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Forest Humus Forms in Northwestern Ontario

R.A. Sims and K.A. Baldwin

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ABSTRACT

This report describes a new provisional classification of forest humus forms within forests of the Boreal and Great Lakes–St. Lawrence forest regions of northwestern Ontario. Four major orders (*Mulls*, *Moders*, *Mors*, and *Peatymors*) are recognized. Humus form groups and subgroups are defined and described, and methodologies and approaches for humus form recognition in the field are briefly discussed.

The first-approximation classification system permits the identification of 11 forest humus form subgroups in northwestern Ontario. The hierarchical system consists of a field key and a set of one-page summaries that describe each of the humus form subgroups.

Common organic layer thickness ranges, the relative occurrence and distribution of the forest humus forms, and other data are summarized in relation to northwestern Ontario's Forest Ecosystem Classification plot network. Forest humus forms in relation to soil/site conditions, vegetation, general climate, and forest management practices in northwestern Ontario are also briefly considered.

RÉSUMÉ

Une nouvelle classification est proposée pour les formes d'humus présentes dans les forêts du nord-ouest de l'Ontario situées dans la région boréale et la région des Grands Lacs et du Saint-Laurent. Elle reconnaît 4 ordres majeurs : mulls, moders, mors et mors tourbeux (*peatymor*). Des groupes et sous-groupes sont définis. Un bref examen des méthodes et approches pouvant être utilisées pour la reconnaissance des formes d'humus sur le terrain est également présenté.

La première approximation du système de classification permet d'identifier 11 ordres, groupes et sous-groupes d'humus dans le nord-ouest de l'Ontario. Le système hiérarchique comprend une clé d'identification sur le terrain et une série de résumés d'une page sur les caractéristiques de chaque classe.

Les intervalles courants d'épaisseur de la couche organique, la fréquence relative des différentes formes d'humus, leur distribution ainsi que d'autres données sont résumés en fonction de la classification des écosystèmes forestiers du nord-ouest de l'Ontario. Les formes d'humus sont également examinées brièvement en fonction des conditions édaphiques/stationnelles, de la végétation, des conditions climatiques générales et des pratiques d'aménagement forestier observées dans cette partie de l'Ontario.

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1. INTRODUCTION

Forest humus forms are natural, biologically active elements of the forest floor that form at the soil surface as a result of the accumulation and decomposition of plant debris and animal residues (Romell and Heiburg 1931; Kononova 1961; Wilde 1966, 1971; Bernier 1968; Klinka et al. 1981; Green et al. 1993). They are local site features that play, through a variety of physical, biological, and chemical mechanisms, vital roles in soil genesis and forest ecosystem function. Forest humus forms affect soil moisture relations and nutrient dynamics, influence the development of vegetation cover, insulate forest soils, and contribute to site stabilization and erosion control (Jenny 1980, Klinka et al. 1981, Brady 1984).

Forest humus forms vary with the climatic, edaphic, and biological circumstances under which they form. Consequently, they typically reflect local soil/site conditions and decompositional processes. Not surprisingly, humus forms often exhibit heterogeneity over short distances as a result of spatial variations in local soil/site, vegetation, and microclimate conditions (Fig. 1) (Wilde 1966, 1971; Bernier 1968; Arp and Krause 1984; Nykvist and Skyllberg 1989; Klinka et al. 1990b). This property can serve to confuse and intimidate the field ecologist, and is one reason why a standardized approach is needed for the description and classification of different forest humus conditions. The "forest humus form", then, is that section of the overall soil profile where nutrients from dead organic materials are released into the soil ecosystem and made available for uptake by living organisms. At the local site or stand level (e.g., about 1:2 000 scale or larger in mapping terms or, on the ground, about 8 ha or smaller in extent), structural characteristics of a forest humus form are the result of both litter quality and decompositional processes and, hence, are indicative of the overall nutrient status of a forest site.

This report provides background information, definitions, and field identification keys for common humus form conditions occurring in association with natural forest ecosystems in northwestern Ontario. For the predominantly boreal forests of northwestern Ontario, no previous studies have specifically attempted to define and describe the various forest humus forms that may be encountered. Summary descriptions of major humus forms, based on a survey of some 2 167 mature forest stands throughout northwestern Ontario, are provided. *Fibrimors* are especially widespread and common in the forest ecosystems of this portion of Ontario; a more detailed but preliminary classification, which appears to reflect ecological relationships, is presented for this group of humus form conditions. Some general recommendations are provided for forest management and for future research directions in the study of forest humus forms in northwestern Ontario. In general, an improved understanding of forest humus forms provides an important basis for better site-specific forest management planning and decision making.

1.1. Decomposed Organic Materials within Forest Ecosystems

Forest humus forms develop from, and within, accumulated organic materials on the forest floor. These materials constitute a reservoir of biologically important substances that have been sequestered by living organisms and then rendered available for release back into the ecosystem. Primarily through the action of microorganisms, litter and other organic debris are transformed into humus with the concommitant release of mineral nutrients, such as nitrogen, phosphorus, sulphur, potassium, magnesium, calcium, and manganese, as well as molecular organic compounds. Microscopic humus particles, as well as their molecular breakdown products, are mixed into the mineral horizons of underlying soils through complex interactions of leaching and weathering, soil faunal/floral activities, and other natural processes (*see* Duchaufour 1982, Klinka et al. 1990b).

The natural incorporation of decomposed organic substances into the upper mineral soil strata is an important aspect of soil genetic processes. Coarse-textured soils, in particular, benefit from decreased pore size and increased cation exchange capacity (CEC), which enhance their ability to retain ionic nutrients (Stoeckler 1961, Olsson 1986, Skyllberg 1990). The chemical characteristics of litter at a forest site influence the degree to which mineral soils are weathered. Litter, such as conifer needles, that releases highly acidic leachates tends to augment the natural acidification of upper soil horizons, displacing nutrient cations in the process (Weetman et al. 1972, Salonius 1983, Troedsson and Nilsson 1984, Klinka et al. 1994). This is particularly important within coarse-textured soils in humid cold–temperate climates, where podzolization is the primary pedogenetic process.

Forest humus forms develop beneath forest canopies and hence are genetically and ecologically linked to the nutrient dynamics, local climate, biological activity, and ecological function of the forests with which they are

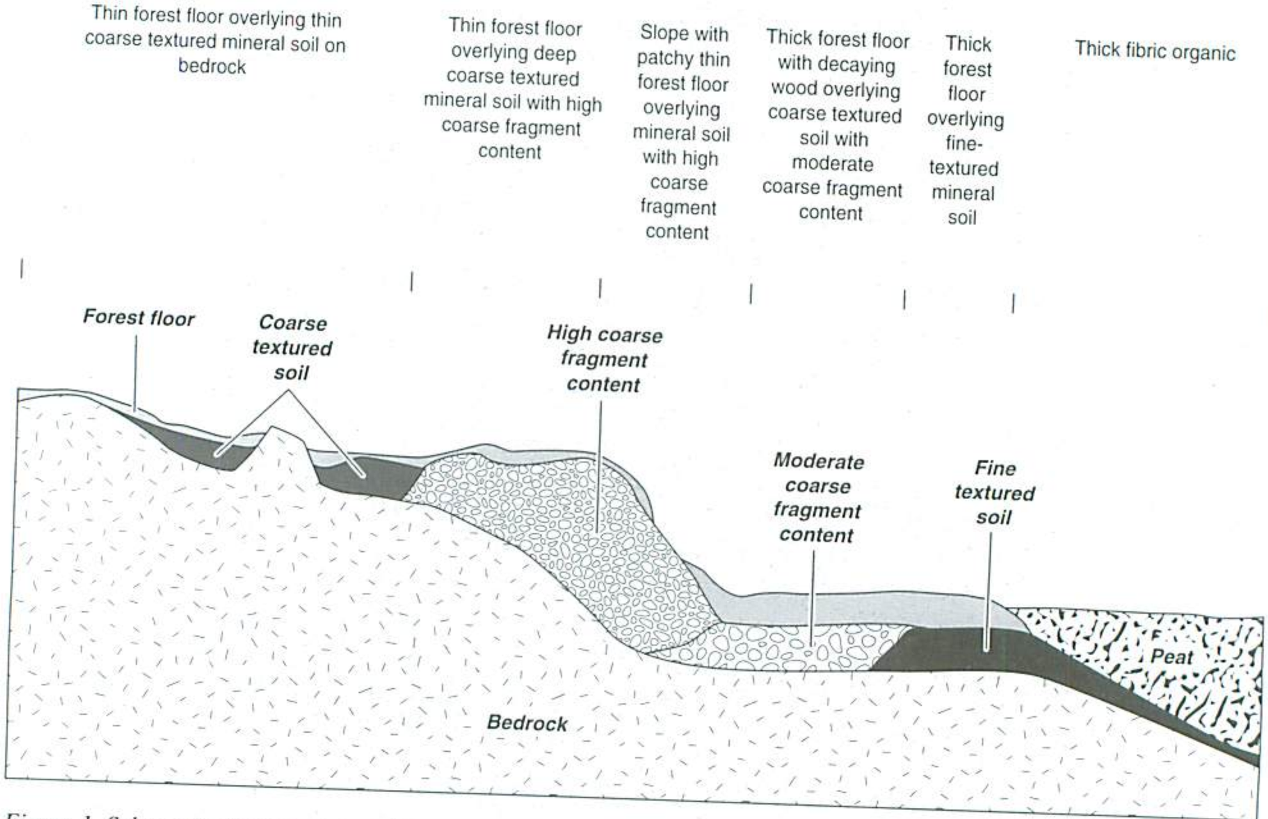


Figure 1. Schematic cross-sectional diagram showing examples of some of the variability that can occur to forest humus profiles over a short distance, along a slope gradient, within the boreal forest.

associated. Many of the mechanisms are still poorly understood. By acting as the principle seed bank within forest stands, humus form conditions may effectively control germination dynamics of understory vegetation species (Gregory 1966, Ahlgren and Ahlgren 1981) and direct successional processes (Archibold 1989, Pickett and McDonnell 1989, Hills and Morris 1992). Fine roots, which are commonly concentrated in the lower layers of the forest humus form and the interface zone between the forest humus form and the underlying mineral soil horizons, play a much greater part in the carbon cycle than has been conventionally accepted (Persson 1983, McClaugherty et al. 1984, Sutton 1991). Complex interactions of soil microorganisms (especially symbiotic fungi and microbes), various soil biochemical processes, and root dynamics continue to be poorly understood (Gonzalez et al. 1970, Geiseking 1975, Visser and Parkinson 1975, Hendrickson and Robinson 1982, Parke et al. 1983, Salonius 1983, Lowe et al. 1987, Perry et al. 1987, Albuzio and Ferrari 1989).

Recently, there has been a growing interest in the subject of biological diversity and its sustainability within natural and managed ecoystems. Biodiversity, as it is usually referred to, is "the variety of life in all of its forms, levels and combinations, and including ecosystem diversity, species diversity and genetic diversity" (McNeely et al. 1990, United States National Research Agency 1992). It has been estimated that the potential number of species in Canada, including undescribed and currently unknown organisms from all phyla, and including viruses, may be 300 000. It is believed that about two-thirds of these species are associated with Canadian forests (Forestry Canada 1992); moreover, a good proportion of these are soil microorganisms, particularly those that inhabit surface litter and humus layers. With respect to soil fauna that inhabits the humus layer within boreal forests, species diversity is very poorly known (Marshall 1993, Mosquin and Whiting[1]). In some preliminary examinations of forest floors in unmanaged mixedwood stands in northwestern Ontario, soil arthropod densities up to 40 000 / m^2 and species numbers of about 40 have been measured (J. Addison, Canadian Forest Service–Sault Ste. Marie, pers. comm.). In rich sites in coastal British Columbia, soil fauna numbers of over a million individuals and hundreds of species have been recorded (Marshall 1993). In general,

[1] Mosquin, T.; Whiting, P.G. Canada country study of biodiversity: Taxonomic and ecological census, economic benefits, conversion costs and unmet needs. Environment Canada, Ottawa, ON. 282 p. (Draft)

even for the larger annelids (earthworms), patterns of abundance and species distributions within various ecosystems are not understood for Canadian forests. Currently, researchers are unable to make predictions about when, where, or how these organisms make their habitat selections, even though they are recognized as playing a critical role in forest humus form development, decompositional processes, soil aeration and permeability, forest site productivity, and within-ecosystem nutrient partitioning and cycling. The ability, then, of forest scientists to address questions about ecological sustainability and biodiversity in relation to forest humus forms within the boreal forest of Canada remains very incomplete.

Humus form horizons are capable of holding large quantities of water, depending on their intrinsic structure and degree of organic decomposition. However, terrestrial humus forms comprising thick layers of undecomposed organic material (especially litter [**L**] and fermentation [**F**] layers; *see* Section 2.1 for definitions) are subject to drying during periods of drought or when exposed by canopy removal (Weetman and Nykvist 1963; Weetman 1968; Page 1974; Covington 1981; Jeglum 1984; Chrosciewicz 1989a, b; Klimo and Grunda 1989). Within coarse-textured mineral soils, microscopic organic matter creates smaller pore spaces that increase moisture retention capacity. In fine-textured mineral soils, incorporation of organic matter (especially by burrowing soil fauna) tends to create larger pore sizes and a more granular structure, thereby generating better soil drainage and aeration as well as facilitating root penetration (Kononova 1961, Persson 1983).

Humus forms are influential in modifying the microclimate of the forest floor and the upper soil horizons (Timmer and Weetman 1969, Olsson 1986, Pritchett and Fisher 1987). Organic materials on the forest floor physically insulate subjacent soil from extremes of temperature and moisture conditions that occur at the ground surface. The magnitude of this influence is largely a function of the depth and bulk density of unincorporated organic material. Soil temperatures and moisture levels fluctuate to a lesser degree, and less rapidly throughout the growing season, beneath thicker, porous forest floor organic layers than beneath thinner, denser layers. In northwestern Ontario, for example, seasonal frost may persist within and beneath thick feathermoss and *Sphagnum*-derived organic horizons under some black spruce (*Picea mariana* [Mill.] B.S.P.) stands until mid- to late June. This effect may be a hindrance to biological activity in humid, cold–temperate climates due to the prolongation of cold soil temperatures in the spring that inhibit root physiology and microorganism activity (Stoeckler 1961; Weetman 1962a, b, 1964; Timmer and Weetman 1969; Stathers 1989). In areas with drier, warm–temperate climates, a deep forest floor organic layer can play a beneficial role in the conservation of soil moisture. An intact organic layer also protects the forest floor from the mechanical effects of heavy rainfall and wind, thereby reducing soil erosion.

Within forest stands of northern Ontario, the forest floor is a particularly important element of the ecosystem. Due to relatively short seasons of biological activity, slow decomposition rates, and low levels of soil fauna activity, organic materials accumulate on the forest floor with minimal incorporation into the mineral soil. This organic material constitutes a major reservoir of nutrients within the ecosystem and, if lost, will take many decades to replace (*see* Weetman 1962a, b, 1964; Wilde et al. 1965; Weetman et al. 1972; Weber et al. 1985). The microclimatic influence of forest floor materials is especially pronounced in those ecosystems where accumulated organic matter insulates underlying mineral soils, thus inhibiting the onset of biological activity in the spring and potentially reducing overall site productivities from colder soils and shorter growing seasons.

Because of their genetic origin, forest humus forms must initially develop below forest canopies. While they are most frequently encountered on the ground surface beneath mature forest canopies, humus forms may also occur on forest lands that have been recently harvested, or where trees have been altered or removed by natural factors (e.g, following insect and disease damage, or where trees have been affected by natural windthrow or crown fires that do not burn the forest floor). Physical characteristics, in particular the moisture-holding status, of forest humus forms represent key factors for the planning of prescribed burns for cutover forest lands (*see* Chrosciewicz 1968; Bunting 1983; Chrosciewicz 1989a, b), or for evaluating the stand-level effects of forest fires within natural stands (*see* Bunting 1983, Cayford and M^c^Rae 1983, Stocks et al. 1990).

Juvenile soils in cold–temperate climates, such as are found in various locations across northern Ontario, typically do not have large organic matter contents, and the replenishment time for lost humus content is in the order of hundreds of years (Olsson 1986). Forest management practices that contribute to the depletion or degradation of the humus content of forest soils may seriously compromise the long-term productive capacity of these forest sites. The capability of forest soils to retain moisture and nutrient ions is related to its organic matter content. Site productivity is thus promoted by management practices that conserve existing humus content in forest soils and which help to maintain the important decomposition processes that sustain the nutrient cycle on the site (Parke et al. 1983, Weber et al. 1985, Wallace and Freedman 1986, Witkowski 1989).

The mechanical incorporation of humus materials into the upper mineral soil horizons, often referred to as mechanical site preparation or scarification, is a common postharvest seedbed preparation within the boreal forest in Canada (von der Gönna 1992, Sutherland and Foreman[2]). Although effective as a silvicultural tool, the practice typically increases overall rates of humus decomposition and soil respiration and alters soil temperature and moisture levels (Salonius 1978, 1983).

1.2. Background: Forest Humus Form Classifications

The term *humus form* was first advanced by Müller (1879) who, in his study of Danish forest soils, also introduced and defined the terms *mull* and *mor*. Since that time, considerable work on the classification of humus forms has been undertaken in Europe (Hartmann 1952, Kubiena 1953, Duchaufour 1982, Berthelin et al. 1994) and the United States (Romell and Heiberg 1931; Heiburg and Chandler 1941; Hoover and Lunt 1952; Wilde 1954, 1966, 1971). As well, a number of books provide additional detail on the dynamics of organic suface layers associated with forest soils (Waksmann 1936, Kononova 1961, Paton 1978, Jenny 1980, Duchaufour 1982, Brady 1984).

