Factors influencing organic matter decomposition and nutrient turn-over in cleaned and spaced, young conifer stands on the Cape Breton Highlands, Nova Scotia

by

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Information Report M-X-41

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March 1974

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Report of work done under contract OSP3-0296 with Maritimes Forest Research Centre.

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ACKNOWLEDGEMENTS

I am indebted to Mr. V.R. Timmer, Canadian Forestry Service, Fredericton, Dr. G.F. Weetman, Associate Professor, Faculty of Forestry, Dr. R.W. Wein, Assistant Professor, Biology Department, and Mr. G.B. Lapointe, Land Management Superintendent, Nova Scotia Forest Industries, for valuable help and advice in the field. I also thank the Canadian Forestry Service, Fredericton, for supplying equipment.

ABSTRACT

A survey was made of young spaced and unspaced stands of balsam fir on the Cape Breton Highlands, Nova Scotia, in July and August 1973. This report includes a vegetation study describing the changes in species composition ranging from treeless cut-over, to spaced regeneration, to very dense young stands. An estimation is made of the changes in the thickness of the organic matter from the spaced to the unspaced stands, together with an estimate of the total biomass of the trees removed during spacing trials.

RESUME

En juillet et août 1973, l'auteur fit un relevé de jeunes peuplements de Sapin baumier (*Abies balsamea*) clairsemés ou non, sis dans le haut pays de l'île du Cap Breton, Nouvelle-Ecosse. Une étude de la végétation décrit la composition en espèces, depuis les aires coupées à blanc étoc, jusqu'à la régénération espacée, et jusqu'aux jeunes peuplements très denses de Sapin baumier. L'auteur estime les différences d'épaisseur de la matière organique entre les peuplements clairsemés et denses. Il estime aussi la biomasse totale des arbres enlevés durant les expériences d'espacement.

INTRODUCTION

In 1969, Nova Scotia Forest Industries Limited started an intensive forest management plan which included spacing young stands (12 to 20 years, at breast height) of balsam fir (*Abies balsamea* (L.) Mill) and white spruce (*Picea glauca* (Moench) Voss) on the Cape Breton Highlands, Nova Scotia. Dense stands (up to 40,000 stems/acre) often develop after clearcutting. These stands are cleaned to a spacing of 8 feet (about 700 stems/acre) regardless of forest site.

The ideal spacing between trees of different species, age classes, and sites, must be found for maximum yield at the end of the rotation period. A thorough knowledge of the nutrient regime in the forest soil profile together with information on factors that determine plant nutrient uptake, is basic to attaining this goal. Therefore, a comprehensive study is required to determine the factors influencing organic matter decomposition and thus nutrient turnover; the distribution of feeding roots in the forest soil profile; the factors determining absorption of nutrients by these roots; and the effects of wind and snow conditions.

Only such a comprehensive study will permit evaluation of the fertility of the forest soils; the identification of the most effective practices for improving the supply of nutrients to the trees; the prediction of future stand conditions; and the direction of the changes in nutrient conditions when certain forest management practices are used in given forest sites.

In Nova Scotia, study of the direct effects of spacing on tree growth, has been limited. In 1968, Meikle and Hughes of the Canadian Forestry Service initiated a current spacing study in stands of balsam fir, on the Cape Breton Highlands. Michaud (1970) found a significant increase in diameter growth from spacing treatments in different areas in Cape Breton. Robertson (1971) published a spacing guide for Nova Scotia, in which a distance of 8 feet between the trees was generally recommended. However, the effects of different spacing treatments on organic matter decomposition, nutrient cycling, and forest soil fertility have not been examined.

A contract was drawn up between the author and the Canadian Forestry Service to 'evaluate factors influencing organic matter and nutrient turnover in spaced young conifer stands on Cape Breton Highlands'. This contract permitted 4 weeks of field study of treated and untreated cutover stands on the Cape Breton Highlands.

The specific objectives of the study were:

1. To undertake a survey of all the spaced areas on the Cape Breton Highlands.
2. To locate a suitable study area within each forest site.
3. To measure in each study area:
   a) the change in vegetation pattern from an open to a spaced and unspaced area;
   b) the thickness of the combined L + F + H layer in both the spaced and unspaced area; and
   c) the dry weight of the total volume of trees that had been cut during spacing treatments.

LITERATURE REVIEW

Removal of portions of the forest canopy is an important management practice. However, any forest harvesting method that will eliminate or reduce the supply of plant material and nutrients to the forest floor and to the soil solution, may possibly lead to deterioration of forest site productivity.

The purpose of this literature review is to demonstrate the effects of thinning and clearcutting upon: (1) humus temperature and moisture content; (2) soil disturbance; and (3) the organic matter decomposition, and thus release of nutrients to the soil solution.

Humus Temperature and Moisture Content

A number of workers have noticed an increase in temperature in the forest soil profile due to thinning treatments in different forest ecosystems. Although a thinned area is more susceptible to early freeze-up in the fall, it is probable that early disappearance of snow cover and soil frost in spring and subsequently higher soil temperatures, extends and intensifies the period of biological activity. Humus decomposition and nutrient turn-over increases (Mikola 1960). Angstrom (1936) noticed 2 to 3°C higher temperatures in the soil profile, in a thinned spruce stand in Sweden, as compared to the control (unthinned). The same has been noticed by Gregory (1956, Juneau, Alaska), Lino Della-Bianca (1960, red pine (Pinus resinosa Ait), Michigan), Ronge (1964, Scots Pine (Pinus sylvestris L), in Sweden), Strand (1968, Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) Oregon), and Timmer and Weetman (1969, black spruce (Picea mariana (Mill.) B.S.P.) northern Quebec, Canada).

An important problem is the relationship between soil freezing and forest cover. Belotelkin (1940) concluded that: (1) there was a delay in ground freezing before snowfall, in soils protected by tree growth; (2) although a deeper frost might occur in the thinned area and a deeper snow cover insulate the ground, the higher spring temperatures melt the snow faster, thus increasing the growing season. The same findings have been noted by Weitzman and Bay (1963, various exosystems, Minnesota), Pierce et al. (1958, various forest conditions from Maine to Pennsylvania) and Yli-Vakkuri (1961, pine stands in Finland).

