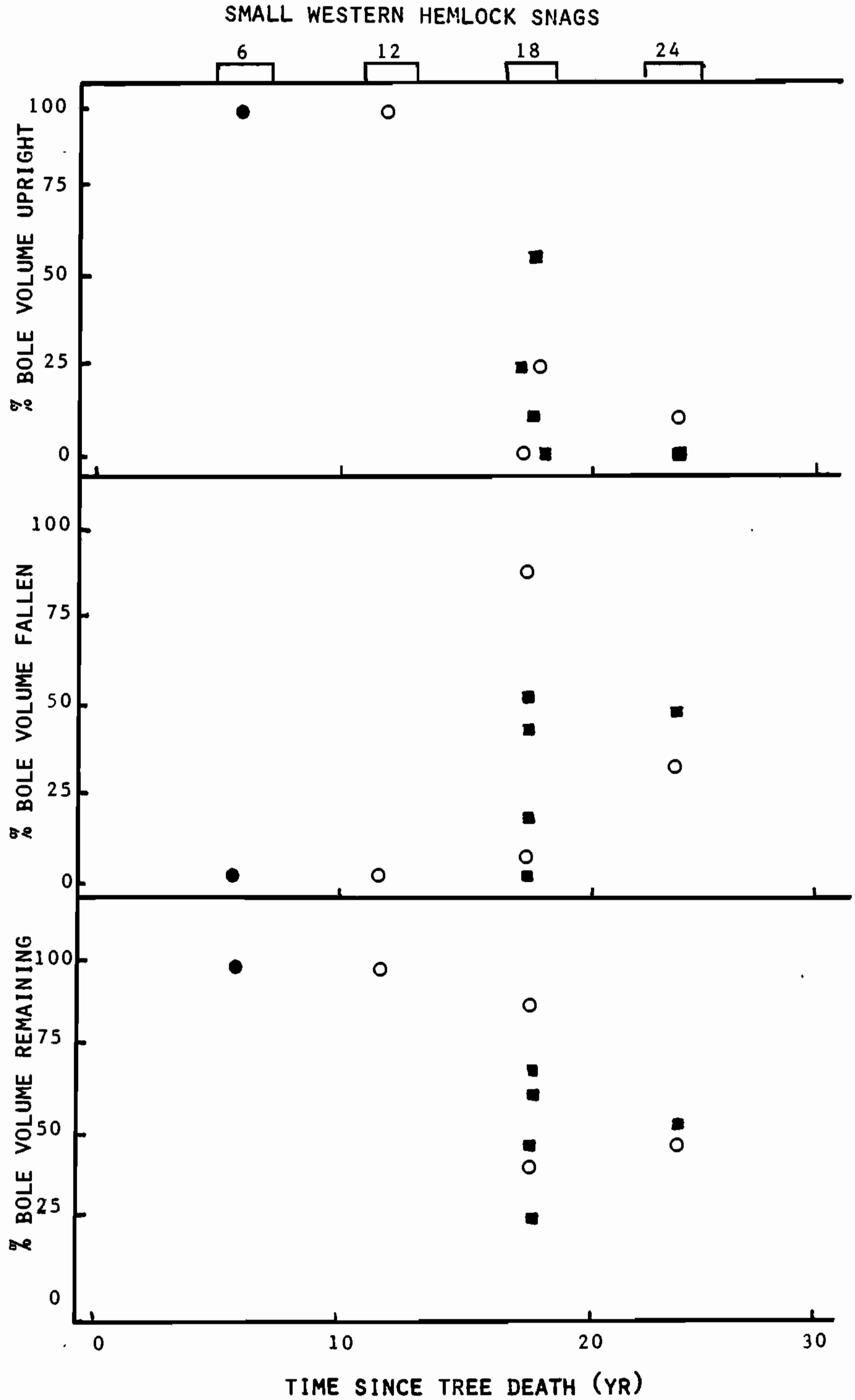

Fig. 11. Fragmentation and breakage of small western hemlock snags from Wind River. See caption to Fig. 9 for explanation of axes and symbols. Data points are clustered at certain years (top graph) because all trees dying between mortality measurements were given the same date of death.

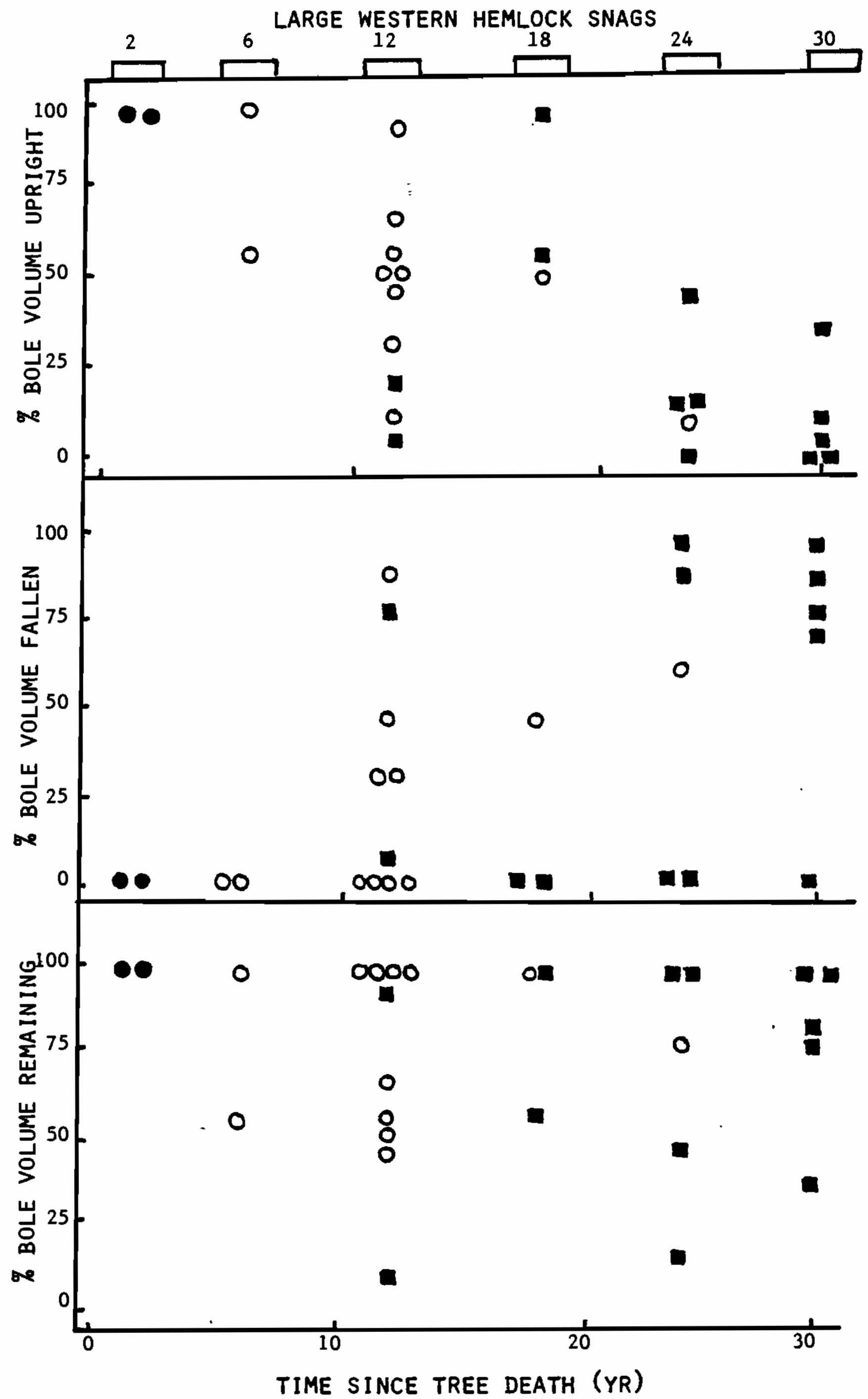

Fig. 12. Fragmentation and breakage of large western hemlock snags from Wind River. See caption to Fig. 9 for explanation of axes and symbols. Data points are clustered at certain years (top graph) because all trees dying between mortality measurements were given the same date of death.

Based on the collective data, representative values for each snag decay class were selected for: 1. the duration of the snag decay class interval (number of years in the decay class state); 2. the percentage of the original bole volume at the beginning and end of the snag decay class interval which was still upright; and 3. the percentage of the original bole volume which was a remnant log at the beginning and end of the decay class interval (Table 13). Two simplifying assumptions were then made: 1. the amount of breakage that had occurred over a decay class interval was equal to the difference in the percent of the original bole volume which was a remnant log at the beginning and at the end of said decay class interval and 2. breakage occurred only once and at the midpoint of the snag decay class interval.

Percent breakage (B) was defined as the percent of the snag volume which became a log at the midpoint of the decay class interval. Then, using an exponential decay function to describe fragmentation losses (as was done in the log study), Eqs. 11 to 13 defined the reduction in volume of a dead upright bole over a given snag decay class interval.

Volume loss of the upright bole due to fragmentation from beginning to midpoint of snag decay class interval.

$$S = S_i \exp(-0.5Fd) \qquad (11)$$

Percent of the upright bole volume which becomes a remnant log due to breakage at the midpoint of the snag decay class interval.

$$B = (R_f - R_i)100/S \qquad (12)$$

Volume loss of the upright bole due to fragmentation after breakage until end of snag decay class interval.

$$S_f = 0.01S(100-B)\exp(-0.5Fd) \qquad (13)$$

Where,

S = percent of original bole volume which is upright at midpoint of decay class interval before breakage

B = percent of snag which becomes a remnant log

F = fragmentation rate of snag (yr^{-1})

S_i = percent of original bole volume which is upright at beginning of snag decay class interval

S_f = percent of original bole volume which is upright at end of snag decay class interval

d = duration of snag decay class interval (yr)

R_i = percent of the original bole volume which is a log remnant at beginning of snag decay class interval

R_f = percent of the original snag volume which is a log remnant at end of snag decay class interval

These three equations were solved for fragmentation rate (F) and breakage of snags (B) in all snag decay classes (Table 14). Fragmentation rates increased with decreasing diameter and with increasing decay (as denoted by decay class). Western hemlocks converted about the same proportion of their original bole volume to remnant logs as Douglas-firs but western hemlocks fragmented much more quickly.

Table 13. Values used in Eqs. 11 to 13 to determine snag fragmentation rates and percent breakage. S_i and S_f are respectively the percent of the original bole volume remaining as a snag at the beginning and at the end of the snag decay class interval. R_i and R_f are respectively the percent of the original bole volume remaining as a remnant log at the beginning and at the end end of the snag decay class interval. "d" is the length of time a snag is in a given decay class. (See Table 3 for dbh range within decay groups.)

		Equation values				
Decay Group	decay class	S_i (%)	S_f (%)	R_i (%)	R_f (%)	d (yr)
Large Douglas-fir	I	100	90	0	10	20
	II	90	20	10	60	40
	III	20	1	60	60	60
Medium Douglas-fir	I	100	100	0	0	15
	II	100	40	0	40	25
	III	40	1	40	40	40
Small Douglas-fir	I	100	100	0	0	8
	II	100	30	0	50	10
	III	30	1	50	50	22
Large western hemlock	I	100	100	0	0	5
	II	100	25	0	50	13
	III	25	1	50	50	22
Small western hemlock	I	100	100	0	0	5
	II	100	25	0	40	10
	III	25	1	40	40	15

Table 14. Snag fragmentation rate and percent breakage by decay class and decay group as determined from Table 13 and Eqs. 11 to 13. (See Table 3 for dbh range within decay groups.)

Decay group	snag decay class	fragmentation rate (yr^{-1})	breakage (%)
Large Douglas-fir	I	0	0.10
	II	0.010	0.67
	III	0.050	0
Medium Douglas-fir	I	0	0
	II	0.012	0.46
	III	0.092	0
Small Douglas-fir	I	0	
	II	0.032	0.59
	III	0.15	0
Large western hemlock	I	0	0
	II	0.032	0.62
	III	0.15	0
Small western hemlock	I	0	0
	II	0.061	0.54
	III	0.21	0

Snag wood density and moisture content:

Average snag wood density of the sampled snags at the H.J. Andrews decreased by 30% going from decay class I to III (Table 15). There appeared to be no diameter and/or species effect on wood density within a given decay class. The moisture content of the snag wood increased going from decay class I to III, particularly for Douglas-fir snags (Table 15). In addition, small snags tended to be drier than their larger counterparts.

Snag wood respiration rate:

Respiration rates for snag wood were calculated for each of the five decay groups (Table 16) by regressing the natural logarithm of the average wood density of a snag decay class against the snag age at the midpoint of the decay class interval. Smaller snags respired more quickly than larger ones if they were Douglas-fir but not if they were western hemlock. In general western hemlock snag wood respired more rapidly than did Douglas-fir, although small Douglas-fir snags had faster respiration rates than small western hemlock snags.

Bark cover on snags:

Bark was retained longer on Douglas-fir snags than it was on western hemlock snags and smaller boles lost their bark faster than larger ones. However, within a decay class, the percent bark cover was constant both within and between species (Table 17). The H.J. Andrews and the snag chronosequence data were not combined because at H.J. Andrews the specific age of the snags was unknown but the data set

Table 15. Average snag wood density and percent wood moisture of snags from the H.J. Andrews. Standard error of the mean is shown in parentheses. (See Table 3 for dbh range within decay groups.)

Decay Group	snag decay class	n	average density content (g/cm^3)		average moisture (% dry weight)	
Large	I	5	0.385	(0.032)	67	(13)
Douglas-fir	II	4	0.375	(0.017)	109	(37)
	III	11	0.322	(0.045)	154	(33)
Medium	I	1	0.475		39	
Douglas-fir	II	5	0.307	(0.072)	73	(22)
	III	4	0.237	(0.057)	124	(67)
Small	I	1	0.473		28	
Douglas-fir	II	6	0.368	(0.037)	61	(11)
	III	4	0.240	(0.056)	228	(115)
Large	I	10	0.379	(0.026)	72	(10)
western	II	11	0.363	(0.093)	55	(9)
hemlock	III	6	0.254	(0.035)	121	(27)
Small	I	5	0.459	(0.029)	43	(6)
western	II	2	0.377	(0.093)	43	(2)
hemlock	III	3	0.319	(0.027)	99	(34)
Douglas-fir	I	7	0.411	(0.027)	58	(11)
	II	15	0.350	(0.028)	78	(13)
	III	19	0.287	(0.027)	163	(32)
western	I	15	0.406	(0.021)	62	(8)
hemlock	II	13	0.365	(0.018)	53	(7)
	III	9	0.276	(0.026)	113	(20)

Table 16. Snag wood respiration rate by decay group as determined by regression of mean wood densities against midpoint ages of snag decay classes. (See Table 3 for dbh range within decay groups.)

Decay Group	n	respiration rate (yr^{-1})	r^2
Large Douglas-fir	4	0.003*	.97
Medium Douglas-fir	3	0.013	.96
Small Douglas-fir	3	0.027	.99
Large western hemlock	3	0.016	.98
Small western hemlock	3	0.017	.98

* included an initial density value of 0.470 at 0 years.

Table 17. Average percent bark cover by decay class of chronosequence and of felled H.J. Andrews snags. (Black Rock and Mt. Hood small Douglas-fir snags are shown separately.) Standard error of the mean is shown in parentheses. (See Table 3 for dbh range within decay groups.)

Decay Group	decay class	n	Chronosequence bark cover (%)	n	H.J. Andrews bark cover (%)
Large	I	7	96 (3)	5	100 (0)
Douglas-fir	II	21	92 (3)	4	92 (1)
	III	-	-	11	46 (5)
Medium	I	2	96 (0)	1	100
Douglas-fir	II	4	92 (2)	5	91 (8)
	III	-	-	4	66 (19)
Small	I	35	100 (0)	1	100
Douglas-fir	II	58	92 (3)	6	73 (8)
(Black Rock)	III	46	86 (3)	4	56 (25)
Small	I	22	100 (0)		
Douglas-fir	II	88	88 (2)		
(Mt. Hood)	III	63	71 (4)		
Large	I	2	100 (0)	10	94 (3)
western	II	12	94 (3)	11	89 (4)
hemlock	III	13	46 (7)	6	64 (8)
Small	I	1	100	5	100 (0)
western	II	4	88 (5)	2	53 (42)
hemlock	III	5	55 (14)	3	98 (2)

covered the ranges of snag conditions in all decay classes while the converse was true for the chronosequence data set.

Snag bark loss rate:

Bark lost from a snag may be divided into- 1. bark lost from the portion of the snag that is fragmenting and 2. bark lost from the portion of the snag that is still upright. If a snag always maintains 100% bark cover even as its volume decreases due to fragmentation and breakage, then the bark loss rate of the snag is equivalent to the wood fragmentation rate. If however, a snag loses all of its bark before significant fragmentation occurrs, then the snag bark loss rate can be calculated as the change in percent bark present on the snag with time, as was done in the log study.

The rate of loss of bark from the remaining upright bole and the rate of loss due to snag fragmentation together determine the total bark loss rate. Rate of loss of bark on the upright bole (Table 18) was calculated by regressing the natural logarithm of average percent bark cover against mean snag age for each decay class in each decay group. The midpoint of the decay class interval was used for the mean age of the undated H.J. Andrews snags. Average rate of bark loss due to snag fragmentation (Table 18) was calculated for each decay group by weighting the previously calculated wood fragmentation rate of each decay class by the length of the decay class interval and determining the weighted average for the decay group. Western hemlock snags lost their bark more readily than did Douglas-fir because the western hemlock boles fragmented faster. Likewise small boles lost their bark sooner than large ones because of the small boles' faster fragmentation rates.

Table 18. Rate of bark loss due to snag fragmentation, rate of loss of bark on remaining upright bole, and total snag bark loss rate. (rate of bark loss due to fragmentation + rate of loss of bark on remaining bole = total snag bark loss rate)

Decay group	Rate of loss due to snag fragmentation (yr^{-1})	rate of loss on remaining upright bole (yr^{-1})	Total bark loss rate (yr^{-1})
Large Douglas-fir	.028	.0095	.038
Medium Douglas-fir	.050	.0082	.058
Small Douglas-fir	.091	.015	.11
Large western hemlock	.074	.022	.096
Small western hemlock	.13	.011	.14

Discussion

Error analysis:

Snag fragmentation and breakage - Numerous assumptions were made in calculating original, upright, and remnant log volumes of dated dead trees at the three snag chronosequence sites. As with windthrown boles in the log study, original bole volumes were based on regression equations rather than actual measurement. Error was also incurred in the calculation of upright volumes of dead trees by assuming or calculating rather than measuring: 1. bole taper; 2. bark thickness; and 3. top diameter. Remnant log volumes have the same measurement errors as the previously discussed volumes of windthrown boles. In addition, remnant log volumes were probably underestimated due to difficulties in locating and identifying all fallen log remnants from a given snag.

Calculation of fragmentation rates and breakage was further confounded by trees which were broken topped before they died. Low volume values for such trees would inflate the fragmentation rate unless the broken top was included as a remnant log. One final source of error came from dating snags; with 10-yr intervals between some mortality checks, a dead tree could be + 5 yr older than the age (midpoint of the interval) that it was given.

Snag wood density- I feel more confident about tracing than any other method that I have used to measure volume of decaying wood, provided that the samples are sufficiently thick that sample depth can be measured with three or more significant digits. I estimate the volume error with this tracing method to be +5%. As there is virtually no error associated with sample mass measurement, the sample wood density is probably also accurate to within + 5%.

Wood decay in snags was much more uniform than in logs. Decay proceeded from the cambial surface inward and tops were usually more rotted than bases. Because of this uniformity, I feel that the weighted snag wood densities were accurate to +10%.

Snag respiration - The regression method used to calculate snag wood respiration rates had three sources of error. First, age, the independent variable, was only approximate and regression analysis demands an exact independent variable. Second, the mean wood densities of all snag decay classes were weighted equally although some means represented three snags and others eleven. Finally, three points, from the three decay classes, were insufficient to accurately predict the slope of a line. The extremely low respiration rate for wood of large Douglas-fir snags is particularly questionable.

Snag bark loss- All the errors incurred in measuring snag fragmentation were automatically included in the rate of loss of snag bark as it was calculated as the sum of the snag fragmentation rate and the bark cover loss rate. The latter rate should have been calculated using a measure of bark mass rather than bark cover. Bark mass loss can occur without any coverage loss, thus a measure of bark mass loss like that used for logs is desireable. Unfortunately, it was necessary to use bark cover, rather than grams of bark per unit volume of wood sample, to calculate bark loss rates on intact upright boles because most of the bark from the snag wood samples fell off when the snags were cut.

The criticisms of snag respiration rate calculations were equally applicable to the calculation of bark loss rates. I estimate that the calculated rates of wood fragmentation, wood respiration, and bark loss were within 50% of the true rate. It is important to realize that even if all the measurements and assumptions had been completely accurate, there still would have been a very large variance for all of the rates because snag breakage and decomposition were not uniform, regular processes.

Results discussion:

"There is a great diversity in types of snags and in individual snags of the same type. Any analysis of the snag problem is consequently rather complex," commented Robert McArdle fifty years ago in one of the first papers on snag decomposition (McArdle 1931). Perhaps because of this complexity and the extreme difficulty encountered in dating snags, the present literature on snag decomposition is largely descriptive and dates mostly from the first half of this century. A body of literature has recently developed on the use of snags by wildlife for feeding and nesting but with the exception of an article by Cline et al.(1980) nothing has been written on decomposition.

Reports on snag decomposition have focused primarily on changes in fire hazard or, more often, merchantability of the wood.

Consequently most of the published data are couched in those terms and are difficult to interpret today; definitions of flammability and merchantability have varied with the years and do not necessarily correspond with any measurable physical parameters. One exception to this general focus was the remarkable work done by Kimmey and Furniss (1943). They analyzed a chronosequence of 602 fire-killed Douglas-fir trees ranging from 1 to 65-yr-old in 63 stands located in Oregon and Washington. Being pathologists they emphasized the succession of decay fungi, loss of bark, and sapwood and heartwood fungal penetration with snag age using original dbh as a covariable.