For Canadian soil ecosystems, comparatively little effort has been expended on the development of detailed descriptions of humus forms. Bernier (1968) outlined a hierarchical classification system for Canadian forest humus forms that was adopted by the Canada Soil Survey Committee (1978a) and has found widespread national use. In an attempt to rectify some deficiencies in Bernier's (1968) original treatment, Klinka et al. (1981) published a revised taxonomic classification of humus forms, as a component of British Columbia's ecological land classification program. A revised version of this taxonomic classification was subsequently produced (Green et al. 1993).

Humus forms can be viewed as organized natural units that reflect local ecological processes by virtue of easily observed structural features. Humus forms typically consist of one or more layers or "horizons" that may be distinguished and described, and which are genetically and ecologically linked (*see* Ontario Institute of Pedology 1985, Luttmerding et al. 1990). The composition of each horizon, and the horizon sequences within a humus form profile, are mainly related to particular types of animal and/or microbial activities.

Ideally, a humus form classification would be based on physical, chemical, and biological properties of humus forms that correlate with recognizable structural properties (Klinka et al. 1981). Unfortunately, little data currently exist that calibrate macroscopic structural properties of humus forms with chemical characteristics and biological responses. Consequently, most existing humus form classifications make exclusive use of field-observable structural properties to discriminate between the various humus form classes. Some properties commonly employed as diagnostic criteria in humus form classifications include: the presence/absence of specific organic horizons, the relative thickness of specific horizons, the physical structure and granule characteristics of specific horizons, and the degree of incorporation of fine humus materials (humified organic matter) into the mineral soil.

Throughout this century, the terminology of humus form classification has become confused as a result of the varying conceptual approaches brought to the science by different workers; this situation has previously been noted by Wilde (1966, 1971), Bernier (1968), and Klinka et al. (1981). The terms used to describe and classify humus forms are inconsistent between classification treatments: in some cases, several terms exist to describe a single property; in other cases, expressions have multiple meanings within the literature. It is often not clear which terms are synonymous or to what degree overlap occurs between two concepts. Every new author starts by bemoaning the state of confusion within the humus forms nomenclature, and then proceeds to add to the muddle by developing a revised classification with new terminology. In this report, the terminology and concepts proposed by Bernier (1968) are largely adhered to. However, an expansion of the *fibrimor* group based upon diagnostic criteria that differ from those proposed by Bernier (1968) is presented.

2. FIELD DESCRIPTION OF FOREST HUMUS FORMS

The first step to describing and classifying forest humus forms requires the assessment of several structural features within the humus form profiles of forest soils. The extent of the formality required to make these observations depends upon the ultimate application of the information. If the objective is simply to field-classify a particular humus form, then the data need only relate to a few descriptive features specified in a humus form classification "key". Such a key may take many forms; for example, it may be constructed primarily for use as a field tool for humus description and classification. In such cases, the key will guide the user in making the appropriate observations. If, however, a database will be constructed for further analysis, a more systematic approach

[2]Sutherland, B.J.; Foreman, F.F. Guide to the use of mechanical site preparation equipment in northwestern Ontario. Nat. Resour. Can., Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. 186 p. (In press)

to field sampling must be taken. A field sampling protocol should be developed, with identified parameters and a standardized format for recording them. The equipment and field procedures required to sample a forest humus form, for the purposes of description or classification, are simple and nonspecialized.

1. Selecting a Location for Humus Form Sampling. It is important to choose a representative field location for sampling; one that is intermediate in terms of the ground conditions, shading, vegetational coverage (especially overstory), and general site features (slope, aspect) that exist in the local area. Keep in mind that humus form conditions, moreso than many other soil characters, may vary considerably over short distances. For example, if the objective of the survey is to represent average humus form conditions within a 10-m x 10-m field plot, then multiple samples within the plot will be required; if divots are to be sampled, it may be necessary to dig six or more within a short distance, and describe them all. Keep in mind that at the microscale level, fallen logs and branches, surface stones or boulders, or vegetation may all cause some significant variations in the forest humus profile. If sampling is being done as part of a reconnaissance soil pit description, then the entire description face (i.e., a 1-m wide exposure) may be used as a reference and average horizon occurrences and thicknesses recorded. Finally, when preparing an exposure for field description, take account of the direction of natural lighting by locating the description face to take optimum advantage of the sun angle.

2. Preparing a Humus Form Profile for Examination. For cutting and exposing most humus form profiles, a knife blade and/or a sharp, square-headed spade are the best tools. Often, the preparation of the humus form profile exposure is done in conjunction with the excavation of a larger soil pit. Care must be taken not to compact or otherwise disrupt the organic material; the organic layer can be particularly fragile if it is in an especially dry or wet state. For thinner, terrestrial forest humus forms, the careful extraction of a small surface divot, which includes the full organic deposit as well as some surface mineral soil material, is suitable for description and classification (Fig. 2). A standard soil auger of the type used in reconnaissance soil surveys is useful and sometimes necessary for sampling thicker (e.g., >30 cm) humus forms and organic deposits (as well as for determining the soil type according to the northwestern Ontario Forest Ecosystem Classification [FEC] system [Sims et al. 1989]). Special peat augers (as described by Jeglum et al. 1991) are required for sampling and sectioning deeper and wetter organic soils.

Regardless of the equipment used, it is recommended that the entire humus form profile be exposed by digging 10 or 20 cm into the mineral soil. This will permit the determination of the limits and the significant characteristics of the humus profile. Once exposed, the humus form profile should be cleaned with a trowel or knife blade to reveal the horizon structure and the full profile depth.

3. Making Field Measurements. A small, retractable carpenter's tape measure can be used for measuring total profile depth, as well as the thickness of individual horizons or layers. However, care must be taken to not compress or deform the profile during these measurements. The physical features of each horizon should be described visually in the field (*see* Ontario Institute of Pedology 1985, Sims et al. 1989, Luttmerding et al. 1990, Host et al. 1993). A 10x or 20x hand lens may be of assistance for observing some of the finer structural characteristics within the profile. Samples should be collected using labeled plastic bags or containers. Normally, this is done for each individual horizon, but in some special cases a composite plane-section of the full humus form profile is desired (Klinka et al. 1981). Depending upon the laboratory analyses to be conducted, samples may require freezing, drying, or other forms of special handling (*see* Klinka et al. 1981, Kalra and Maynard 1991). When describing humus forms in the field, it is important to record separate information on each layer or horizon.

Figure 2. Sampling a forest humus form in the field.

Some features that can be included in a humus form sampling protocol include (*after* Luttmerding et al. 1990):

- Average depth of the humus form profile, and thicknesses of individual organic horizons as well as surface or subjacent mineral horizons;
- Designation of the horizons present within the humus form profile (i.e., **L**, **F**, **H**, **Hi**, **Ah**, or **O** horizons, as defined in Section 2.1);
- Differentiation, using standard conventions, of the litter (**L**) layer from the **living moss** layer, in those humus form profiles where the latter occurs (*see* Section 2.1.1);
- A measurement of the degree of incorporation of organic matter into the mineral soil, and the degree of abruptness or discontinuity associated with the organic/mineral soil interface;
- An estimation of the biological origin (botanical, faunal) of the organic material from which the humus form is primarily derived;
- Measurement of presence and abundance, by size and species, of roots observed in each humus form horizon;
- Presence and abundance of decaying wood or charcoal in each humus form horizon;
- Bulk density and/or an estimate of the degree of compaction or matting of the organic material within each humus form horizon;
- Presence and abundance, by color types, of fungal mycelia within each humus form horizon;
- Estimated moisture status of the materials in each humus form horizon;
- Presence and abundance of soil fauna, by generalized taxonomic groups; if insect droppings are visible, description of the general sizes and amounts; and
- Description of other soil/site parameters that could be relevant to the analysis of a humus form database: including, forest site classification units; soil texture class(es); soil moisture regime; soil drainage class; elevation, latitude, and longitude; topographic site position and aspect; etc.

2.1. Forest Humus Horizons

For classification purposes, it is convenient to divide forest humus forms into two major groups: *terrestrial* and *semiterrestrial* (Table 1; Bernier 1968). *Terrestrial* humus forms typically overlie dry to moist, very rapidly to poorly drained mineral soils (soil moisture regimes [SMR] Ø to 6, *see* Ontario Institute of Pedology 1985). Most merchantable forest stands in northwestern Ontario occur on upland mineral soils that support the development of terrestrial humus forms. *Semiterrestrial* humus forms develop on imperfectly to very poorly drained soils that are saturated throughout most of the year. They are primarily associated with moist mineral or wet organic soils (SMR 5 to 9) which, in northwestern Ontario, may be associated with noncommercial forest stands. As Klinka et al. (1981) indicated, however, some difficult transitional "hybrids" that incorporate characteristics of both terrestrial and semiterrestrial humus forms occasionally occur.

Table 1. Useful characteristics for differentiating between terrestrial and semiterrestrial forest humus forms (*after* Canada Soil Survey Committee 1978a, Klinka et al. 1981).

	Terrestrial	Semiterrestrial
Characteristic horizons	**L**, **F**, and **H**; **Hi**	**Of**, **Om**, **Oh**
Physiography	Sloping to level	Low-lying, depressions
Soil moisture regime*	Ø–4 (5 or 6)	(5 or 6) 7–9
Soil drainage class*	Very rapid to imperfect	Poor to very poor
Water level	Absent in horizons	At or near soil surface
Dissolved O_2	Present	Absent or present
Origin of materials	Nonhydrophytic vegetation	Hydrophytic vegetation
Biota	Mainly aerobic; fungal mycelia present; mites and springtails present at some time during the year	Anaerobic; few flora or fauna can be observed beneath the surface

* As defined by the Ontario Institute of Pedology (1985) and Sims et al. (1989).

Humus forms are classified on the basis of horizon characteristics within the humus form profile. Diagnostic humus form horizons are named using standardized alphabetic abbreviations: including, **L**, **F**, **H**, **Hi**, **Ah**, and **O**. Of these, all but **Ah** represent organic horizons (*see* definitions and descriptions in Sections 2.1.1. and 2.1.2.). While the **L**, **F**, **H**, **Hi**, and **Ah** horizons typify upland, terrestrial humus forms, **O** horizons are characteristic of perpetually moist or wet, semiterrestrial humus forms (Bernier 1968). Definitions provided here for the diagnostic forest humus form horizons are derived from conventions outlined by the Canadian System of Soil Classification (Canada Soil Survey Committee 1978a) and from descriptions provided by Klinka et al. (1981).

2.1.1. Organic Horizons

Organic horizons are defined by the Canadian System of Soil Classification as containing greater than 17 percent organic carbon (approximately 30 percent organic matter) by weight (Canada Soil Survey Committee 1978a). Organic horizons are most commonly found within organic soils and overlying the surface of mineral soils; however, rarely they may also occur as buried horizons within mineral soils when fresh parent materials are deposited over existing soil profiles.

L, **F**, and **H** are organic horizons that develop primarily from accumulation on the ground surface of leaves, twigs, and woody materials, with or without a minor component of dead mosses (but not including the living moss layer of the forest floor). **L**, **F**, and **H** horizons are usually not saturated with water for prolonged periods and are typically found at the surface of mineral soils. In most forest stands, the **L**, **F**, or **H** horizons contain 60 percent or more organic matter by weight (Canada Soil Survey Committee 1978a). Any, or all, of the **L**, **F**, or **H** layers may be present in a given terrestrial forest humus form. **L**, **F**, or **H** layers that are very thin or poorly differentiated may be lumped together and collectively described as a single horizon, e.g., an **FH** horizon. The **Hi** horizon is essentially a special case of the **H** horizon, having been modified and intermixed with mineral particles by the action of soil fauna.

The **L**, or *litter*, horizon is usually the uppermost layer of a terrestrial humus form profile. Living plant material is not included as part of the **L** horizon; however, distinguishing living from dead components of extensive moss and lichen forest floor cover may be problematic in the forests of northwestern Ontario. This difficulty has also been recognized by Green et al. (1993) in British Columbia and they have recommended that these distinct surface layers of living bryophtes be identified and named in the humus form profile description. In the humus form descriptions presented here for northwestern Ontario, the term **living moss** has been used for this layer.

Below the **living moss** layer, the **L** horizon is characterized by an accumulation of essentially undecomposed organic residues, such as recently fallen foliage, twigs, and other woody materials, and plant reproductive structures. Most original structures are intact and readily discernible. Materials in the **L** horizon may be discolored and/or exhibit some minor mechanical disintegration, but there are no macroscopic signs of biological decomposition. Roots are typically absent in the **L** horizon. The **L** horizon may or may not be sharply delineated from underlying humus horizons or mineral soil. In classifying forest humus forms, the **L** horizon is not usually considered to be diagnostic since it is transitory and occurs in association with most of the terrestrial humus forms.

The **F**, or *fermentation*, layer is characterized by an accumulation of partially decomposed organic matter derived mainly from foliage, twigs, and other woody materials; plant reproductive structures; and roots. Morphological decomposition is very apparent at a macroscopic level and, although the origins of most materials may be identified, some of the plant structures are not discernible. Original materials may be somewhat altered in appearance by the action of soil fauna, or they may be permeated and matted by fungal hyphae. In forest humus forms, roots are commonly present in the **F** horizon. The **F** horizon may or may not be sharply delineated from underlying organic or mineral horizons; a composite **FH** horizon is sometimes described when delineation from the **H** horizon is not readily discernable. In classifying terrestrial forest humus forms, variations in the relative thickness, as well as in the macroscopic structure, of the **F** horizon are important diagnostic characteristics.

The **H**, or *humic*, horizon is characterized by an accumulation of decomposed organic matter in which the original structures are largely indiscernible (recognizable plant residues may constitute a small proportion of **H** materials). The **H** horizon differs from the **F** horizon in its greater degree of humification, chiefly from the action of soil organisms. Materials in the **H** horizon consist mainly of fine, greasy-textured, black–brown to black, organic substances. They may be permeated by fungal hyphae and/or contain the excrement of soil fauna. In forest ecosystems, roots are commonly present in the **H** horizon. Where humification is chiefly dependent on fungal activity, the **H** horizon is often sharply delineated from the underlying mineral soil; where soil fauna activity is high, the **H** horizon is commonly intermixed with, or incorporated into, the mineral soil.

An *incorporated humic* or **Hi** horizon is characterized by an accumulation of small, spherical or cylindrical, organic granules (animal droppings). As in the **H** horizon, fine, dark-colored, well-decomposed organic substances predominate. However, in the **Hi** horizon, these materials have been substantially reworked by active populations of nonburrowing soil fauna, resulting in the development of a coarse, granular texture. In forest ecosystems, roots are commonly present in the **Hi** horizon. Intermixing with mineral soil particles is common in the **Hi** horizon and, consequently, its typically poorly delineated boundary with the underlying mineral soil is a diagnostic feature. Genetically, the **Hi** horizon can be considered an intermediate stage between the **H** and **Ah** horizons.

Organic **O** horizons are characteristic of wetland or semiterrestrial ecosystems. Organic **O** horizons develop primarily from the accumulation of mosses, especially *Sphagnum* spp., sedges and rushes, and woody materials (Canada Soil Survey Committee 1978a) under conditions where the water table is situated at, or near, the soil surface for a significant portion of the annual period of biological activity. Humification processes are predominantly influenced by the physical and chemical conditions of the local hydric environment, such as pH levels and degree of seasonal water table fluctuation. **O** horizons are most commonly found either within wet organic soils or overlying moist mineral soils. Occasionally, they are associated with fresh, upland mineral soils that occur in pockets of restricted drainage (*see* Table 1 for diagnostic criteria). As with **L**, **F**, and **H** horizons, **O** horizons typically contain 60 percent or more organic matter by weight (Canada Soil Survey Committee 1978a). Three designations of **O** may be defined within semiterrestrial humus forms, based upon the degree of decomposition within a given horizon: **Of** (*fibric*), **Om** (*mesic*), or **Oh** (*humic*). The degree of organic soil decomposition is estimated using the ten-class von Post scale of decomposition (Table 2, Fig. 3).

An **Of**, or *fibric*, horizon consists predominantly of **O** materials that are classified into von Post decomposition classes 1 to 4. Fibric materials constitute the least decomposed **O** matter, comprising recognizable fibers that are readily identifiable as to botanical origin. By volume, an **Of** horizon contains at least 40 percent "rubbed fiber" content. An estimated measure of rubbed fiber content can be obtained by examining the proportion of fiber materials that remains after rubbing a small sample about ten times between the thumb and forefinger.

Table 2. Estimation of organic soil decomposition using the ten-point von Post scale (*after* Ontario Institute of Pedology 1985, Sims et al. 1989).