Investigations of the moisture content in the forest floor profile under different cover types have been made by various workers. Douglass and Tedrow (1960, loblolly pine (Pinus taeda L.)) noticed a higher moisture content in open areas as compared to undisturbed stands. The same trend was noticed by Orr (1968, ponderosa pine (Pinus ponderosa Laws)). However, where temperatures are high, evaporation in open areas decreases the moisture content and drought conditions might result which could retard plant growth (Bethlahmy, 1962, Douglas fir, Oregon).

Soil Disturbance

Logging operations cause surface soil disturbance, ranging from removal of the protective organic litter to complete removal of top soil. The amount of erosion and stream sedimentation after logging may vary directly with the degree of disturbance. Therefore, it is important for forest land managers to have some knowledge of relative amounts of disturbance caused by different methods of logging. As early as 1930, Lowdermilk (California) noticed that destruction of the litter and the consequent exposure of the soil greatly increased the amount of eroded material, especially in steep slopes. Garrison and Rummell (1951), concluded that tractor logging destroyed the surface vegetation more than did logging with cable and horse. Later, the same conclusion was made by Wooldridge (1960, ponderosa pine, Washington) and Dyrness (1965, Douglas-fir, Oregon).

Organic Matter Decomposition

Undecomposed organic debris, which characterizes the upper layer of a forest soil profile, is composed primarily of dead organic material lost from the trees. Through the process of decomposition, inorganic and organic chemical elements of the litter are returned to the soil solution. The maintenance of forest soil fertility is largely dependent on the periodic return of plant material to the forest floor, its decomposition, and the release of elements which are important in forest tree nutrition. A number of investigators using both laboratory and field methods have studied the decomposition rate of plant materials under a variety of conditions in different ecosystems.

Cole and Gessel (1963), working with Douglas-fir near Seattle, Washington, concluded that removal of the forest vegetation (clear cut) increased the forest floor decomposition as assessed by the release of elements. However, little of the additional release was lost from the forest floor profile. This was noticed also by Dickerson (1972) working with loblolly pine in Mississippi. He observed a decrease in thickness of organic matter after clearcutting. On the contrary, Weetman (1965) using litterbags in a black spruce forest stand in Quebec, obtained an inverse relationship between weight loss of litterbags and thinning treatment. The highest weight loss was encountered in the control (uncut) and this was attributed to more favorable moisture and temperature. Boyle and Ek (1972) experimenting in mixed hardwood stands in Wisconsin (full tree logging) concluded that no serious depletion of available nutrients would occur. However, depletion could occur if shorter rotation periods were implemented in the future. The same trend was noticed by Weetman and Webber (1972) working in a balsam fir stand in Quebec. Bormann et al (1968), working in deciduous forest in New Hampshire, found an accelerated loss of nutrients in a clear cut area as compared to the controls (watershed approach). The same trend was noticed by Smith et al. (1968 using the same approach in a hardwood ecosystem in New Hampshire).

Influence of Environmental Parameters on Organic Matter Decomposition

Lundegardh (1926) noticed that almost all CO_2 produced from selected forest soils was given off from the soil surface and he concluded that the moving force of soil respiration is gas diffusion. He also observed seasonal trends in respiration including maxima in spring and fall. Witkamp (1969) recorded a predawn minimum and an afternoon maximum in respiration which paralleled the daily temperature cycle in an oak forest. Similar observations were made by Lieth and Quelette (1962) and Witkamp and Frank (1969) in a pine stand. Chiba and Tsutsumi (1967) measured soil respiration in eight Japanese forest types and concluded that soil respiration increased exponentially with increase in temperature. The same was noticed by Kucera and Kirkham (1971) working in a Missouri tallgrass prairie, Wiant (1967) working with eastern white pine, (Pinus strobus L.), black spruce, and eastern hemlock (Tsuga canadensis (L.) Carr.), and Reiners (1968) working with various hardwood species. Wiant (1967) collected cores under eastern white pine, and found that the CO_2 production doubled for each 10°C increase in temperature between 20 and 40°C. Elkan and Moore (1960) using a silt loam soil, noticed a higher CO_2 output at 39° than at 10°C. Similar observations were made by Mork (1938) working with humus from various forest biotypes. Bunt and Rovira (1955) measured respiration of subarctic and subtropical soils and concluded that respiratory rate increased with increase in temperature from 10 to 37°C. The gas evolution decreased between 37 and 50°C, but increased with a further increase in temperature. The same observation was made by Drobnik (1961) in a meadow soil.

Humfeld (1929) noticed an increase in respiration whenever rainfall occurred in sufficient amounts to cause a definite increase in soil moisture (corn plots). Klein et al. (1972) observed an increase in respiration when the moisture was increased from 5 to 15% in grasslands. Elkan and Moore (1960) concluded that maximum CO_2 activity was found above 30% moisture in forest soils. Bhaumik and Clark (1947) correlated respiration with moisture tension in different soils. Maximum CO_2 production was observed at, or very near to, moisture tension at the aeration porosity limit. Rovira (1953), showed that maximum respiration in different soil types was at moisture levels above field capacity, and less respiration was noticed in saturated soils. Douglas and Tedrow

(1959) concluded that maximum respiration in Arctic brown soils at 19.5°C occurred at 50% moisture content. They also showed that as temperature decreases, differences in moisture content have less effect on organic matter decomposition. Wiant (1967) noticed a decrease in respiration for pine, hemlock, and spruce litter when moisture content of the unincorporated materials increased above about 100%. Witkamp (1963) found a significant positive correlation between moisture content in oak leaves and respiration. He further concluded that temperature would more rapidly become a limiting factor for microbial activity than would moisture content. Bartholomew and Norman (1946) noticed that increases in moisture content in the lower moisture range increased respiration of oat straw more than comparable moisture increases in the upper moisture range. He also noticed that at 25 to 37°C the moisture content threshold (pine needles) for respiration was 15 to 17%. Van Cleve and Sprague (1971), working with aspen and birch forest floor organic matter, concluded that temperature is two to five times more important than moisture in explaining variability in respiration data. Witkamp (1966) measured respiration in an oak forest and found that it was significantly ($p=0.01$) correlated with temperature, litter age, and moisture in decreasing order of influence. Chase and Gray (1957) observed a linear relationship between time and rate of O_2 uptake. Melin (1930), working with _Picea_ spp., and _Betula_ spp., measured CO_2 output and found that total nitrogen content paralleled decomposition rate. Species with high nitrogen content decomposed more rapidly than did species with low nitrogen content. The same observation was made by Millar _et al_ (1936). Bollen (1941) added ammonium sulfate to sandy and heavy loam soils and found that the CO_2 output increased during the first 10 to 25 days, after which the intensity of respiration dropped in comparison with the controls. The same observation was made by Roberge (1969). Lyda and Robinson (1969) noticed an increase in respiratory activity when mature crop residues were added to soils. Elkan and Moore (1962) noticed a decreased CO_2 output with a decrease in added substrate.