As in the present study of non-fire killed trees, Kimmey and Furniss found that small diameter snags decayed much more quickly than large, both with regard to percent of the bole volume that was invaded by fungi and the radial rate (cm/yr) at which the fungi penetrated. They found it took 10 yr for complete fungal penetration of a 30 cm dbh bole, 20 yr for a 40 cm dbh bole, and over 60 yr for a 100 cm dbh bole. A chronosequence of fire-created snags on the Oregon coast showed the same increase in rate of deterioration with decrease in dbh (Cline 1978). Kimmey and Furniss attributed the observed slow fungal penetration rates in older and larger trees to the tighter ring structure found in these boles. Examination of decay in boles of similar size but with varying ring widths supported their hypothesis. They noted as have other researchers with different species (Johnson et al. 1970, Wright and Wright 1954, Keen 1955, Lyon 1977), that decay proceeded from the cambial surface inward and that bole tops rotted quicker than bole butts. Kimmey and Furniss also provided detailed data which showed that the white rot Hirshioporus abietinus (Dicks. ex Fr.) Donk dominated initially but was superceded by the brown rot Fomitopsis pinicola (Swartz ex Fr.) Karst. as decay progressed in Douglas-fir snags of all sizes. Interestingly, age rather than extent of decay seemed to determine when brown rot appeared. The smaller snags which decayed more quickly were predominantly rotted by white rot and the larger snags by brown rot. In all cases evidence of insect activity (galleries, borings, etc) was extensive and fungal penetration and succession appeared dependent on this activity. The same phenomena appeared to have occurred in Douglas-fir snags of the present study which were not killed by fire. Further, much more extensive work on the interrelation between fungi, insects, and snag wood decay and their relation to snag decay class is in progress at Oregon State University.

One major difference between fire-killed and disease or insect-killed trees was their bark loss rates. Fire-killed Douglas-fir snags in both Kimmey and Furniss' (1943) and McArdle's (1931) studies lost their bark much faster than the disease and insect-killed snags of the present study. Both fire studies reported complete bark loss in all snags by year 20 whereas 30-yr-old snags with 100% bark cover were common in the present study. This difference in bark retention may explain why case hardened (outer shell of dry firm wood) Douglas-fir and western hemlock snags were rare within intact forest but were commonly reported for burned areas. The tenacity with which non-fire killed boles held their bark was quite striking; we felled some Douglas-fir snags which were 100%

bark covered but whose wood was like wet red sawdust collapsing in a heap when the bole crashed to the ground.

Very little information is available on western hemlock snag decay. McArdle (1931) noted that western hemlock snags rotted much faster than Douglas-fir snags but gave no supporting data. Helmers (1948) reported that girdled western hemlock in the Northern Rocky Mountains broke at least once within the first 11 yr after death and that secondary branches were three quarters gone after 4 to 7 yr. In coastal Alaska, Embry (1963) reported that 6 to 9 yr after death half of his study western hemlock snags had broken, that bark was still mostly intact, and secondary branches nearly gone. In the few western hemlock snags that they examined Kimmey and Furniss (1943) found complete fungal penetration of the bole in fire-killed western hemlock snags after 9 yr, even with those of large diameter. In summary, western hemlock appeared to decay quickly in any environment.

More specific information on snag decay, such as rate of remnant log production, change in wood density, or even change in total bole volume with age is absent from the literature. A little information on change in snag height with age is available; because of the tremendous variability in decay among snags of even the same age and original size, most of the published information is quite general. McArdle (1931) working primarily with large-diameter, fire-killed, Douglas-fir snags in Washington and Oregon reported that snag height halved in the first 20 yr and averaged 6 m after 60 yr. Cline's thesis work (1978), on the basis of which I dated large and medium decay class III Douglas-fir snags, provided detailed information on change in Douglas-fir snag height with age. His height decreases in Douglas-fir snags greater than 20 cm dbh were almost identical to those reported by McArdle. Helmers (1948) recorded that girdled western hemlock snags decreased in height by two-thirds during the first 11 years of decay. All three studies involved exposed snags which may explain why height losses were more rapid than what I obtained in the protected, forest-surrounded snags.

The moisture regimes of snags in the five decay groups offered a partial explanation for their wood respiration rates. Fungal decay of wood preceeds most rapidly at 50 to 100% moisture (Shea 1960). Hemlock boles, at 55 and 121% moisture in decay class II and III, presented a much more favorable habitat for fungal decay than did Douglas-fir snags at 109 and 154% moisture. (Note that these moisture measurements were taken during the driest season of the year. During the winter rain season these values would be higher yet.) This explanation is confounded, however, because the two species were decayed by different rot types; western hemlock was rotted predominantly by white rots and Douglas-fir by brown rots.

Fragmentation rates were three to seven times faster than respiration rates within the same decay group and both rates increased markedly with smaller diameter boles. The slower fragmentation rate of Douglas-fir than western hemlock was not surprising considering the dimensional differences (large snags decayed more slowly and Douglas-fir snags tended to be larger than hemlock) but was surprising considering the different types of decay. I had expected that brown rot snags would fragment more rapidly than white rot snags due to the chunky cubical nature of brown rot. Certainly evidence of fragmentation was more obvious in brown rotted boles which would accumulate piles of rotted wood around their bases.

In summary, snag decay was highly individualistic with regard to breakage both within and between sites, but fairly uniform with regard to respiration rates (proportion of bole which was rotted at a given age). Size and species profoundly affected the rate of decomposition but in a consistent manner. Residence time of a snag in the forest was strongly and positively correlated with its initial dimensions.

SECTION III. FREQUENCY OF TREE DEATH DUE TO WINDTHROW

Methods

To the determine the probability that a tree would die as a wind thrown bole rather than as a snag, the number of snags and windthrown boles recorded in the Wind River, Black Rock, and Mt. Hood mortality data sets were tallied. Twelve detailed maps of permanent one hectare reference plots in mature and old-growth forests in the Cascade Range (J. Franklin, personal communication) were also examined for the presence of snags and windthrown boles (as denoted on the maps by a mass of roots at the end of a log). Frequency data from the reference plots were analyzed both by plot and as a pooled data set.

Results

Hemlock trees were more likely to die due to windthrow than Douglas-fir trees (Table 19). This was expected as western hemlock has a shallower root system than Douglas-fir (Eis 1974). It was surprising, however, that in both species the frequency of windthrows decreased with increasing diameter provided that the stand was mature. I had expected that small trees, low in the canopy would be less likely to die due to windthrow. Young Douglas-fir stands such as those at Black Rock and Mt. Hood did not show this trend and windthrown boles were extremely rare.

Table 19. Summary of mortality survey of Douglas-fir and western hemlock trees from maps of reference plots and from snag chronosequence study sites. Map data were analysed by total number of trees that were snags or windthrown boles on all plots and by percent of dead trees which were snags on each plot. Dead trees other than small Douglas-fir are from old-growth stands. Standard error of mean is given in parentheses. (See Table 3 for dbh range within decay groups)

Decay Group	Data Source	# trees	# plots	Frequency that tree death produced a Snag	Wind-thrown bole
Large	Maps	-	12	.85* (4)	.15
Douglas-fir	Maps	274	-	.88	.12
	Wind River	35	-	.80	.20
weighted mean		309	-	.87	.13
Medium	Maps	-	11	.82* (10)	.18
Douglas-fir	Maps	72	-	.76	.24
	Wind River	6	-	.83	.17
weighted mean		78	-	.77	.23
Small	Maps	-	10	.72* (9)	.28
Douglas-fir	Maps	118	-	.64	.36
(old-growth)	Wind River	25	-	.75	.25
weighted mean		143	-	.66	.34
Small	Mt. Hood #1	143	-	.91	.09
Douglas-fir	Mt. Hood #2	141	-	.97	.03
(successional)	Black RockI	100	-	.88	.12
	Black RockII	73	-	.93	.07
weighted mean		457	-	.93	.07
Large	Maps	-	8	.63* (10)	.37
western hemlock	Maps	110	-	.67	.33
	Wind River	54	-	.50	.50
weighted mean		164	-	.61	.39
Small	Maps	-	9	.51* (9)	.49
western hemlock	Maps	57	-	.54	.46
	Wind River	24	-	.50	.50
weighted mean		81	-	.50	.50

* average of individual plot frequencies

Discussion

Error analysis:

Data from the snag chronosequence sites suggested that some of the "windthrown boles" tallied from the reference maps may actually have resulted from root rot which caused the tree to topple over at death or soon after death. Many small western hemlocks at the snag chronosequence sites appeared to be windthrown boles but the original field notes did not record them as windthrows. Presumably these tree died upright and then later fell over. Pine trees typically die upright and then fall over as a result of root rot (Dahms 1949).

Small trees often die when they are knocked over by a larger falling tree (J. Franklin, personal communication). Although not actual windthrows, such trees on the maps and at the chronosequence sites would have been tallied and considered as windthrows. Thus, the high frequency of small western hemlock windthrows may not actually have been windthrow of the trees but rather an artifact of root rot and the falling of other trees. These "windthrown boles" did, however, decay and function in the forest as logs not snags.

There was a tacit assumption in using the reference maps to determine the frequency of windthrow as a mode of death, that a snag persisted in the forest as long as an uprooted dead tree. If this had been true, the ratio of present snags to windthrown boles would have reflected the ratio of trees which had died standing to trees which had been windthrown. Snags, however did not persist as long as windthrown boles, so reference map data tended to overestimate the frequency of windthrow in that area. Opposing this bias was the fact that windthrown boles often occurred in patches and larger patches were avoided in placing the reference plots. In all, the map data were remarkably consistent with the actual mortality data recorded at the three chronosequence sites, considering that there was a diverse set of stands included in the maps.

Results discussion:

There are very few published data on tree mortality with which to compare these results. Falinski (1978) found that 50% of the spruce trees (*Picea abies* (L.) Karst.) in a virgin spruce forest in Poland had died as windthrown boles. Grier (1978) noted that most of the mortality over the last 35 yr in a 121-yr-old western hemlock/Sitka spruce forest along the Oregon coast was due to windthrow. Cline (1978) remarked that windthrow frequency increased with bole dbh in coastal Oregon although neither he nor Grier presented data supporting their observations. In mature coastal western hemlock/Sitka spruce stands on the Olympic Peninsula, a tally of snags and windthrown boles showed that an average of 60% of the western hemlock and 30% of the spruce trees had died due to windthrow (Lambert 1980). The lesser frequency of windthrown boles in the present data set may reflect climatic differences between the Cascade and Coast ranges. Major windstorms, a fairly common occurrence on the Pacific Northwest coast are less frequent in the Cascade mountains (United States Department of the Interior 1970).

SECTION IV. CONCLUSIONS

Bole decomposition is a complex process even when regarded from its simplest aspect, loss of mass. Both rate and cause of bole decomposition fluctuated with bole age, bole size, bole species, and bole position. Variability, both within and between boles, was the most consistent characteristic of bole decomposition. The factor most affecting bole decomposition was the position of the bole relative to the forest, whether the bole was upright or prostrate (a snag or a log).

Snags decomposed more rapidly than logs. Only 1.2% of the mass of a large Douglas-fir log was decomposed each year. A snag of the same species and dimensions lost 3.1% of its mass annually. Large western hemlock snags lost 9% of their mass each year while similar logs lost only 2.1%.[3] For both species the increase was attributable almost solely to a difference in the fragmentation rate of the logs and snags.[4] The ecosystem significance of this difference between snags and logs is considerable. First, the relative frequency of windthrown boles versus snags will have a profound effect on the quantity of dead bole biomass which can accumulate in a stand. If tree mortality resulted only in snags, there would be a third less dead bole mass in

3. These values were calculated by adding together the respiration and fragmentation rates of snags and logs. The snag fragmentation rate was the same as that used to calculate bark mass loss from snags.

4. Small and medium Douglas-fir boles did appear to respire faster when upright but the paucity of log data for that size bole precludes much speculation.

the forest than if tree mortality was entirely due to windthrow and there were no snags.[5] Secondly, if fragments of wood respire faster than intact boles due to increased surface area and exposure to the environment (Fogel and Cromack 1977, Blanchette and Shaw 1978), then snag wood cycles through the detrital pools of the ecosystem faster than log wood. Thus the nutrients contained in snag bole wood are also released sooner than the nutrients in log wood.[6] Thirdly, rapid decomposition of snags means that to maintain a population of snags for wildlife, a forest requires frequent additions of fresh snags (Cline et al. 1980). Even large snags from old-growth forests barely persisted the duration of a rotation and small snags decomposed in only 30 yr. Long term maintainance of snags in managed forests will require creative planning; leaving some snags at the beginning of the rotation will not suffice. Maintenance of corridors of old-growth forest may be the best solution with regard to wildlife (McClellan et al. 1979).

Species was the second most important factor in determining rate and manner of bole wood decomposition. Hemlock boles had faster decomposition rates than Douglas-fir boles even when differences in size and position were accounted for. This confirmed the qualitative

5. This is a rough estimate based on the assumption that snags persist half as long as logs and that half of the snag bole breaks to become a log. A simulation model is needed for more exact values.

6. By growing on nurse logs some plants appear to circumvent the typical slow recycling of bole nutrients which is the result of slow log decomposition rates.

descriptions of other researchers (Boyce 1929, Buchanon and Englerth 1940, Kimmey and Furniss 1943, and Engelhardt 1957). Differences in heartwood seem to be responsible for the differing rates of decomposition. Childs (1939) in an investigation of decomposition rates of burned and unburned logging slash, noted that while the heartwood from Douglas-fir boles decayed considerably slower than the heartwood from western hemlock boles of comparable dimensions, the sapwood of such boles and the branches of the two species decayed at the same rate. The difference in decomposition rate may also be the result of more successful insect attack on western hemlock; three years after death western hemlock windthrows were more damaged by insects than Douglas-fir windthrows (Shea and Johnson 1962).

Several researchers have noted that although western hemlock decomposed more rapidly than Douglas-fir, the decomposition was also more variable on a tree to tree basis. I observed the same phenonmenon in this study and in the Olympic Peninsula (Lambert 1980). Perhaps the thin bark of a western hemlock bole makes its underlying bole wood more responsive to the microenvironment which surrounds each bole and therefore, western hemlock bole decomposition is more variable due to greater sensitivity to differences in microenvironment. Childs and Clark (1953), in an investigation on decomposition of windthrown boles, felt that Douglas-fir boles decayed more slowly because their thick bark kept the underlying wood wetter, inhibiting fungal growth. They reported that moisture contents of 250% were not uncommon in wood found just underneath the bark. This undoubtably does affect the decomposition rates but intrinsic differences in the wood itself must also as Douglas-fir lumber is well known to rot more slowly than western hemlock (United States Forest Products Laboratory 1974).

The effect of bole size on decomposition is complex. This study found that small snags of either Douglas-fir or western hemlock fragmented faster than large snags. Respiration rates of Douglas-fir snags also increased with decreasing diameter but western hemlock rates stayed the same. These rate trends agreed with previous, more descriptive research which had found that small Douglas-fir snags whether killed by insects or by fire decomposed more rapidly than large Douglas-fir snags (Kimmey and Furniss 1943, Wright and Harvey 1967). Although no data were available for western hemlock snags, other species such as Ponderosa pine (*Pinus ponderosa* Laws.) and balsam fir (*Abies balsamea* (L.) Mills.) were also reported to decay faster if the snag boles were of small diameter (Keen 1955, Basham and Belyea 1960)).

In contrast to the sampled snags, the sampled logs showed no relation between size and respiration rate in this study. These results conflict with those in the literature. In an extensive study of the decomposition of windthrown boles on the Olympic Peninsula, Boyce (1929) and Buchanon and Englerth (1940) found that decomposition proceeded more slowly in larger boles of either Douglas-fir or western hemlock. They did however, only follow the first 15 yr of decompsition; perhaps over a longer interval of time bole size would not have affected the decomposition rate. The failure of this study to observe any relationship between log size and decomposition rate may also have resulted from measuring the decomposition rate of the small end of a large boles rather than the decomposition rate of small boles. Wood density, sapwood to heartwood ratios, and bark thickness may all differ between small boles, particularly fast-growing small boles, and tops of mature trees. Until more density data are collected for small decaying boles, the real effect of bole size on respiration rate will be uncertain. In addition, fragmentation rates of large and small logs were not examined in this study and may well be different.

The methodology presented here for studying woody debris decomposition is analogous to studying litter decomposition leaf by leaf. The resolution at a single bole was almost too fine to discern gross bole decay trends at a stand level; any trends present tended to be lost in the welter of individual bole variation. At the same time, the resolution was too coarse to examine the processes of bole decay. To understand the processes of decay, bole substrates must be separated, agents of decay must be more clearly defined, and differences in environment must be accounted for. Such work is in progress and hopefully will make some order out of the seemingly random variability present in bole decay when viewed at the resolution of a whole bole.

At the stand level, evaluation of the significance of woody debris in forest dynamics demands an ability to predict changes in the amount and kind of dead bole material. Such prediction requires a much better understanding than we currently have, of tree mortality in stands of different ages, particularly old-growth stands. Models which can integrate the bole mass dynamics of wood decomposition at a forest stand level are also needed. The data and decay rates presented in this paper have been used to develop a stand level model of snag and log decay which can be used to predict the amounts of woody debris in Douglas-fir/western hemlock forests in the Central Cascade Range. This model, to be described in a subsequent paper, in combination with better information on tree mortality and nutrient dynamics of decomposing wood, will allow a more complete evaluation of the role of large woody debris in the forest ecosystem.

BIBLIOGRAPHY

Allison, F. E. and C. J. Klein. 1961. Comparative rates of decomposition in soil of wood and bark particles of several softwood species. Soil Science Society of America Proceedings 24: 193-196.

Basham, J. T. and R. M. Belyea. 1960. Death and deterioration of balsam fir weakened by spruce budworm defoliation in Ontario. Forest Science 6: 78-96.

Berg, A. B. 1970. Growth and yield in managed stands. Pages 83-88 in A. B. Berg, editor. Management of young growth Douglas-fir and western hemlock. Forest Research Laboratory Research Bulletin 19, Oregon State University School of Forestry, Corvallis, Oregon, USA.

Blanchette, R. A. and C. G. Shaw. 1978. Management of forest residues for rapid decay. Canadian Journal of Botany: 2904-2909.

Brown, H. R., A. J. Panshin, and C. C. Forsaith. 1949. Textbook of wood technology- Volume 1. McGraw-Hill Book Company, New York, New York, USA.

Boyce, J. S. 1923. The deterioration of felled western yellow pine on insect-control projects. Department Bulletin 1140, United States Department of Agriculture, Washington, District of Columbia, USA.

Boyce, J. S. 1929. Deterioration of wind-thrown timber on the Olympic Peninsula, Washington. Technical Bulletin 104. United States Department of Agriculture, Washington, District of Columbia, USA.

Buchanon, T. S. 1940. Fungi causing decay in wind-thrown Northwest conifers. Journal of Forestry 38: 276-281.

Buchanon, T. S. and G. H. Englerth. 1940. Decay and other volume losses in windthrown timber on the Olympic Peninsula, Washington. Technical Bulletin 773, United States Department of Agriculture, Washington, District of Columbia, USA.

Childs, T. W. 1939. Decay of slash on clear-cut areas in the Douglas-fir region. Journal of Forestry 37: 955-959.

Childs, T. W. and J. W. Clark. 1953. Decay of wind-thrown timber in western Washington and northwestern Oregon. Forest Pathology Special Release 40, United States Department of Agriculture, Washington, District of Columbia, USA.

Cline, S. P. 1978. The characteristics and dynamics of snags in Douglas-fir forests of the Oregon Coast Range. Dissertation. Oregon State University, Corvallis, Oregon, USA.

Cline, S. P., A. B. Berg, and H. M. Wight. 1980. Snag characteristics and dynamics in Douglas-fir forests, western Oregon. Journal of Wildlife Management 44: 773-786.

Dahms, W. G. 1949. How long do ponderosa pine snags stand?. Forest Service Research Note 57, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, USA.

Eis, S. 1974. Root system morphology of western hemlock, western red cedar, and Douglas-fir. Canadian Journal of Forest Research 4: 28-38.

Embry, R. S. 1963. Estimating how long western hemlock and western red cedar have been dead. Forest Service Research Note 2, Northern Forest Experiment Station, Juneau, Alaska, USA.

Emmingham, W. H. and C. A. Lundberg. 1977. Climatic and physiological data summaries for the H. J. Andrews reference stand network. Internal Report 166, United States/International Biological Programme, Coniferous Biome, University of Washington, Seattle, Washington, USA.

Engelhardt, N. T. 1957. Pathological deterioration of looper-killed western hemlock on southern Vancouver Island. Forest Science 3: 125-136.

Englerth, G. 1942. Decay of western hemlock in western Oregon and Washington. Yale University School of Forestry Bulletin 50, New Haven, Connecticut, USA.

Falinski, J. B. 1978. Uprooted trees, their distribution and influence in the primeval forest biotope. Vegetatio 38: 175-183.

Fogel, R. and K. Cromack, Jr. 1977. Effect of habitat and substrate quality on Douglas-fir litter decomposition in western Oregon. Canadian Journal of Botany 55: 1632-1640.

Franklin, J. F., K. Cromack, Jr., W. Denison, A. McKee, C. Maser, J. Sedell, F. Swanson, and G. Juday. 1981. Ecological characteristics of old-growth Douglas-fir forests. Forest Service General Technical Report PNW-118, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, USA.

Gholz, H. L., C. C. Grier, A. G. Campbell, and A. T. Brown. 1979. Equations for estimating biomass and leaf area of plants in the Pacific Northwest. Forest Research Laboratory Research Paper 41, Oregon State University School of Forestry, Corvallis, Oregon, USA.

Graham, R. L. L. and K. Cromack, Jr. 1981. Mass, nutrient content, and decay rate of dead boles in rain forests of Olympic National Park. Canadian Journal of Forest Research: submitted.

Grier, C. C. 1978. A Tsuga heterophylla-Picea sitchensis ecosystem of coastal Oregon: decomposition and nutrient balances of fallen logs. Canadian Journal of Forest Research 8: 198-206.

Harvey, A. E., M. J. Larsen, and M. F. Jurgensen. 1979a. Fire-decay: interactive roles regulating wood accumulation and soil development in the Northern Rocky Mountains. Forest Service Research Note INT-263, Intermountain Forest Experiment Station, Ogden, Utah, USA.

Harvey, A. E., M. J. Larsen, and M. F. Jurgensen. 1979b. Comparative distribution of ectomycorrhizae in soils of three western Montana forest habitat types. Forest Science 25: 350-358.

Harvey, A. E., M. F. Jurgensen, and M. J. Larsen. 1978. Role of residue in and inpacts of its management on forest soil biology. Eighth World Forestry Congress, Jakarta, Indonesia, October 16-28, 1978.

Helmers, A. E. 1948. Disintegration of girdled western hemlock and grand fir. Forest Service Station Paper 17, Northern Rocky Mountain Forest and Range Experiment Station, Missoula, Montana, USA.