Of - FIBRIC	
1. Undecomposed	Plant structure unaltered; yields only clear, light yellow–brown colored water
2. Almost undecomposed	Plant structure distinct; yields only clear, light yellow–brown colored water
3. Very weakly decomposed	Plant structure distinct; yields distinctly turbid brown water; no peat substance passes between the fingers; residue not mushy
4. Weakly decomposed	Plant structure distinct; yields strongly turbid brown water; no peat substance escapes between the fingers; residue rather mushy
Om - MESIC	
5. Moderately decomposed	Plant structure clear but becoming indistinct; yields much turbid brown water; some peat escapes between the fingers; residue very mushy
6. Well decomposed	Plant structure somewhat indistinct but clearer in the squeezed residue than in the undisturbed peat; yields much turbid brown water; about a third of the peat escapes between the fingers; residue strongly mushy
Oh - HUMIC	
7. Strongly decomposed	Plant structure indistinct but recognizable; about half of the peat escapes between the fingers
8. Very strongly decomposed	Plant structure very indistinct; about two-thirds of the peat escapes between the fingers; residue almost entirely of resistant remnants such as root fibers and wood
9. Almost completely decomposed	Plant structure almost unrecognizable; nearly all of the peat escapes between the fingers
10. Completely decomposed	Plant structure unrecognizable; all of the peat escapes between the fingers

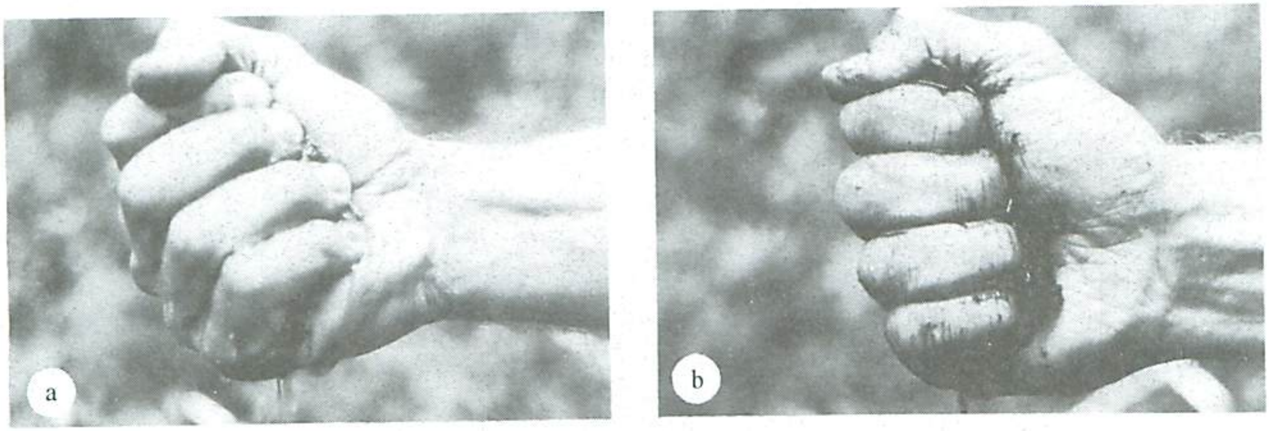


Figure 3. Estimating the degree of decomposition by squeezing a small sample of peat; the turbidity (degree of yellow or brown coloration) of the water expressed from the sample provides a key to ranking the organic soil using the von Post scale of decomposition. (a) Low turbidity: very clear water is squeezed out, representing a decomposition class 2 on the von Post scale. (b) Considerable turbidity: dark colored water is squeezed out, representing a decomposition class 5 on the von Post scale.

An **Om**, or *mesic*, horizon consists predominantly of **O** materials that are classified into von Post decomposition classes 5 and 6. Mesic materials constitute **O** matter at a stage of decomposition that is intermediate between fibric and humic materials. An **Om** horizon contains partially altered (both physically and biochemically) organic material; rubbed fiber content is between 10 percent and 39 percent.

An **Oh**, or *humic*, horizon consists mainly of **O** materials that are classified into von Post decomposition classes 7 to 10. Humic materials constitute the most highly decomposed state of **O** matter, and contain only small amounts of well preserved, recognizable fiber. Humic materials typically have a high bulk density, and a low saturated water-holding capacity. An **Oh** horizon contains less than 10 percent rubbed fiber.

2.1.2. Mineral Horizons

Like humus forms, mineral soils are classified on the basis of horizon characteristics within the soil profile. Mineral horizons are defined by the Canadian System of Soil Classification as containing ≤17 percent organic carbon (approximately 30 percent organic matter) by weight (Canada Soil Survey Committee 1978a). In the Canadian System of Soil Classification, three primary mineral horizons are recognized using uppercase letters: **A**, **B**, and **C**. Subdivisions of these horizons are designated by adding lowercase suffixes to the primary horizon symbols; each suffix describes a specific range of modifying conditions that are present within a particular primary mineral horizon. The only mineral horizon that will be described here is the **Ah** horizon, since it is a component of some of the terrestrial and semiterrestrial forest humus forms described in this report.

The **A** horizon develops at the surface of the mineral soil profile. It is a product of both the loss of water-soluble materials (i.e., leaching of substances to the **B** horizon below) and the accumulation of humic materials from overlying organic layers. The former process typically results in a lighter color near the soil surface (an *eluviated* **Ae** horizon); the latter process is usually indicated by a darkening of the surface soil due to humus staining (a *humified* **Ah** horizon). Thus, an **Ah** horizon is a mineral **A** horizon that has been enriched with organic matter. Movement of organic matter into the mineral soil can be effected by both biotic and abiotic processes. Since it is a mineral horizon, the **Ah** horizon must contain ≤17 percent organic carbon, by weight. In forest ecosystems, roots are commonly present in the **Ah** horizon. The **Ah** horizon may, or may not, be sharply delineated from other organic (**L**, **F**, or **H**) or mineral (**A**, **B**, or **C**) horizons.

2.2. The Main Classification Units: Forest Humus Form Orders and Groups

The hierarchical system used for describing forest humus forms in northwestern Ontario is based upon Bernier's (1968) system, which recognizes *orders* at the broadest level, *groups* at the secondary level, and *subgroups* at the tertiary level (Table 3, Fig. 4).

For terrestrial humus forms, the northwestern Ontario forest humus form classification uses three main, internationally recognized humus form orders — *mull*, *moder*, and *mor*. In addition, *peatymor* is treated here at the rank of humus form order to describe semiterrestrial or forest wetland organic deposits. These four humus form orders reflect distinctly different processes of humus formation, as indicated by diagnostic combinations of organic horizons and the degree of organic matter incorporation into mineral soil.

Table 3. Hierarchy of classification units for forest humus form description in northwestern Ontario (*adapted from* Bernier [1968], Klinka et al. [1981], and Green et al. [1993]).

Level of classification hierarchy	Terrestrial				Semiterrestrial
Order	*mull*	*moder*	*mor*		*peatymor*
Group			*fibrimor*	*humifibrimor* *humimor*	*fibric peatymor* *mesic/humic peatymor*
Subgroup			*litter fibrimor* *mycelial fibrimor* *typical fibrimor* *subhumic fibrimor* *humic fibrimor*		

The four orders are subdivided into humus form groups (Bernier 1968) according to criteria that represent the degree of humification within the organic profile (as in *mors* and *peatymors*) or the rate and type of zoological activity at the interface between mineral soil and organic matter (as in *mulls* and *moders*). At the group level, the units can typically be related more directly to variations in the ecological characteristics of forest sites (e.g., soil moisture, soil chemistry, and litter type).

Following are summary descriptions for four humus form orders (*mull*, *moder*, *mor*, and *peatymor*) and three groups (*fibrimor*, *humifibrimor*, and *humimor*), as adopted by the northwestern Ontario forest humus form classification. Subgroups in the northwestern Ontario forest humus form classification are described elsewhere (*see* Section 3.6). The names and definitions of orders and groups are derived, for the most part, from Bernier's (1968) descriptions. Wherever possible, linkages with

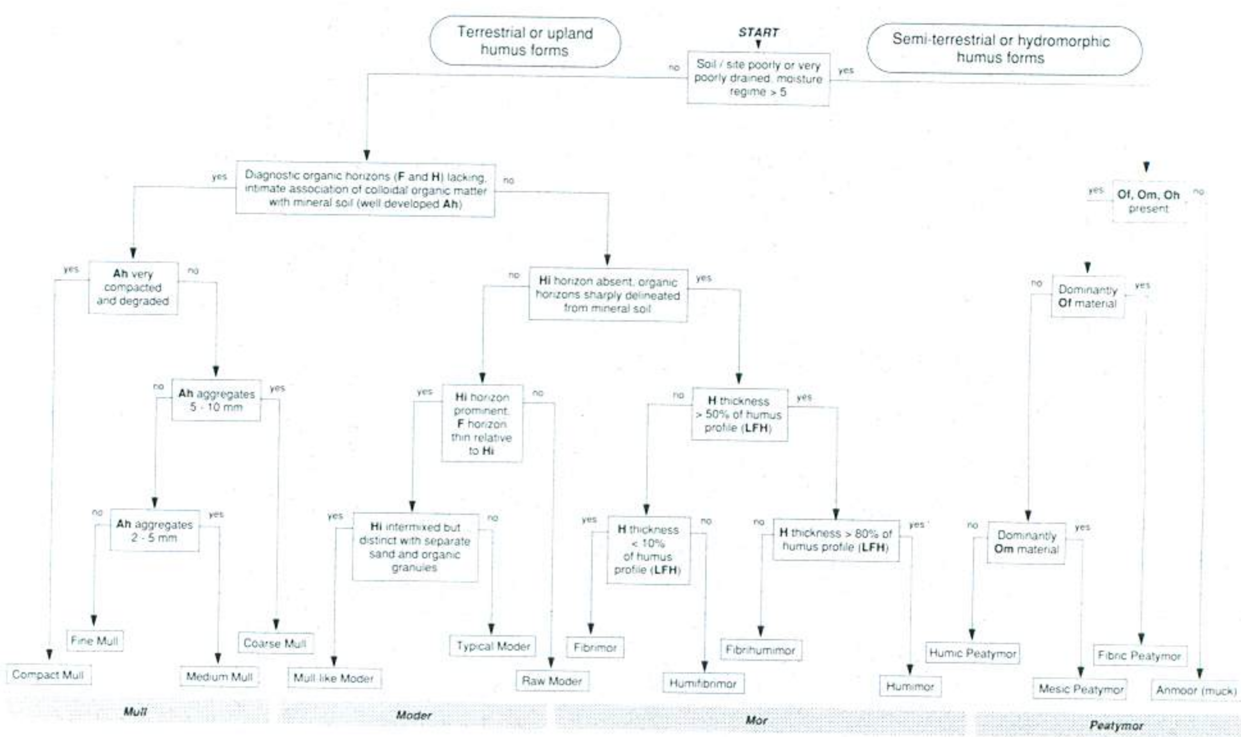


Figure 4. Bernier's (1968) system, presented as a hierarchical key, for classifying forest humus forms (after *Ontario Institute of Pedology 1985*).

the British Columbia humus form classification (Klinka et al. 1981, Green et al. 1993) are also provided.

2.2.1. Mull

The *mull* order includes terrestrial forest humus forms in which decomposed organic matter has become intimately mixed into the surface layers of the mineral soil. Diagnostic **F** and **H** horizons are lacking. *Mulls* typically consist of a thin litter (**L**) layer overlying an **Ah** horizon in which organic material has been well incorporated into the mineral soil, primarily as a result of the action of soil fauna (especially earthworms). Structurally, in the **Ah** horizon, *mull* humus forms appear as porous, granular, dark gray to black soil masses (Bernier 1968). At a microscopic level, they are characterized by a mechanically inseparable complex of colloidal humus and mineral soil, referred to sometimes as Bernier's *clay–humus complex*. The boundary between the **Ah** horizon and its underlying mineral horizon is usually not abrupt (Ontario Institute of Pedology 1985, Green et al. 1993).

Mulls develop under conditions that support the rapid decomposition and humification of forest litter, processes which are driven by biological activity in the upper soil layers. Habitat conditions that promote this activity include favorable temperatures, a supply of easily decomposable litter, good soil aeration, intermediate levels of soil moisture, and soil substrates that are inherently nutrient-rich or subject to nutrient input from seepage of subsurface water (Klinka et al. 1981). In Ontario, optimum development of forest *mulls* tends to occur beneath temperate, upland, broadleaved forests on well to imperfectly drained, fine-textured soils — conditions that provide for an abundant supply of broadleaf litter and which favor the development of active, burrowing soil fauna (Bernier 1968). Development of forest *mulls* implies a steady rate of faunal activity, with consumption and excretion of large quantities of organic matter and mineral particles by earthworms.

Mulls tend to have higher pH values and higher levels of base saturation than do *moders* and *mors*; carbon/nitrogen ratios are typically lower (Klinka et al. 1990a, b). Organic matter content is generally less than 25 percent in the **Ah** horizon (Bernier 1968). Compared to *moders* and *mors*, *mulls* are considered to provide the greatest amount of available nutrients, especially nitrogen, to plants (Klinka et al. 1981, Kabzems and Klinka 1987).

Bernier (1968) defined four *mull* groups on the basis of granule sizes within the **Ah** horizon (*see* Fig. 4). This approach distinguishes the type of faunal activity and tentatively relates it to soil nutrient and moisture conditions. In British Columbia, Klinka et al. (1981) subdivided *mulls* into four categories based upon the soil moisture status and the type of **Ah** horizon present. Klinka et al. (1981) also included wet, well-humified humus forms (i.e., containing **Oh** horizons) in their definition of the *mull* order. In the current northwestern Ontario forest humus form classification (*see* Section 3.4), these humus forms have been reassigned to the *mesic/humic peatymor* group. Because *mulls* were encountered relatively infrequently in the field in northwestern Ontario, no subdivisions within the *mull* order were formally recognized (*see* Sections 3.4 and 3.6); future investigations may provide a better basis for a more comprehensive treatment of the *mull* order.

2.2.2. Moder

This terrestrial humus form order is essentially intermediate, in terms of its physical and chemical characteristics, between the *mor* and *mull* orders. *Moders* typically comprise, as in the case of *mors*, an accumulation of partially humified organic material overlying the mineral soil; in other words, a well-developed **F** horizon is typically present. Like *mulls*, however, *moders* are zoogenous humus forms, i.e., the breakdown and incorporation of organic matter is accomplished largely by the action of soil fauna. The **F** horizon is loose, rather than matted (as is characteristic of *mors*), and contains very small to microscopic animal droppings (Klinka et al. 1981, Olsson 1986). Humified organic matter is typically present as an **Hi** horizon. The degree of incorporation of decomposed organic matter into the mineral soil is greater than in *mors* but less than in *mulls*. No appreciable organo–mineral *clay–humus complex* develops, although loose mineral grains are intermixed with organic granules in the **Hi** horizon (Bernier 1968).

Like humus forms in the *mull* order, *moders* require a climatic regime that facilitates a relatively high level of biological activity in the forest floor and surface soil strata. Under a fixed set of climatic circumstances, *moders* tend to develop on soils that are generally less moist and/or poorer in nutrient status or clay content than soils which give rise to *mull* formation. *Moders* are most common on fresh, well-drained upland soils under broadleaved or mixed forest stands that provide an abundance of readily decomposable litter. In Ontario, they are especially common under upland, cold–temperate and boreal mixedwood or hardwood stand conditions (Bernier 1968). A variety of soil invertebrates, as well as fungal and bacterial organisms, contribute to *moder* formation, but large populations of earthworms are typically absent. Since none of the organisms concerned with *moder* formation burrow deeply, intermixing of organic material occurs only in the surface layers of the mineral soil. These species consume very little mineral material, so their casts consist almost exclusively of organic matter.

In terms of chemical properties, *moders* also tend to be intermediate between *mulls* and *mors*. Although **Hi** horizons in *moders* are acidic, pH values are generally higher than those found in the **H** horizons of *mors* (Bernier 1968, Klinka et al. 1990a). Base saturation levels are, on average, somewhat higher than those found in *mors* but considerably lower than those observed in *mulls* (Bernier 1968; Klinka et al. 1981, 1990b). Carbon/nitrogen ratios are usually higher than in *mulls* but lower than in *mors* (*see* Klinka et al. 1990b). Organic matter content in the **Hi** horizon is generally between 40 percent and 60 percent (Bernier 1968).

Bernier (1968) subdivided the *moder* humus form order into three groups based upon the relative prominence of **F** and **Hi** horizons, as well as the extent of intermixing of humified organic matter with the underlying mineral soil (*see* Fig. 4). These groups include a "modal" group and transitional groups to *mull* or *mor*, in terms of structural characteristics. Klinka et al. (1981) subdivided the *moder* order into seven classes on the basis of soil moisture regime, as well as biological origin and relative thickness/abundance of individual organic horizons. They also included wet, moderately humified humus forms (i.e., containing **Om** horizons), assigned here to the *mesic/humic peatymor* group, in their definition of the *moder* order. In the current forest humus form classification for northwestern Ontario, no subdivisions within the *moder* order are recognized (*see* Sections 3.4 and 3.6) because *moders* were encountered relatively infrequently in the field; future investigations may provide a better basis for a more comprehensive treatment of the *moder* order.

2.2.3. Mor

The *mor* order contains the least biologically active terrestrial humus forms. Because of slow rates of decomposition, *mors* are characterized by an accumulation of organic material overlying the mineral soil surface. Soil fauna activity is low and decomposition of organic matter is achieved primarily by cellulose-decomposing fungi. The diagnostic organic horizons are **F** and **H**; intermixing of organic matter with the mineral soil is minimal. In *mor* humus forms, the **F** horizon has a characteristically matted appearance, with fungal hyphae often visibly interwoven throughout. With the lack of significant soil fauna activity, and its consequent interlayer mixing, the **H** horizon is typically free of mineral particles. With the exception of some granular *mors*, animal droppings are scant or absent altogether.

Mors occur wherever climatic or edaphic conditions or the nature of the litter are not conducive to the development of the more biologically active upland humus forms (*mulls* and *moders*). In Ontario, *mors* are most common under upland, boreal forests, although they do occur under cold–temperate, broadleaved and mixed forests (Bernier 1968). *Mors* develop on a wide range of soil and site conditions, and are especially common within the Boreal Forest Region (Rowe 1972).