Karpacevskij and Kiseleva (1969) discussed CO_2 evolution under various species within two forest types in Russia. The rate of CO_2 evolution from the soil varied with type of cover; variation in the rate being greatest under spruce and least under oak. The rate of CO_2

evolution was directly correlated with the amount of litter plus surface humus, and inversely correlated with the earthworm population of the soil. Wiant (1966) measured CO_2 evolution in the air under white pine and black spruce and found that the concentration of the gas was higher under the latter. Earlier Wiant (1964), observed a sharp decrease in CO_2 content from the forest (oak and white pine) to the open field. Schulze (1967) measured soil respiration in different forest communities in Costa Rica and found CO_2 production to be 300-400 mg/hr/m^2 in deciduous forest and 2556 mg/hr/m^2 in secondary growth vegetation (gallery forest). Similar studies were done by Lieth and Quelette (1962) in the Gaspé Peninsula and by Wanner (1970) in a mountain rain forest soil at Tijbidas (223 mg /hr/m^2)

Birch (1958) noticed a burst in CO_2 output after a dried soil was rewetted. This burst, he assumed, was due to the physiological youth of the microorganisms when a dry period was followed by rewetting. Similar observations were made by Soulides and Allison (1961), Nevo and Hagin (1965), Arsjad and Giddens (1966), Van Schreven (1967), and Stevenson (1956). Lebedjantzev (1924) noticed that during the process of drying, a large increase in the solubility of organic substances occurred and the mineralization of nitrogen was stimulated. Later, the same trends were noticed by Birch (1959, 1964), Enwezor (1967), Jager (1967, 1968), Soulides and Allison (1961), and Van Schreven (1967).

Methods to study decomposition rates of organic matter fall into two groups, direct and indirect.

Direct Methods for Study of Organic Matter Decomposition

Respiration measurements

1. Description of methods

The release of CO_2 from soil and litter is generally accepted as a measure of the metabolic activity in the forest floor. However, forest floor respiration does not reflect total metabolic activity, because other carbon compounds released, such as acids, alcohols, methane, and carbon monoxide, are not measured (Reiners 1968).

Numerous methods have been used to determine the CO_2 released from the soil profile. The three principal methods are the manometric, the static, and the dynamic.

In the manometric method, tissue is allowed to respire in a closed vessel, and the pressure changes within the vessel are measured by manometers. A rise or a fall of liquid level indicates a decrease or an increase in pressure. A decrease in pressure within the vessel is due to the uptake of O_2 by the tissue. This decrease, however, is offset by the CO_2 given off, which tends to increase pressure. By measuring respiration in vessels with and without KOH, this difficulty is solved. In the vessel with KOH, CO_2 is absorbed by the alkali, which keeps the CO_2 pressure at a constant level and permits the measurement of pressure changes caused by O_2 consumption alone. In the second vessel, no KOH is provided and the difference between O_2 uptake and CO_2 evolution can be determined. These two values permit calculation of both O_2 consumption and CO_2 release for a known weight of the sample and for a specific time period.

In the static method, CO_2 alone is usually measured. A known mass of sample material is enclosed in a standard size container. A CO_2-absorbent alkali (KOH) is placed in the container with the sample. Evolution of CO_2 is determined by standard acid titration of aliquots of the basic solution and is expressed as mass of CO_2 produced per unit weight of sample (or unit area of sample) per unit time.

The dynamic method also emphasizes CO_2 measurement only. A stream of CO_2-free air (or air with a known amount of CO_2) passed over the respiring sample, sweeps the microbially respired CO_2 through an absorption tower or an infrared gas analyzer. The tower is filled with a basic solution capable of absorbing CO_2. Respiration is expressed as mass of CO_2 produced on a unit time, weight, or area basis.

2. Evaluation of the three principal methods of measuring respiration.

In nature, free diffusion to the atmosphere, is the chief factor in the liberation of CO_2 that is accumulated in the pores of the forest soil and in the organic matter. Any method, such as the static method, which measures the liberation of CO_2 by diffusion, would be preferred in respiration studies in the field.

In both the static and the dynamic method, CO_2 measurements can be made near the existing temperature and moisture content of the forest floor and the amount of CO_2 evolved can be measured directly by titration. Both methods utilize a simple inexpensive apparatus which can be set up quickly in the field, and valuable estimates of total forest floor respiration, or respiration from separate layers, can be obtained. Using discrete core samples, it may be possible to eliminate the effects of root respiration from decomposition measurements. Another important aspect is that forest floor respiration can be measured with minimum disturbance of the forest floor itself. In both methods, it is difficult to measure the moisture content in the sample, (hopefully, thermocouple psychrometers will solve this problem). Continuous measurements of CO_2 evolution cannot be obtained with the static method, because titration usually has to be performed once a day. Also, in this method, O_2 consumption cannot be measured except by a gas chromatograph. As previously mentioned, in the dynamic method soil or litter is aerated by a gas stream sweeping out CO_2 respired by the sample. Excessive rates of gas flow over the sample may stimulate respiration and produce unreliable results.