Hemstrom, M. A. 1979. A recent disturbance history of forest ecosystems at Mount Rainier National Park. Dissertation. Oregon State University, Corvallis, Oregon, USA.

Hunt, H. W. 1977. A simulation model for decomposition in grasslands. Ecology 58: 368-384.

Johnson, N. E., K. R. Shea, and R. L. Johnsey. 1970. Mortality and deterioration of looper-killed hemlock in western Washington. Journal of Forestry: 68: 162-163.

Jurgensen, M. F., M. J. Larsen, and A. E. Harvey. 1979. Forest biology-timber harvesting relationships. Forest Service General Technical Report INT-69, Intermountain Forest and Range Experiment Station, Ogden, Utah, USA.

Keen, F. P. 1955. The rate of natural felling of beetle killed ponderosa pine snags. Journal of Forestry 53:720-723.

Kimmey, J. W. and R. L. Furniss. 1943. Deterioration of fire-killed Douglas-fir. Technical Bulletin 851, United States Department of Agriculture, Washington, District of Columbia, USA.

King, J. P. 1961. Growth and mortality in the Wind River Natural Area. Journal of Forestry 59: 768-769.

Kollmann, F. F. P. and W. A. Cote. 1968. Principles of wood science and technology. Springer-Verlag, New York, New York, USA.

Lambert, R. L. 1980. The biomass, coverage, and decay rates of dead boles in terrace forests, South Fork Hoh River, Olympic National Park. Pages 64-79 in American Institutes of Biological Sciences. Second Conference on Scientific Research in the National Parks, San Francisco, November 1979, Volume 7.

Lambert, R. L., G. E. Lang, and W. A. Reiners. 1980. Loss of mass and chemical change in decaying boles of a subalpine balsam fir forest. Ecology 61: 1460-1473.

Lang, G. E. and R. T. Forman. 1978. Detrital dynamics in a mature oak forest: Hutcheson Memorial Forest, New Jersey. Ecology 59:580-595.

Lang, G. E. and D. H. Knight. 1979. Decay rates for the boles of tropical trees in Panama. Biotropica 11: 316-317.

Larsen, M. J., Jurgensen, M. F., and A. E. Harvey. 1978. N_2 fixation associated with wood decayed by some common fungi in western Montana. Canadian Journal of Forest Research 8: 341-345.

Lyon, L. J. 1977. Attrition of lodgepole pine snags on the Sleeping Child Burn, Montana. Forest Service Research Note INT-219, Intermountain Forest and Range Experiment Station, Ogden, Utah, USA.

Maser, C., R. G. Anderson, K. Cromack,Jr., J. T. Williams, and R. E. Martin. 1979. Dead and woody materials. Pages 78-79 in J. W. Thomas, editor. Wildlife habitats in managed forests- the Blue mountains of Oregon and Washington. Agriculture Handbook 553, United States Department of Agriculture, Forest Service, Washington, District of Columbia, USA.

McArdle, R. E. 1931. Overtopping of Douglas-fir snags by reproduction. Forest Service Research Note 8, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, USA.

McClelland, B. R., S. S. Frissell, W. C. Fischer, and C. H. Halvorson. 1979. Habitat management for bole-nesting birds in forests of western larch and Douglas-fir. Journal of Forestry 77: 480-484.

Means, J., K. Cromack, Jr., and P. C. Macmillan. 1981. Comparison of decomposition models using wood density of Douglas-fir logs. Journal of Ecology; submitted.

Minore, D. 1972. Germination and early growth of coastal tree species on organic seed beds. Forest Service Research Paper PNW-135, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, USA.

Olson, J. S. 1963. Energy storage and the balance of producers and decomposers in ecological systems. Ecology 44:322-331.

Pritsker, A. A. B. 1974. The GASP simulation language. John Wiley and Sons, New York, New York, USA.

Shea, K. R. 1960. Fungus succession and the significance of environment in the deterioration of logs. Weyerhaeuser Company Forestry Research Note 30, Western Forestry Research Center, Centralia, Washington, USA.

Shea, K. R. and N. E. Johnson. 1962. Deterioration of wind-thrown conifers three years after blowdown in southwestern Washington. Weyerhaeuser Company Forestry Research Note 44, Western Forestry Research Center, Centralia, Washington, USA.

Sollins, P. 1981. Input and decay of coarse woody debris in coniferous stands in western Oregon and Washington. Canadian Journal of Forest Research: accepted.

Sollins, P., C. C. Grier, F. M. McCorison, K. Cromack, Jr., R. Fogel, and R. L. Fredriksen. 1980. The internal element cycles of an old-growth Douglas-fir ecosystem in western Oregon. Ecological Monographs 50: 261-285.

Thomas, J. W., R. G. Andersson, C. Maser, and E. Bull. 1979. Snags. Pages 60-77 in J. W. Thomas, editor. Wildlife habitats in managed forest- the Blue Mountains of Oregon and Washington. Agriculture Handbook 553, United States Department of Agriculture, Forest Service, Washington, District of Columbia, USA.

Triska, F. J. and K. Cromack, Jr. 1980. The role of wood debris in forests and streams. Pages 171-190 in R. H. Waring, editor. Forests: fresh perspectives from ecosystem analysis. Proceedings of the 40th annual biology colloquium, Oregon State University, 1979. Oregon State University Press, Corvallis, Oregon, USA.

United States Department of the Interior. 1970. National Atlas of United States of America. Geological Survey, Washington, District of Columbia, USA.

United States Forest Product Laboratory. 1974. Wood handbook: wood as an engineering material. Handbook Number 72 revised, United States Department of Agriculture, Washington, District of Columbia, USA.

Wiley, K. N., D. R. Bower, D. L. Shaw, and D. G. Kovich. 1978. Standard cubic-foot tables for total-and merchantable-stem volumes and tariff access for western hemlock in Washington and Oregon. Weyerhaeuser Company Forestry Research Paper 18, Western Forestry Research Center, Centralia, Washington, USA.

Williamson, R.L. 1963. Growth and yield records from well-stocked stands of Douglas-fir. Forest Service Research Paper PNW-4, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, USA.

Wright, E. and K. H. Wright. 1954. Deterioration of beetle killed Douglas-fir in Oregon and Washington. Forest Service Research Paper 10, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, USA.

Wright, K. H. and G. M. Harvey. 1967. The deterioration of beetle-killed Douglas-fir in western Oregon and Washington. Forest Service Research Paper PNW-50, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, USA.

Zobel, D., A. McKee, G. Hawk, and C. T. Dyrness. 1976. Relationships of environment to composition, structure, and diversity of forest communities of the Central Western Cascades of Oregon. Ecological Monographs 46: 135-146.

APPENDIX

MODEL DEFINITION

Statement of problem:

I wished to know how the quantity and type of wood and bark of dead boles would vary in a Douglas-fir/western hemlock forest at mid-altitude in the Cascade Range given annual mortality which was composed of variable species, bole sizes, and bole numbers.

Description of system:

Structure- Bole necromass (dead biomass) is sorted by species (Douglas-fir and western hemlock) and diameter (dbh) into the five decay groups- large Douglas-fir, medium Douglas-fir, small Douglas-fir, large western hemlock, and small western hemlock (Table 3). Within each decay group, bole necromass is separated according to whether it is from a snag or log and if it is wood or bark. Snag and log bark are two separate pools. Snag wood is separated into three snag wood pools corresponding to the three snag decay classes (Table 10). Log wood is separated into five pools corresponding to the five log decay classes (Table 2) if it is Douglas-fir. If it is western hemlock, there are only four log pools I to IV, under the presumption that western hemlock wood does not decay to a class V state. In total there are 48 bole necromass pools- ten for each of the three Douglas-fir decay groups and nine for each of the two western hemlock decay groups. The five decay groups can be considered as five almost identical subsystems, separate and with two exceptions, not interacting.

Mortality- Mortality occurs annually at the beginning of the year and initially enters the system in the form of single dead boles of a given dbh and species. The necromass of the boles is separated into four subpools depending on whether it is bark or wood and whether the bole died as a snag or a windthrow. Once within a subpool, the identity of the single bole is lost. When all the boles of a single year's mortality have been tallied, the subpool masses in each decay group are added to the necromass pools to which they belong- snag bark, log bark, class I snag wood, or class I log wood. At the same time, the identities of the wood subpools are retained. New subpools are created with each year's mortality; these subpools can be thought of as cohorts of bole wood of a common age and origin and will be referred to as "snag cohort" or "log cohort". The cohorts are tracked through time as they decay. The distinction between the 48 necromass pools and the potential hundreds of wood cohorts is important; cohorts move in and out of wood necromass pools and the sum of the individual masses of the cohorts within a necromass pool determines the magnitude of that pool.

Transfers- There are four types of transfer from one necromass pool to another. Each occurs at the beginning of a year and generally within the same decay group. A log cohort can transfer from one log pool to another log pool in a fixed sequence (eg. a cohort in a class III log pool can only transfer to a class IV log pool). A snag cohort can transfer from one snag pool to another snag pool, again in a fixed sequence. Third, part of the necromass of a snag cohort can be transferred to a log pool and assigned to a certain log cohort. Finally, an amount of bark proportional to the transferred snag wood will be transferred from the snag bark pool to the log bark pool if there is a snag-log transfer. Transfer from a snag to a log pool represents snag breakage while the log-log and snag-snag transfers simply recognise that as boles decay they change decay classes.

There are only two transfers between decay groups. Cohorts within large Douglas-fir and large western hemlock class I snags will transfer some necromass to medium Douglas-fir and small western hemlock class II log cohorts respectively. These transfers represent top breakage on large new snags.

The year a given cohort will make a transfer from one pool to another depends entirely on the age (years since tree death) of the cohort. After a specified number of years within a pool, each cohort will make a certain type of transfer. In this way all cohorts stay a similar length of time within each pool.

<u>Losses</u>- Necromass is lost from the pools in three ways. One, a specified percentage of a wood pool is lost at the end of each year due to bole fragmentation and two, a specified percentage is lost due to bole respiration. (A given percentage of the bark pools is also lost due to fragmentation and respiration but the two types of loss are not separated as they are for wood.) There is a third loss, apart from fragmentation and respiration, which occurs when a log cohort becomes so decayed that it is no longer discernable on the forest floor and is transferred out of the bole necromass pools. Thus, a

cohort can stay in the decay class V pool (if it is a Douglas-fir) or decay class IV pool (if it is a hemlock) for only so many years, at which time it is transferred out of the pool and "disappears". Its necromass at that time is then subtracted from the necromass of the pool it was in. Fig. 13 depicts the organization, input, outputs, and transfers within the small Douglas-fir decay group. The other decay groups are almost identical.

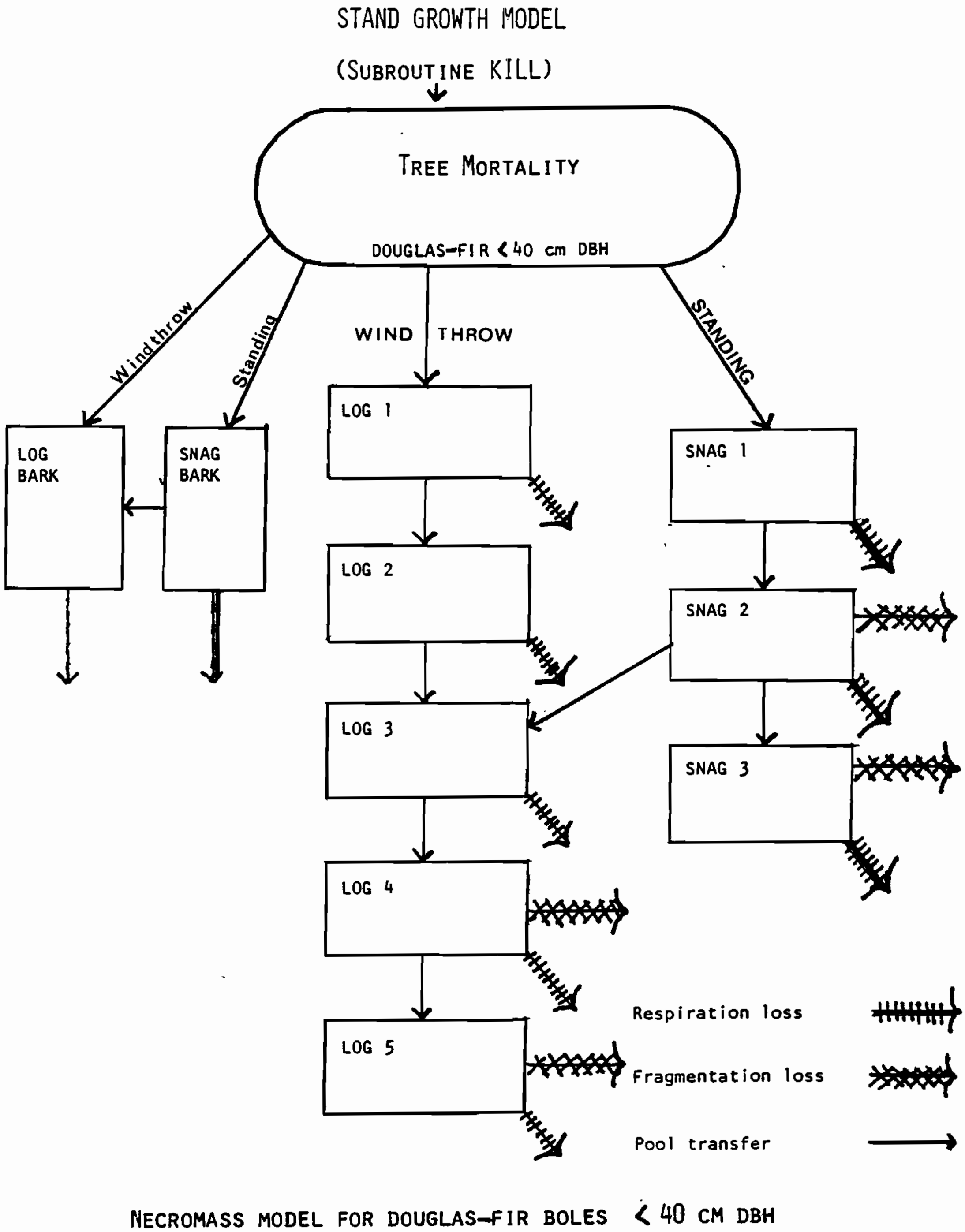

Fig. 13. Box diagram of decomposition model for small Douglas-fir boles. Large arrow from log decay class 5 box represents "disappearance" of the boles.

MECHANICS OF MODEL

Simulation objective:

To create a simulation model which would track, given species and dbh of boles dying each year, the cumulative amount and kind of bole necromass resulting from such mortality. The model would also be able to monitor cumulative mortality, and annual and cumulative respiration and fragmentation losses.

Brief introduction to GASP concepts and structure:

GASP is a FORTRAN based simulation language. The user supplies a main program and a series of FORTRAN subroutines which interact with the GASP main program and a few GASP subroutines. GASP can be used to model time events, state events, and continuous processes both with and without state and time events. The model presented here is a time event simulation containing some pertinant GASP features which I will discuss below.

A GASP time event model uses files (called (Filem(j), j=1,n) to keep track of time events and entities. Each file has entries and every entry has a fixed set of attributes (Atrib(h),h=1,k) which are filed in a fixed order in the file. For instance, Filem(16) contains the snag cohorts within the snag class I necromass pool of large Douglas-fir. Each entry in Filem(16) represents a single snag cohort. Each cohort is defined by four attributes. In this case, Atrib(1)=the year the cohort entered the file, Atrib(2)= the mass of the cohort when it entered the file, Atrib(3)= the year the cohort should leave the file, and Atrib(4)= the year that part of the cohort's mass should be transferred to a log pool. The attributes for a single entry are fixed in order and meaning. The number of entries in a single file can vary from zero to a limit set by the user and the particular type of computer. When an entry from a particular file is requested and located, the variables "Atrib(j)" take on the attribute values originally assigned for that entry in that file. Thus the variable Atrib(1) represents many different variables and values throughout the course of the simulation depending on the file and entry it represents at the time. Files can be searched for entries with specific attributes. For instance, each year Filem(16) is searched to see if there is cohort whose third attribute indicates that it should be transferred to log decay class II (ie. Atrib(3)= the present year, "TNOW" in GASP).

GASP uses Filem(1) as the "event file"; the user creates a subroutine EVNTS which is called by the main program GASP in conjunction with Filem(1) to determine what "event", action will take place next. In a time event model, each entry within Filem(1) is a command to do something at a specific time- ie. a "time event". The first attribute of an entry gives the time at which the event is supposed to occur and the second attribute is a numeric label which tells what event is to occur. Events are ranked so that if more than one type of event is scheduled to occur at the same time, the events will occur in a certain order. Each time subroutine EVNTS is called, Filem(1) is searched for the next event to occur on the basis of Atrib(1). Once the entry is found, the model automatically sets its time counter (GASP variable TNOW) to the value of the first attribute. The model is thus pulled along a time line, event by event. On the basis of Atrib(2) of the event entry, subroutine EVNTS goes to a user written subroutine or set of lines which processes the event (causes it to occur). For example, Atrib(2) might tell the model to go to a subroutine which transfers cohorts from pool to pool.

The concepts of files, attributes, events, and entries are key to a GASP time event simulation. This is but a very brief introduction to GASP; the language and its capabilities are described in detail in Pritsker (1974).

Basic outline of bole necromass simulation model:

This is a discrete time event model. The initial amounts of bole necromass in each of the 48 pools are read into the model from a tape in subroutine INTLC. (I use the word "tape" to refer to outside computer files and the word "file" to refer to GASP files.) Values for model parameters such as pool respiration and fragmentation rates are also read from a tape in subroutine INTLC. There are four major events each represented by a subroutine which is called in the directing subroutine EVNTS. The four event subroutines are:

1. STATUS- respires and fragments necromass pools, records amounts of bole necromass in the 48 pools onto a tape.

2. INPUT- takes mortality data from a tape and creates new bole cohorts and increases necromass pools by the new mortality necromass.

3. TRANFER-transfers cohorts from pool to pool and updates amount of necromass in pools after transfers.

4. GROUP- combines sets of six consecutive years of cohorts of Douglas-fir log decay class IV into one cohort. GROUP also transfers cohorts from class IV to V and transfers class V cohorts out of system.

STATUS, INPUT,and TRANFER are called each year in that order. GROUP is called once every six years after TRANFER. All events occur at the beginning of the year. STATUS determines the amount of respiration and fragmentation that occurred in the preceeding year after all inputs, and transfers had occurred; it also files the "status" of the necromass pools at the beginning of the new year before any new transfers or mortality occurs. Mortality (subroutine INPUT) and transfers of cohorts (subroutines TRANFER and GROUP) occur at the beginning of the year after the necromass pools have been updated for the previous year's fragmentation and respiration losses. Necromass pools which lost or gained cohorts are updated for that loss or gain at the time of the transfer. The pools then decay for a year until they are updated by STATUS at the beginning of the next new year, and the cycle continues. The mass in a pool is tracked by a variable ST(j) and the cohorts in a pool are tracked by Filem(j). The model stops at a specific year defined by the user.

The model uses nine outside computer files listed in the FORTRAN program statement as:

TAPE1- mortality data by species and dbh

TAPE5- GASP input for running the model

TAPE6- initial necromass in Mg/ha for each pool

TAPE7- scratch file needed by GASP

TAPE8- output file of cumulative inputs and losses

TAPE9- output file of necromass present in each pool

TAPE10- file of parameter values

TAPE11- output file of respiration and fragmentation losses for the previous year

TAPE20- GASP output file, lists status of model

Organization and description of non-GASP variables

Numbering systems:

All variables are referenced to the 48 necromass pools using the following five sets of numbering systems.

Ngroup or I- identifies to which of the five decay groups a variable belongs.

Ngroup or I	decay group	diameter
1	large Douglas-fir	65 cm
2	medium Douglas-fir	65 cm but 40 cm
3	small Douglas-fir	40cm
4	large western hemlock	25cm
5	small western hemlock	25cm

J- identifies to which decay class a variable belongs

J	decay class
1	class I log wood
2	class II log wood
3	class III log wood
4	class IV log wood
5	class V log wood
6	class I snag wood
7	class II snag wood
8	class III snag wood
9	log bark
10	snag bark

Ntype- identifies the necromass pool to which a variable or cohort belongs.

Ntype equals Ngroup times ten plus J. For example, large class II snag wood in the small hemlock decay group (Ngroup=5 and J=7) has a Ntype equal to 50 +7, or 57; while class II log wood in the large Douglas-fir decay group has an Ntype of 10+3, or 13. As Ngroup ranges from one to five and J ranges from one to ten, there are a potential 50 Ntypes ranging in value from 11 to 60; but because there is no decay class V (J=5) for either hemlock decay group, Ntype 45 and 55 do not exist.

Ntype	necromass pool
11	large Douglas-fir class I log wood
12	large Douglas-fir class II log wood
13	large Douglas-fir class III log wood
14	large Douglas-fir class IV log wood
15	large Douglas-fir class V log wood
16	large Douglas-fir class I snag wood
17	large Douglas-fir class II snag wood
18	large Douglas-fir class III snag wood
19	large Douglas-fir log bark
20	large Douglas-fir snag bark
21	medium Douglas-fir class I log wood
22	medium Douglas-fir class II log wood
23	medium Douglas-fir class III log wood
24	medium Douglas-fir class IV log wood
25	medium Douglas-fir class V log wood
26	medium Douglas-fir class I snag wood
27	medium Douglas-fir class II snag wood
28	medium Douglas-fir class III snag wood
29	medium Douglas-fir log bark
31	small Douglas-fir class I log wood
32	small Douglas-fir class II log wood
33	small Douglas-fir class III log wood
34	small Douglas-fir class IV log wood
35	small Douglas-fir class V log wood
36	small Douglas-fir class I snag wood
37	small Douglas-fir class II snag wood
38	small Douglas-fir class III snag wood
39	small Douglas-fir log bark
40	small Douglas-fir snag bark

Ntype	necromass pool
41	large western hemlock class I log wood
42	large western hemlock class II log wood
43	large western hemlock class III log wood
44	large western hemlock class IV log wood
46	large western hemlock class I snag wood
47	large western hemlock class II snag wood
48	large western hemlock class III snag wood
49	large western hemlock log bark
50	large western hemlock snag bark
51	small western hemlock class I log wood
52	small western hemlock class II log wood
53	small western hemlock class III log wood
54	small western hemlock class IV log wood
56	small western hemlock class I snag wood
57	small western hemlock class II snag wood
58	small western hemlock class III snag wood
59	small western hemlock log bark
60	small western hemlock snag bark

<u>L</u>- identifies all the wood for a given species in a certain decay class.