Mors are the most acidic of the major upland humus forms; pH values in the **H** horizon are often less than 4.0 (*see* Kabzems and Klinka 1987; Nykvist and Skyllberg 1989; Klinka et al. 1990b, 1994; Green et al. 1993). Base saturation levels are somewhat lower than those of *moders*. Organic matter content in the **H** horizon is high, averaging about 80 percent (Bernier 1968). Carbon/nitrogen ratios and cation exchange capacities are typically high in *mors*, reflecting slow rates of decomposition that result in the storage of organic matter in the humus form and the slow release of nutrients into the soil environment (Klinka et al. 1981, 1990b).

Bernier (1968) proposed subdivisions of the *mor* order based upon the relative thickness of the **F** and **H** horizons in the organic profile. This approach stresses the degree of humification in the organic profile and contains an inference of site-level productivity (Bernier 1968). Bernier described four humus form groups in the *mor* order: *fibrimor*, *humifibrimor*, *fibrihumimor*, and *humimor*. Klinka et al. (1981) subdivided the *mor* order into seven categories on the basis of soil moisture regime as well as type and relative thickness of the organic horizons. They included wet, fibric humus forms (i.e., containing **Of** horizons) in their definition of the *mor* order; here these humus forms are considered in the *fibric peatymor* group. As described in Section 3.4, the northwestern Ontario forest humus form classification recognizes the *fibrimor* and *humifibrimor* groups according to Bernier's (1968) criteria, while the *fibrihumimor* and *humimor* groups are pooled and the *fibrimor* group is further divided into five subgroups.

The three humus form groups representing the *mor* order in the northwestern Ontario forest humus form classification (*fibrimor*, *humifibrimor*, and *humimor*) are described in more detail below.

Fibrimor

Fibrimors are *mor* humus forms at the group level in which the **H** horizon comprises less than 10 percent of the organic profile (Bernier 1968). Consisting largely of semidecomposed organic material overlying the mineral soil, *fibrimors* represent the poorest degree of organic matter/mineral soil intermixing within the *mor* order. The dominant organic horizon is **F**, which commonly comprises over 75 percent of the organic profile. The **H** horizon is thin and discontinuous, or lacking altogether, and may be replaced by a transitional **FH** layer when humification is incomplete. On dry sites, *fibrimors* can be extremely thin, often developing from lichen or feathermoss materials and subject to frequent disturbance by fire.

Fibrimors are the least humified of the *mor* humus forms, developing typically within sites associated with dry, boreal climates. They are common under young boreal forest stands, where they may reflect an immature humus form condition (Klinka et al. 1981). In Ontario, *fibrimors* are extremely common across a broad range of boreal soil, site, and stand conditions (Bernier 1968); in particular, *fibrimors* are characteristic of dry to fresh, well-drained, upland soils associated with a cold–temperate climate.

Bernier (1968) suggested recognizing *fibrimor* subgroups on the basis of the botanical origin of the **F** horizon. In the northwestern Ontario forest humus form classification, as presented in Section 3.4, the *fibrimor* group is subdivided into five subgroups using the criteria of absolute **H** horizon thickness and relative **L**, **F**, and **FH** horizon thicknesses (similar to those principles employed for subdividing the *mor* order). The overall *fibrimor* group, together with its five subgroups, are individually described in Section 3.6.

Humifibrimor

Humifibrimors are *mor* humus forms in which the **H** horizon constitutes between 10 percent and 50 percent of the total organic profile (Bernier 1968). Within the *mor* order, the *humifibrimor* group represents an intermediate degree of humification between *fibrimors* and *humimors*. The dominant organic horizon is **F**, typically comprising between 35 percent and 70 percent of the organic profile on upland boreal sites. The **H** horizon has a greasy texture, typically is structureless, and is distinct from the upper layer (**A** horizon) of the mineral soil.

In northern Ontario forests, *humifibrimors* tend to be found on fresh to moist, well drained upland soils. On average, moisture regimes associated with *humifibrimors* tend to be moister than those associated with *fibrimors* and drier than those associated with *humimors*, generally in the range of SMR 3 to 6. *Humifibrimors* occur under a variety of stand conditions, but are typically associated with mesic, mixed and broadleaved, boreal forests.

Bernier (1968) suggested recognizing *humifibrimor* subgroups on the basis of the botanical origin of the **F** horizon. In the northwestern Ontario forest humus form classification, the *humifibrimor* group, as described in Sections 3.4 and 3.6, is not further subdivided.

Humimor

The *humimor* group is characterized by *mors* in which the **H** horizon comprises greater than 50 percent of the organic profile. *Humimors* are the most humified *mors* and may attain a greater thickness than other *mor* humus forms. The dominant **H** horizon may exhibit a slightly granular structure and a small degree of intermixing with upper mineral soil layers.

Humimors may reflect a mature humus form condition, and are often associated with sites where forest fire frequency is low (Klinka et al. 1981). In Ontario, *humimors* tend to develop in sites associated with humid, cold–temperate climates, and in particular along cooler and moister lower slope positions. They are commonly associated with productive boreal stands on fresh to moist, often fine-textured, soils.

In Bernier's (1968) *mor* classification, two related groups with dominant **H** horizons were distinguished. *Humimors* were defined as *mors* in which the **H** horizon constitutes >80 percent of the organic profile; *fibrihumimors* were considered to have **H** horizons that comprise between 50 percent and 80 percent of the organic profile. The northwestern Ontario treatment (*see* Sections 3.4 and 3.6) lumps these two groups, applying the term *humimor* to all *mors* in which **H** is the dominant horizon. Bernier (1968) further suggested subdividing **H**-dominant *mors* on the basis of structural features of the **H** horizon; in the current treatment of *humimors*, no subgroups are recognized.

2.2.4. Peatymor

The *peatymor* order includes semiterrestrial humus forms that develop under conditions of prolonged saturation due to elevated water tables (Bernier 1968). This order is defined by the dominance of **O**, rather than terrestrial (i.e., composed of **L**, **F**, and/or **H**) organic horizons. *Peatymors* are distinguished from true organic soils in that they do not meet the minimum thickness criterion for the definition of an organic soil as prescribed by the Canadian System of Soil Classification (Canada Soil Survey Committee 1978a). According to CSSC definitions, under most circumstances, at least 40 cm of **O** material (measured from the surface of the forest floor) are required to constitute an organic soil. Thus, any organic deposit consisting primarily of **O** material that fails to meet this thickness criterion is a *peatymor* humus form. *Peatymors* may or may not represent the initial stages of peat formation, depending upon the relative rates of accumulation and depletion of **O** material. As is the case with *mors* and *moders*, *peatymors* generally comprise an accumulation of partially decomposed organic material overlying the mineral soil. However, especially in the more highly humified *peatymor* groups, organic materials are often incorporated into the mineral soil to some extent by the action of water table fluctuations and seepage. Compared to upland humus forms, *peatymors* often show little horizon differentiation. However, the degree of organic matter decomposition may increase downward within the organic profile, thereby permitting the differentiation of layers based upon the degree of organic decomposition (Bernier 1968), as estimated by the von Post scale (Fig. 3, Table 2).

Peatymors occur under circumstances where the climatic regime or soil/site conditions lead to prolonged saturation of the soil, thus suppressing the decomposition rate of organic materials (Klinka et al. 1981). *Peatymors* are found throughout Ontario in temperate, boreal, and subarctic climates, wherever site position or edaphic conditions result in elevated water tables. However, *peatymor* humus forms occur most extensively in the boreal forest zone and the subarctic wetlands of the Hudson Bay Lowlands, where they are primarily associated with nonforested peatlands, especially bogs and fens. Within the boreal forest, *peatymors* occur primarily under stand types dominated by black spruce, tamarack (*Larix laricina* [Du Roi] K.Koch), and eastern white cedar (*Thuja occidentalis* L.) on lower and toe-slope site positions. At the more highly decomposed end of the von Post scale (e.g., von Post decomposition classes 8, 9, or 10 in Table 2), *peatymors* grade into *anmoor* forest humus forms (Ontario Institute of Pedology 1985). Since the semiterrestrial, wetland-related *anmoor* is not associated with terrestrial forest communities in northwestern Ontario, it is not described or considered further in this report.

In *peatymors*, organic material accumulations are the result of suppressed levels of decomposition due to more or less permanent saturation by ground water (Klinka et al. 1981). The degree to which decomposition rates are suppressed depends on physical and chemical qualities of the hydric environment, such as temperature, degree of water table fluctuation, and levels of available oxygen and nutrients. In general, the higher the levels of temperature, oxygen, and nutrients within the organic materials, the faster the rate of decomposition and the higher the degree of humification observed in the organic profile. To a certain extent, the degree of humification observed within a *peatymor* is indicative of the chemical regime of the ground water. *Peatymors* are typically acidic, although the pH level depends on water chemistry and composition of the prevailing vegetation community (Crum 1988); for example, most *Sphagnum* mosses tend to acidify the surrounding environment. Available nitrogen levels tend to be low, especially in highly acidic habitats (Sjörs 1952, Crum 1988); carbon/nitrogen ratios are high.

Bernier (1968) proposed subdividing the *peatymor* order into three groups according to the dominant degree of organic matter decomposition, as estimated by the von Post scale of decomposition (Fig. 3, Table 2). This approach mirrors classification principles adopted for organic soils by the Canadian System of Soil Classification (Canada Soil Survey Committee 1978a). Thus, *fibric peatymors* are defined as *peatymors* comprising mainly fibric (**Of**) materials (von Post 1–4), *mesic peatymors* are those *peatymors* in which mesic (**Om**) horizons predominate (von Post 5–6), and *humic peatymors* are dominated by humic (**Oh**) materials (von Post 7–10). Klinka et al. (1981) included all semiterrestrial humus forms treated here as *peatymors* within the *mor*, *moder*, and *mull* orders, instead assigning them according to their relative levels of humification. In the northwestern Ontario forest humus form classification (*see* Sections 3.4 and 3.6), Bernier's criteria are employed to distinguish between *fibric* and *mesic/humic peatymors*; the latter group pools *mesic* and *humic peatymors* because these semiterrestrial humus forms are relatively uncommon in northwestern Ontario.

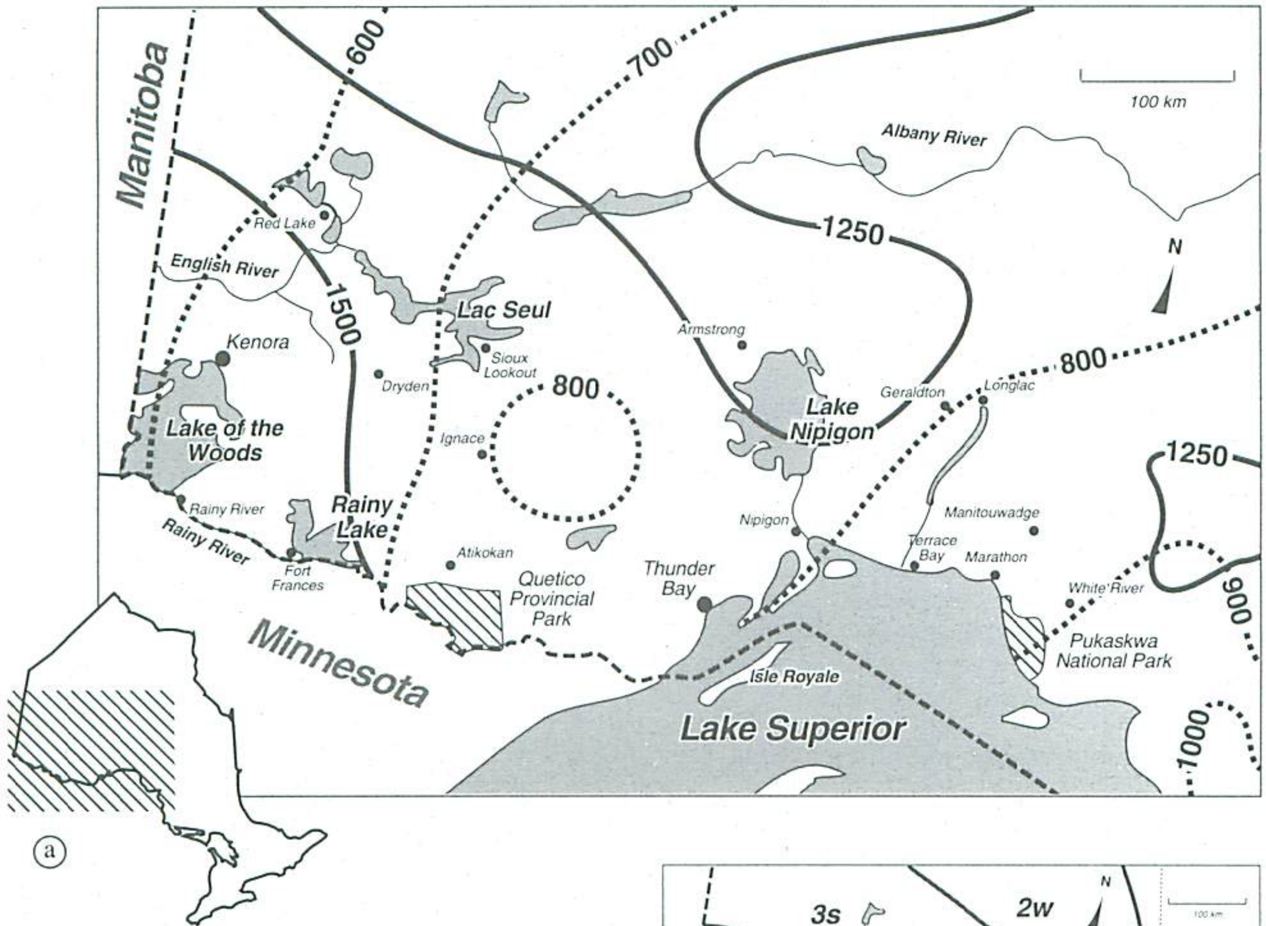
3. FOREST HUMUS FORMS IN NORTHWESTERN ONTARIO

3.1. The Northwestern Ontario Study Area

Geographically, the northwestern Ontario study area extends from Manitouwadge and White River in the east to the Ontario–Manitoba border in the west, and from the Ontario–Minnesota border in the south to just north of the physiographic limit of the Canadian Precambrian Shield (Fig. 5). An overview of forest vegetation, landforms, and soil features is provided below; a more detailed description of the area is provided by Sims et al. (1989).

The forests of northwestern Ontario consist predominantly of elements of the Boreal Forest Region (Rowe 1972). These include pure or mixed stands of jack pine (*Pinus banksiana* Lamb.), trembling aspen (*Populus tremuloides* Michx.), white birch (*Betula papyrifera* Marsh.), balsam fir (*Abies balsamea* [L.] Mill.), white spruce (*Picea glauca* [Moench] Voss), and black spruce. To the west of Lake Superior, along the United States border, the forests belong to part of the Great Lakes–St. Lawrence Forest Region. In this area mixedwood stands are more extensive, including scattered stands of red pine (*Pinus resinosa* Ait.) and eastern white pine (*Pinus strobus* L.). Especially in the southwestern corner of the study area, occasional occurrences of yellow birch (*Betula lutea* Michx. f.), basswood (*Tilia americana* L.), Manitoba maple (*Acer negundo* L.), bur oak (*Quercus macrocarpa* Michx.), red maple (*Acer rubrum* L.), white elm (*Ulmus americana* L.), black ash (*Fraxinus nigra* Marsh.), and red ash (*F. pennsylvanica* Marsh.) reflect the mixed and more diverse nature of forests of the Great Lakes–St. Lawrence Forest Region (Rowe 1972).

With the exception of a zone of strongly broken topography along the Lake Superior coast, the study area is characterized by an undulating, bedrock dominated terrain. Surficial landform features generally reflect the effects of four major glaciations, the last ending approximately 10 000 to 8 000 years ago (Zoltai 1965, 1967; Sims and Baldwin 1991). The most commonly occurring glacial deposit is a shallow, bouldery, sandy or coarse loamy till (Sado and Carswell 1987), which typically reveals the



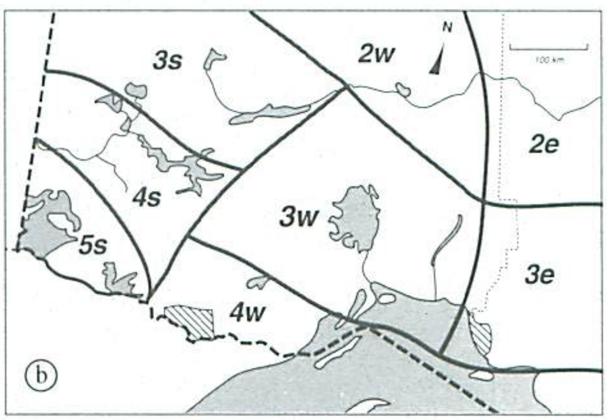


*Figure 5. Maps of northwestern Ontario showing (a) major climatic gradients (*from *Sims et al. 1989), where dotted lines (.....) indicate mean annual total precipitation in mm (1951 to 1980) and solid lines (—) indicate growing degree-days above 5°C (1951 to 1980), and (b) site regions* (Hills 1961).

topographic character of the underlying Shield bedrock. A finer-textured till, derived from the carbonate bedrock of the Hudson Bay Lowland and spread southward onto the Shield by moving ice, occurs within discrete dispersion trains and locally thin smears. Ice-contact and outwash glaciofluvial deposits, consisting of sorted sands and gravels, are found throughout the area. These deposits, including features such as eskers, kames, kame moraines, and deltas, are among the most prominent landforms in northwestern Ontario. Numerous glacial lakes (including Lake Agassiz), which historically inundated much of northwestern Ontario, deposited a range of materials including beach and near-shore sand deposits as well as deeper basin silts and clays. These glaciolacustrine deposits are frequently in close proximity to glaciofluvial landforms. Aeolian deposits occur throughout northwestern Ontario, although with restricted spatial distribution. Typically sandy in nature, these materials tend to be associated with both glaciofluvial and glaciolacustrine landforms. Organic deposits are generally of limited areal extent in the study area, usually occupying poorly drained bedrock depressions and lower landscape positions. Occasionally, organic materials extensively overlie fine-textured (silt and clay), low-relief glaciolacustrine basins.