In the manometric method, continuous measurements of CO_2 evolution or O_2 consumption can be obtained under controlled conditions in the laboratory or in the field. Laboratory measurements are valuable in defining relationships among organic matter decomposition, temperature, and moisture. In the laboratory, root tissue can be removed and an over-estimate of the CO_2 output avoided. It must be remembered, however, that the laboratory CO_2 measurements are obtained under artificial conditions. In some cases, samples are taken from the forest floor, ground in a Wiley mill, and remoistened. In addition an extremely small sample (about 0.5 g) is used, limiting extrapolation with respect to the mosaic of conditions encountered in the field.

Weight loss of confined and unconfined litter placed in or on top of the forest floor

Several workers have studied the decay of organic matter by enclosing it in mesh bags of different mesh sizes (Gustavson 1943; Bocock and Gilbert 1957; Heath and Edwards 1962; Witkamp *et al*. 1963; Wiegert *et al*. 1964; Heath and Arnold 1965; Witkamp 1966; Latter and Cragg 1967; Madge 1969; Van Cleve 1971), or enclosed in hairnets (Bocock *et al*. 1960). Mikola (1954) placed litter between layers of glass wool, and Heath and Arnold (1966) pinned leaves directly to the forest floor.

A weakness of these techniques is the method of exposure of the sample. The natural form of the material, and the way in which it accumulates on the ground and creates variable microclimates, may be altered in such a way as to produce questionable results. Any method that involves enclosing the organic material within a container is subject to this type of error. However, it can give valuable relative results, and it is possible to recover original material with very little loss. Another important aspect is the size of the mesh that is used. Witkamp (1963) reported a weight loss two to three times greater in unconfined samples than in confined samples. Small-mesh bags will exclude larger invertebrates and hence underestimate field weight loss. When the unconfined method is used, the material is in direct contact with forest floor organic matter and probably is exposed to natural environmental conditions. However, there can be considerable physical loss of original material, thus overestimating weight loss due to decomposition.

Thomas (1968), using nylon bags, recorded a weight loss after 1 year of decomposition, of about 44%, in loblolly pine at Oak Ridge, Tennessee. Ando (1970), noticed a weight loss of 16 to 24%, varying with mesh size, in Pinus densiflora (L.). Mikola (1960) noticed a weight loss after 1 year, of about 35%, in spruce and pine stands in Finland. Broadfoot and Pierre (1939) observed a weight loss after 6 months, of about 18%, in white pine litter. Gustafson (1943) found a weight loss after 1 year, of about 20%, in red pine needles in Michigan. Heath and Arnold (1966) observed a weight loss after 8 months, of 15%, in Corsican pine needles. Weetman (1965), using black spruce needles, found a weight loss of approximately 10%, after 1 year. He, furthermore, found an inverse relationship between weight loss of the litter bags and thinning treatment; the least thinned areas (in stands near Montreal, Canada) had the greatest weight loss. To the contrary, Dickerson (1972) found that areas that were the most heavily thinned, had a greater loss of organic material than did the unthinned areas in a loblolly pine stand in northern Mississippi.

Chemical changes during decomposition of plant materials

1. Percentages of elements

Several workers have studied the chemical changes of organic matter during decomposition of plant materials. Waksman and Purvis (1932), working with peat, noticed a percentage increase in total nitrogen content during decomposition. The same trends have been shown by Lunt (1933), Broadfoot and Pierre (1939), Saito (1957) in beech litter, Bocock (1963) in ash litter, Jaro (1963) in beech and oak litter, Katagiri et al. (1970) in Pinus densiflora litter percentage. Percentage increase in nitrogen content could be caused by a fast rate of decomposition of compounds and the release of elements associated with nitrogen. However, some workers have noticed a decrease in absolute amounts of nitrogen (Hayes 1965; Carballas and Ojea 1966; Will 1967).

Decreases in other elements such as Na, K, Mg, Ca and P during decomposition, have been reported. Burges (1956), using leaves from Casuarina suberosa L., found that the loss of elements during decomposition followed the order of Na > K > Mg > Ca, where Ca was released at the slowest rate. Similar trends have been found by Katagiri et al. (1970) using leaves from Pinus densiflora, Attiwill (1967), using leaves from Eucalyptus obliqua L. Herit,

2. Ratios of elements

The determination of the C/N ratio in organic matter provides information on the rate of decomposition and therefore on the nutrient availability and soil fertility. In the initial stages of the decomposition processes, the organic material has a large C/N ratio. The development of the microflora carrying out the decomposition is limited by the available mineral and nitrogen supply. All immediately available nitrogen may be assimilated and bound in organic complexes. In the first stage, no nitrogen is lost, but CO_2 is released, and the C/N ratio decreases (Sowden and Ivarson 1962; Evers 1967; Hayes 1965), until an equilibrium ratio is reached. At this point, the organic nitrogen that is mineralized is no longer necessary for microbial growth, and will be available for vascular plant growth. Based on the same reasoning, the C/P ratio would be expected to decrease during decomposition and phosphorus would not be available for plant growth until an equilibrium ratio had been reached. Studies have shown that compared to other elements, potassium is lost from organic matter very rapidly during decomposition. Although CO_2 is liberated and potassium is used during decomposition, one would probably expect a faster release of potassium than of carbon, which would result in an increase of potassium than of carbon, which would result in an increase of the C/K ratio, with time.

Evers (1967) considered a C/N ratio of 20, a C/P ratio of 112 and a C/K ratio of 92, necessary for maximum microbial decomposition in a Norway spruce (*Picea abies* (L.) Karst.) stand.

Cellulose pulp placed in or on top of the forest floor

As early as 1924, Starkey used filter paper to study the speed of cellulose decomposition. In laboratory studies, he found that filter paper decomposed much more slowly than did alfalfa and rye straw. Later, Witkamp and Van Der Drift (1961) placed filter paper between the mineral and litter layers in an oak forest and concluded that the paper decomposed more rapidly than did lignified tissue and decayed more rapidly in mor than in mull. Lahde (1966), using bleached paper pulp, noticed a more rapid decomposition in a birch forest than in a spruce forest, and the rate of decomposition decreased with increasing depth in the soil profile in all stands. Went and Jong (1966), using cellophane, noticed the greatest weight loss in an orchard on clay soil and the lowest on mor.