L	description
1	Douglas-fir class I log wood
2	Douglas-fir class II log wood
3	Douglas-fir class III log wood
4	Douglas-fir class IV log wood
5	Douglas-fir class V log wood
6	Douglas-fir class I snag wood
7	Douglas-fir class II snag wood
8	Douglas-fir class III snag wood
9	western hemlock class I log wood
10	western hemlock class II log wood
11	western hemlock class III log wood
12	western hemlock class IV log wood
13	western hemlock class I snag wood
14	western hemlock class II snag wood
15	western hemlock class III snag wood

<u>K</u>- identifies for a given species all the bark on snags or logs

K	description
1	Douglas-fir log bark
2	Douglas-fir snag bark
3	western hemlock log bark
4	western hemlock snag bark

Non-GASP variables:

Parameters

Name	description (subroutine location)
DUR(Ntype)	number of years cohort stays in necromass pool (INTLC, INPUT, TRANLOG, TRANSNA, GROUP)
FRAG(Ntype)	Fraction of pool that is fragmented yearly, is also used for bark loss rate. (INTLC, STATUS, JOE)
PERB(Ntype)	a fraction representing the ratio of the mass of bark to mass of wood of a snag bole. It is used to calculate how much bark should be transferred from the snag bark pool to the log bark pool when a snag wood cohort loses some of its mass to a log pool. (INTLC, TRANSB)
PERS(Ntype)	fraction of the biomass of a snag cohort that will be transferred to a specified log pool. (INTLC, TRANSB)
RESP(Ntype)	fraction of a necromass pool that is respired yearly (INTLC, STATUS, JOE)
THROW(Ngroup)	the fraction of mortality that is due to windthrow (INTLC, WIND)

Wood respiration variables

RESP(Ngroup)	cumulative amount of wood necromass lost from a decay group due to wood respiration. (DEBUG)
RESPTOC(Ngroup)	the yearly amount of wood necromass lost from a decay group due to wood respiration. (INTLC, STATUS, DEBUG)
RESPTOT(L)	the yearly amount of wood necromass lost by a decay class within a species due to wood respiration. (INTLC, STATUS)
PRESP	cumulative amount of wood necromass lost from Douglas-fir boles due to wood respiration. (DEBUG)
TRESP	cumulative amount of wood necromass lost from western hemlock boles due to wood respiration. (DEBUG)

Wood fragmentation variables

FRAG(Ngroup) cumulative amount of wood necromass lost from a decay group due to wood fragmentation. (DEBUG)

FRAGTOC(Ngroup) the yearly amount of wood necromass lost from a decay group due to wood fragmentation. (INTLC, STATUS, DEBUG)

FRAGTOT(L) the yearly amount of wood necromass lost by a decay class within a species due to wood fragmentation. (INTLC, STATUS)

PFRAG cumulative amount of wood necromass lost from Douglas-fir boles due to wood fragmentation. (DEBUG)

TFRAG cumulative amount of wood necromass lost from hemlock boles due to wood fragmentation. (DEBUG)

Bark loss variables

BARKF(Ngroup) cumulative amount of bark necromass lost from a decay group due to bark fragmentation and respiration. (INTLC, STATUS, DEBUG)

BARKTOC(Ngroup) the yearly amount of bark necromass lost from a decay group due to bark fragmentation and respiration. (INTLC, STATUS, DEBUG)

BARKTOT(K) the yearly amount of bark necromass lost by snags or logs within a species due to bark respiration and fragmentation. (INTLC, STATUS)

PBARKF cumulative amount of bark lost from Douglas-fir boles due to bark fragmentation and respiration. (DEBUG)

TBARKF cumulative amount of bark lost from western hemlock boles due to bark fragmentation and respiration. (DEBUG)

Loss due to disappearance after log decay class IV or V

PSMEOUT	annual loss of class V Douglas-fir wood due to "disappearance". (INTLC, GROUP, STATUS, DEBUG)
TSHEOUT	annual loss of class IV western hemlock wood due to "disappearance". (INTLC, TRANLOG, STATUS, DEBUG)
POUT	cumulative loss of class V Douglas-fir wood due to "disappearance". (DEBUG)
TOUT	cumulative loss of class IV western hemlock wood due to "disappearance". (DEBUG)

Necromass pool variables

ST(Ntype)	amount of necromass present in each of the 48 pools. (INTLC, INPUT, TRANLOG, TRANSNA, TRANSB, GROUP) (STATUS, DEBUG)
Wood(Ngroup)	amount of wood necromass present in a decay group. (DEBUG)
PWOOD	amount of Douglas-fir wood present. (DEBUG)
TWOOD	amount of western hemlock wood present. (DEBUG)
BARK(NGROUP)	amount of bark present in a decay group. (DEBUG)
PBARK	amount of Douglas-fir bark present. (DEBUG)
TBARK	amount of western hemlock bark present. (DEBUG)

Mortality variables

W(Ngroup,1)	yearly addition of log wood necromass by decay group due to mortality. (INTLC, INPUT, WIND, DEBUG)
W(Ngroup,2)	yearly addition of snag wood necromass by decay group due to mortality. (INTLC, INPUT, WIND, DEBUG)
WB(Ngroup,1)	yearly addition of log bark necromass by decay group due to mortality. (INTLC, INPUT, WIND, DEBUG)
WB(Ngroup,2)	yearly addition of snag bark necromass by decay group due to mortality. (INTLC, INPUT, WIND, DEBUG)

WINPUT(Ngroup)	cumulative addition to the model of wood necromass by decay group due to mortality. (DEBUG)
BINPUT(Ngroup)	cumulative addition to the model of bark necromass by decay group due to mortality. (DEBUG)
PWINPUT	cumulative addition to the model of Douglas-fir wood necromass due to mortality. (DEBUG)
TWINPUT	cumulative addition to the model of western hemlock wood necromass due to mortality. (DEBUG)
PBINPUT	cumulative addition to the model of Douglas-fir bark necromass due to mortality. (DEBUG)
TBINPUT	cumulative addition to the model of western hemlock bark necromass due to mortality. (DEBUG)

Summation variables

TOTIN(Ngroup)	cumulative total necromass from mortality plus original necromass by decay group. (DEBUG)
TOTAL(Ngroup)	total wood and bark in pools plus total amount of necromass ever lost to fragmentation and respiration. (DEBUG)
PTOTIN	cumulative total Douglas-fir necromass from mortality plus original necromass. (DEBUG)
TTOTIN	cumulative total western hemlock necromass from mortality plus original necromass. (DEBUG)

Miscellaneous variables (in order that they appear in the model)

NOUT	number of years the model should run. (EVNTS)
OUT	year which original cohort leaves specific necromass pool. (INTLC)
HOUT	year which original cohorts of Douglas-fir IV and V wood leave their necromass pools. (INTLC)

NSPECIE	species of tree that died 16= Douglas-fir; 18= western hemlock. (INPUT)
DBH	diameter (cm) at 1.3 m of dead tree. (INPUT)
NTIME	year tree died. (INPUT)
BOLMASS	wood necromass of dead tree bole. (INPUT, WIND)
BARMASS	bark necromass of dead tree bole. (INPUT, WIND)
LOUT	lowest value of Atrib(3) of any entry in a specific file- identifies the cohort soonest to leave a necromass pool. (TRANLOG, TRANSNA, TRANSB, GROUP)
ORIGBIO	necromass of cohort when it first entered pool. (TRANLOG, TRANSNA, TRANSB, JOE)
LENGTH	number of years in pool since origbio was updated. (TRANLOG, TRANSNA, TRANSB, JOE)
BMASS	current necromass of cohort. (TRANLOG, TRANSNA, TRANSB, JOE)
OUTBIO	current necromass of "disappearing" cohort. (TRANLOG)
NTYPE	current necromass pool of cohort. (TRANLOG, TRANSNA, TRANSB)
NTYPE1	pool to which cohort is being transferred. (TRANLOG, TRANSNA ,TRANSB)
TMASS	amount of necromass of snag cohort. (TRANSB)
SNEW	amount of necromass left in a snag cohort after part of it is transferred to a log pool. (TRANSB)
TRANBIO	amount of necromass removed from the snag necromass pool and transferred to a log pool. (TRANSB)
TRANBAR	amount of necromass in snag bark pool that is transferred to log bark pool. (TRANSB)
NBTYPE	snag bark pool that is losing bark to log bark pool. (TRANSB)
NBTYPE1	log bark pool that is receiving bark from a snag bark pool. (TRANSB)
BIO	the summed necromass of six sequential class IV Douglas-fir cohorts. (GROUP)

GASP file system:

Event file- Filem(1)

Atrib(1)- year of event

Atrib(2)- type of event

1.0= STATUS event
2.0= INPUT event
3.0= TRANSFER event
4.0= GROUP event

(Secondary ranking is on Atrib(2) low values first)

Log Necromass pool files- Filem(k); k=11-15, 21-25, 31-35, 41-44, 51-54

Atrib(1)- year log cohort entered pool
or
year log cohort acquired more mass from a snag transfer

Atrib(2)- necromass of log cohort when it entered pool
or
necromass of log cohort just after it acquired more mass from snag-log transfer

Atrib(3)- year log cohort will leave pool

Atrib(4)- year in which log cohort could acquire snag mass in a snag-log transfer

(Ranking is on Atrib(3), first in first out)

Snag necromass pool files- Filem(k); k=6-18, 26-28, 36-38, 46-48, 56-58

Atrib(1)- year snag cohort entered pool
or
year snag cohort lost mass in a snag-log transfer

Atrib(2)- necromass of snag cohort when it entered pool
or
necromass of snag cohort just after it lost mass from snag-log transfer

Atrib(3)- year snag cohort will leave pool

Atrib(4)- year in which snag mass could be transferred to log cohort in a snag-log transfer

(Ranking in on Atrib(3), first in first out)

INPUT TAPES USED FOR RUNNING MODEL

TAPE1- annual mortality data

Line format- (3X,I3,F6.1,I3)
Variables- NSPECIES, DBH, NTIME

Each line gives the species code, dbh, and year of death of a single tree. Data for sequential years are separated by a marker line in which NSPECIES has a negative value.

Printout of part of TAPE1 used in test run-

```
 -1              DATA FOR DEAD TREES * SPECIES DBH YEAR
 -1              DATA FOR DEAD TREES * SPECIES DBH YEAR
 16 49.80   2
 -1              DATA FOR DEAD TREES * SPECIES DBH YEAR
 16 28.50   3
 19 19.48   3
 -1              DATA FOR DEAD TREES * SPECIES DBH YEAR
 16 17.73   4
  7 23.80   4
 -1              DATA FOR DEAD TREES * SPECIES DBH YEAR
 16 75.70   5
 -1              DATA FOR DEAD TREES * SPECIES DBH YEAR
 16 24.70   6
 16 88.00   6
 18 35.00   6
  7  0.19   6
 -1              DATA FOR DEAD TREES * SPECIES DBH YEAR
 16 22.30   7
 16 56.90   7
 16 30.40   7
  7  0.10   7
 -1              DATA FOR DEAD TREES * SPECIES DBH YEAR
  7  0.14   8
 -1              DATA FOR DEAD TREES * SPECIES DBH YEAR
 16 17.80   9
  2 16.72   9
 18 22.52   9
 -1              DATA FOR DEAD TREES * SPECIES DBH YEAR
 16 69.80  10
 16 25.60  10
 -1              DATA FOR DEAD TREES * SPECIES DBH YEAR
 16 30.90  11
 16 28.40  11
 16 85.50  11
 16 49.20  11
 16 98.80  11
 -1              DATA FOR DEAD TREES * SPECIES DBH YEAR
 16 36.80  12
 16 20.96  12
 19 65.00  12
  7 17.72  12
```

TAPE5- GASP input data

Line format- free form

This tape initializes the GASP variables necessary for running the simulation. Pritsker (1974) gives a detailed explanation of variables and file order and structure.

Printout of TAPE5 used in test run-

```
GEN,GRAHAM,1,8,3,1981,1,7,Y,Y,N,Y,N*
LIM,0,0,700,4,0,20000,0,0,0*
PRI,1,LVF,2*
PRI,2*
PRI,3*
PRI,4*
PRI,5*
PRI,6*
PRI,7*
PRI,8*
PRI,9*
PRI,10*
PRI,11*
PRI,12*
PRI,13*
PRI,14*
PRI,15*
PRI,16*
PRI,17*
PRI,18*
PRI,19*
PRI,20*
PRI,21*
PRI,22*
PRI,23*
PRI,24*
PRI,25*
PRI,26*
PRI,27*
PRI,28*
PRI,29*
PRI,30*
PRI,31*
PRI,32*
PRI,33*
PRI,34*
PRI,35*
PRI,36*
PRI,37*
PRI,38*
PRI,39*
PRI,40*
PRI,41*
PRI,42*
PRI,43*
PRI,44*
PRI,45*
PRI,46*
PRI,47*
PRI,48*
PRI,49*
PRI,50*
PRI,51*
PRI,52*
PRI,53*
PRI,54*
PRI,55*
PRI,56*
PRI,57*
PRI,58*
PRI,59*
PRI,60*
CON,0,0,,,1,1,0*
INI,1,Y,Y,0,700,Y*
SEE,1,1,1,1,1*
FIN*
```

TAPE6- initial necromass values in pools at model startup

Line format- (5X,10F6.2)
Variables- ST(NTYPE), NTYPE= NCLASS to NEND
where, NCLASS= NTYPE of log class I and
NEND= NTYPE of snag bark in same decay group

Each line on this five line tape contains the initial amounts of mass (Mg/ha) in the necromass pools of one decay group. The pools are ordered across the line- log I to V, snag I to III, log bark, snag bark. The five lines are ordered- large, medium, small Douglas-fir, large, small western hemlock.

Printout of TAPE6 used in test run-

```
MPSME  0.00  0.00  5.40 13.30  8.90  3.10  3.30  2.70  1.59
SPSME  0.00  1.20  7.70 10.40  2.80  3.80 12.90  1.80  1.18
LTSHE  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
STSHE  0.00  0.00  0.00  0.00  0.00  0.30  0.00  0.00  0.00
1
```

TAPE7- scratch file needed by GASP software

TAPE8- output file of cumulative inputs and losses

Line format- (1X, 9F10.3, F6.3)
Variables- PTOTIN, PTOTAL, PWINPUT, PBINPUT,PWOOD, PBARK, PRESP, PFRAG, PBARKF, TNOW (lines 1 to 4); TTOTIN, TTOTAL, TWINPUT, TBINPUT,TWOOD, TBARK, TRESP, TFRAG, TBARKF, TNOW (lines 5 to 7)

Values of cumulative inputs and losses at specific year are printed on seven lines. The first three lines are for large, medium and small Douglas-fir. The fourth line is for all Douglas-fir and is the sum of the previous three lines. The fifth and sixth lines are for large and small western hemlock and the last line is for all western hemlock and is the sum of the previous two lines. The model prints the values annually for the first 20 yr and then on 10-yr intervals for the remainder of the simulation run.

Example of TAPE8 printout from test run-

TTOTIN	TTOTAL	WINPUT	BINPUT	WOOD	BARK	RESP	FRAG	BARKF	TNOW
22.120	22.120	21.800	.320	21.059	.314	.088	.653	.006	1.0
38.290	38.290	36.700	1.590	35.956	1.553	.278	.465	.037	1.0
41.780	41.780	40.600	1.180	39.200	1.140	.628	.772	.040	1.0
102.190	102.190	99.100	3.090	96.215	3.007	.994	1.891	.083	1.0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.0
.300	.300	.300	0.000	.295	0.000	.005	0.000	0.000	1.0
.300	.300	.300	0.000	.295	0.000	.005	0.000	0.000	1.0
22.120	22.120	21.800	.320	20.351	.307	.173	1.276	.013	2.0
38.290	38.290	36.700	1.590	35.249	1.518	.550	.902	.072	2.0
41.780	41.780	40.600	1.180	37.904	1.101	1.223	1.474	.079	2.0
102.190	102.190	99.100	3.090	93.504	2.926	1.945	3.651	.164	2.0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.0
.300	.300	.300	0.000	.290	0.000	.010	0.000	0.000	2.0
.300	.300	.300	0.000	.290	0.000	.010	0.000	0.000	2.0
22.120	22.120	21.800	.320	19.675	.301	.256	1.869	.019	3.0
45.257	45.257	42.773	2.484	40.647	2.377	.814	1.312	.107	3.0
41.780	41.780	40.600	1.180	36.698	1.064	1.787	2.114	.116	3.0
109.157	109.157	105.173	3.984	97.020	3.742	2.857	5.295	.242	3.0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.0
.300	.300	.300	0.000	.268	0.000	.015	.017	0.000	3.0
.300	.300	.300	0.000	.268	0.000	.015	.017	0.000	3.0
22.120	22.120	21.800	.320	19.030	.295	.336	2.434	.025	4.0
45.257	45.257	42.773	2.484	39.934	2.298	1.141	1.698	.186	4.0
43.437	43.437	42.027	1.410	37.001	1.258	2.325	2.702	.152	4.0
110.814	110.814	106.599	4.214	95.964	3.851	3.802	6.834	.363	4.0

TAPE9- Output file of mass present in necromass pools

Line format- (F5.1, I2, 10F8.4)
Variables- TNOW, NGROUP, ST(NTYPE) NTYPE=NCLASS, NEND

Values for necromass pools (Mg/ha) at specified year are printed on five lines. The first three lines are for large, medium and small Douglas-fir. The last two lines are for large and small western hemlock. The model prints the values annually for the first 20 yr and then on 10-yr intervals for the remainder of the simulation run.

Example of TAPE9 printout from test run-

TNOW	I	LOG1	LOG2	LOG3	LOG4	LOG5	SNAG1	SNAG2	SNAG3	LBARK	SBARK
1.0	1	0.0000	0.0000	0.0000	4.1414	3.7470	0.0000	2.4676	10.7028	.3136	0.0000
1.0	2	0.0000	0.0000	5.3687	13.1144	8.7758	3.0597	3.2180	2.4197	1.5534	0.0000
1.0	3	0.0000	1.1930	7.6553	10.2549	2.7609	3.6974	12.1500	1.4887	1.1399	0.0000
1.0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1.0	5	0.0000	0.0000	0.0000	0.0000	0.0000	.2949	0.0000	0.0000	0.0000	0.0000
2.0	1	0.0000	0.0000	0.0000	4.0836	3.6947	0.0000	2.4356	10.1372	.3073	0.0000
2.0	2	0.0000	0.0000	5.3375	12.9315	8.6534	3.0199	3.1381	2.1686	1.5177	0.0000
2.0	3	0.0000	1.1861	7.6109	10.1118	2.7224	3.5976	11.4437	1.2312	1.1011	0.0000
2.0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2.0	5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	.2899	0.0000	0.0000	0.0000
3.0	1	0.0000	0.0000	0.0000	4.0266	3.6432	0.0000	2.4040	9.6014	.3012	0.0000
3.0	2	1.3967	0.0000	5.3066	12.7510	8.5326	7.6565	3.0601	1.9434	1.6884	.6885
3.0	3	0.0000	1.1792	7.5668	9.9707	2.6844	3.5004	10.7784	1.0183	1.0637	0.0000
3.0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3.0	5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	.2676	0.0000	0.0000	0.0000
4.0	1	0.0000	0.0000	0.0000	3.9705	3.5923	0.0000	2.3728	9.0940	.2952	0.0000
4.0	2	1.3886	0.0000	5.2758	12.5731	8.4136	7.5570	2.9841	1.7417	1.6496	.6485
4.0	3	.4851	1.1724	7.5229	9.8316	2.6470	.9417	13.5577	.8422	1.1058	.1520
4.0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4.0	5	.2319	0.0000	0.0000	0.0000	0.0000	.2319	.2470	0.0000	.0257	.0257
5.0	1	0.0000	0.0000	0.0000	3.9151	3.5422	0.0000	2.3420	8.6134	.2893	0.0000
5.0	2	1.3805	0.0000	5.2452	12.3977	8.2962	7.4587	2.9099	1.5609	1.6117	.6109
5.0	3	.6249	1.1656	7.4793	9.6944	2.6100	1.1930	3.2079	10.2581	1.0931	.1836
5.0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5.0	5	.2270	0.0000	0.0000	0.0000	0.0000	.2279	.2280	0.0000	.0241	.0221
6.0	1	2.3403	0.0000	0.0000	3.8604	3.4928	15.6621	2.3117	8.1581	.6050	2.1520
6.0	2	1.3725	0.0000	5.2148	12.2247	8.1804	7.3618	2.8376	1.3989	1.5746	.5755
6.0	3	.6212	0.0000	8.5947	9.5592	2.5736	1.1608	3.0214	8.4840	1.0560	.1634
6.0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6.0	5	.2222	0.0000	0.0000	0.0000	0.0000	.2241	.2104	0.0000	.0225	.0190
7.0	1	5.7858	0.0000	0.0000	3.8066	3.4440	38.7642	2.2817	7.7270	1.0565	5.1728
7.0	2	1.3646	0.0000	5.1845	12.0542	8.0663	4.4374	5.5958	1.2537	1.5384	.5421
7.0	3	.9523	0.0000	8.5449	9.4258	2.5377	1.7790	2.8458	7.0167	1.0754	.2528
7.0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7.0	5	.2175	0.0000	.0777	0.0000	0.0000	.2202	.1165	0.0000	.0302	.0072
8.0	1	5.7522	0.0000	0.0000	3.7535	3.3960	38.6479	2.2521	7.3186	1.0354	4.9763
8.0	2	3.3305	0.0000	5.1545	11.8860	7.9538	10.9877	5.4568	1.1235	1.7873	1.4624
8.0	3	1.7770	0.0000	8.4953	9.2943	2.5023	3.3426	2.6803	5.8031	1.1736	.4866
8.0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8.0	5	.2129	0.0000	.0761	0.0000	0.0000	0.0000	.3241	0.0000	.0282	.0062

TAPE10- Decomposition parameters defining system

```
Line format- (20X, 10F4.0);      DUR(NTYPE) values for decay group
             (5X, 10F6.4);       RESP(NTYPE) values for decay group
             (5X, 10F6.4);       FRAG(NTYPE) values for decay group
             (5X, 10F6.3);       PERS(NTYPE) values for decay group
             (5X, 10F6.3);       PERB(NTYPE) values for decay group
             (5X, F4.2);         THROW(NTYPE) value for decay group
```

This tape defines parameters for all necromass pools. Each set of six lines covers the six parameters for one decay group. The first three sets are for large, medium, and small Douglas-fir. The last two sets are for large and small western hemlock. One note of caution must be added here. Because all events are scheduled on a yearly interval, duration parameters must be set so that no transfer occurs at the half year interval. In particular, the transfer every six yr from log class IV to V must occur with the scheduled GROUP events.