In general, the climate of northwestern Ontario is microthermal (C'21 to C'22) and humid (B'1 to B'3 – B'4) (Sanderson 1948). However there are two broad climatic gradients—temperature and humidity—that generally stratify the area. Seasonal temperatures tend to increase with decreasing latitude and are moderated in proximity to Lake Superior (Chapman and Thomas 1968); mean annual temperatures, for example, range from 0° C in northern parts of the study area to over +3°C near the United States border in the southwestern sector of northwestern Ontario. Humidity (and precipitation) trends from drier conditions in the west to moist conditions in the east (Chapman and Thomas 1968); mean annual precipitation ranges from less than 550 mm west of Kenora to over 800 mm in the Marathon/Manitouwadge area. Because of this stratification, northwestern Ontario encompasses four Site Regions, and portions of four others, as defined by Hills (1961): 5S, 4S, and the southern half of 3S ("Subhumid Western" Site Regions); 4W, 3W, and the southern portion of 2W ("Humid Western" [driest humid] Site Regions); and the western edges of 3E and 2E ("Humid Eastern" [medium humid] Site Regions).

3.2. Northwestern Ontario FEC Field Data Collection

Information on the distribution of humus forms and other soil, site, and vegetational features in forest ecosystems of northwestern Ontario was collected as part of the northwestern Ontario Forest Ecosystem Classification program. Under a cooperative research agreement between the Canadian Forest Service and the Ontario Ministry of Natural Resources, field work was conducted from 1983 to 1988. Different geographic areas were visited during each of the six field seasons. During the field sampling, an attempt was made to systematically sample the full range of forest site conditions, including detailed descriptions of forest floor cover and humus forms, that exist throughout northwestern Ontario.

In total, 2 167 10-m x 10-m sample plots were examined to acquire descriptions of general site, soils, vegetational composition and cover, and forest stand characteristics. At each FEC plot the forest humus form was initially classified using Bernier's (1968) humus form key (*see* Fig. 4). Thickness of each horizon in the humus profile was recorded along with total thickness of the organic layer (Table 4). Ancillary information was obtained on the soil profile, including horizon descriptions according to Canadian System of Soil Classification (Canada Soil Survey Committee 1978a, b) standards. Soil texture (surface 25 cm and **C** horizon), soil moisture regime (SMR), soil drainage class, amount of lateral seepage, slope position, depth to bedrock, depth to soil calcareousness, and

Table 4. Definitions of forest humus form thickness classes, as recorded during northwestern Ontario Forest Ecosystem Classification field surveys.

Class	Horizon/ material	Thickness range (cm)
Very thin	**LFH**	<5
Thin	**LFH** or **O**	5–15
Thick	**LFH** or **O**	16–40
Deep	**LFH** or **O**	>40

soil coarse fragment content were recorded in the field using standard survey methods as described by Sims et al. (1989).

The northwestern Ontario FEC system consists of sets of simple, hierarchical field keys and summary factsheets that provide modal descriptions of vegetation and soil types (Sims et al. 1989). In total, there are 38 vegetation types (V-types) and 22 soil types (S-types) (Fig. 6). It is recommended that V-types and S-types be determined in the field in order to have an adequate appreciation of vegetation and soil conditions present at a given site. For broadlevel forest management purposes, V-types and S-types are combined into more generalized treatment units (Fig. 7) (Racey et al. 1989). Within each V-type and S-type factsheet in the FEC field guide (Sims et al. 1989), reference to the forest humus condition includes information on typical humus form and organic layer thickness. This information provides a basis for relating the distribution of forest humus forms across V-types and S-types occurring in northwestern Ontario.

3.3. The Northwestern Ontario FEC Vegetation Types Ordination

Plotted diagrams shown in Figures 6 and 8 are based on a computer assisted ordination analysis (Hill 1979, Gauch 1982) of vegetation data collected during the northwestern Ontario FEC program. The ordination graphically presents cover–abundance information for vegetation species recorded in 2 167 field plots (Sims et al. 1989). Each of the 38 plotted points (**V1–V38**) in the ordination diagram represents an average vegetational composition for a FEC vegetation type such that V-types that are close together on the ordination (e.g., **V20** and **V33**) tend to be more alike in terms of their general vegetation conditions than those which are far apart (e.g., **V27** and **V2**). The distance between any two points (V-types) graphically illustrates (and mathematically represents) the relative degree of similarity or difference between those vegetation types.

Vegetation type names

V1 Balsam Poplar Hardwood and Mixedwood
V2 Black Ash Hardwood and Mixedwood
V3 Other Hardwoods and Mixedwoods
V4 White Birch Hardwood and Mixedwood
V5 Aspen Hardwood
V6 Trembling Aspen (White Birch)–Balsam Fir/Mountain Maple
V7 Trembling Aspen–Balsam Fir/Balsam Fir Shrub
V8 Trembling Aspen (White Birch)/Mountain Maple
V9 Trembling Aspen Mixedwood
V10 Trembling Aspen–Black Spruce–Jack Pine/Low Shrub
V11 Trembling Aspen–Conifer/Blueberry/Feathermoss
V12 White Pine Mixedwood
V13 Red Pine Mixedwood
V14 Balsam Fir Mixedwood
V15 White Spruce Mixedwood
V16 Balsam Fir–White Spruce Mixedwood/Feathermoss
V17 Jack Pine Mixedwood/Shrub Rich
V18 Jack Pine Mixedwood/Feathermoss
V19 Black Spruce Mixedwood/Herb Rich
V20 Black Spruce Mixedwood/Feathermoss
V21 Cedar (inc. Mixedwood)/Mountain Maple
V22 Cedar (inc. Mixedwood)/Speckled Alder/*Sphagnum*
V23 Tamarack (Black Spruce)/Speckled Alder/Labrador Tea
V24 White Spruce–Balsam Fir/Shrub Rich
V25 White Spruce–Balsam Fir/Feathermoss
V26 White Pine Conifer
V27 Red Pine Conifer
V28 Jack Pine/Low Shrub
V29 Jack Pine/Ericaceous Shrub/Feathermoss
V30 Jack Pine–Black Spruce/Blueberry/Lichen
V31 Black Spruce–Jack Pine/Tall Shrub/Feathermoss
V32 Jack Pine–Black Spruce/Ericaceous Shrub/Feathermoss
V33 Black Spruce/Feathermoss
V34 Black Spruce/Labrador Tea/Feathermoss (*Sphagnum*)
V35 Black Spruce/Speckled Alder/*Sphagnum*
V36 Black Spruce/Bunchberry/*Sphagnum* (Feathermoss)
V37 Black Spruce/Ericaceous Shrub/*Sphagnum*
V38 Black Spruce/Leatherleaf/*Sphagnum*

Soil type names

S1 Dry/Coarse Sandy
S2 Fresh/Fine Sandy
S3 Fresh/Coarse Loamy
S4 Fresh/Silty–Silt Loamy
S5 Fresh/Fine Loamy
S6 Fresh/Clayey
S7 Moist/Sandy
S8 Moist/Coarse Loamy
S9 Moist/Silty–Silt Loamy
S10 Moist/Fine Loamy–Clayey
S11 Moist/Peaty Phase
S12F Wet/Organic [Feathermoss]
S12S Wet/Organic [*Sphagnum*]
SS1 Discontinuous Organic Mat on Bedrock
SS2 Extremely Shallow Soil on Bedrock
SS3 Very Shallow Soil on Bedrock
SS4 Very Shallow Soil on Boulder Pavement
SS5 Shallow–Moderately Deep/Sandy
SS6 Shallow–Moderately Deep/Coarse Loamy
SS7 Shallow–Moderately Deep/Silty–Fine Loamy–Clayey
SS8 Shallow–Moderately Deep/Mottles–Gley
SS9 Shallow–Moderately Deep/Organic–Peaty Phase

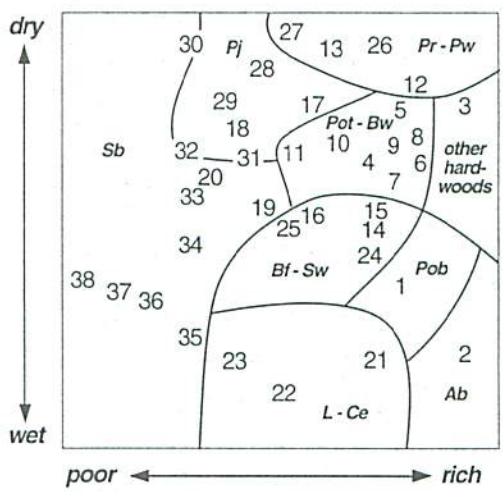
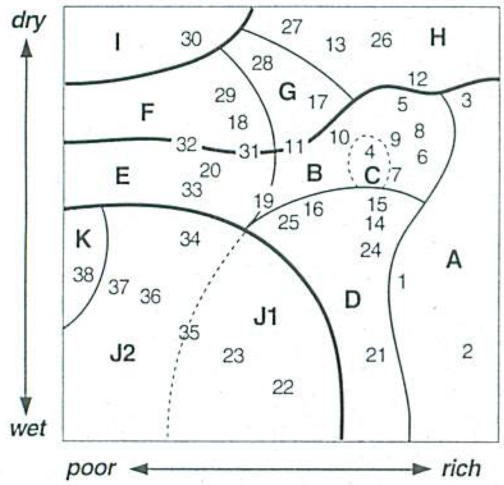


*Figure 6. The 38 vegetation types and 22 soil types of the Forest Ecosystem Classification for northwestern Ontario (*after *Sims et al. 1989). Major tree species distributions are shown as an overlay on the vegetation types ordination.*

Although neither axis of the ordination is calibrated to an absolute scale, two main gradients can be interpreted (Figs. 6 and 8): Axis 1, from left to right, represents a nutrient-poor to nutrient-rich (richness) gradient, while Axis 2, from bottom to top, represents a wet to dry (moisture) gradient. The ordination provides a two-dimensional representation within which V-types can be related to generalized patterns of moisture/nutrient conditions. Information about various soil/site or vegetation parameters may be overlain on the V-types ordination (Figs. 6 and 8). Such overlays help in the recognition of groups of V-types that share similar conditions.

For forest management interests, various other ordination overlays have been developed that effectively group the northwestern Ontario FEC V-types according to similar responses to particular management activities. Examples of overlays are provided by Racey et al. (1989), Sims et al. (1990), Stocks et al. (1990), Wickware et al. (1990), Bell



A Miscellaneous Hardwoods and Mixedwoods

B Aspen Hardwood and Mixedwood
  B1 Dry–Fresh Soils
  B2 Moist Soils

C White Birch Hardwood and Mixedwood

D Balsam Fir–White Spruce Conifer and Mixedwood
  D1 Fresh / Sandy Soils
  D2 Moist / Loamy Soils

E Black Spruce–Jack Pine / Feathermoss
  E1 Dry Soils
  E2 Fresh Soils
  E3 Moist Soils

F Jack Pine / Feathermoss

G Jack Pine / Shrub Rich

H Red or White Pine Conifer and Mixedwood

I Jack Pine–Black Spruce / Blueberry / Lichen
  I1 Very Shallow Soils
  I2 Deep–Moderately Deep / Sandy Soils

J Black Spruce / Wet Organic
  J1 *Alnus rugosa*
  J2 Shrub Poor

K Black Spruce / Leatherleaf / *Sphagnum*

Figure 7. Treatment units and phases may be referred to by short, descriptive names or alphabetic identifiers (the latter may be adaptable for air photo or map annotation), and related to the northwestern Ontario FEC V-types ordination (after *Racey et al. 1989).*

(1991), Kershaw et al. (1994a, b), and Sutherland and Foreman.[3]

3.4. Classification of Forest Humus Forms for Northwestern Ontario

For almost 25 years, Bernier's (1968) forest humus form classification (*see* Fig. 4) has been used to describe forest humus forms in Ontario. In particular, Bernier's treatment is responsible for providing the definitions of *mull*, *moder*, and *mor* that are in common use today by soil surveyors and ecologists.

During the northwestern Ontario FEC sampling program, Bernier's classification was employed for the description of forest humus forms. Inspection of the FEC data indicated that several of Bernier's forest humus form classes were rarely encountered under the forest and climatic conditions of northwestern Ontario. In particular, *mulls* and *moders* were underrepresented in the FEC data set (comprising about 10 percent of all humus forms sampled and 12 percent of terrestrial humus forms; Table 5); *medium mulls* and *raw moders* predominated within these respective categories. Conversely, *mors* were very common, comprising 88 percent of terrestrial humus forms. Fully two-thirds (67 percent) of all terrestrial *mors* sampled were *fibrimors*.

Although Bernier (1968) proposed the subdivision of *mull*, *moder*, and *mor* orders and groups into subgroups based upon criteria such as moisture condition and structural characteristics of the **H** horizon, the practice has not been widely adopted in Ontario. For *fibrimors* and *humifibrimors*, Bernier suggested the recognition of subgroups according to the botanical origin of the organic material. He further proposed six classes of botanical materials on which to define subgroups of humus forms: feathermoss; *Sphagnum* moss; lichen; ericaceous litter and root mat; conifer needle litter; and broadleaf litter. Although this nomenclature carries some additional information regarding the nutrient quality of a humus form, especially when presented in the context of the V-types ordination (*see* Fig. 6), it is limited in its usefulness due to the lack of calibration of nutrient and other characteristics for the proposed subgroups.

The approach taken in the development of the northwestern Ontario forest humus form classification involved several steps. Initial procedures included a combination of hand-sorting and computer tabling and graphing of the FEC field plot data, using allocations of humus forms according to Bernier's (1968) original classification system. Preliminary results showed that some of the orders,

[3]Sutherland, B.J.; Foreman, F.F. Guide to the use of mechanical site preparation equipment in northwestern Ontario. Nat. Resour. Can., Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. 186 p. (In press)

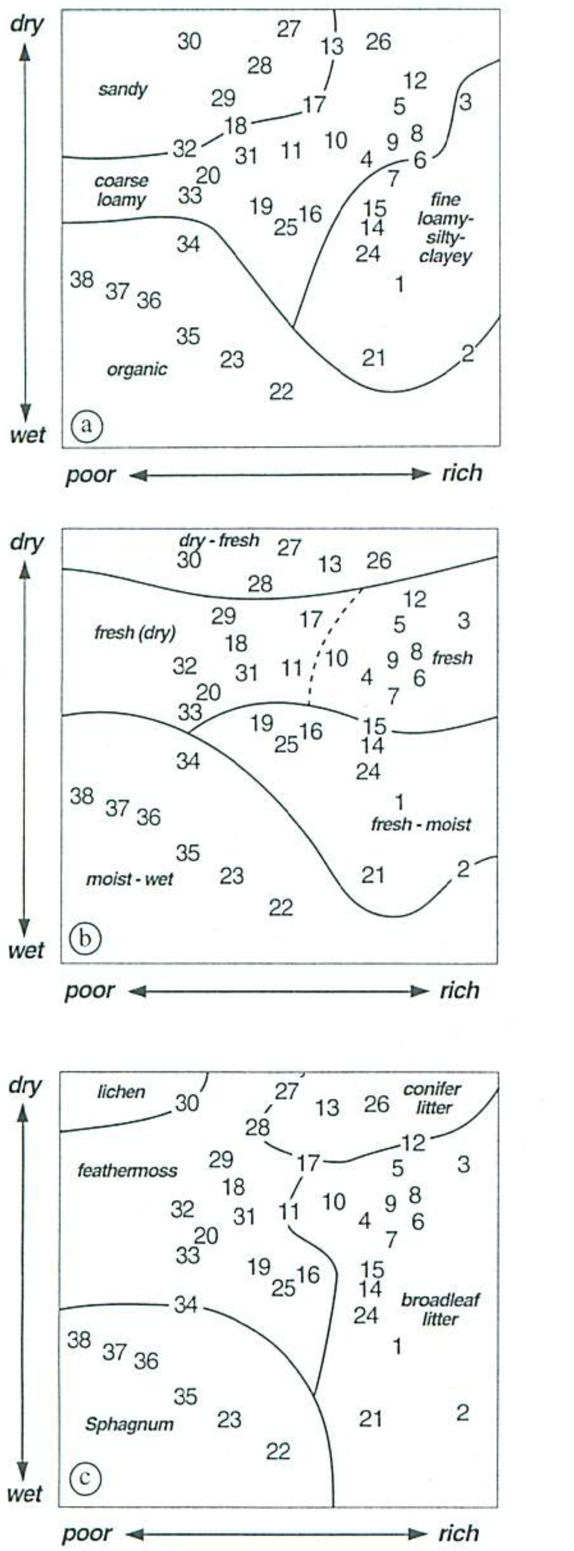


Figure 8. Northwestern Ontario FEC vegetation types ordination diagrams with major gradients associated with horizontal (richness) and vertical (moisture) axes. Overlain with general distributions of (a) dominant soil texture classes, (b) general soil moisture regimes, and (c) forest floor cover.

groups, and subgroups of the Bernier classification were absent or very underrepresented in the FEC data. Because of the extent of the FEC sampling program, this suggested that these conditions were likely to be relatively infrequent throughout northwestern Ontario. As a next step, original field cards and tally sheets were examined by hand in order to clarify some of the soil/site relationships and to examine the data to see if any trends existed in the geographic distribution of humus form conditions. On these bases, additional analyses of the data were conducted and several of Bernier's original units were modified, as described below. Efforts were also focused on subdividing the very large *fibrimor* group using some logical approaches based upon the relative thicknesses of humus form horizons. As these modifications were tested and checked, an iterative approach was taken to develop the final classification units and to encorporate them into a simple, operational field key. Additional ecological soil/site data from the FEC plots were summarized according to the final classification units and, using a commercial graphics software package, ordination overlays were constructed.