The use of paper pulp in the study of decomposition rates in different forest ecosystems can give valuable relative results if accompanied by careful measurements of temperature and moisture. It is a convenient method, since a large number of bags can be put out in the study area with a minimum amount of work. A relatively large number of samples can be obtained at each sampling period, providing a more accurate estimation of the variation in decomposition rate within each area.

Paper pulp consisting of about 95% alpha cellulose is an easily decomposed substance. Therefore, it would not be possible to use this paper pulp over periods longer than 3 to 4 years in areas where the decomposition rate is expected to be high. Furthermore, a somewhat artificial index of decomposition is obtained, because naturally occurring cellulose associated with other organic compounds such as lignin and resins, greatly alter its decomposition rate. Also, as mentioned for the litter bags, the paper bags create artificial microclimates and would exclude larger invertebrates, thus underestimating decomposition rates. This underestimation in the rate of decomposition would also occur, if natural cellulose particles which invade the alpha cellulose while in the litter layers, are not washed out during the cleaning processes in the laboratory, and are included in the final weights.

The use of isotope labelling for studying decomposition rates

Plant material labelled with an isotope is added to the forest floor and the different pathways of the isotope can be followed during time of decomposition.

Indirect Method for Study of Organic Matter Decomposition

Some authors (Jenny et al. 1949; Nye 1961; Shidei and Tsutsumi 1962) have used the indirect method to measure decomposition rates in forest communities. It involves the calculation of a decomposition constant, k.

In an equilibrium forest, the annual rate of addition of organic material is assumed to be equal to the annual rate of loss. The rate of addition, A, is obtained from the average annual fall of leaves, twigs, and other parts of the tree. The rate of loss, L, is obtained from the average amount of forest floor that disappears during a certain time period. The losses consist of evolution of gas and of migration of soluble humus substances and nutrients into the mineral soil. As mentioned above, in an equilibrium forest the rate of addition of organic matter to the forest floor is equal to the loss from the forest floor: $A = L$. This means, that the rate of loss from the forest floor can be calculated by measuring the addition to the forest floor.

$$A = k\ (A + B)$$

where B is the amount of forest floor present at a certain time. From this equation, the decomposition constant can be calculated:

$$k = A/(A + B)$$

This constant represents the average annual fractional loss of organic matter or nutrients from the forest floor. The inverse of this calculation represents the residence time for organic matter in the forest floor. The rate of disappearance of organic matter from the forest floor, can be calculated if the rate of litter fall, A, and the amount of litter on the ground are known. The annual litter fall can be estimated by using litter screens, and the amount of litter (L + F + H layers) on the ground can be estimated using direct volumetric measurements of the forest floor.

Selection of Method to Measure Decomposition Rate in Forest Ecosystems

It is very difficult to decide which method or methods to use for measuring decomposition rates in forest ecosystems. I think the first question that must be asked is "What is the purpose of the study and are the absolute or relative values of decomposition to be determined"? If it is the absolute rates that are to be determined, none of the methods mentioned in the previous section can be used. A method has to be developed that can measure the absolute rate of decomposition without disturbing the forest floor.

If the purpose of the study is to compare rates between areas, the length of the planned study and the expected decomposition rate have to be considered. If the study is planned for 3 to 4 years and fast decomposition rates are expected, alpha cellulose, for example, should not be used because of its fast decomposition rate.

In any case, if litter or cellulose is used for decomposition material, accurate measurements of temperature and moisture in the field during the experimental time must be obtained. These measurements are lacking in many published studies.

Possibly, for future studies, a combination of techniques would be desirable to get a reliable measurement of the decomposition rate in different forest systems. For example, direct measurement of decomposition rate in the field should be obtained using respiration chambers. In addition, the litter and cellulose bag technique could be used together with the isotope labelling procedure.

1973 FIELD WORK

Survey of Spaced Areas

The purpose of the survey was two-fold:

(1) To obtain a general impression of the spaced areas and specifically to look for changes in forest site based on the following criteria; ground vegetation, depth of soil profile, and height-age relationships in mature (40 to 55 years old) stands.

(2) To locate representative areas for future research projects. An area was considered suitable if spaced, unspaced, mature, and open stands were found in the immediate vicinity of each other.

Limited time prevented a systematic survey to determine changes in forest site, and although a considerable variation of forest soil profile depth was encountered, the spaced areas were divided into "poor" and "good" forest sites (Fig. 1).

The "poor" site had an extremely thin organic and mineral soil profile and in many places bedrock was exposed. The height of the mature stands (40 to 55 years old) was about three-quarters of the height of a corresponding stand in the "good" site. Figure 1 shows the location of the proposed study area A. Only the "good" site was selected for more intensive study and is represented by the study area B.

General impressions from the spaced areas

Nova Scotia Forest Industries is one of a few companies that is practicing spacing trials in young stands in Canada. The Company deserves attention for its extensive programs that are aimed at increasing the yield per acre of merchantable timber.

In general, the spaced areas looked in good shape, and credit should be given to the spacing crews.

On the Highlands, wind storms often occur which are a potential danger for the spaced areas, especially stands on poor sites which have a very shallow rooting zone. On these sites, some damage was encountered. A possible method to minimize this damage would be to space these stands at an earlier age than is now practiced. Hopefully, a better rooting system would develop and the stands would be less susceptible to storms.

METHODS

General Description of the Study Area

The study area has an elevation of about 1250 ft located about 2 miles from mile 3.6 on Highland Road in Victoria County, Nova Scotia, at latitude 46°09'N and longitude 60°49'W. It is on Crown Land under license to Nova Scotia Forest Industries. The area is within the Cape Breton Highland District of the Gaspé - Cape Breton Ecoregion (Loucks 1962).

The climate is humid and temperate but warm winds often prevail in the winter. The mean annual temperature is about 43°F and mean annual precipitation is 50 inches. One-third of this amount falls during the winter as snow. The frost-free period is about 90 days (Bailey and Mailman 1972).

The study area was clearcut by Bowaters-Mersey Company in the early 1950's, and dense stands (about 22,423 stems/hectare) of balsam fir established. Scattered white birch (Betula papyrifera Marsh.) and sugarmaple (Acer saccharum Marsh.) are also found. In the fall of 1971, the trees were spaced to about 8 feet (1462 stems/hectare).