Printout of TAPE10 used in test run-

```
RESP  .0058 .0058 .0058 .0058 .0058 .0030 .0030 .0030
FRAG  .0000 .0000 .0000 .0082 .0082 .0000 .0100 .0500 .0200 .0380
PERS                                .100  .550  .000
PERB                                .127  .105  .000
THROW .13
MEDIUM DOUGLAS-FIR    10  16  26  63  78  14  26  40
RESP  .0058 .0058 .0058 .0058 .0058 .0130 .0130 .0130
FRAG  .0000 .0000 .0000 .0082 .0082 .0000 .0120 .0920 .0230 .0580
PERS                                .000  .400  .000
PERB                                .000  .166  .000
THROW .23
SMALL DOUGLAS-FIR      5  12  22  63  72   8  10  22
RESP  .0058 .0058 .0058 .0058 .0058 .0270 .0270 .0270
FRAG  .0000 .0000 .0000 .0082 .0082 .0000 .0320 .1500 .0340 .1100
PERS                                .000  .500  .000
PERB                                .000  .189  .000
THROW .34
LARGE HEMLOCK          7   8  10  26       6  12  22
RESP  .0211 .0211 .0211 .0211       .0160 .0160 .0160
FRAG  .0000 .0000 .0000 .0000       .0000 .0320 .0150 .0210 .0960
PERS                                .000  .500  .000
PERB                                .000  .104  .000
THROW .39
SMALL HEMLOCK          5   8   6  20       4  10  16
RESP  .0211 .0211 .0211 .0211       .0170 .0170 .0170
FRAG  .0000 .0000 .0000 .0000       .0000 .0610 .2100 .0650 .1400
PERS                                .000  .400  .000
PERB                                .000  .118  .000
THROW .50
```

TAPE11- output file of yearly respiration and fragmentation losses and yearly wood and bark inputs

Line format- (F5.1, I2, 2X, 3F9.4, 4F7.4)
Variables- TNOW, RESPTOC(I), FRAGTOC(I), BARKTOC(I),W(I,1),W(I,2), WB(1),WB(I,2)

Values for yearly respiration, fragmentation, and bark losses and yearly wood and bark input within decay groups are printed on five lines. The first three lines are for large, medium, and small Douglas-fir. The last two lines are for large and small western hemlock. The model prints the values annually for the first 20 yr and then on 10-yr intervals for the remainder of the simulation run.

Example of TAPE11 printout from test run-

TNOW	I	RESPTOC	FRAGTOC	BARKTOC	WTHROW	SNAG	WBTHRO	WBSNAG
1.0	1	.0878	.6534	.0064	0.0000	0.0000	0.0000	0.0000
1.0	2	.2784	.4652	.0366	0.0000	0.0000	0.0000	0.0000
1.0	3	.6277	.7720	.0401	0.0000	0.0000	0.0000	0.0000
1.0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1.0	5	.0051	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2.0	1	.0853	.6224	.0063	0.0000	0.0000	0.0000	0.0000
2.0	2	.2712	.4363	.0357	0.0000	0.0000	0.0000	0.0000
2.0	3	.5949	.7017	.0388	0.0000	0.0000	0.0000	0.0000
2.0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2.0	5	.0050	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3.0	1	.0828	.5930	.0061	0.0000	0.0000	0.0000	0.0000
3.0	2	.2644	.4100	.0349	1.3967	4.6758	.2056	.6885
3.0	3	.5648	.6406	.0374	0.0000	0.0000	0.0000	0.0000
3.0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3.0	5	.0049	.0174	0.0000	0.0000	0.0000	0.0000	0.0000
4.0	1	.0805	.5651	.0060	0.0000	0.0000	0.0000	0.0000
4.0	2	.3269	.3862	.0788	0.0000	0.0000	0.0000	0.0000
4.0	3	.5371	.5874	.0362	.4851	.9417	.0783	.1520
4.0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4.0	5	.0045	.0160	0.0000	.2319	.2319	.0257	.0257
5.0	1	.0783	.5386	.0059	0.0000	0.0000	0.0000	0.0000
5.0	2	.3201	.3646	.0756	0.0000	0.0000	0.0000	0.0000
5.0	3	.5398	.6468	.0543	.1426	.2768	.0249	.0483
5.0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5.0	5	.0130	.0148	.0053	0.0000	0.0000	0.0000	0.0000
6.0	1	.0761	.5135	.0058	2.3403	15.6621	.3216	2.1520
6.0	2	.3135	.3449	.0725	0.0000	0.0000	0.0000	0.0000
6.0	3	.5209	1.6974	.0574	0.0000	0.0000	0.0000	0.0000
6.0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6.0	5	.0125	.0137	.0047	0.0000	0.0000	0.0000	0.0000
7.0	1	.1346	.4897	.0939	3.4591	23.1491	.4636	3.1026
7.0	2	.3073	.3270	.0696	0.0000	0.0000	0.0000	0.0000
7.0	3	.4658	1.4312	.0539	.3346	.6496	.0553	.1074
7.0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7.0	5	.0121	.0126	.0041	0.0000	0.0000	0.0000	0.0000

TAPE20- GASP output file on how the model ran.

Line format- GASP specified
Variables- includes information on file contents, varies with directions given in TAPE5

Example of TAPE20 printout from test run-

```
 1                              SIMULATION PROJECT NUMBER   1  BY  GRAHAM

                                DATE  8/  3/ 1981       RUN NUMBER    1 OF     1
                                           GASP IV VERSION 01JAN76

  NNCLT=     0   NNSTA=     0   NNHIS=     0   NNPRM=     0   NNPLT=     0   NNSTR=     5   NNTRY=   700
  NNATR=     4   NNFIL=    60   NNSET= 20000   NNEQD=     0   NNEQS=     0   NFLAG=     0
  IIPOF=     Y   IIPOS=     N   IISUM=     Y   IIPIR=     N

  PRIORITY FILE   1=LVF ( 2)
  PRIORITY FILE   2=FIFO
  PRIORITY FILE   3=FIFO
  PRIORITY FILE   4=FIFO
  PRIORITY FILE   5=FIFO
  PRIORITY FILE   6=FIFO
  PRIORITY FILE   7=FIFO
  PRIORITY FILE   8=FIFO
  PRIORITY FILE   9=FIFO
  PRIORITY FILE  10=FIFO
  PRIORITY FILE  11=FIFO
  PRIORITY FILE  12=FIFO
  PRIORITY FILE  13=FIFO
  PRIORITY FILE  14=FIFO
  PRIORITY FILE  15=FIFO
  PRIORITY FILE  16=FIFO
  PRIORITY FILE  17=FIFO
  PRIORITY FILE  18=FIFO
  PRIORITY FILE  19=FIFO
  PRIORITY FILE  20=FIFO
  PRIORITY FILE  21=FIFO
  PRIORITY FILE  22=FIFO
  PRIORITY FILE  23=FIFO
  PRIORITY FILE  24=FIFO
  PRIORITY FILE  25=FIFO
  PRIORITY FILE  26=FIFO
  PRIORITY FILE  27=FIFO
  PRIORITY FILE  28=FIFO
  PRIORITY FILE  29=FIFO
  PRIORITY FILE  30=FIFO
  PRIORITY FILE  31=FIFO
  PRIORITY FILE  32=FIFO
  PRIORITY FILE  33=FIFO
  PRIORITY FILE  34=FIFO
  PRIORITY FILE  35=FIFO
  PRIORITY FILE  36=FIFO
  PRIORITY FILE  37=FIFO
  PRIORITY FILE  38=FIFO
  PRIORITY FILE  39=FIFO
  PRIORITY FILE  40=FIFO
  PRIORITY FILE  41=FIFO
  PRIORITY FILE  42=FIFO
  PRIORITY FILE  43=FIFO
  PRIORITY FILE  44=FIFO
  PRIORITY FILE  45=FIFO
  PRIORITY FILE  46=FIFO
  PRIORITY FILE  47=FIFO
  PRIORITY FILE  48=FIFO
  PRIORITY FILE  49=FIFO
  PRIORITY FILE  50=FIFO
  PRIORITY FILE  51=FIFO
```

GASP status at end of simulation run

CURRENT TIME = .7000E+03

GASP FILE STORAGE AREA DUMP AT TIME .7000E+03

MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA =528

PRINTOUT OF FILE NUMBER 1
TNOW = .7000E+03
QQTIM= .7000E+03

TIME PERIOD FOR STATISTICS .7000E+03
AVERAGE NUMBER IN FILE 4.0000
STANDARD DEVIATION 0.0000
MAXIMUM NUMBER IN FILE 4

FILE CONTENTS

ENTRY	1	=	.7000E+03	.2000E+01	.7050E+03	.7020E+03
ENTRY	2	=	.7000E+03	.3000E+01	.7020E+03	0.
ENTRY	3	=	.7010E+03	.1000E+01	0.	0.
ENTRY	4	=	.7020E+03	.4000E+01	.6960E+03	0.

PRINTOUT OF FILE NUMBER 11
TNOW = .7000E+03
QQTIM= .6230E+03

TIME PERIOD FOR STATISTICS .7000E+03
AVERAGE NUMBER IN FILE 1.0857
STANDARD DEVIATION 1.5788
MAXIMUM NUMBER IN FILE 6

THE FILE IS EMPTY

PRINTOUT OF FILE NUMBER 12
TNOW = .7000E+03
QQTIM= .6430E+03

TIME PERIOD FOR STATISTICS .7000E+03
AVERAGE NUMBER IN FILE 1.0857
STANDARD DEVIATION 1.5788
MAXIMUM NUMBER IN FILE 6

THE FILE IS EMPTY

PRINTOUT OF FILE NUMBER 13
TNOW = .7000E+03
QQTIM= .6730E+03

TIME PERIOD FOR STATISTICS .7000E+03
AVERAGE NUMBER IN FILE 2.3571
STANDARD DEVIATION 3.1921
MAXIMUM NUMBER IN FILE 13

THE FILE IS EMPTY

LISTING OF COMPUTER PROGRAM

MAIN PROGRAM

```
      PROGRAM THESIS(TAPE5,TAPE6,TAPE10,TAPE1,TAPE7,TAPE8,TAPE9,TAPE11,
     1  TAPE20)
      DIMENSION NSET(20000)
      COMMON QSET(20000)
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NGCOM1
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEGGCOM1
     2,TTCLR,TTFIN,TTRIB(25),TTSET                                      GCOM1
      COMMON /GCOM2/ DD(100),DDL(100),DTFUL,DTNOW,ISEES,LFLAG(50),NFLAG,GCOM2
     1NNEQD,NNEQS,NNEQT,SS(100),SSL(100),TTNEX                          GCOM2
      COMMON /GCOM3/ AAERR,DTMAX,DTMIN,DTSAV,IITES,LLERR,LLSAV,LLSBV,RREGCOM3
     1RR,TTLAS,TTSAV                                                    GCOM3
      COMMON /GCOM4/ DTPLT(10),HHLOW(25),HHWID(25),IICRD,IITAP(10),JJCELGCOM4
     1(500),LLABC(25,2),LLABH(25,2),LLABP(11,2),LLABT(25,2),LLPHI(10),LLGCOM4
     2PLO(10),LLPLT,LLSUP(15),LLSYM(10),MMPTS,NNCEL(25),NNCLT,NNHIS,NNPLGCOM4
     3T,NNPTS(10),NNSTA,NNVAR(10),PPHI(10),PPLO(10)                     GCOM4
      COMMON /GCOM5/ IIFVT,IISED(6),JJBEG,JJCLR,MMNIT,MMON,NNAME(3),NNOFGCOM5
     1T,NNDAY,NNPT,NNSET,NNPRJ,NNPRM,NNRNS,NNRUN,NNSTR,NNYR,SSEED(6)    GCOM5
      COMMON /GCOM6/ EENQ(100),IINN(100),KKRNK(100),MMAXQ(100),QQTIM(100GCOM6
     1),SSOBV(25,5),SSTPV(25,6),VVNQ(100)                               GCOM6
      COMMON/UCOM1/DUR(60),RESP(60),FRAG(60),THROW(5),W(5,2),WB(5,2)
      COMMON/UCOM2/PERS(60),PERB(60),PSMEOUT,TSHEOUT
      COMMON/UCOM3/ RESPTOT(15),FRAGTOT(15)
      COMMON/UCOM4/BARKTOT(4),RESPTOC(5),FRAGTOC(5),BARKTOC(5)
      COMMON/UCOM5/BARKF(5),ST(60)
      EQUIVALENCE(NSET(1),QSET(1))
C
C        THE MAIN PROGRAM STARTS AND STOPS THE MODEL."NCRDR" GIVES THE
C        TAPE WHICH HAS THE GASP INPUT NECESSARY FOR RUNNING THE MODEL.
C        "NPRNT" GIVES THE TAPE ON WHICH GASP OUTPUT IS TO BE WRITTEN.
C        GASP OUTPUT FILE TELLS HOW THE PROGRAM RAN, THE FILE STRUCTURE, AND
C        ALL THE GASP PARAMETERS.  NON-GASP OUTPUT CAN BE WRITTEN ON THIS
C        TAPE.
C
      NCRDR=5
      NPRNT=20
      CALL GASP
      CALL EXIT
      STOP
      END
```

SUBROUTINE EVNTS

```
      SUBROUTINE EVNTS(IX)
      COMMON QSET(1)
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NGCOM1
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEGGCOM1
     2,TTCLR,TTFIN,TTRIB(25),TTSET                                      GCOM1
C
C        THIS SUBROUTINE DETERMINES WHAT "EVENT" WILL HAPPEN ON THE
C        BASIS OF "IX" WHICH IS THE VALUE OF THE SECOND ATTRIBUTE OF
C        THE PULLED EVENT ENTRY FROM FILEM(1).  EACH EVENT IS REPRESENTED
C        BY A DIFFERENT SUBROUTINE- STATUS, INPUT, TRANFER, OR GROUP.
C        SUBROUTINES STATUS,INPUT AND TRANFER ARE CALLED AT THE BEGINNING OF
C        EACH YEAR IN THAT ORDER.  EVERY SIXTH YEAR SUBROUTINE GROUP IS CALLED
C        AFTER TRANFER.  THE RECORD KEEPING SUBROUTINE "DEBUG" IS CALLED AFTER
C        GROUP IF THERE IS A GROUP EVENT AND AFTER TRANFER IF THERE IS NO
C        GROUP EVENT THAT YEAR.  THE TIME LINE BEGINS WITH ZERO SO "TNOW=1"
C        MEANS THAT ONE YEAR HAS PASSED.
C
C
      IF(IX-2) 101,102,103
  101 CALL STATUS
      GO TO 108
  102 CALL INPUT
      GO TO 108
  103 IF(IX.EQ.3)GO TO 104
      CALL GROUP
C
C  CALL DEBUG TO RECORD STATUS OF POOLS AND OUTPUT VARIABLES
C
      CALL DEBUG
      GO TO 108
  104 CALL TRANFER
C
C  CHECK TO SEE IF A GROUP EVENT IS ALSO SCHEDULED FOR TNOW.  IF NO GROUP
C  EVENT IS SCHEDULED THEN CALL "DEBUG" TO RECORD NECROMASS POOLS AND UPDATE
C  CUMULATIVE VARIABLES. OTHERWISE GO TO RETURN
C
      NOUT=MFE(1)
      IF(QSET(NOUT+1).EQ.TNOW) GO TO 108
      CALL DEBUG
  108 RETURN
      END
```

SUBROUTINE INTLC

```
      SUBROUTINE INTLC
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NGCOM1
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEGGCOM1
     2,TTCLR,TTFIN,TTRIB(25),TTSET                                      GCOM1
      COMMON /GCOM2/ DD(100),DDL(100),DTFUL,DTNOW,ISEES,LFLAG(50),NFLAG,GCOM2
     1NNEQD,NNEQS,NNEQT,SS(100),SSL(100),TTNEX                          GCOM2
      COMMON/UCOM1/DUR(60),RESP(60),FRAG(60),THROW(5),W(5,2),WB(5,2)
      COMMON/UCOM2/PERS(60),PERB(60),PSMEOUT,TSHEOUT
      COMMON/UCOM3/ RESPTOT(15),FRAGTOT(15)
C
C         THIS SUBROUTINE SETS USER VARIABLES TO ZERO AND THEN SUPPLIES
C         VALUES FOR THE NON-GASP PARAMETER VARIABLES FROM TAPE10. IT
C         ALSO SUPPLIES INITIAL NECROMASS VALUES (MG/HA) FOR THE NECROMASS
C         POOL VARIABLES ST(NTYPE) FROM TAPE6.  IT THEN SCHEDULES THE INITIAL
C         INPUT, TRANSFER, STATUS, AND GROUP EVENT.  FINALLY IT LOADS EACH
C         OF THE WOOD NECROMASS FILES WITH AN INITIAL COHORT.
C
C
C  SET VARIABLES TO ZERO
C
      DO 100 NTYPE=1,60
       ST(NTYPE)=0.0
       DUR(NTYPE)=0.0
       RESP(NTYPE)=0.0
       PERS(NYTPE)=0.0
       PERB(NTYPE)=0.0
  100 CONTINUE
      DO 110 I=1,5
        FRAGTOC(I)=0.0
        RESPTOC(I)=0.0
        BARKTOC(I)=0.0
        THROW(I)=0.0
        BARKF(I)=0.0
        W(I,1)=0.0
        W(I,2)=0.0
        WB(I,1)=0.0
         WB(I,2)=0.0
  110 CONTINUE
      DO 120 J=1,4
         BARKTOT(J)=0.0
  120 CONTINUE
      DO 130 L=1,15
      FRAGTOT(L)=0.0
      RESPTOT(L)=0.0
  130 CONTINUE
      PSMEOUT=0.0
      TSHEOUT=0.0
      WRITE(20,2000)
C
C  READ IN INITIAL VALUES BY DECAY GROUP FOR MASS IN NECROMASS POOLS
C  (ST(NTYPE)) AND DECAY PARAMETERS OF POOLS.
C
      DO 200 I=1,5
        NCLASS=I*10+1
        NEND=NCLASS+9
        READ(6,1001)(ST(NTYPE),NTYPE=NCLASS,NEND)
        READ(10,1002)(DUR(NTYPE),NTYPE=NCLASS,NEND)
        READ(10,1003)(RESP(NTYPE),NTYPE=NCLASS,NEND)
        READ(10,1004)(FRAG(NTYPE),NTYPE=NCLASS,NEND)
        READ(10,1007)(PERS(NTYPE),NTYPE=NCLASS,NEND)
        READ(10,1008)(PERB(NTYPE),NTYPE=NCLASS,NEND)
        READ(10,1009)(THROW(I) )
```

INTLC continued

```
C
C  PRINT OUT INITIAL POOLS AND PARAMETERS ON GASP OUTPUT TAPE.
C
        WRITE(20,2001)I,(ST(NTYPE),NTYPE=NCLASS,NEND)
        WRITE(20,2002)(DUR(NTYPE),NTYPE=NCLASS,NEND)
        WRITE(20,2003)(RESP(NTYPE),NTYPE=NCLASS,NEND)
        WRITE(20,2004)(FRAG(NTYPE),NTYPE=NCLASS,NEND)
        WRITE(20,2007)(PERS(NTYPE),NTYPE=NCLASS,NEND)
        WRITE(20,2008)(PERB(NTYPE),NTYPE=NCLASS,NEND)
        WRITE(20,2009) THROW(I)
        WRITE(20,2010)
  200 CONTINUE
C
C SCHEDULE STARTING EVENTS FOR END OF FIRST YEAR- INPUT,TRANSFER,STATUS,GROUP
C
      ATRIB(1)=1.0
      ATRIB(2)=1
      CALL FILEM(1)
      ATRIB(2)=2
      CALL FILEM(1)
      ATRIB(2)=3
      CALL FILEM(1)
      ATRIB(1)=6.0
      ATRIB(2)=4
      CALL FILEM(1)
C
C  NOTE THAT FIRST "GROUP" EVENT OCCURS AT YEAR 6
C
 1001 FORMAT (5X,10F6.2)
 1002 FORMAT (20X,10F4.0)
 1003 FORMAT (5X,10F6.4)
 1004 FORMAT (5X,10F6.4)
 1007 FORMAT (5X,10F6.3)
 1008 FORMAT (5X,10F6.3)
 1009 FORMAT (5X,F4.2)
 2000 FORMAT("                    I     II     III   IV     V    VI  ",
     1 "  VII  VIII   IX    X  ")
 2001 FORMAT(I3,"  ST(NTYPE)     ",10F6.2)
 2002 FORMAT(3X,"  DUR(NTYPE)    ",10F6.1)
 2003 FORMAT(3X,"  RESP(NTYPE)   ",10F6.4)
 2004 FORMAT(3X,"  FRAG(NTYPE)   ",10F6.4)
 2007 FORMAT(3X,"  PERS(NTYPE)   ",10F6.4)
 2008 FORMAT(3X,"  PERB(NTYPE)   ",10F6.4)
 2009 FORMAT(3X,"  THROW(NTYPE) ",F5.2)
 2010 FORMAT(" ----------------------------------------------")
C
C  LOAD BOLE AND BARK FILES (FILEM(NTYPE)) WITH COHORTS WHOSE NECROMASS
C  (ATRIB(2)) EQUALS ST(NTYPE).  THESE INITIAL COHORTS WILL BE TRANSFERRED OUT
C  OF THE THEIR ORIGINAL POOLS IN HALF THE NORMAL YEARS (0.5DUR).  SNAGS
C  ARE PRESUMED TO HAVE ALREADY BROKEN.
C
C
```