Based upon this analysis and interpretation of the northwestern Ontario FEC data, a modified version of Bernier's (1968) general forest humus form classification is presented here (*see* Table 3, Fig. 9). The proposed system is intended to better address the specific characteristics of the forests in northwestern Ontario. The most notable modifications to Bernier's (1968) original classification are:

1. Due to low frequencies of occurrence in the northwestern Ontario FEC data set, Bernier's subdivisions of the *mull* and *moder* orders are not formally recognized;
2. Due to low frequencies of occurrence in the northwestern Ontario FEC data set, Bernier's *fibrihumimor* group is not distinguished from the *humimor* group, and the *mesic peatymor* and *humic peatymor* groups are pooled; and
3. Due to the large representation of the *fibrimor* group in the northwestern Ontario FEC data set, and the inadequacies of Bernier's (1968) approach to subdividing this group, a new classification of the *fibrimor* group is proposed. This approach uses structural criteria within the humus form profile, retaining the style of Bernier's general classification; however, some of the decision criteria are similar to ones proposed by Klinka et al. (1981). The intent of the classification analysis was to subdivide the *fibrimor* group into recognizable, logical subgroups that could be viewed as having ecological significance in terms of either vegetation or soil/site conditions.

Table 5. Total and terrestrial frequencies (percentage occurrence), range of organic layer thickness, and soil moisture regime for the *mull*, *moder*, *mor*, and *peatymor* orders in forest ecosystems of northwestern Ontario (based upon northwestern Ontario FEC data [Sims et al. 1989]).

		Mull	Moder	Mor	Peatymor
Total frequency (n=2 163)[1]		3.5	6.8	75.3	14.4
Terrestrial frequency (n=1 852)		4.1	7.9	87.9	—
Range of organic layer	**LFH/O**	0–31	1–36	0–45	0–75
thickness (cm)	**Ah**	3–60	1–34	1–35	1–91
Soil moisture regime[2]		0–6	Ø–6	Ø–6	Ø–9

[1]Although the overall northwestern Ontario FEC program consisted of a survey of 2 167 plots, four plots were excluded from these summaries due to missing humus form data.

[2]As defined by the Ontario Institute of Pedology (1985) and Sims et al. (1989).

The revised classification of northwestern Ontario's forest humus forms, as presented here, attempts to recognize humus form classes that commonly occur in the forests of northwestern Ontario. It employs the basic framework, in terms of nomenclature and definitions, of Bernier's (1968) work. A taxonomic reference convention, similar to that employed by Klinka et al. (1981) for the British Columbia classification, is adopted, and the classification is organized into humus form orders, groups, and subgroups (*see* Table 3).

This should be considered as a provisional classification; revisions may be warranted based upon future field studies or following experience gained in using the current classification. It may be desirable at some point to modify the classification so that it can be extended to other geographic areas or expanded to include other ecosystem conditions (e.g., wetlands). As well, it may be appropriate to recognize additional humus form conditions at the subgroup level, in particular, subdivisions of the *moder* and *mull* orders.

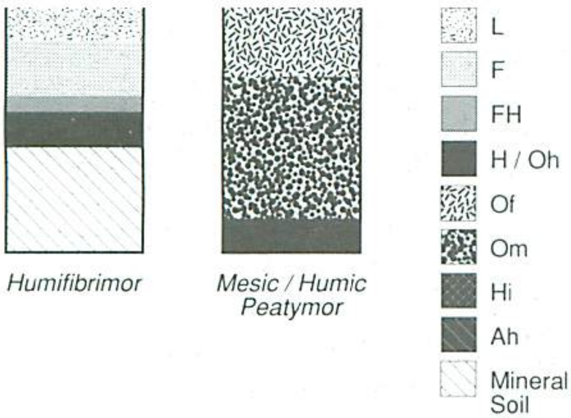
3.5. Introduction to the Northwestern Ontario Forest Humus Form Classification

The northwestern Ontario forest humus form classification is presented in Figure 9 as a pair of hierarchical dendrogram-style keys, in which simple yes/no answers are requested at a series of decision points. The northwestern Ontario classification of forest humus form orders and groups (the upper key) is essentially Bernier's (1968) forest humus form classification, modified to reflect the reduced number of humus form groups that occur in northwestern Ontario forest ecosystems. Since the vast majority of forest humus form occurrences in northwestern Ontario are *fibrimors*, an attempt has been made to further divide this group into subgroups that represent a range of ecological circumstances (the lower key). These subgroups are strictly defined according to the relative thickness of the organic horizons, and bear no resemblance to Bernier's (1968) suggested *fibrimor* subgroups based on the botanical origin of the F horizon.

In order to classify northwestern Ontario forest humus forms in the field, the practitioner would need to expose the organic profile and, on occasion, excavate 10 or 20 cm of the top mineral horizon. The approach described in Section 2 should be followed. Diagnostic criteria at the decision points of the keys refer to characteristics of selected horizons in the organic profile and in the upper mineral strata. Assessment of these features can be done in the field without the use of any special equipment.

Each humus form summary page in Section 3.6 graphically displays northwestern Ontario FEC information regarding typical organic profiles, soil moisture/drainage conditions, organic layer thicknesses, and distribution of the humus form among northwestern Ontario FEC V-types:

1. A representative organic profile shows a typical horizon sequence and relative horizon thicknesses for the humus form. Horizon thicknesses and the presence/absence of certain horizons vary from location to location. However, since the northwestern Ontario forest humus form classification uses relative thicknesses to segregate humus form classes, these diagrams closely represent the proportions within the various humus form profiles. A legend for the graphic patterns used to denote the individual horizons is provided below.



2. A cross-tabulation of grouped moisture regime and drainage classes illustrates the generalized, seasonal moisture status of soils associated with the humus form. Frequency occurrence classes are defined, in the legend below, as the percentage of total occurrences for a particular humus form. Soil moisture regime (SMR) and soil drainage class (SDC), derived using standard tables (Ontario Institute of Pedology 1985, Sims et al. 1989), are grouped to create a 4 x 4 gridded framework.

The groupings are as follows:

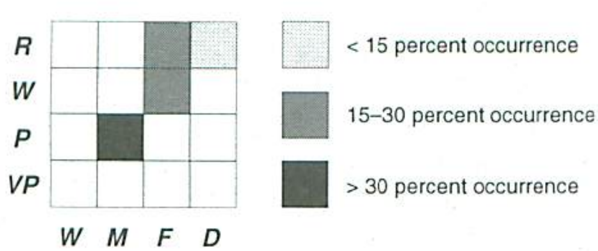
Soil Moisture Regime:

dry (D)	dry, moderately dry	SMR Ø,0
fresh (F)	moderately fresh, fresh, very fresh	SMR 1,2,3
moist (M)	moderately moist, moist, very moist	SMR 4,5,6
wet (W)	moderately wet, wet, very wet	SMR 7,8,9

Soil Drainage Class:

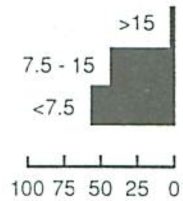
rapid (R)	very rapid, rapid	SDC 1,2
well (W)	well, moderately well	SDC 3,4
poor (P)	imperfect, poor	SDC 5,6
very poor (VP)	very poor	SDC 7

For example:



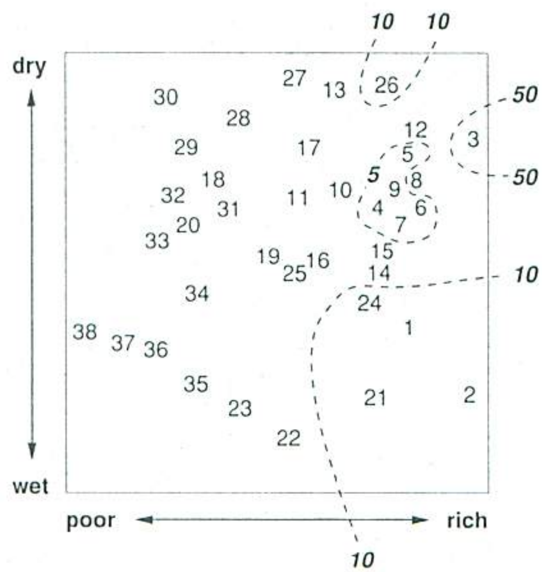
3. The range of thicknesses for the entire organic profile on northwestern Ontario FEC plots where the humus form occurred is summarized in histogram format. Within each diagram, frequency occurrence values (percentage of total occurrences for a given humus form) for three thickness classes are represented by the length of the histogram bars. From bottom to top, the thickness classes are: <7.5 cm, 7.5–15 cm, and >15 cm.

For example:



4. Distribution of the humus form among the northwestern Ontario FEC V-types is presented as a frequency occurrence overlay upon the V-types ordination. A brief interpretation of the distribution pattern associated with each humus form is provided in an accompanying caption. These ordination overlays illustrate relationships between the humus forms and both the range of forest vegetation conditions described by the FEC V-types and the moisture–nutrient continua represented by the ordination's principal axes. The dashed isolines delineate portions of the ordination (i.e., groups of northwestern Ontario FEC V-types) where the frequency occurrence of a given humus form falls within a specified range. The numeric labels on the lines represent the frequency thresholds.

For example:



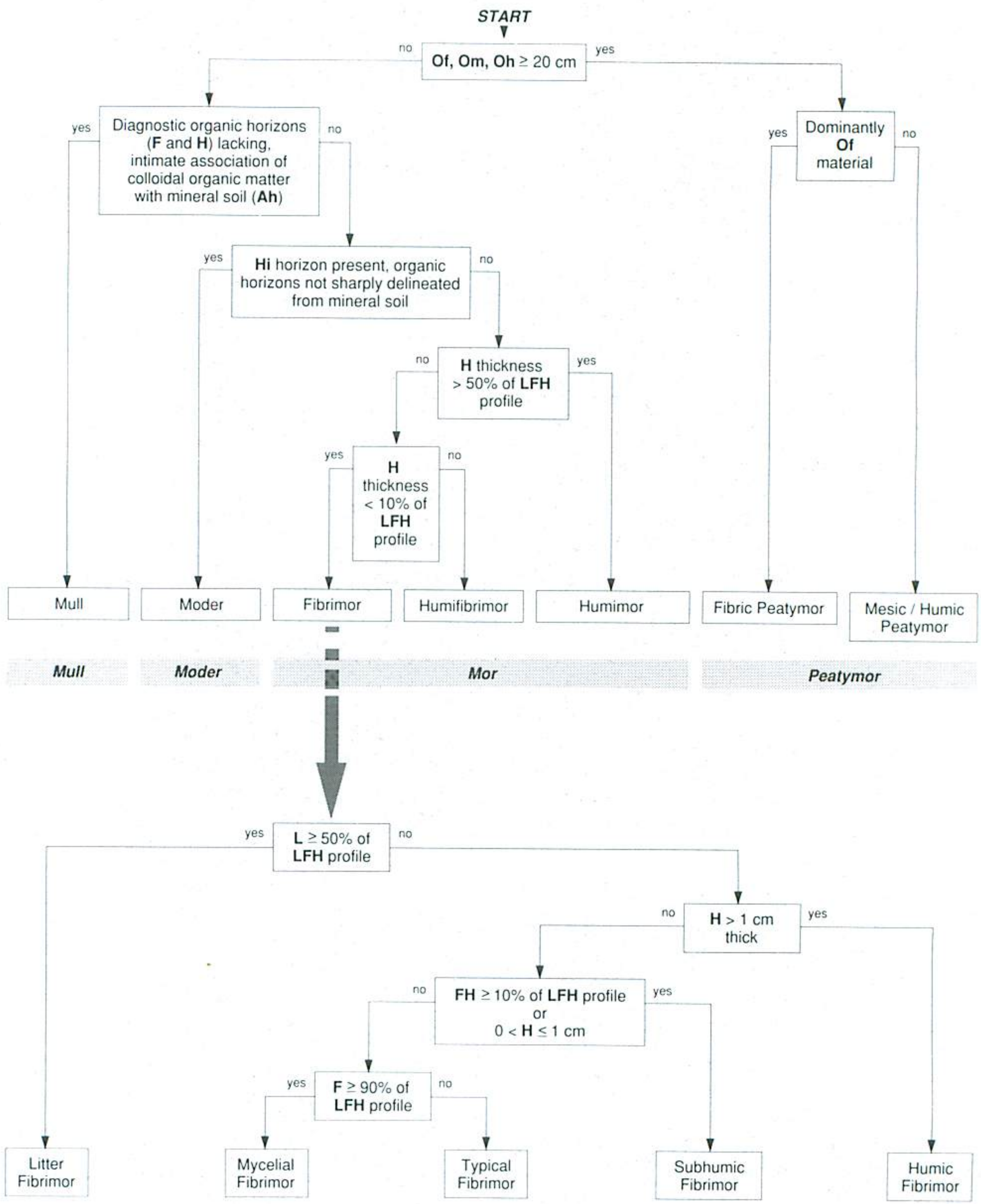
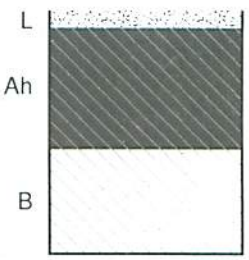


Figure 9. Field key to forest humus forms in northwestern Ontario.

3.6.1. Mull

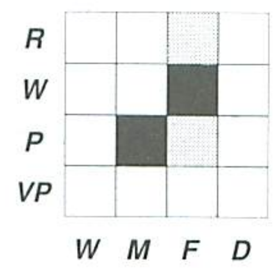


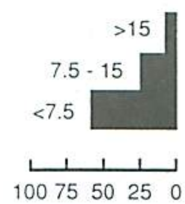
General Description

In *mull* humus forms, organic material is extensively and intimately incorporated into the mineral soil by the action of burrowing soil invertebrates, especially earthworms. Relative to other boreal humus forms, decomposition of forest litter occurs rapidly in *mulls*. A thick **Ah** horizon is characteristic; **F** and **H** horizons are absent.

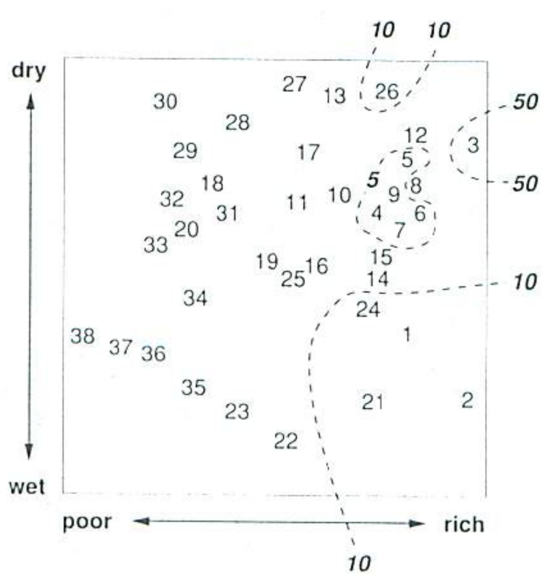
FEC Summary

Mulls are neither common nor widespread throughout the Boreal Forest Region of northwestern Ontario. They are most common in the southern portions of the region where climatic conditions favor higher rates of biological soil activity (i.e., decomposition processes and soil fauna activity). In the northwestern Ontario FEC data, *mulls* occurred most frequently in the Rainy River/Lake of the Woods portion of the Great Lakes–St. Lawrence Forest Region. *Mulls* formed most commonly in fresh to moist, well to poorly drained, fine-textured soils; this humus form was well represented in S-types **S6**, **S8**, **S10**, and **SS8**. *Mulls* were generally associated with graminoid-rich and/or shrub-rich and/or hardwood-dominated V-types (**V1–V7**, **V9**, **V21**, **V24**, and **V26**; Treatment Units **A**, **B**, **C**, and **D**); broadleaf litter constituted the predominant forest floor material on soils in which *mulls* developed. Due to rapid incorporation of humified material into the mineral soil during *mull* development, total organic layer thickness was typically limited to the thickness of the litter (**L**) layer.





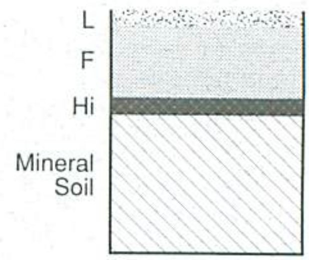
Compared to other forest humus forms, the frequency of mull *occurrences was relatively low in the northwestern Ontario FEC data set.* Mulls *were primarily observed in V-types located toward the rich end of the horizontal ordination gradient. Highest percentage occurrences were found in **V1, V2, V3, V21**, and **V24** (>10 percent), followed by **V26** (10 percent), and **V4, V5, V6, V7**, and **V9** (5 percent).*



Moder 3.6.2.