The thickness of the combined L + F + H layer, ranges from 24 mm in the spaced area to 60 mm in the unspaced area. The soil profile indicates a very thin leached layer (Ae Horizon) on top of a shallow to deep mineral soil profile (B_{fh} and B_f horizons) mixed with metamorphosed sedimentary rocks.

Experimental Design

Study areas, 15 x 15 m, were located, one in the unspaced area, and one in the spaced area. Each area was divided into 36 study plots (Fig. 2).

This grid system is convenient for sampling. Samples may be picked at random from the study plots using a "random numbers" table.

Description of Intensive Study Site

The purpose of the description was two-fold:

(1) To obtain a general characterization of the vegetation of the forest site which is valuable when sites in different regions are compared.

(2) To follow changes in species composition, particularly in the spaced area, with time.

In the non-revegetated cut-over area, species were collected and identified. A square plot, 15 x 15 m (50 x 50 ft) was laid out which contained the species, listed in Table 1. For each species the Braun-Blonquet cover-sociability index was given (Table 2). The same procedure was followed for the unspaced and spaced areas.

Thickness of the Combined L + F + H Layer

In order to detect a possible decrease in thickness of organic matter caused by an increase in organic matter decomposition, the thickness of the combined L + F + H layer adjacent to each study plot was measured both in the spaced and unspaced areas. Thus a total of 72 samples were examined (see experimental design). A 10 x 10 cm square, was cut from the forest floor and placed on a firm base. A standard weight was placed on top of the core and the thickness measured. The core was then replaced in the forest floor.

Slash Disposal

For a future study, it will be important to measure the number of trees that have been cut down in the spaced area and thus to estimate nutrient additions to the forest floor.

In each of the 25 squares (3.1 x 3.1 m), the diameter of the tree stumps was measured (about 20 cm above the ground). To obtain the corresponding heights for each diameter class, the heights of the dead trees were measured. By using biomass tables (Baskerville 1968), the total dry matter including roots that has been added to the forest floor during spacing trials, can be estimated.

RESULTS AND DISCUSSION

Vegetational Description of the Forest Site

For each area, a list of the vegetation was prepared with the species ranked in order of abundance. Table 1 shows the rating (note that the first number is a cover-abundance index, the second, sociability).

It is interesting to notice that wild raspberry (Rubus strigosus Michx) is the dominant species in the non-regenerated cut-over area. Several areas that have been clear cut are now totally occupied by this species, and probably it has delayed the establishment and growth of young conifers. These areas could be sprayed to ensure more immediate regeneration. In the spaced area, bunchberry, (Cornus canadensis L.) is the most abundant invading species just after spacing; wild raspberry is the least.

Because of lack of light in the unspaced area, very few species are present. Of those present, Oxalis montana Raf. and Dicranum spp. are the most abundant.

Thickness of the L + F + H Layer

A statistical analysis was done to see if there was a significant difference between the unspaced and spaced areas in thickness (the average thickness: unspaced area 44.0 mm, spaced area 37.8 mm) of total organic matter. Using Student's t-test, the difference was significant at p = 0.01. This same trend has been reported by Dickerson (1972). The decrease in thickness of organic matter in the spaced areas can be explained as follows.

As a result of spacing, the temperature in the organic matter has increased and thus increased respiration rates and organic matter decomposition. However, this area was spaced in the fall of 1971, and the difference observed cannot be explained by this factor alone. A heavier snow cover in the spaced area, as compared to the unspaced area, would compress the organic matter and reduce its thickness.

An interesting feature, is the accumulation of needles under the trees that have been cut down in the spaced area. These accumulations will create microclimates that will delay thawing of the ground and thus delay organic matter decomposition.

Slash Disposal

Figure 3 shows the number of trees and the total dry weight (roots included) distributed among the different diameter classes. The largest number of trees is concentrated in the lower diameter classes (10 - 35 mm) while the bulk of the dry weight is concentrated in the 50 - 100-mm diameter classes. The total dry weight of the trees removed during spacing trials was 57,762.0 kg/ha.

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Table 1. Rating of the species from the three experimental areas using Braun-Blanquet combined scale for cover and sociability

Cut-over area		Spaced	
Rubus strigosus Michx.	4[a].5[b]	Cornus canadensis (L.)	4[a].1[b]
Agrostis alba L.	2.3	Pleurozium schreberi (BSG.) Mitt	1.3
Elymus virginicus L.	2.3	Dicranum scoparium Hedw.	1.3
Fragaria virginiana Duchesne	2.2	Hylocomium splendens (Hedw.) BSG.	X.1
Polytrichum commune Hedw.	1.3	Dryopteris noveboracensis (L.) Gray	X.1
Daphalis morgaritacea C.B. Clarke	1.2	Dryopteris spinulosa (O.F. Muell.) Watt	X.1
Pleurozium schreberi (BSG.) Mitt	1.2	Aralis nudicaulis L.	X.1
Cornus canadensis L.	1.1	Hypnum crista-castrensis Hedw.	X.1
Carex trisperma Dew.	X.2	Oxalis montana Raf.	X.1
Carex intumescens Rudge	X.2	Ribes glandulosum Grauer	X.1
Juncus effusus L.	X.1	Maianthemum canadense Desf.	X.1
Senecio vulgaris L.	X.1	Polytrichum commune Hedw.	X.1
Rumex Acetosella L.	X.1	Rubus strigosus Michx.	X.1
Ribes glandulosum Grauer	X.1	Unspaced area	
Sonchus asper (L.) Hill.	X.1	Oxalis montana Raf.	X.2
Arnica sp.	X.1	Dicranum scoparium Hedw.	X.2
Athyrium filix-femina (L.) Roth	X.1	Dryopleris spinulosa (O.F. Muell.) Watt	X.1
		Hylocomium splendens (Hedw.) BSG	X.1
		Hypnum crista-castrensis Hedw.	X.1

[a]cover-abundance index.

[b]sociability.