INTLC continued

```
C  FIRST LOAD DOUGLAS-FIR FILES WITH COHORTS.  IF A CLASS IV OR V LOG
C  COHORT (J=4 or 5), MAKE SURE IT IS SCHEDULED TO LEAVE AT THE CORRECT YEAR
C  IN THE SIX YEAR CYCLE.  OTHERWISE, THE MODEL WILL NEVER TRANSFER
C  THE COHORT OUT OF THE SYSTEM!
C
       DO 300 I=1,3
        DO 350 J=1,8
           NTYPE=I*10+J
           IF(ST(NTYPE).EQ.0.0) GO TO 350
           ATRIB(1)=0.0
           ATRIB(2)=ST(NTYPE)
           IF(J.EQ.4.OR.J.EQ.5) GO TO 325
           OUT=0.5*DUR(NTYPE)
           ATRIB(3)=IFIX(OUT)
           GO TO 326
C
C  CALCULATE YEAR THAT CLASS IV BOLE ARE TRANSFERRED AND CLASS V BOLES LEAVE
C
  325      OUTL=((0.5*DUR(NTYPE))+6.0)/6.0
           KOUT=IFIX(OUTL)
           HOUT=KOUT*6
           ATRIB(3)=HOUT
  326      ATRIB(4)=0.0
           CALL FILEM(NTYPE)
  350   CONTINUE
  300 CONTINUE
C
C LOAD WESTERN HEMLOCK FILES WITH COHORTS
C
      DO 400 I=4,5
        DO 450 J=1,8
          IF(J.EQ.5) GO TO 450
          NTYPE=I*10+J
          IF(ST(NTYPE).EQ.0.0) GO TO 450
          ATRIB(1)=0.0
          ATRIB(2)=ST(NTYPE)
          OUT=0.5*DUR(NTYPE)
          ATRIB(3)=IFIX(OUT)
          ATRIB(4)=0.0
          CALL FILEM(NTYPE)
  450  CONTINUE
  400 CONTINUE
C
C CALL SUBROUTINE DEBUG TO PRINT OUT INITIAL VALUES IN ALL VARIABLES
C
      CALL DEBUG
      RETURN
      END
```

SUBROUTINE STATUS

```
      SUBROUTINE STATUS
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NGCOM1
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEGGCOM1
     2,TTCLR,TTFIN,TTRIB(25),TTSET                                        GCOM1
      COMMON /GCOM2/ DD(100),DDL(100),DTFUL,DTNOW,ISEES,LFLAG(50),NFLAG,GCOM2
     1NNEQD,NNEQS,NNEQT,SS(100),SSL(100),TTNEX                            GCOM2
      COMMON /GCOM3/ AAERR,DTMAX,DTMIN,DTSAV,IITES,LLERR,LLSAV,LLSBV,RREGCOM3
     1RR,TTLAS,TTSAV                                                      GCOM3
      COMMON /GCOM4/ DTPLT(10),HHLOW(25),HHWID(25),IICRD,IITAP(10),JJCELGCOM4
     1(500),LLABC(25,2),LLABH(25,2),LLABP(11,2),LLABT(25,2),LLPHI(10),LLGCOM4
     2PLO(10),LLPLT,LLSUP(15),LLSYM(10),MMPTS,NNCEL(25),NNCLT,NNHIS,NNPLGCOM4
     3T,NNPTS(10),NNSTA,NNVAR(10),PPHI(10),PPLO(10)                       GCOM4
      COMMON /GCOM5/ IIFVT,IISED(6),JJBEG,JJCLR,MMNIT,MMON,NNAME(3),NNOFGCOM5
     1T,NNDAY,NNPT,NNSET,NNPRJ,NNPRM,NNRNS,NNRUN,NNSTR,NNYR,SSEED(6)     GCOM5
      COMMON /GCOM6/ EENQ(100),IINN(100),KKRNK(100),MMAXQ(100),QQTIM(100GCOM6
     1),SSOBV(25,5),SSTPV(25,6),VVNQ(100)                                 GCOM6
      COMMON/UCOM1/DUR(60),RESP(60),FRAG(60),THROW(5),W(5,2),WB(5,2)
      COMMON/UCOM2/PERS(60),PERB(60),PSMEOUT,TSHEOUT
      COMMON/UCOM3/ RESPTOT(15),FRAGTOT(15)
      COMMON/UCOM4/BARKTOT(4),RESPTOC(5),FRAGTOC(5),BARKTOC(5)
      COMMON/UCOM5/BARKF(5),ST(60)
C
C         SUBROUTINE STATUS IS CALLED AT THE BEGINNING OF EACH NEW YEAR BEFORE
C         ALL OTHER EVENTS.  STATUS CALCULATES THE NECROMASS THAT WAS LOST IN
C         THE PREVIOUS YEAR TO RESPIRATION AND FRAGMENTATION.  IT UPDATES THE
C         POOLS FOR THE LOSSES AND IT DETERMINES THE VALUES FOR ALL THE ANNUAL
C         LOSS VARIABLES.  FRAGMENTATION AND RESPIRATION LOSSES ARE CALCULATED
C         AS FIXED FRACTIONS OF THE POOL USING FRAG(NTYPE) AND RESP(NTYPE) AS
C         THE FRACTIONS.
C
C  RESET ALL ANNUAL LOSS VARABLES TO ZERO
C
       DO 300 I=1,5
        FRAGTOC(I)=0.0
        RESPTOC(I)=0.0
        BARKTOC(I)=0.0
  300 CONTINUE
      PSMEOUT=0.0
      TSHEOUT=0.0
      DO 310 L=1,15
         RESPTOT(L)=0.0
         FRAGTOT(L)=0.0
  310  CONTINUE
       DO 320 K=1,4
        BARKTOT(K)=0.0
  320 CONTINUE
```

STATUS continued

```
C
C  DOUGLAS-FIR
C  SUBTRACT WOOD FRAGMENTATION AND RESPIRATION LOSSES FROM NECROMASS POOLS.
C  TALLY ANNUAL FRAGMENTATION AND RESPIRATION OUTPUTS IN VARIABLES RESPTOT,
C  RESPTOC, FRAGTOT, AND FRAGTOC.
C  RESPTOT(L)=SUM OF ALL WOOD RESPIRATION LOSSES IN LOG DECAY CLASS L.
C  RESPTOC(I)=SUM OF ALL WOOD RESPIRATION LOSSES IN DECAY GROUP I.
C  FRAGTOT(L)=SUM OF ALL WOOD FRAGMENTATION ON LOG DECAY CLASS L.
C  FRAGTOC(I)=SUM OF ALL WOOD FRAGMENTATION IN DECAY GROUP I.
C
      DO 100 I=1,3
        DO 110 J=1,8
          NTYPE=I*10+J
           R=RESP(NTYPE)
           F=FRAG(NTYPE)
          L=J
          FRAGTOT(L)=FRAGTOT(L)+ST(NTYPE)*(F-F*R)
          FRAGTOC(I)=FRAGTOC(I)+ST(NTYPE)*(F-F*R)
          RESPTOT(L)=RESPTOT(L)+ST(NTYPE)*R
          RESPTOC(I)=RESPTOC(I)+ST(NTYPE)*R
          ST(NTYPE)=ST(NTYPE)*(1.0-R-F+F*R)
  110   CONTINUE
C
C  DOUGLAS-FIR
C  SUBTRACT BARK LOSSES FROM BARK POOLS.  TALLY ANNUAL BARK LOSS VARIABLES.
C  BARKTOT(K)=SUM OF SNAG OR BARK LOSSES.
C  BARKTOC(I)=SUM OF BARK LOSSES IN DECAY GROUP I
C
        DO 120 J=9,10
          NTYPE=I*10+J
          K=J-8
          F=FRAG(NTYPE)
          BARKTOT(K)=BARKTOT(K)+ST(NTYPE)*F
          BARKTOC(I)=BARKTOC(I)+ST(NTYPE)*F
          ST(NTYPE)=ST(NTYPE)*(1.0-F)
  120   CONTINUE
  100 CONTINUE
C
C  WESTERN HEMLOCK
C  SUBTRACT WOOD RESPIRATION LOSSES FROM LOG NECROMASS POOLS.
C  TALLY ANNUAL RESPIRATION OUTPUTS IN VARIABLES RESPTOT AND RESPTOC.
C  NOTE THAT WESTERN HEMLOCK LOGS DO NOT FRAGMENT.
C
      DO 200 I=4,5
        DO 210 J=1,4
          L=J+8
          NTYPE=I*10+J
          R=RESP(NTYPE)
          RESPTOT(L)=RESPTOT(L)+ST(NTYPE)*R
          RESPTOC(I)=RESPTOC(I)+ST(NTYPE)*R
          ST(NTYPE)=ST(NTYPE)*(1.0-R)
  210   CONTINUE
```

STATUS continued

```
C
C  WESTERN HEMLOCK
C  SUBTRACT WOOD RESPIRATION AND FRAGMENTATION LOSSES FROM WESTERN HEMLOCK
C  SNAGS.  TALLY ANNUAL RESPIRATION AND FRAGMENTATION LOSSES.
C
         DO 220 J=6,8
           L=J+7
           NTYPE=I*10+J
           R=RESP(NTYPE)
           F=FRAG(NTYPE)
           RESPTOT(L)=RESPTOT(L)+ST(NTYPE)*R
           RESPTOC(I)=RESPTOC(I)+ST(NTYPE)*R
           FRAGTOC(I)=FRAGTOC(I)+ST(NTYPE)*(F-F*R)
           FRAGTOT(L)=FRAGTOT(L)+ST(NTYPE)*(F-F*R)
           ST(NTYPE)=ST(NTYPE)*(1.0-R-F+R*F)
  220      CONTINUE
C
C  WESTERN HEMLOCK
C  SUBTRACT BARK LOSSES FROM BARK POOLS.  TALLY ANNUAL BARK LOSS VARIABLES.
C  BARKTOT(K)=SUM OF SNAG OR BARK LOSSES.
C  BARKTOC(I)=SUM OF BARK LOSSES IN DECAY GROUP I
C
         DO 230 J=9,10
           K=J-6
           NTYPE=I*10+J
           F=FRAG(NTYPE)
           BARKTOT(K)=BARKTOT(K)+ST(NTYPE)*F
           BARKTOC(I)=BARKTOC(I)+ST(NTYPE)*F
           ST(NTYPE)=ST(NTYPE)*(1.0-F)
  230    CONTINUE
  200  CONTINUE
C
C SCHEDULE NEXT STATUS EVENT- ATRIB(2)=1
C
      ATRIB(1)=TNOW+1.0
      ATRIB(2)=1
      CALL FILEM(1)
      RETURN
      END
```

SUBROUTINE INPUT

```
      SUBROUTINE INPUT
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NGCOM1
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEGGCOM1
     2,TTCLR,TTFIN,TTRIB(25),TTSET                                     GCOM1
      COMMON /GCOM2/ DD(100),DDL(100),DTFUL,DTNOW,ISEES,LFLAG(50),NFLAG,GCOM2
     1NNEQD,NNEQS,NNEQT,SS(100),SSL(100),TTNEX                         GCOM2
      COMMON/UCOM1/DUR(60),RESP(60),FRAG(60),THROW(5),W(5,2),WB(5,2)
      COMMON/UCOM2/PERS(60),PERB(60),PSMEOUT,TSHEOUT
      COMMON/UCOM5/BARKF(5),ST(60)
C
C        THIS EVENT SUBROUTINE CONVERTS ANNUAL MORTALITY DATA FROM TAPE1 TO
C        NECROMASS (MG) THEN APPORTIONS THE MASS INTO THE APPROPRIATE POOLS
C        (ST(NTYPE)) AND FILES (FILEM(NTYPE)).  EACH LINE ON TAPE1 DATA IS A
C        SINGLE BOLE WITH A SPECIES NUMBER AND DBH.  A LINE WITH A NEGATIVE
C        SPECIES CODE MARKS THE END OF A YEAR OF DATA.  TAPE1 DATA REPRESENTS
C        MORTALITY FROM A FIFTH HECTARE PLOT.
C        THEREFORE ONCE THE SINGLE BOLE MASS IS CALCULATED IT IS MULTIPLIED BY
C        5 TO PUT ITS MASS ON A HECTARE BASIS.
C
C
C
C  RESET INPUT VECTOR VALUES TO ZERO
C
      DO 101 J=1,2
         DO 102 I=1,5
          W(I,J)=0.0
          WB(I,J)=0.0
  102    CONTINUE
  101 CONTINUE
C
C  READ IN DATA FROM TAPE 1 (MORTALITY FROM STAND GROWTH MODEL)
C
  100 READ(1,1000) NSPECIE,DBH,NTIME
C
C  CHECK FOR END OF MORTALITY IN THAT TIME PERIOD
C
      IF(NSPECIE.LT.0) GO TO 500
C
C  DETERMINE SPECIES 16=PSME,19=TSHE
C
      IF(NSPECIE.EQ.16) GO TO 200
      IF(NSPECIE.NE.19) GO TO 100
C
C  BARK AND WOOD MASS OF DEAD TREES ARE CALCULATED BY SPECIES SPECIFIC
C  REGRESSION EQUATIONS (GHOLZ ET AL. 1978) BASED ON DBH.  THE MASSES
C  ("BOLMASS" FOR WOOD AND "BARMASS" FOR WOOD) ARE SORTED BY DECAY GROUP AND
C  SENT TO LINE 300 TO APPORTION THE MASSES TO SNAG OR LOG CLASSES.
C
C
C
C  CALCULATE WOOD AND BARK FROM DEAD WESTERN HEMLOCK BOLE AND THEN SORT INTO
C  CLASS (I) BY DBH.
C
      BOLMASS=EXP(-2.172+2.257* ALOG(DBH))/200.
      BARMASS=EXP(-4.373+2.258* ALOG(DBH))/200.
      IF(DBH.LT.25.0) I=5
      IF(DBH.GE.25.0) I=4
      GO TO 300
```

INPUT continued

```
C
C  CALCULATE WOOD AND BARK FROM DEAD DOUGLAS-FIR BOLE AND THEN SORT INTO
C  CLASS (I) BY DBH.
C
  200 BOLMASS=EXP(-3.0396+2.5951* ALOG(DBH))/200.
      BARMASS=EXP(-4.3101+2.4300* ALOG(DBH))/200.
      IF(DBH.LT.40.) I=3
      IF(DBH.GT.40..AND. DBH.LT.65.) I=2
      IF(DBH.GE.65.) I=1
C
C  SUBROUTINE WIND IS NOW CALLED TO DETERMINE WHAT PORTION OF THE DEAD WOOD IS
C  FROM A SNAG OR A WINDTHROW AND PUTS IT IN W(I,1) IF WINDTHROW AND W(I,2) IF
C  SNAG.  WB(I,1) AND WB(I,2) ARE FOR THE BARK ON WINDTHROWS AND SNAGS
C  RESPECTIVELY
C
  300 CALL WIND(BOLMASS,BARMASS,I )
C
C CHECK FOR MORE MORTALITY IN YEAR TNOW
C
      GO TO 100
C
C
C
C  NOW THAT ALL THE MORTALITY HAS BEEN TALLIED AND SORTED, PUT THE NEW SNAGS
C  AND BOLES INTO THEIR APPROPRIATE FILES.  UPDATE THE NECROMASS POOLS
C  ST(NTYPE).
C
  500 DO 110 I=1,5
       DO 120 K=1,2
        LS=1
        IF(K.EQ.2) LS=6
        IF(W(I,K).EQ.0.0) GO TO 120
C
C  PUT NEW COHORT (W(I,K)) INTO NECROMASS POOL (FILEM(NTYPE).  IF LS=6, COHORT
C  IS SNAG MATERIAL; IF LS=1, COHORT IS LOG MATERIAL
C
C
        NTYPE=I*10+LS
        ATRIB(1)=TNOW
        ATRIB(2)=W(I,K)
        ATRIB(3)=TNOW+DUR(NTYPE)
C
C  IF COHORT IS LARGE DOUGLAS-FIR OR LARGE WESTERN HEMLOCK SNAG, SET A DATE
C  FOR SNAG TO BREAK AT LINE 233
C
        IF(LS.EQ.6 .AND. I.EQ.1.OR.I.EQ.4)  GO TO 233
        GO TO 234
  233   ATRIB(4)=(ATRIB(1)+ATRIB(3))*0.5
  234   CALL FILEM(NTYPE)
C
C  UPDATE NECROMASS POOLS BY MASS OF NEW COHORT.  FIRST WOOD THEN BARK
C
        ST(NTYPE)=ST(NTYPE)+W(I,K)
        NTYPEB=I*10+K+8
        ST(NTYPEB)=ST(NTYPEB)+WB(I,K)
  120  CONTINUE
  110 CONTINUE
C
C  CREATE NEXT INPUT EVENT IN ONE YEAR- ATRIB(2)=2
C
      ATRIB(1)=TNOW+1.
      ATRIB(2)=2
      CALL FILEM(1)
 1000 FORMAT(3X,I3,F6.1,I3)
      RETURN
      END
C
```

SUBROUTINE TRANFER

```
      SUBROUTINE TRANFER
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NGCOM1
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEGGCOM1
     2,TTCLR,TTFIN,TTRIB(25),TTSET                                      GCOM1
C
C         THIS EVENT SUBROUTINE DIRECTS ALL THE TRANSFERS.  EACH TYPE OF
C         TRANSFER IS REPRESENTED BY A DIFFERENT SUBROUTINE.
C
C
C  FIRST TRANSFER LOG COHORTS TO NEW LOG POOLS AND REMOVE LOG CLASS IV WESTERN
C  HEMLOCK FROM FILEM(44 or 54) and ST(44 or 54) AND PLACE IN TSHEOUT.
C
      CALL TRANLOG
C
C NEXT TRANSFER SNAG COHORT TO NEW SNAG POOL.
C
      CALL TRANSNA
C
C  FINALLY TRANSFER SNAG MASS TO LOG COHORT USING "TRANBOT".  TRANBOT CALLS
C  SUBROUTINE TRANSB TO DO THE ACTUAL TRANSFERS.   ATRIB(4) TELLS WHEN TO
C  TRANSFER SNAG MASS TO LOG COHORT
C
      CALL TRANBOT
C
C  SCHEDULE NEXT TRANSFER EVENT-  ATRIB(2)=3
C
      ATRIB(1)=TNOW+1
      ATRIB(2)=3
      CALL FILEM(1)
      RETURN
      END
```

SUBROUTINE TRANLOG

```
      SUBROUTINE TRANLOG
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NGCOM1
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEGGCOM1
     2,TTCLR,TTFIN,TTRIB(25),TTSET                                     GCOM1
      COMMON /GCOM2/ DD(100),DDL(100),DTFUL,DTNOW,ISEES,LFLAG(50),NFLAG,GCOM2
     1NNEQD,NNEQS,NNEQT,SS(100),SSL(100),TTNEX                         GCOM2
      COMMON/UCOM1/DUR(60),RESP(60),FRAG(60),THROW(5),W(5,2),WB(5,2)
      COMMON/UCOM2/PERS(60),PERB(60),PSMEOUT,TSHEOUT
      COMMON/UCOM5/BARKF(5),ST(60)
C
C         THIS SUBROUTINE TRANSFERS LOG COHORTS FROM LOG POOL TO LOG POOL
C         EXCEPT FOR DOUGLAS-FIR CLASS IV COHORTS GOING TO CLASS V POOLS.
C         THE SUBROUTINE ALSO UPDATES THE APPROPRIATE POOLS ST(NTYPE) AND
C         ST(NTYPE1).  NTYPE IS THE POOL FROM WHICH THE COHORT CAME AND
C         NTYPE1 IS THE POOL TO WHICH IT GOES
C
C
      DO 100 I=1,5
        DO 110 J=1,3
            NTYPE=I*10+J
            NTYPE1=NTYPE+1
            L=J+1
C
C  CHECK TO SEE IF THERE ARE COHORTS IN THE POOL "NTYPE"(NNQ .NE.0).  IF THERE
C  ARE COHORTS CHECK TO SEE IF ANY ARE READY TO BE TRANSFERRED (ATRIB(3)=TNOW)
C  IF NOT RETURN TO 110.  IF YES, REMOVE COHORT WITH THE ATRIB(3)=TNOW, UPDATE
C  COHORT BIOMASS, AND PUT COHORT IN NEXT POOL (NTYPE1). CALCULATE TIME
C  FOR FALLING SNAG MASS TO BE ADDED TO COHORT (ATRIB(4)).
C
C     *THE FOLLOWING SEQUENCE OF LINES ARE USED REPEATEDLY TO PULL COHORTS
C     *WHICH ARE READY TO BE TRANSFERRED FROM A POOL ON THE BASIS OF AN
C     *ATTRIBUTE.  FIRST THE POOL IS CHECKED TO SEE IF IT HAS ANY COHORTS.
C     *NEXT THE COHORTS IN THE POOL ARE CHECKED TO SEE IF ANY HAVE A SPECIFIC
C     *VALUE FOR A SPECIFIC ATTRIBUTE. FINALLY IF SUCH A COHORT IS FOUND,
C     *IT IS REMOVED FROM THE POOL AND ITS CURRENT MASS CALCULATED USING A
C     *SPECIAL SUBROUTINE CALLED "JOE".
C
C
C  ARE THERE COHORTS IN THE POOL? (IE. ARE THERE ENTRIES IN THE FILE?)
C
            IF(NNQ(NTYPE).EQ.0) GO TO 110
C
C  IS THERE A COHORT READY TO BE TRANSFERRED? (IE. IS THERE AN ENTRY IN
C    THE FILE WITH ATRIB(3)=TNOW?)
C
            LOUT=NFIND(TNOW,5,NTYPE,3,0.1)
            IF(LOUT.EQ.0) GO TO 110
C
C  REMOVE COHORT FROM POOL
C
            CALL RMOVE(LOUT,NTYPE)
C
C  DETERMINE MASS OF COHORT AT CURRENT TIME (BMASS) USING SUBROUTINE JOE
C
            ORIGBIO=ATRIB(2)
            LENGTH=ATRIB(3)-ATRIB(1)
            CALL JOE(LENGTH,ORIGBIO,BMASS,NTYPE)
```

TRANLOG continued

```
C  PUT COHORT INTO NEW LOG POOL, WITH NEW MASS (ATRIB(2)), NEW DATE TO
C  LEAVE POOL (ATRIB(3)), AND DATE FOR SNAG MASS TO BE ADDED (ATRIB(4))

C
            ATRIB(1)=ATRIB(3)
            ATRIB(2)=BMASS
            ATRIB(3)=ATRIB(1)+DUR(NTYPE1)
            IF(L.NE.4)ATRIB(4)=TNOW+0.5*DUR(NTYPE1)
            CALL FILEM(NTYPE1)
C
C RESET NECROMASS POOLS TO REFLECT TRANSFER
C
            ST(NTYPE)=ST(NTYPE)-BMASS
            ST(NTYPE1)=ST(NTYPE1)+BMASS
C
C  CHECK NEXT LOG POOL
C
  110     CONTINUE
  100  CONTINUE
C
C
C
C  AFTER ALL LOG TRANSFERS HAVE BEEN MADE, WESTERN HEMLOCK LOGS IN CLASS IV
C  ARE TRANSFERRED OUT OF THEIR NECROMASS POOL AND INTO "TSHEOUT".
C
      TSHEOUT=0.0
      DO 200 I=4,5
       NTYPE=I*10+4
       IF(NNQ(NTYPE).EQ.0) GO TO 200
C
       LOUT=NFIND(TNOW,5,NTYPE,3,.1)
       IF(LOUT.EQ.0) GO TO 200
C
       CALL RMOVE(LOUT,NTYPE)
       ORIGBIO=ATRIB(2)
       LENGTH=ATRIB(3)-ATRIB(1)
       CALL JOE(LENGTH,ORIGBIO,OUTBIO,NTYPE)
C
C  TRANSFER CURRENT COHORT MASS (OUTBIO) OUT OF POOL AND INTO TSHEOUT
C
       TSHEOUT=TSHEOUT+OUTBIO
       ST(NTYPE)=ST(NTYPE)-OUTBIO
  200 CONTINUE
      RETURN
      END
```