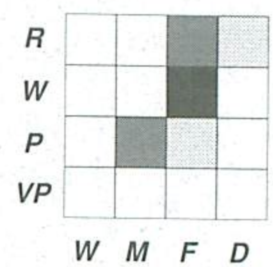
General Description

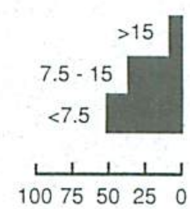
Moders are humus forms with physical, biological, and chemical characteristics that are intermediate between those of *mulls* and *mors*. The degree of incorporation of organic material into mineral soil is slight. This allows the development of a moderately thick **F** horizon, as in *mors*. As in *mulls*, soil fauna play an important decomposition role in *moders*, giving rise to a characteristic **Hi** horizon.

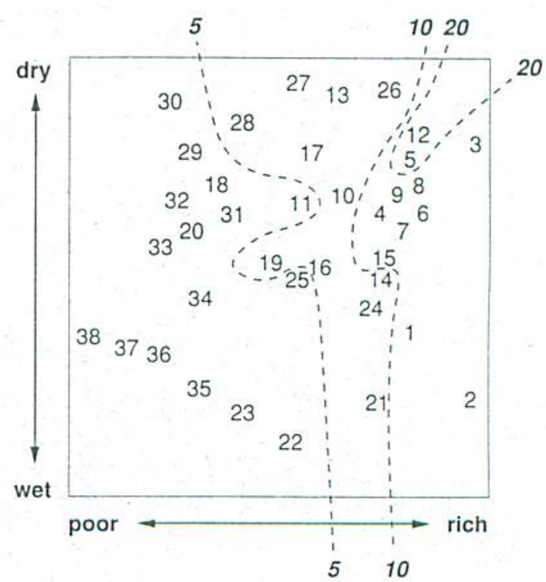


FEC Summary

Like *mulls*, *moders* occur most frequently in the southern portions of northwestern Ontario, where rates of biological soil activity are highest. In the northwestern Ontario FEC data, they were especially common in the Quetico/ Rainy River region. *Moders* typically developed in fresh, well-drained, fine-textured soils; they were well represented in fine loamy and clayey S-types (**S6**, **S10**, and **SS8**), as well as **S3** (fresh, coarse loamy soils). *Moder* formation was predominantly associated with shrub-rich, hardwood-dominated mixedwoods (**V1**, **V2**, **V5**, **V6**, **V7**, **V9**, and **V12**; Treatment Units **A** and **B**). Forest floor cover on soils supporting *moder* development was composed primarily of broadleaf and conifer litter. The average thickness of *moder* profiles described in the northwestern Ontario FEC data set was greater than that of *mulls* and less than that of *mors*.



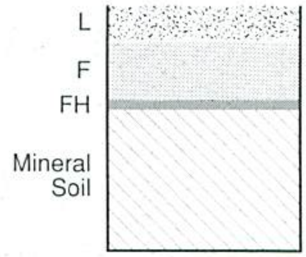




Occurrence of moders *trended toward the right of the FEC ordination, i.e., toward the rich end of the horizontal gradient. The 5 percent frequency level coincided with the division of the ordination between V-types in which forest floor cover is dominated by moss or lichen (left side) and V-types in which broadleaf and conifer litter comprise the main component of forest floor cover (right side).*

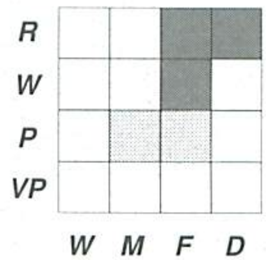
General Description

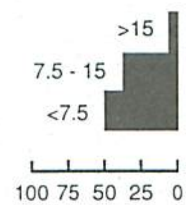
Fibrimors are *mor* humus forms in which the **H** horizon comprises less than 10 percent of the organic profile. The degree of humification in *fibrimors* is minimal; an **H** horizon is often lacking and **F** is the dominant organic horizon.

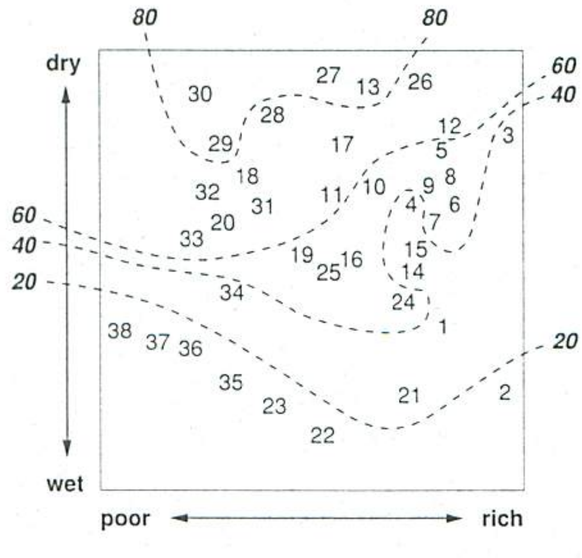


FEC Summary

Fibrimors are, by far, the most widespread and prevalent humus forms in northwestern Ontario. They represent the characteristic humus condition of upland forests in the boreal region. Although *fibrimors* were found, in the northwestern Ontario FEC data, to be common on all S-types (except **S11**, **S12F**, **S12S**, and **SS9**), they were typical of upland, dry to fresh, well to rapidly drained, coarse-textured soils. *Fibrimor* profiles tended, on average, to be thinner than profiles of the other *mor* humus groups. *Fibrimors* were commonly associated with all upland vegetation types and treatment units, occurring infrequently under forest conditions that develop on wet, low-lying sites (**V1**, **V2**, **V22**, **V23**, and **V34–V38**; Treatment Units **A**, **J**, and **K**). Forest floor materials supporting the development of *fibrimors* tended to comprise a mixture of feathermosses with broadleaf and conifer litter.





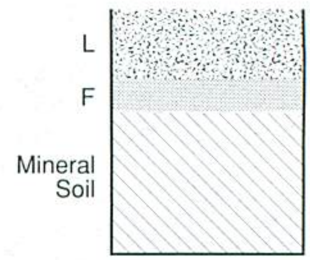


The frequencies of fibrimor *occurrence showed a clear trend along the moisture gradient of the FEC ordination. Low percentage occurrences were observed at the bottom of the ordination, in wet V-types that are characterized by* peatymor *humus forms. High frequencies were evident at the dry, top end of the ordination.*

Litter Fibrimor

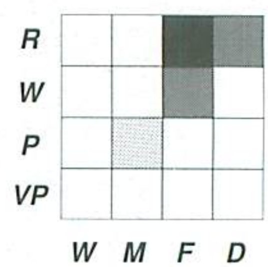
General Description

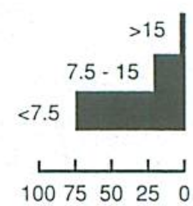
In the northwestern Ontario humus form classification, *litter fibrimors* are *fibrimors* that consist mainly of an accumulation of undecomposed litter. Specifically, the **L** horizon comprises one-half, or more, of the organic profile. **H** and **FH** horizons are very thin or lacking; the balance of the organic profile comprises an **F** layer.

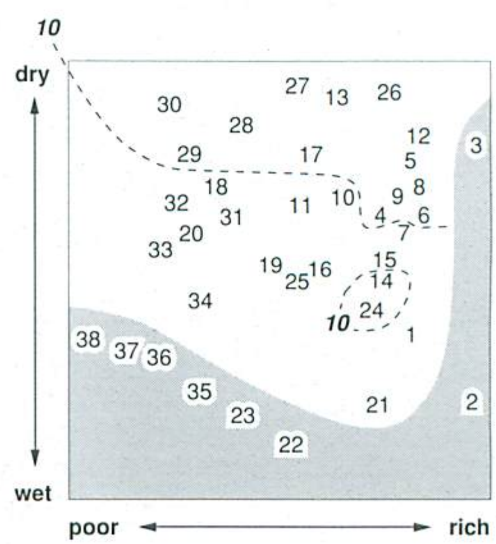


FEC Summary

In the northwestern Ontario FEC data, *litter fibrimors* occurred on dry to fresh, well to very rapidly drained soils. They were most common on the dry to fresh, sandy S-types (**S1**, **S2**, and **SS5**), but also occurred frequently on very shallow S-types (**SS1**, **SS2**, and **SS4**). *Litter fibrimors* were most commonly associated with upland red pine (**V13**, **V27**), white pine (**V12**, **V26**), and jack pine (**V17**, **V28**, **V29**, and **V30**) stands (Treatment Units **F**, **G**, **H**, and **I**), where conditions favor relatively high rates of litterfall and slow rates of decomposition. The average thickness of *litter fibrimors* was less than that of other *fibrimors*. Feathermoss and/or lichen ground cover, mixed with conifer and broadleaf litter, contributed the bulk of forest floor materials in which *litter fibrimors* developed.





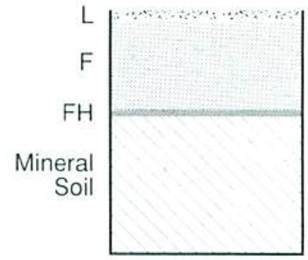


Litter fibrimors *were encountered infrequently in the FEC data. Their highest frequencies of occurrence were found in V-types that are located at the dry/fresh, top end of the ordination (V4, V12, V17, and V26–V30) as well as in V14 and V24 in the fresh/moist sector.*

3.6.5. Mycelial Fibrimor

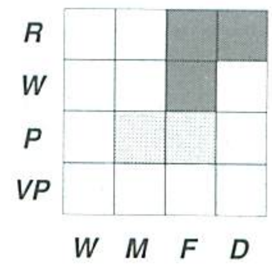
General Description

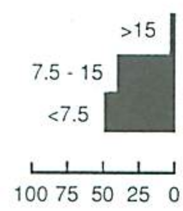
In the northwestern Ontario humus form classification, *mycelial fibrimors* are *fibrimors* in which the **F** horizon constitutes 90 percent, or more, of the organic profile. These humus forms lack a well defined **H** horizon, although a thin, discontinuous **FH** layer may be present at the mineral soil interface. In general, they can be distinguished from *typical fibrimors* by a thinner **L** layer, which is usually composed predominantly of feathermosses.



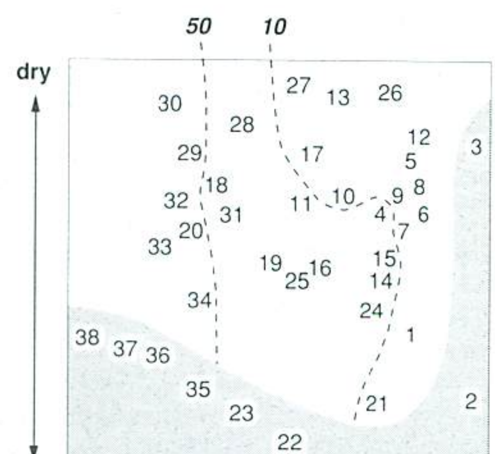
FEC Summary

In the northwestern Ontario FEC data, *mycelial fibrimors* were prevalent in feathermoss-rich, black spruce and jack pine dominated V-types (**V20**, **V29**, **V30**, and **V32–V34**; Treatment Units **E**, **F**, and **I**). They characteristically occurred on dry to fresh, well to rapidly drained, upland mineral soils (**S1–S6**, and **SS2–SS8**). Within this range of soil conditions, *mycelial fibrimors* were more commonly associated with dry moisture regimes (compared to *typical fibrimors* that occurred more frequently on fresh soils). Forest floor cover was predominantly feathermoss, with minor components of broadleaf and conifer litter.





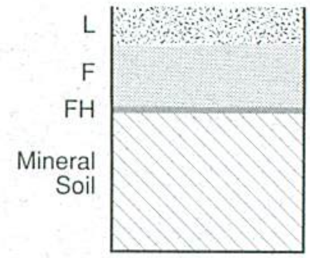
The percentage occurrences of mycelial fibrimors *showed a distinct trend, from left to right, along the richness gradient of the FEC ordination. High frequencies of occurrence (≥50 percent) were observed at the left-hand edge of the ordination, where the proportion of forest floor cover by lichen and feathermoss is high (V20, V30, and V32–V34). As the predominance of feathermoss ground cover diminishes toward the right-hand side of the ordination, percentage occurrences of* mycelial fibrimors *decreased.*



Typical Fibrimor

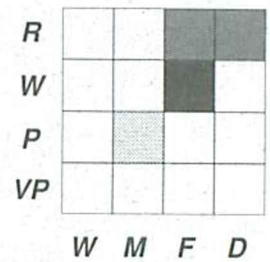
General Description

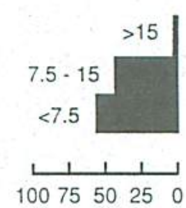
In the northwestern Ontario humus form classification, *fibrimors* that do not meet any of the specific criteria for the four defined *fibrimor* subgroups are termed *typical fibrimors*. These humus forms lack a well defined **H** horizon but may contain a thin, usually discontinuous, **FH** layer at the mineral soil surface. They can generally be distinguished from *mycelial fibrimors* by a thicker **L** layer, which typically contains a large component of broadleaf litter.



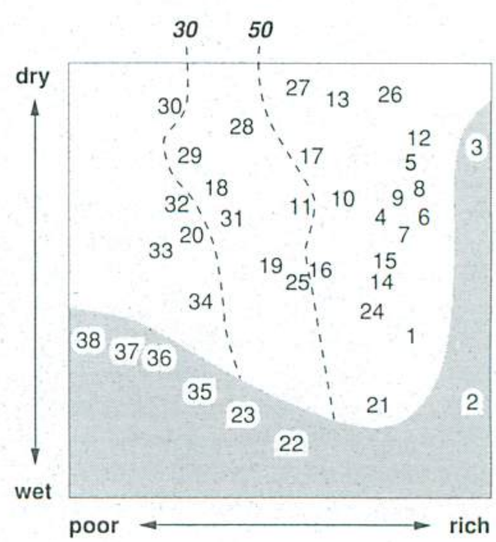
FEC Summary

In the northwestern Ontario FEC data, *typical fibrimors* occurred in a wide range of forest conditions. Although they developed on all S-types (except **S11**, **S12F**, **S12S**, and **SS9**), they developed primarily on dry to fresh, upland mineral soils. Relative to *mycelial fibrimors*, which were more common on dry soils, *typical fibrimors* were mainly associated with fresh moisture regimes. *Typical fibrimors* were most common under upland forest stands with high rates of both conifer (**V21**, **V24**, **V26**, and **V27**) and broadleaf (**V1**, **V4–V10**, and **V12–V17**) litterfall (Treatment Units **B**, **C**, **D**, and **H**). Forest floor cover was predominantly broadleaf and conifer litter.





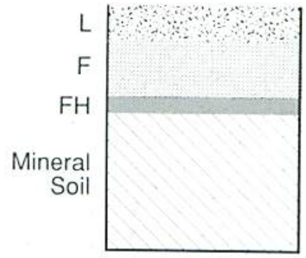
Percentage occurrences of typical fibrimors *showed a pattern of distribution on the FEC ordination that is the reverse of that displayed for* mycelial fibrimors. *High frequencies of occurrence (≥50 percent) were observed at the right-hand side of the ordination, where the forest floor cover is dominated by broadleaf litter. Low percentage occurrences of* typical fibrimors *were observed toward the left-hand, poor end of the richness gradient, where feathermoss and lichen cover predominates in the forest floor.*



3.6.7. Subhumic Fibrimor

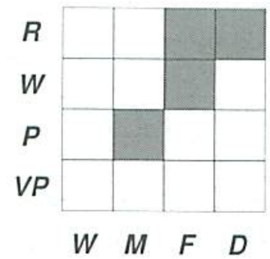
General Description

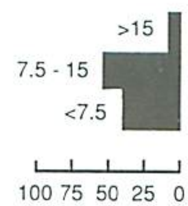
In the northwestern Ontario humus form classification, *subhumic fibrimors* are *fibrimors* where either an **FH** horizon comprises at least 10 percent of the organic profile or an **H** horizon occurs that is ≤1 cm thick. As is the case for *fibrimors* in general, most of the total organic profile consists of **L** and **F** layers.



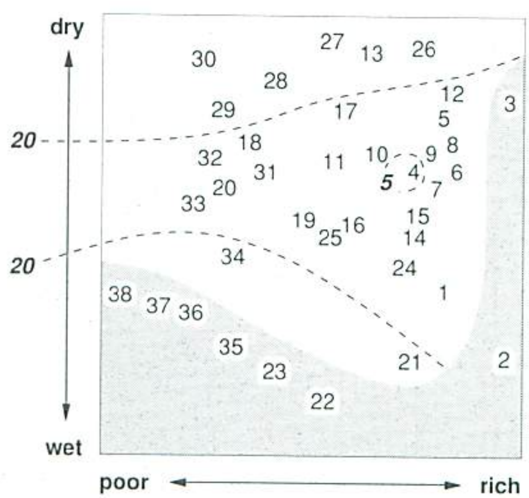
FEC Summary

In the northwestern Ontario FEC data, *subhumic fibrimors* occurred on all S-types except **S11**, **S12S**, **S12F**, and **SS9** (wet, organic soils). They were especially common on coarse-textured soils, ranging from dry to moist (i.e., **S1**, **S2**, **S7**, and **S8**). This humus form was commonly associated with a broad range of upland forest conditions. It was notably uncommon, however, in dry birch (**V4**; Treatment Unit **C**) and pine (**V13**, **V26–V30**; Treatment Units **F**, **G**, **H**, and **I**) forest conditions. *Subhumic fibrimors* were, on average, slightly thicker than all other *fibrimors*, except for *humic fibrimors*. Forest floor materials comprised a mixture of feathermoss cover with broadleaf and conifer litter.