Table 2. The combined cover-abundance scale and sociability scale of Braun-Blanquet

Cover and Abundance	
x	= sparsely or very sparsely present, cover very small
1	= plentiful but of small cover value
2	= very numerous, or covering at least 1/20 of the area
3	= any number of individuals covering 1/4 to 1/2 the area
4	= any number of individuals covering 1/2 to 3/4 the area
5	= covering more than 3/4 of the area
Sociability	
Soc. 1	= growing one in a place, singly
Soc. 2	= grouped or tufted
Soc. 3	= in troops, small patches, or cushions
Soc. 4	= in small colonies, in extensive patches, or forming carpets
Soc. 5	= in great crowds (pure populations)

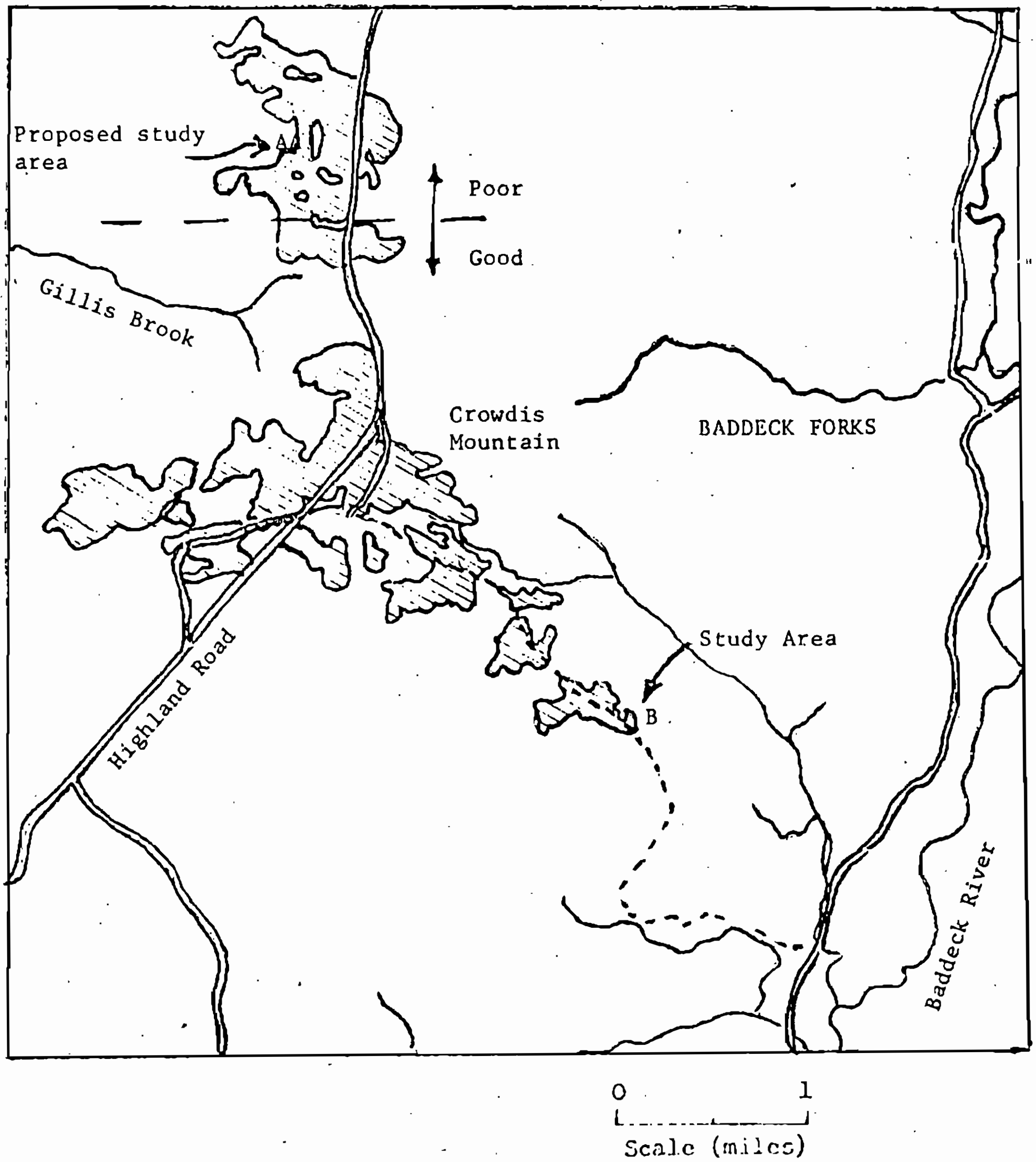

Figure 1. Location of proposed study areas.