SUBROUTINE TRANSNA

```
      SUBROUTINE TRANSNA
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NGCOM1
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEGGCOM1
     2,TTCLR,TTFIN,TTRIB(25),TTSET                                     GCOM1
      COMMON /GCOM2/ DD(100),DDL(100),DTFUL,DTNOW,ISEES,LFLAG(50),NFLAG,GCOM2
     1NNEQD,NNEQS,NNEQT,SS(100),SSL(100),TTNEX                         GCOM2
      COMMON/UCOM1/DUR(60),RESP(60),FRAG(60),THROW(5),W(5,2),WB(5,2)
      COMMON/UCOM5/BARKF(5),ST(60)
C
C       THIS ROUTINE TRANSFERS COHORTS FROM SNAG CLASS I TO CLASS II AND CLASS
C       II TO TO CLASS III.  IT ALSO UPDATES THE NECROMASS IN EACH POOL TO
C       REFLECT THE TRANSFERS.  NTYPE IS THE PRESENT POOL AND NTYPE1 IS THE
C       POOL TO WHICH A COHORT IS TRANSFERRED.
C
C
      DO 100 I=1,5
        DO 110 J=6,7
          NTYPE=I*10+J
          NTYPE1=NTYPE+1
C
C  CHECK IF ANY SNAG COHORT IN THE POOL IS READY TO BE TRANSFERRED TO ANOTHER
C  POOL
C
          IF(NNQ(NTYPE).EQ.0) GO TO 110
          LOUT=NFIND(TNOW,5,NTYPE,3,.1)
          IF(LOUT.EQ.0) GO TO 110
C
C  REMOVE COHORT FROM POOL, DETERMINE CURRENT MASS, AND TRANSFER IT TO
C  NEXT POOL.  SET COHORT'S NEW TRANSFER TIME (ATRIB(3)), SET BREAKAGE DATE
C  (ATRIB(4)), AND SET NEW MASS (ATRIB(2)).
C
C
           CALL RMOVE(LOUT,NTYPE)
C
           ORIGBIO=ATRIB(2)
           LENGTH=ATRIB(3)-ATRIB(1)
           CALL JOE(LENGTH,ORIGBIO,BMASS,NTYPE)
C
           ATRIB(1)=TNOW
           ATRIB(2)=BMASS
           ATRIB(3)=TNOW+DUR(NTYPE1)
           ATRIB(4)=0
           IF(J.EQ.6)ATRIB(4)=TNOW+.5*DUR(NTYPE1)
           CALL FILEM(NTYPE1)
C
C UPDATE NECROMASS POOLS AFTER TRANSFER
C
           ST(NTYPE)=ST(NTYPE)-BMASS
           ST(NTYPE1)=ST(NTYPE1)+BMASS
C
C  CHECK FOR NEXT SNAG POOL
C
  110    CONTINUE
  100  CONTINUE
      RETURN
       END
```

SUBROUTINE TRANBOT

```
      SUBROUTINE TRANBOT
C
C        THIS SUBROUTINE TRANSFERS SNAG MASS TO LOG COHORTS TO SIMULATE SNAG
C        BREAKAGE.  FIRST, MASS FROM LARGE DOUGLAS-FIR AND LARGE WESTERN
C        HEMLOCK CLASS I SNAGS ARE TRANSFERRED TO MEDIUM DOUGLAS-FIR CLASS II
C        LOGS AND SMALL WESTERN HEMLOCK CLASS II LOGS.  SECOND, MASS FROM
C        CLASS II SNAGS IS TRANSFERRED TO CLASS III LOG COHORTS WITHIN THE
C        SAME DECAY GROUP.  NCLASS IS THE DECAY GROUP OF THE SNAG AND HCLASS
C        IS THE DECAY GROUP OF THE LOG.
C
C
C  TRANSFER LARGE CLASS I SNAGS TO LOG COHORTS OF SMALLER DIMENSIONS
C
      DO 100 I=1,4,3
          NCLASS=I
          HCLASS=1
          J=6
          CALL TRANSB(NCLASS,HCLASS,J)
  100 CONTINUE
C
C  TRANSFER CLASS II SNAG MASS TO CLASS III LOG COHORTS IN THE SAME DECAY
C  GROUP.
C
      DO 200 I=1,5
        NCLASS=I
        HCLASS=0
        J=7
        CALL TRANSB(NCLASS,HCLASS,J)
C
C  CHECK FOR NEXT POOL
C
  200 CONTINUE
      RETURN
      END
```

SUBROUTINE TRANSB

```
      SUBROUTINE TRANSB(NCLASS,HCLASS,J)
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NGCOM1
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEGGCOM1
     2,TTCLR,TTFIN,TTRIB(25),TTSET                                    GCOM1
      COMMON /GCOM2/ DD(100),DDL(100),DTFUL,DTNOW,ISEES,LFLAG(50),NFLAG,GCOM2
     1NNEQD,NNEQS,NNEQT,SS(100),SSL(100),TTNEX                        GCOM2
      COMMON/UCOM1/DUR(60),RESP(60),FRAG(60),THROW(5),W(5,2),WB(5,2)
      COMMON/UCOM2/PERS(60),PERB(60),PSMEOUT,TSHEOUT
      COMMON/UCOM5/BARKF(5),ST(60)
C
C          THIS ROUTINE TRANSFERS SNAG NECROMASS TO LOG POOLS AND COHORTS
C          HALFWAY THROUGH THE SNAG COHORT'S YEARS IN THE PARTICULAR SNAG DECAY
C          CLASS POOL.  THE SNAG MASS GOES TO THE LOG COHORT READY TO RECEIVE
C          IT.  IF THERE IS NO COHORT READY TO RECEIVE IT, A NEW LOG COHORT IS
C          CREATED FROM THE "FALLEN" NECROMASS.  NTYPE REFERS TO THE SNAG POOL
C          AND NTYPE1 REFERS TO THE LOG POOL TO WHICH THE SNAG MASS IS
C          TRANSFERRED.
C
C
      NTYPE=NCLASS*10+J
      NTYPE1=(NCLASS +HCLASS)*10+J-4
C
C  CHECK TO SEE IF THERE ANY SNAGS TO BE BROKEN. IF NOT RETURN TO TRANBOT.
C
       IF(NNQ(NTYPE).EQ.0) GO TO 110
       LOUT=NFIND(TNOW,5,NTYPE,4,.1)
       IF(LOUT.EQ.0) GO TO 110
C
C  THE SNAG COHORT READY TO BE BROKEN(IE.LOSE MASS) IS REMOVED.  THE CURRENT
C  MASS OF THE COHORT BEFORE BREAKAGE IS CALCULATED (BMASS).  THEN THE PORTION
C  TO BE TRANSFERRED IS CALCULATED (TRANBIO) AND SUBTRACTED FROM THE SNAG
C  MASS.  THE NEW SNAG MASS (SNEW) IS THEN FILED IN THE POOL; ATRIB(1) IS
C  SET TO TNOW; ATRIB(2) IS SET TO SNEW; ATRIB (3), DATE TO LEAVE POOL, STAYS
C  THE SAME.
C
C
       CALL RMOVE(LOUT,NTYPE)
C
       ORIGBIO=ATRIB(2)
       LENGTH=ATRIB(4)-ATRIB(1)
       CALL JOE(LENGTH,ORIGBIO, BMASS,NTYPE)
C
       TRANBIO= PERS(NTYPE) *BMASS
       SNEW=BMASS - TRANBIO
       TRANBAR=PERB(NTYPE)*TRANBIO
C
       ATRIB(1)=TNOW
       ATRIB(2)=(SNEW)
       ATRIB(3)=ATRIB(3)
       ATRIB(4)=0
       CALL FILEM(NTYPE)
```

TRANSB continued

```
C  NEXT THE SNAG POOL MASS (NTYPE) IS UPDATED AS ARE THE BARK POOLS.
C  "NBTYPE" IS FOR SNAG BARK POOL AND "NBTYPE1" IS FOR LOG BARK POOL.
C  SNAG BARK LOSES AN AMOUNT OF BARK PROPORTIONAL TO THE WOOD LOST BY
C  THE SNAG COHORT.
C
        NBTYPE=NCLASS*10+10
        NBTYPE1=(NCLASS+HCLASS)*10+9
        ST(NTYPE)=ST(NTYPE)-TRANBIO
        ST(NBTYPE)=ST(NBTYPE)-TRANBAR
        ST(NBTYPE1)=ST(NBTYPE1)+TRANBAR
C
C  NOW CHECK TO SEE IF THERE IS A LOG COHORT (NTYPE1) READY FOR FOR THE SNAG
C  MATERIAL (ATRIB(4)=TNOW).  IF NOT, CREATE A NEW LOG COHORT TO ABSORB THE
C  SNAG MASS (LINE 120).  IF THERE IS A LOG COHORT READY, REMOVE COHORT FROM
C  POOL FILE.  DETERMINE CURRENT MASS OF LOG COHORT BEFORE THE SNAG MASS IS
C  ADDED, SET ATRIB (2) TO CURRENT LOG MASS + SNAG MASS, AND SET ATRIB(1) TO
C  TNOW.  SET ATRIB (4)=0 AND LEAVE ATRIB(3) THE SAME.  PLACE COHORT BACK IN
C   LOG POOL FILE
C
C
       IF(NNQ(NTYPE1).EQ.0) GO TO 120
       LOUT=NFIND(TNOW,5,NTYPE1,4,.1)
C
C  IF NO COHORT IS READY, GO TO LINE 120 AND CREATE NEW COHORT
C  OTHERWISE ADD SNAG MASS TO APPROPRIATE COHORT
C
       IF(LOUT.EQ.0) GO TO 120
C
         CALL RMOVE(LOUT,NTYPE1)
C
         ORIGBIO=ATRIB(2)
         LENGTH=ATRIB(4)-ATRIB(1)
         CALL JOE(LENGTH,ORIGBIO,BMASS,NTYPE1)
C
         ATRIB(1)=TNOW
         ATRIB(2)=BMASS+TRANBIO
         ATRIB(3)=ATRIB(3)
         ATRIB(4)=0
         CALL FILEM(NTYPE1)
         GO TO 130
C
C  LINE 120-CREATE NEW LOG COHORT WITH SNAG MASS.  SCHEDULE COHORT TO LEAVE
C  LOG POOL IN HALF THE NORMAL YEARS.
C
C
  120          ATRIB(1)=TNOW
               ATRIB(2)=TRANBIO
               ATRIB(3)=TNOW+.5*DUR(NTYPE1)
               ATRIB(4)=0
               CALL FILEM(NTYPE1)
C
C  UPDATE THE LOG NECROMASS POOL TO ACCOUNT FOR THE TRANSFER
C
  130 ST(NTYPE1)=ST(NTYPE1)+TRANBIO
C
C  CHECK FOR NEXT TRANSFER
C
  110 RETURN
      END
```

SUBROUTINE GROUP

```
      SUBROUTINE GROUP
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NGCOM1
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEGGCOM1
     2,TTCLR,TTFIN,TTRIB(25),TTSET                                     GCOM1
      COMMON /GCOM2/ DD(100),DDL(100),DTFUL,DTNOW,ISEES,LFLAG(50),NFLAG,GCOM2
     1NNEQD,NNEQS,NNEQT,SS(100),SSL(100),TTNEX                         GCOM2
      COMMON/UCOM1/DUR(60),RESP(60),FRAG(60),THROW(5),W(5,2),WB(5,2)
      COMMON/UCOM2/PERS(60),PERB(60),PSMEOUT,TSHEOUT
      COMMON/UCOM5/BARKF(5),ST(60)
C
C         THIS SUBROUTINE IS CALLED EVERY 6 YEARS. IT GROUPS 6 SEQUENTIAL
C         YEARS  OF LOG CLASS IV COHORTS INTO ONE COHORT.  THE SUBROUTINE ALSO
C         TRANSFERS CLASS IV LOG COHORTS TO THE LOG CLASS V POOL AND TRANSFERS
C         CLASS V COHORTS OUT OF THE SYSTEM INTO PSMEOUT.
C
      DO 100 I=1,3
       BIO=0.0
       NTYPE=I*10+4
C
C  CHECK TO SEE IF THERE ARE COHORTS LOG CLASS IV POOL. IF YES, THEN GROUP ALL
C  THE COHORTS WHICH HAD ENTERED THE POOL IN THE PREVIOUS SIX YEARS INTO ONE
C  COHORT.
C
       IF(NNQ(NTYPE).EQ.0) GO TO 100
C
C  REMOVE COHORTS WHICH HAD ENTERED THE CLASS IV POOL DURING THE PREVIOUS SIX
C  YEARS, CALCULATE CURRENT MASS OF COHORT, THEN PUT MASS IN NEW POOL (BIO)
       DO 110 L=1,6
         K=L-1
         TTHEN=TNOW-K
         LOUT=NFIND(TTHEN,5,NTYPE,1,0.01)
         IF(LOUT.EQ.0) GO TO 110
C
         CALL RMOVE(LOUT,NTYPE)
         ORIGBIO=ATRIB(2)
         CALL JOE(K,ORIGBIO,BMASS,NTYPE)
         BIO=BIO+BMASS
  110  CONTINUE
C
C  NEXT PLACE THIS SUMMED NECROMASS IN LOG CLASS IV POOL AND SCHEDULE IT
C  TO TRANSFER TO THE LOG CLASS V POOL IN (DUR(NTYPE)-3) YEARS.  NOTE THE
C  MASS FROM A COHORT WHICH ORIGINALLY ENTERED THE POOL STAYS IN THE POOL AN
C  AVERAGE OF DUR(NTYPE) YEARS BUT SOME COHORTS ARE IN FOR 3 YEARS LESS AND
C  SOME FOR THREE YEARS MORE.    NOTE ALSO THAT DUR(NTYPE)-3 MUST BE AN
C  INTERVAL OF 6!!  OTHERWISE THE COHORT WILL NEVER LEAVE THE CLASS IV
C  POOL.  THE COHORTS ARE CONSOLIDATED TO REDUCE THE NUMBER OF ENTRIES IN
C  THE FILE.
C
      ATRIB(1)=TNOW
      ATRIB(2)=BIO
      ATRIB(3)=ATRIB(1)+DUR(NTYPE)-3
      ATRIB(4)=0
      CALL FILEM(NTYPE)
  100 CONTINUE
```

GROUP continued

```
C  THE SECOND PART OF THE SUBROUTINE TRANSFERS CLASS IV COHORTS TO CLASS V
C  POOLS ON THE BASIS OF ATRIB(3).  NEXT, CLASS V LOGS THAT ARE SCHEDULED TO
C  DISAPPEAR GO TO PSMEOUT.
C
      DO 200 I=1,3
        NTYPE=I*10+4
        IF(NNQ(NTYPE).EQ.0) GO TO 200
        LOUT=NFIND(TNOW,5,NTYPE,3,0.1)
        IF(LOUT.EQ.0) GO TO 200
C
        CALL RMOVE(LOUT,NTYPE)
C
        NTYPE1=NTYPE+1
        ORIGBIO=ATRIB(2)
        LENGTH=ATRIB(3)-ATRIB(1)
        CALL JOE(LENGTH,ORIGBIO,BMASS,NTYPE)
C
        ATRIB(1)=TNOW
        ATRIB(2)=BMASS
        ATRIB(3)=TNOW+DUR(NTYPE1)
        ATRIB(4)=0
        CALL FILEM(NTYPE1)
C
C UPDATE LOG CLASS IV AND V TO REFLECT TRANSFER AND MOVE TO NEXT DECAY GROUP.
C
        ST(NTYPE)=ST(NTYPE)-BMASS
        ST(NTYPE1)=ST(NTYPE1)+BMASS
  200 CONTINUE
C
C  REMOVE THE CLASS V WOOD IN EACH OF THE THREE DECAY GROUPS WHICH IS READY TO
C  BE TRANSFERRED OUT OF THE SYSTEM.  (ATRIB(3)=TNOW)  THEN PUT MASS INTO
C  PSMEOUT, AND UPDATE CLASS V NECROMASS POOL TO REFLECT THE LOSS.
C
      PSMEOUT=0.0
      DO 300 I=1,3
       NTYPE=I*10 +5
       IF(NNQ(NTYPE).EQ.0) GO TO 300
       LOUT=NFIND(TNOW,5,NTYPE,3,.1)
       IF(LOUT.EQ.0) GO TO 300
C
       CALL RMOVE(LOUT,NTYPE)
C
       ORIGBIO=ATRIB(2)
       LENGTH=ATRIB(3)-ATRIB(1)
       CALL JOE(LENGTH,ORIGBIO,BMASS,NTYPE)
C
       ST(NTYPE)=ST(NTYPE)-BMASS
       PSMEOUT=BMASS+PSMEOUT
  300 CONTINUE
C
C SCHEDULE NEXT GROUP EVENT IN 6 YEARS
C
      ATRIB(1)=TNOW+6
      ATRIB(2)=4
      CALL FILEM(1)
      RETURN
      END
```

SUBROUTINE DEBUG

```
      SUBROUTINE DEBUG
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NGCOM1
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEGGCOM1
     2,TTCLR,TTFIN,TTRIB(25),TTSET                                    GCOM1
      COMMON /GCOM2/ DD(100),DDL(100),DTFUL,DTNOW,ISEES,LFLAG(50),NFLAG,GCOM2
     1NNEQD,NNEQS,NNEQT,SS(100),SSL(100),TTNEX                        GCOM2
      COMMON/UCOM1/DUR(60),RESP(60),FRAG(60),THROW(5),W(5,2),WB(5,2)
      COMMON/UCOM2/PERS(60),PERB(60),PSMEOUT,TSHEOUT
      COMMON/UCOM3/ RESPTOT(15),FRAGTOT(15)
      COMMON/UCOM4/BARKTOT(4),RESPTOC(5),FRAGTOC(5),BARKTOC(5)
      COMMON/UCOM5/BARKF(5),ST(60)
      DIMENSION WINPUT(5),BINPUT(5),WOOD(5),TOTIN(5),BARK(5),TOTAL(5)
C
C       SUBROUTINE DEBUG IS THE PRINTING SUBROUTINE . IT ALSO CALCULATES ALL
C       THE CUMULATIVE VARIABLES SUCH AS TOTIN, WINPUT, AND BINPUT.  IT IS
C       CALLED IN "INTLC" AT THE START OF THE SIMULATION TO INITIALIZE THE
C       CUMULATIVE VARIABLES.  ONCE THE SIMULATION HAS STARTED IT IS CALLED
C       EACH YEAR AFTER "TRANFER" OR "GROUP" AND STARTS AT LINE 90.  IT
C       UPDATES THE CUMULATIVE VARIABLES FOR THE EVENTS THAT HAVE OCCURRED
C       SINCE DEBUG WAS LAST CALLED.  IF IT IS A PRINT YEAR IT ALSO PRINTS 1.
C       CURRENT VALUES FOR NECROMASS POOLS (TAPE9) 2. ANNUAL RESPIRATION AND
C       FRAGMENTATION LOSSES AND ANNUAL INPUT, AND 3. CURRENT VALUES FOR
C       VARIABLES WHICH TRACK CUMULATIVE LOSSES AND INPUTS.  PRINT YEARS ARE
C       ARE SCHEDULED EVERY YEAR FOR THE FIRST 20 YEARS AND EVERY TENTH YEAR
C       THEREAFTER.
C
C
C  IF TNOW IS 0, THEN INITIALIZE ALL CUMULATIVE VARIABLES.  OTHERWISE GO TO
C  LINE 90.
C
      IF(TNOW.NE.0.0) GO TO 90
      DO 20 I=1,5
        WINPUT(I)=0.0
        BINPUT(I)=0.0
   20 CONTINUE
      DO 50 I=1,5
        DO 45 J=1,10
          NTYPE=I*10+J
          IF(J.GE.9) GO TO 40
          WINPUT(I)=WINPUT(I)+ST(NTYPE)
          GO TO 45
   40     BINPUT(I)=BINPUT(I)+ST(NTYPE)
   45     FRAG(I)=0.0
          RESP(I)=0.0
          BARKF(I)=0.0
          TOTIN(I)=0.0
          TOTAL(I)=0.0
   50 CONTINUE
      POUT=0.0
      TOUT=0.0
      PTOTIN=0.0
      PTOTAL=0.0
      PWINPUT=0.0
      PBINPUT=0.0
      PWOOD=0.0
      PBARK=0.0
      PRESP=0.0
      PFRAG=0.0
      PBARKF=0.0
      TTOTIN=0.0
      TTOTAL=0.0
      TWINPUT=0.0
```

DEBUG continued

```
      TBINPUT=0.0
      TWOOD=0.0
      TBARK=0.0
      TRESP=0.0
      TFRAG=0.0
      TBARKF=0.0
C
C  WRITE HEADINGS ON TAPES
C
      WRITE(8,1006)
      WRITE(9,1007)
      WRITE(11,1030)
      WRITE(11,1004)
      WRITE(8,1004)
      WRITE(9,1004)
       RETURN
C
C  AFTER TIME 0 INITIALIZATION START HERE.  FIRST DECIDE IF TNOW IS A
C  PRINT YEAR
C
   90 Z=0.0
      IF(TNOW.LT.20.) GO TO 95
      X=TNOW/10.
      HTEN=IFIX(X)
      Z=X-HTEN
C
C  UPDATE CUMULATIVE VARIABLES FOR PREVIOUS YEARS LOSSES
C
   95 DO 100 I=1,5
        WINPUT(I)=WINPUT(I)+W(I,1)+W(I,2)
        FRAG(I)=FRAG(I)+FRAGTOC(I)
        RESP(I)=RESP(I)+RESPTOC(I)
        BARKF(I)=BARKF(I)+BARKTOC(I)
        BINPUT(I)=BINPUT(I)+WB(I,1)+WB(I,2)
        WOOD(I)=0.0
        BARK(I)=0.0
C
C  CALCULATE TOTAL CURRENT WOOD NECROMASS IN DECAY GROUP I
C
         DO 110 J=1,8
           NTYPE=I*10+J
           WOOD(I)=WOOD(I)+ST(NTYPE)
  110    CONTINUE
C
C  CALCULATE TOTAL BARK NECROMASS IN DECAY GROUP I
C
         ND=I*10+9
         NS=I*10+10
         BARK(I)=ST(ND)+ST(NS)
```