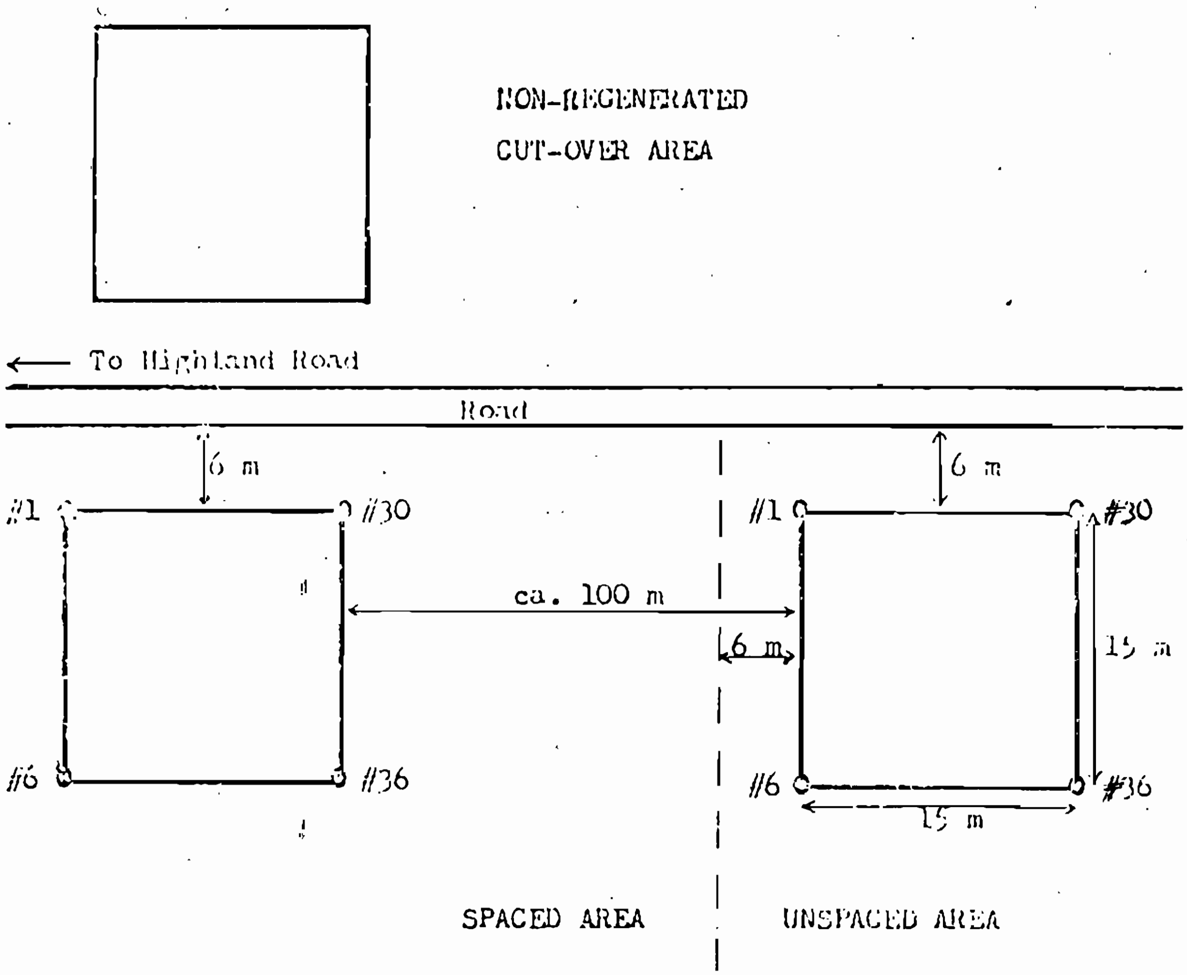

Figure 2. Design of the study areas.

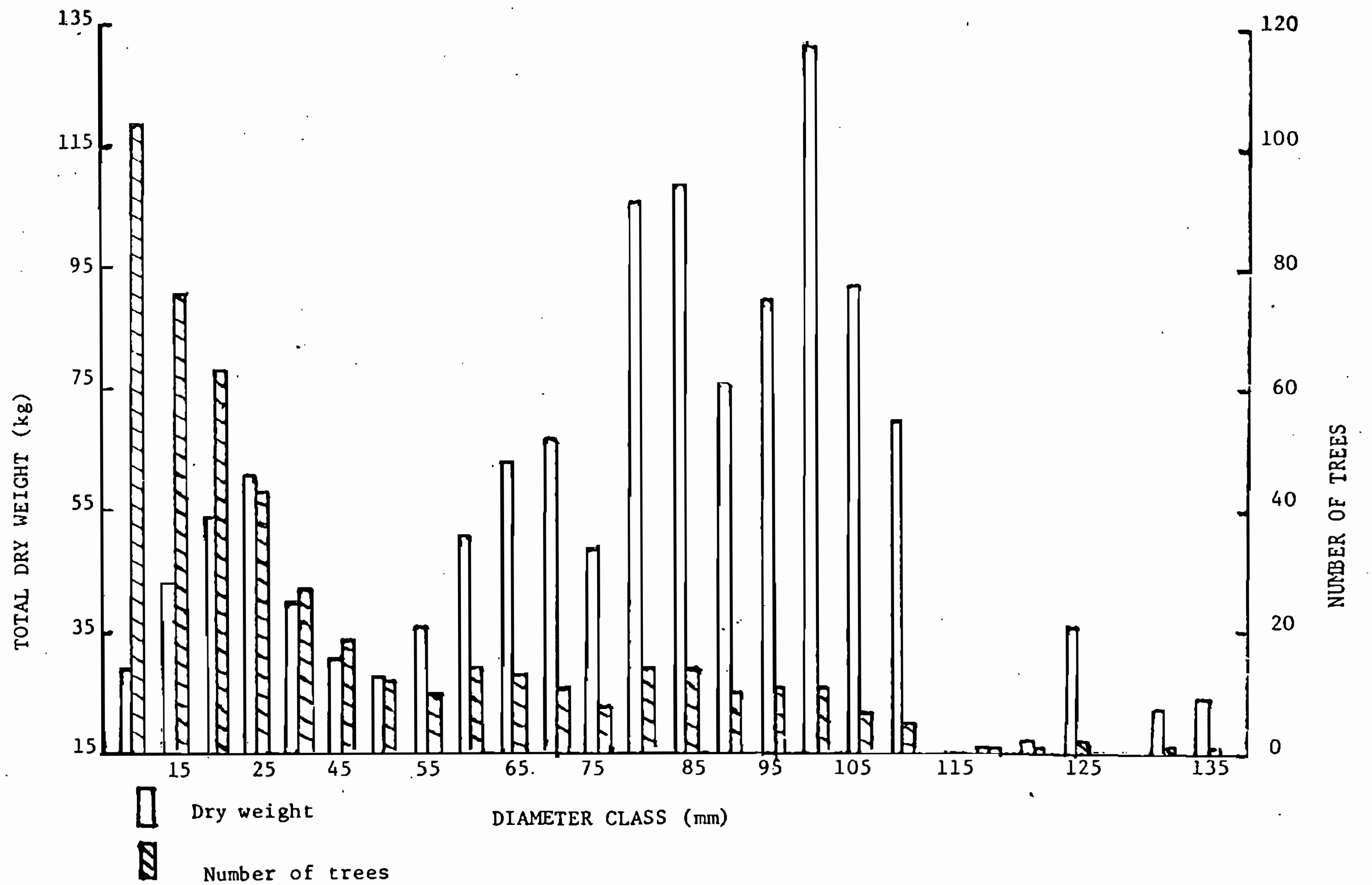

Figure 3. Number of trees and total dry weight distributed among diameter classes (spaced area).