DEBUG continued

```
C  CALCULATE CUMULATIVE TOTAL NECROMASS INPUT BY DECAY GROUP ( TOTIN).
C  CROSS CHECK CALCULATIONS BY CALCULATING SUM OF PRESENT NECROMASS AND ALL
C  PREVIOUS NECROMASS LOSSES IN DECAY GROUP (TOTAL).
C  IF MODEL IS WORKING TOTAL=TOTIN.
C
         TOTIN(I)=WINPUT(I)+BINPUT(I)
         TOTAL(I)=WOOD(I)+BARK(I)+RESP(I)+BARKF(I)+FRAG(I)
C
C  IF IT IS NOT A PRINT YEAR THEN CONTINUE CALCULATIONS.  IF IT IS A PRINT
C  YEAR THEN PRINT DECAY GROUP VALUES FOR CUMULATIVE VARIABLES.
C
        IF(Z.NE.0.0) GO TO 115
      WRITE(8,1003)TOTIN(I),TOTAL(I),WINPUT(I),BINPUT(I),WOOD(I),
     1  BARK(I),RESP(I),FRAG(I),BARKF(I),TNOW
C
C  IF ALL DOUGLAS-FIR DECAY GROUPS HAVE BEEN TALLIED THEN GO TO LINE 120 TO
C  CALCULATE DOUGLAS-FIR TOTALS.  IF ALL WESTERN HEMLOCK DECAY GROUPS HAVE
C  BEEN TALLIED THEN GO TO LINE 130 TO CALCULATE WESTERN HEMLOCK TOTALS.
C  OTHERWISE MOVE TO NEXT DECAY GROUP.
C
C  115 IF(I.EQ.3) GO TO120
      IF(I.EQ.5) GO TO 130
      GO TO 70
C
C TALLY ALL DOUGLAS-FIR WHEN I=3
C
  120 DO 125 M=1,3
       PTOTIN=PTOTIN+TOTIN(M)
       PTOTAL=PTOTAL+TOTAL(M)
       PWINPUT=PWINPUT+WINPUT(M)
       PBINPUT=PBINPUT+BINPUT(M)
       PWOOD=PWOOD+WOOD(M)
       PBARK=PBARK+BARK(M)
       PRESP=PRESP+RESP(M)
       PFRAG=PFRAG+FRAG(M)
       PBARKF=PBARKF+BARKF(M)
  125 CONTINUE
      POUT=POUT+PSMEOUT
      PTOTAL=PTOTAL+POUT
C
C  PRINT DOUGLAS-FIR TOTAL IF ITS A PRINT YEAR
C
      IF(Z.NE.0.0) GO TO 126
      WRITE(8,1003)PTOTIN,PTOTAL,PWINPUT,PBINPUT,PWOOD,PBARK,
     1 PRESP,PFRAG,PBARKF,TNOW
      WRITE(8,1004)
C
C  RESET TOTAL VARIABLES
C
  126  PTOTIN=0.0
      PTOTAL=0.0
      PWINPUT=0.0
      PBINPUT=0.0
      PWOOD=0.0
      PBARK=0.0
      PRESP=0.0
      PFRAG=0.0
      PBARKF=0.0
      GO TO 100
```

DEBUG continued

```
C
C TALLY WESTERN HEMLOCK AFTER I=5
C
  130 DO 135 M=4,5
         TTOTIN=TTOTIN+TOTIN(M)
        TTOTAL=TTOTAL+TOTAL(M)
        TWINPUT=TWINPUT+WINPUT(M)
        TBINPUT=TBINPUT+BINPUT(M)
        TWOOD=TWOOD+WOOD(M)
        TBARK=TBARK+BARK(M)
        TRESP=TRESP+RESP(M)
        TFRAG=TFRAG+FRAG(M)
        TBARKF=TBARKF+BARKF(M)
  135 CONTINUE
      TOUT=TOUT+TSHEOUT
      TTOTAL=TTOTAL+TOUT
C
C  PRINT WESTERN HEMLOCK TOTALS IF TNOW IS A PRINT YEAR
C
        IF(Z.NE.0.0) GO TO 136
      WRITE(8,1003)TTOTIN,TTOTAL,TWINPUT,TBINPUT,TWOOD,TBARK,
     1  TRESP,TFRAG,TBARKF,TNOW
    . WRITE(8,1004)
      WRITE(8,1004)
C
C  RESET WESTERN HEMLOCK TOTALS
C
  136 TTOTIN=0.0
      TTOTAL=0.0
      TWINPUT=0.0
      TBINPUT=0.0
      TWOOD=0.0
      TBARK=0.0
      TRESP=0.0
      TFRAG=0.0
   70 TBARKF=0.0
  100 CONTINUE
C
C  THE SECOND (AND SHORTER HALF) OF DEBUG WRITES ON TAPE9 AND TAPE 11.  IT
C  LISTS THE CURRENT VALUES FOR NECROMASS POOLS (TAPE9) and CURRENT NECROMASS
C  LOSSES AND INPUTS (TAPE11).  IF IT IS NOT A PRINT YEAR THEN GO TO END OF
C  SUBROUTINE OTHERWISE PRINT TAPE9 AND TAPE11 AND THEN RETURN.
C
C
        IF(Z.NE.0.0) GO TO 201
      DO 200 I=1,5
       NCLASS=I*10
       WRITE(9,1005)TNOW,I,(ST(NCLASS+J),J=1,10)
       WRITE(11,1031)TNOW,I,RESPTOC(I),FRAGTOC(I),BARKTOC(I),W(I,1),
     1  W(I,2),WB(I,1),WB(I,2)
  200 CONTINUE
      WRITE(9,1004)
      WRITE(11,1004)
 1003 FORMAT(" ",9F10.3,F6.1)
 1004 FORMAT("  ")
 1005 FORMAT(F5.1,I2,10F8.4)
 1031 FORMAT(F5.1,I2,2X,3F9.4,4F7.4)
 1006 FORMAT("    TTOTIN    TTOTAL    WINPUT    BINPUT     WOOD    ",
     1 "   BARK       RESP       FRAG       BARKF      TNOW  ")
 1007 FORMAT(" TNOW I  LOG1   LOG2    LOG3    LOG4    LOG5    SNAG1 ",
     1 "  SNAG2  SNAG3   LBARK   SBARK")
 1030 FORMAT(" TNOW I   RESPTOC  FRAGTOC   BARKTOC  WTHROW  SNAG",
     1  "  WBTHRO WBSNAG")
      RETURN

  201 END
 EOI ENCOUNTERED.
```

SUBROUTINE WIND and SUBROUTINE JOE

SUBROUTINE WIND

```
      SUBROUTINE WIND(BOLMASS,BARMASS,I )
      COMMON/UCOM1/DUR(60),RESP(60),FRAG(60),THROW(5),W(5,2),WB(5,2)
C
C         THROW(I) GIVES THE PROPORTION OF MORTALITY DUE TO WINDTHROW
C
C  DETERMINE AMOUNT OF LOG WOOD AND BARK MASS IN DECAY GROUP (I)
C
      W(I,1)=W(I,1)+BOLMASS*THROW(I)
      WB(I,1)=WB(I,1)+BARMASS*THROW(I)
C
C DETERMINE AMOUNT OF SNAG WOOD AND BARK MASS IN DECAY GROUP (I)
C
      W(I,2)=W(I,2)+BOLMASS*(1-THROW(I))
      WB(I,2)=WB(I,2)+BARMASS*(1-THROW(I))
      RETURN
      END
```

SUBROUTINE JOE

```
      SUBROUTINE JOE(LENGTH,ORIGBIO,BMASS,NTYPE)
      COMMON/UCOM1/DUR(60),RESP(60),FRAG(60),THROW(5),W(5,2),WB(5,2)
      DIMENSION X(200)
C
C         SUBROUTINE JOE TAKES THE ORIGINAL MASS OF THE COHORT AS IT ENTERED
C         THE POOL (ORIGBIO) AND CALCULATES ITS CURRENT MASS(BMASS) BY
C         SUBTRACTING THE RESPIRATION AND FRAGMENTATION LOSSES OF EVERY YEAR
C         IT WAS IN THE POOL.
C
      NEND=LENGTH+1
      X(1)=ORIGBIO
      R=RESP(NTYPE)
      F=FRAG(NTYPE)
      DO 100 K=2,NEND
         L=K-1
         X(K)=X(L)*(1.0-F-R+F*R)
  100 CONTINUE
      BMASS =X(NEND)
      RETURN
      END
```

SIMULATION

Run conditions-

The model was run to simulate dead bole dynamics in a mid-elevation Douglas-fir/western hemlock stand in the central Cascade Range as the stand developed from age 125 to 800 yr. Necromass quantities (TAPE6) which had been measured on a 0.25 ha plot in a 125-yr-old stand were used to fill the necromass pools at the model's start. Decay parameters (TAPE10) were taken from my work on snag and log decomposition. The yearly tree mortality for running the decomposition model (TAPE1) was supplied by the annual mortality output from a stand growth simulation of 0.20 ha of this forest type run by Dr. V. Adams of University of Washington, Seattle, Washington.

Mortality input-

Comparison to live tree data from a chronosequence of stands showed that the stand growth model for Douglas-fir/western hemlock forests could realistically simulate growth and mortality of the primary species, Douglas-fir, in forests 125 to 400-yr-old.[7] After year 420 however, the model allowed only two huge Douglas-fir trees to remain in the fifth hectare plot. As a result, in the following 300 years there were only two instances of mortality- a 153 cm dbh tree in year 477 and a 197 cm dbh tree in year 727. Because the simulation

7. The stand growth model could not simulate western hemlock growth or mortality. It "killed" any western hemlock tree in the plot as soon as the tree had a dbh greater than 11 cm.

began with a mature 125-yr-old forest, there were few medium or small Douglas-fir trees in the stands. Thus there was very little mortality in these decay groups (200 Mg/ha of medium Douglas-fir and 37 Mg/ha of small Douglas-fir between year 125 and 450).

The mortality output from the stand growth model fluctuated annually because the model had simulated mortality by using a random probability distribution to "kill" trees. In addition, the stand growth model's average annual Douglas-fir mortality from year 125 to 450 of 4.8 Mg/ha was 30% higher than reported total tree mortality for two mature (age 100 yr) stands of this forest type (Sollins 1981).

Validation data-

Values for bole necromass measured in five Douglas-fir/western hemlock stands of age 250, 450, 450, 450, and 750 yr were used to validate the necromass model. The original bole dimension data were collected on four 125 m^2 subplots within a 1 hectare reference plot in each stand. T. Thomas and J. Franklin of the U.S.D.A. Forest Service, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon supplied the bole dimension data and the decay class of the logs. I classified the snags post facto on the basis of field notes on bark cover, branch size, and crown condition. Bole dimensions were converted to bole volume using the Smalian formula for Douglas-fir and the sub-neiloid formula for western hemlock. Necromass was determined by multiplying the sum of the bole volumes in a decay class by the specific gravity of the wood of the decay class.

The area sampled in each stand (0.25) unfortunately was too small, given the considerable spatial variability in bole necromass in the stands, to give necromass values representing the stand average. The necromass values in the four 125 m^2 plots in each stand often differed five-fold. The necromass in the 450-yr-old stands differed by almost a factor of two. As the stand growth model was also based on a small plot size (0.20), the reference stand data and the decomposition model input (stand growth model's mortality output) were equally uncertain.

Results-

I analyzed the decomposition model's output only for wood necromass of large Douglas-fir and only between yr 125 and 450 because of the unreliable mortality input from the stand growth model for any other decay groups and for older stands. (The model had been verified previously by running it with simplistic parameters and known inputs for 50 yr and tracing the decomposition of each cohort through each of the pools.)

The stochastic nature of the mortality input defined the dynamics of the snag necromass pools (Fig. 14). Snag classes I and II fluctuated from 0 to 150 Mg/ha but both averaged about 60 Mg/ha. Snag class III wood varied from almost none to about 30 Mg/ha but averaged 10 Mg/ha and didn't fluctuate as wildly as the other snag classes. Class III snag wood appeared to increase with stand age. The other

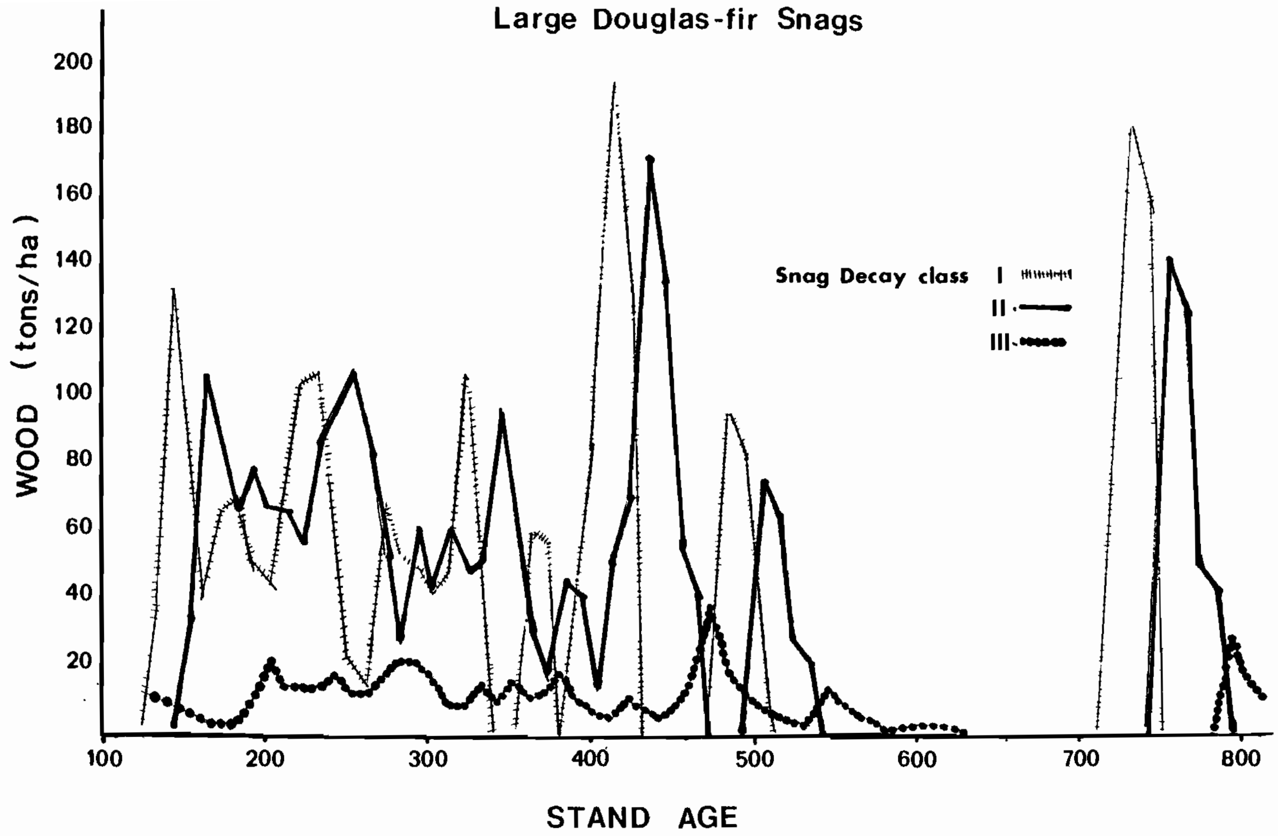

Fig. 14. Decomposition model output plotted at ten year intervals for large Douglas-fir snag necromass pools.

two classes showed no trends with stand age except to fluctuate more strongly as tree mortality became more infrequent and individual bole size larger.

Log pools appeared less sensitive to the stochastic nature of the mortality (Fig. 15). The decay class I and II pools never exceeded 30 Mg/ha and often were empty. The model considered a fixed 10% of the annual mortality as windthrow; as a result, the log class I and II pools stayed small while the snag class I and II pools were large. The log class III pool, which ranged from 0 to 99 Mg/ha and averaged 21 Mg/ha, received all the snag breakage from the snag class II pool and varied the most due to the fluctuations in the snag breakage. The class IV pool gradually increased and stayed at a very high level (50 Mg/ha). The class V pool trailed behind the class IV pool, increased gradually and then maintained a fairly constant level of about 25 Mg/ha.

Discussion:

Given the stochastic mortality input to the decomposition model and the variability evident in the validation stand data (table 20), the model output for large Douglas-fir bole necromass did agree with the stand necromass data (Table 20). The model tended to overestimate all decay classes, but the range of the fluctuations were realistic. Given the model's high average annual mortality for large Douglas-fir (3.8 Mg/ha), exaggerated pool sizes were to be expected.

The model predicted an average of 286 Mg/ha of Douglas-fir bole necromass for Douglas-fir/western hemlock stands between the age of

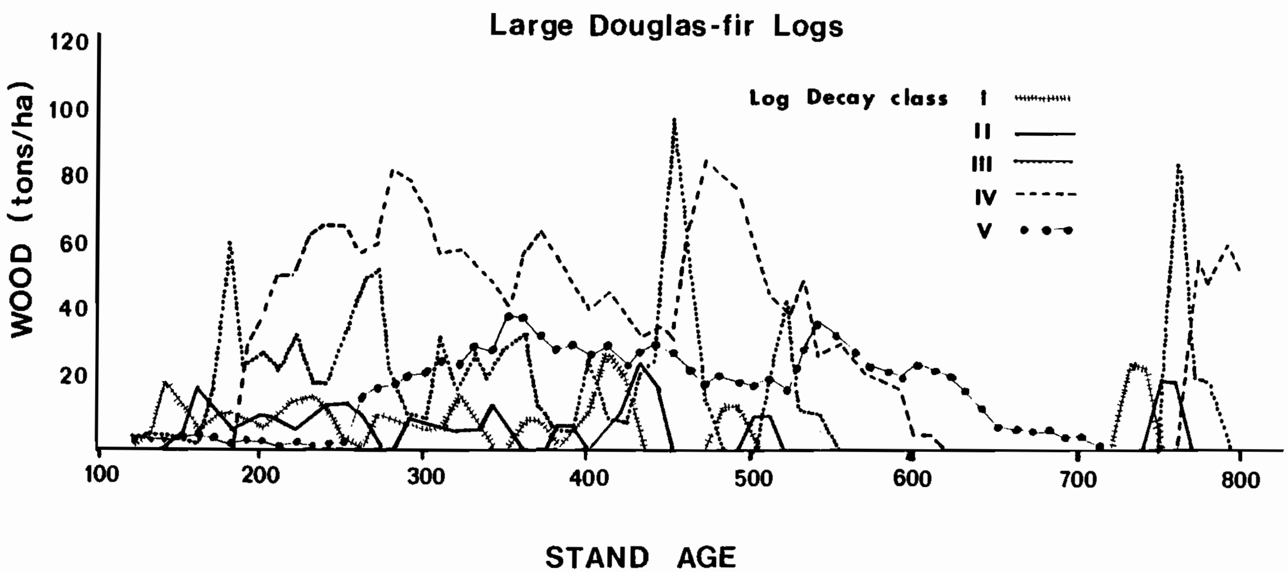

Fig. 15. Decomposition model output plotted at ten year intervals for large Douglas-fir log necromass pools.

Table 20. Douglas-fir necromass of large boles (in detail) and of all boles in reference stands of the ages 125, 250, 450, 450, 450, and 750 yr. Model values (average, maximum, and minimum) for Douglas-fir necromass between years 230 and 270 and between years 430 and 470 are shown for comparison.

Stand age(yr)	Initial 125	Stand 250	Model 230 - 270 ave.	min	max	Stand 450	Stand 450	Stand 450	Model 430 - 470 ave	min	max	Stand 750
Class I log	0	0	9.6	1.0	16.8	0	0	0	5	0	13.6	0
Class II log	0	0	10.9	5.7	9.9	13.6	0.5	0.3	11	0	26.0	5.9
Class III log	0	9.2	31.0	19.6	49.2	23.6	26.0	19.4	41	6.0	99.0	2.2
Class IV log	4.2	48.2	62.0	54.3	69.6	17.2	27.6	13.5	41	34.0	66.0	36.5
Class V log	3.8	22.7	3.8	15.6	0.7	22.6	38.0	20.8	28	24.1	31.8	35.9
Class I snag	0	0	63.0	11.0	102.0	0	0	na	27	0	134.0	0
Class II snag	2.5	70.6	84.0	54.0	110.0	12.2	36.9	na	95	38.0	174.0	111.0
Class III snag	11.3	10.5	13.4	12.7	15.6	14.9	29.5	na	9.1	3.6	15.1	50.6
Total Large Douglas-fir	21.8	161.2	277.7	243.7	310.9	104.1	158.3	54*	257.1	194.7	326.0	242.1
All Douglas-fir	99.1	258.2	345.0	295.2	382.8	114.8	178.0	69*	285.0	215.7	358.6	245.2

*value is only for Douglas-fir logs

125 and 450 yr. The five stands averaged 162 Mg/ha of Douglas-fir bole necromass. The overall decay rate of Douglas-fir boles in the model (0.017 yr^{-1}) was calculated crudely by dividing the average annual input (4.8 Mg/ha) by average standing crop. The rate is low compared to the 0.03 yr^{-1} rate reported for all boles in a mature Douglas-fir/western hemlock forest (Sollins 1981). The mature forest however, contained western hemlock (not included in the simulation) which decays much more rapidly than Douglas-fir.

No age trends were apparent from the model output. The amount and type of dead bole wood did not vary or change after the stand had matured but rather fluctuated randomly within a given range which was determined by the stochastic fluctuations in mortality. If annual mortality increased then so did bole necromass. For both the model and the stands, the variability due to small plot size masked any potential trends in bole necromass dynamics. Input mortality and validation data must taken from much larger areas if the stochastic fluctuations in mortality are to be sufficiently dampened to allow observation of any long-term trends. Boles perhaps are like molecules, one needs to have a myriad of them to know what they are doing. Life on just a hectare is a random affair.