Subhumic fibrimors *occurred most frequently in V-types that occupy the central band of the vertical moisture gradient on the FEC ordination (≥20 percent occurrence). A notable exception within this band was V4, the white birch-dominated stand condition, which had <5 percent occurrence of this humus form.* Subhumic fibrimors *were observed less frequently (<20 percent occurrence) in V-types found at the dry (top) and moist (bottom) ends of the moisture gradient.*



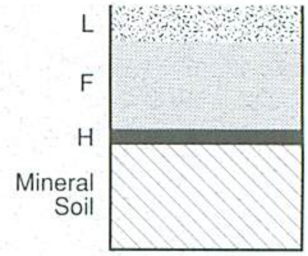
Humic Fibrimor 3.6.8.

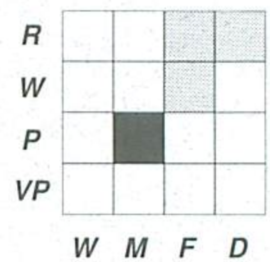
General Description

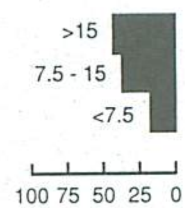
In the northwestern Ontario humus form classification, *fibrimors* in which the thickness of the **H** horizon exceeds 1 cm are termed *humic fibrimors*. Since the **H** horizon can only constitute a maximum of 10 percent of the total organic profile, *humic fibrimors* occur only in thicker *fibrimors*, i.e., those >10 cm in total depth.

FEC Summary

Humic fibrimors are rarely encountered in northwestern Ontario; most *mors* that are >10 cm thick are *humifibrimors* and *humimors*, humus form groups in which the degree of humification is greater than in *fibrimors*. *Humic fibrimors* develop under circumstances where decomposition rates are slow and the rate of accumulation of organic material is relatively high. The majority of *humic fibrimors* sampled during the FEC program occurred in association with black spruce/feathermoss V-types (**V20**, **V31–V35**; mainly Treatment Unit **E**). Soil conditions consisted primarily of moist, imperfectly, or poorly drained S-types (**S7-S10**, and **SS8**). Forest floor materials in which *humic fibrimors* had developed were predominantly feathermoss, with small proportions of conifer and broadleaf litter.



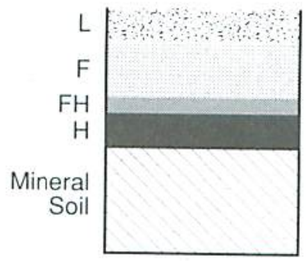




Note: *An insufficient number (n = 18) of* humic fibrimors *was sampled to display their distribution on the FEC ordination diagram.*

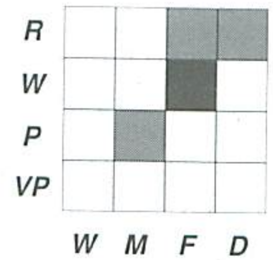
General Description

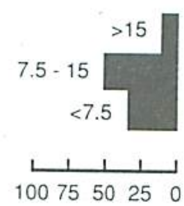
Humifibrimors are *mor* humus forms in which the **H** horizon comprises between 10 and 50 percent of the organic profile. The degree of humification in *humifibrimors* is intermediate between that found in *fibrimors* and *humimors*. **F** is the dominant organic horizon.

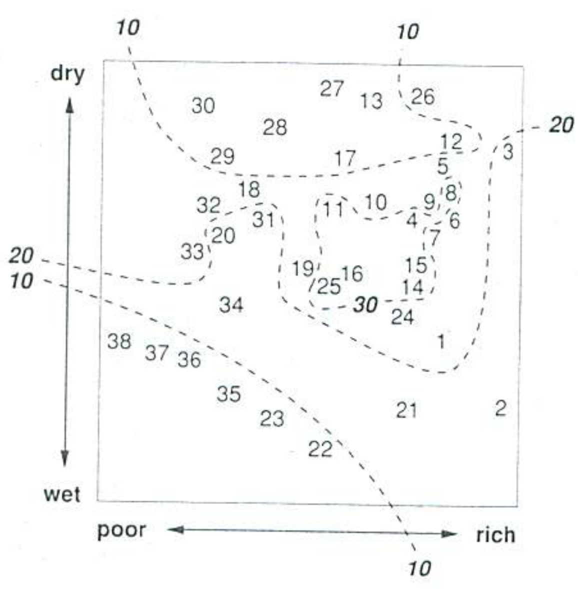


FEC Summary

In the northwestern Ontario FEC data, *humifibrimors* were found to be humus forms of upland forests, typically occurring on fresh to moist, well to rapidly drained, coarse-textured soils. Moisture regimes of soils associated with *humifibrimors* tended to be moister than those associated with *fibrimors* and drier than those associated with *humimors*. *Humifibrimors* were especially common in deep, moist, sandy soils (**S7**), although they were generally well distributed across all fresh/moist S-types. *Humifibrimors* were most commonly associated with mesic, trembling aspen or white birch dominated V-types (**V4–V10**; Treatment Units **B** and **C**) and with V-types containing a predominance of balsam fir and white spruce (**V14, V15, V16, V24,** and **V25**; Treatment Unit **D**). These humus forms were poorly represented in wetlands or on soils supporting stands of any species of pine (**V12, V13, V17,** and **V27–V30**; Treatment Units **G, H,** and **I**). The most common black spruce V-types under which *humifibrimors* tended to be found were **V19** and **V32**. Broadleaf litter and feathermoss comprised the majority of forest floor materials in which *humifibrimors* developed. The average thickness of *humifibrimor* profiles was intermediate between the average thicknesses of *fibrimor* and *humimor* profiles.



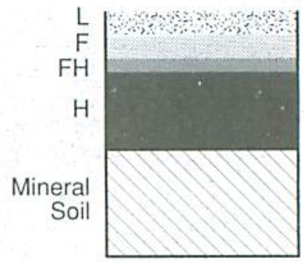




Humifibrimors *had their highest frequencies of occurrence in V-types that are situated in the fresh and fresh/moist sectors of the FEC ordination (V1, V4–V11, V14–V16, V18, V19, V24–V26, V32, and V33). V-types at the dry, moist, and rich extremes of the ordination gradients tended to have low frequencies of* humifibrimor *occurrence.*

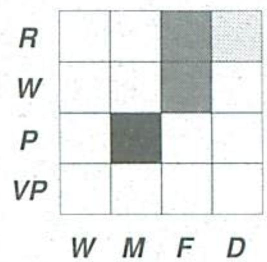
General Description

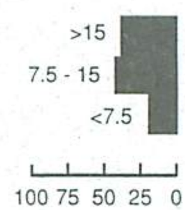
In the northwestern Ontario humus form classification, *humimors* are defined as *mor* humus forms in which the **H** horizon comprises over one-half of the total organic profile. This definition includes the *fibrihumimor* group, as recognized by Bernier (1968). *Humimors* are the most highly humified *mors*; **H** is the dominant organic horizon.



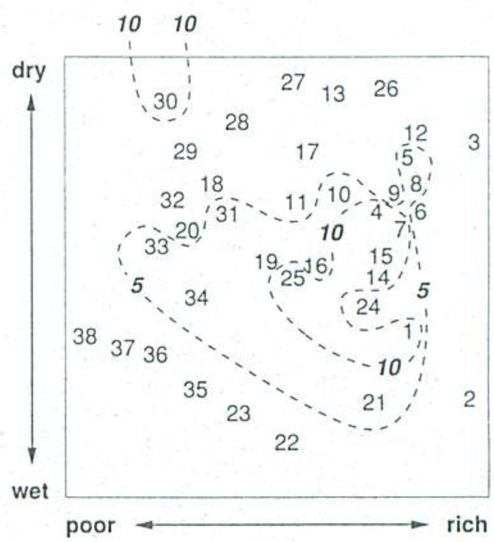
FEC Summary

In the northwestern Ontario FEC data, *humimors* typically occurred on fresh to moist, lower and toe slope positions. Although a wide range of drainage and soil texture conditions was observed, imperfectly and poorly drained, fine loamy and clayey soils were common. This humus form was most commonly encountered in the moist S-types (**S7–S10**, and **SS8**). *Humimors* were commonly associated with stands of balsam poplar (**V1**; Treatment Unit **A**), white birch (**V4**; Treatment Unit **C**) and balsam fir–white spruce (**V14**, **V15**, and **V25**; Treatment Unit **D**). With an average thickness of 15.7 cm, *humimor* profiles tended to be thicker than profiles of any other humus form, except for *peatymors*. Broadleaf and conifer litter, in combination with feathermoss, constituted the main forest floor materials in which *humimors* tended to develop.



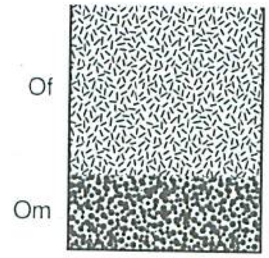


In the northwestern Ontario FEC database, humimors *occurred less frequently than any other forest humus form order or group, except for* mulls *(a total of 107 observations). They were most commonly observed in V-types located in the fresh/moist and, to a lesser extent, fresh sectors of the FEC ordination (V1, V4, V5, V7, V8, V10, V14–V16, V19, V21, V25, V31, V33, and V34). Humus forms identified as* humimors *in V30 may be better described by the* humic fibrimor *subgroup.*



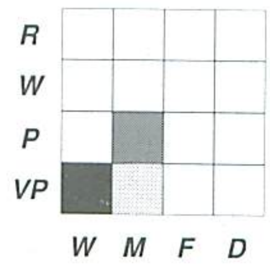
General Description

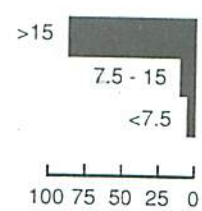
Peatymors develop under conditions of prolonged saturation due to perpetually elevated water tables. *Fibric peatymors* are composed mainly of relatively undecomposed, fibric materials (i.e., **Of** is the dominant organic layer).

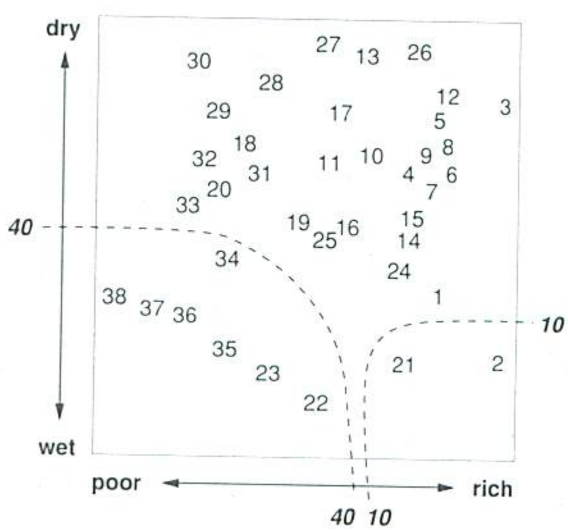


FEC Summary

Peatymors, in general, occur on wet, poorly to very poorly drained soils, typified by S-types **S11**, **S12F**, **S12S**, and **SS9**. In northwestern Ontario, especially on terrain underlain by the Precambrian Shield, these sites tend to be located in depressional landscape positions. In the northwestern Ontario FEC data, *fibric peatymors* were found mainly under cedar (**V22**), tamarack (**V23**), and black spruce (**V34–V38**) wetland forest conditions (Treatment Units **J** and **K**); they were observed less frequently on richer, minerotrophic soils supporting black ash (**V2**; Treatment Unit **A**) and cedar (**V21**; Treatment Unit **D**) stands. *Sphagnum* mosses constituted the majority of forest floor materials within which *fibric peatymors* developed; broadleaf, conifer, and graminoid litter, together with small amounts of woody matter, comprised a minor proportion. *Fibric peatymors* are the predominant humus forms in wetland ecosystems throughout northwestern Ontario. They often develop into organic soils, with thicknesses exceeding 40 cm. Most peat deposits in northwestern Ontario consist primarily of fibric peat (**Of**), sometimes reaching depths of over 3 m.





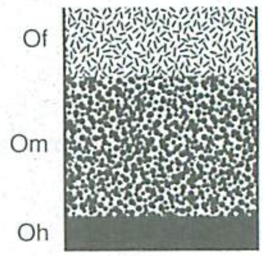


The occurrence of fibric peatymors *was concentrated in the lower left-hand corner of the FEC ordination (V22, V23, and V34–V38). With the exception of some elements of V22, these V-types develop on wet, relatively nutrient-poor, typically organic soils. The majority of* fibric peatymors *in northwestern Ontario, as suggested by their association with this group of V-types, develop into organic soils, comprising over 40 cm of* ***Of*** *material.*

Mesic/Humic Peatymor

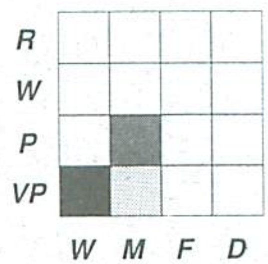
General Description

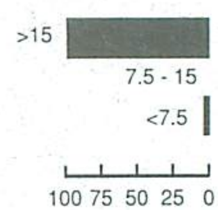
Peatymors develop under conditions of prolonged saturation due to perpetually elevated water tables. *Mesic/humic peatymors* are those in which the **Om** and/or **Oh** layers are dominant. The degree of organic matter decomposition ranges from moderate to high.



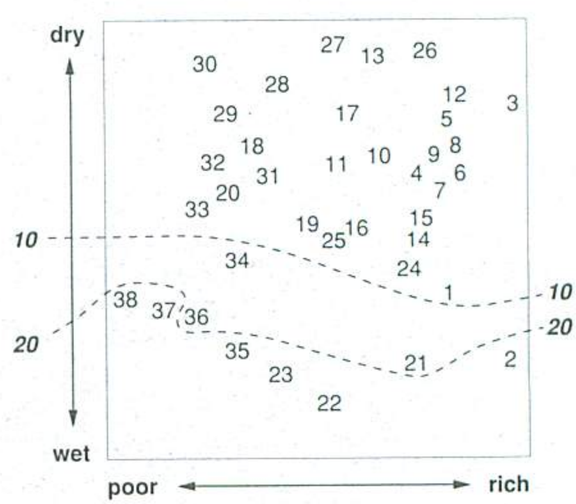
FEC Summary

In northwestern Ontario, *mesic/humic peatymors* are found in wetland environments where higher levels of oxygen exist due to the lateral movement of groundwater. This contributes to higher rates of decomposition than are found in organic soils consisting primarily of *fibric peatymors*. *Mesic/humic peatymors* are encountered less frequently than are *fibric peatymors*. In the northwestern Ontario FEC data, they were most commonly observed in deep, organic **S12F** soils, although they also occurred in other wet, very poorly drained S-types (**S11**, **S12S**, and **SS9**). Cedar swamps (**V22**; Treatment Unit **J**) and black ash stands (**V2**; Treatment Unit **A**) contained the highest proportion of *mesic/humic peatymors*. A small proportion of stands in the tamarack (**V23**; Treatment Unit **J**) and lowland black spruce V-types (**V34–V38**; Treatment Units **J** and **K**) were also associated with *mesic/humic peatymors*. Although *Sphagnum* mosses represented the main forest floor materials from which *mesic/humic peatymors* developed, broadleaf, conifer, and graminoid litter all occurred in higher proportions than for *fibric peatymors*. These humus forms often develop into organic soils with thicknesses exceeding 40 cm.





In general, mesic/humic peatymors *occur less frequently in the wetland ecosystems of northwestern Ontario than do* fibric peatymors. *The pattern of distribution on the FEC ordination was somewhat different than for* fibric peatymors: mesic/humic peatymors *occurred with a low percentage occurrence in V-types that span the richness gradient across the wet end of the ordination.* Mesic/humic peatymors *were more common than* fibric peatymors *in nutrient-rich, minerotrophic black ash stands (V2).*



4. HUMUS FORMS AND FOREST ENVIRONMENT CONDITIONS IN NORTHWESTERN ONTARIO

As evidenced by the summaries provided in Section 3.6, there is a variety of environmental variables that can be generally correlated with the occurrence of forest humus forms at the order, group, and subgroup levels. This section summarizes and describes some of these general relationships, based upon data summaries and analyses of the northwestern Ontario FEC data.

Results presented in this section should be considered preliminary. Future investigations, directed toward gaining a better understanding and appreciation of these, and other, environmental relationships, are needed. In order to clarify the nature and magnitude of some of these relationships, future research would be valuable in the areas of soil chemistry, soil microfaunal ecology, and nutrient relations and nutrient cycling characteristics of different humus form conditions in northwestern Ontario.

4.1. Humus Forms in Relation to FEC Vegetation Types

General relationships between the forest humus forms and FEC vegetation types of northwestern Ontario are highlighted by the ordination overlays in Section 3.6 and in Figures 10 and 11. In addition, Figures 12 to 15 show examples of humus forms in association with certain characteristics of the forest sites within which they commonly develop.

For the four humus form orders, clear differences can be seen among the occurrences of *mulls, moders, mors*, and *peatymors* in relation to FEC V-types. *Mulls* and *moders*

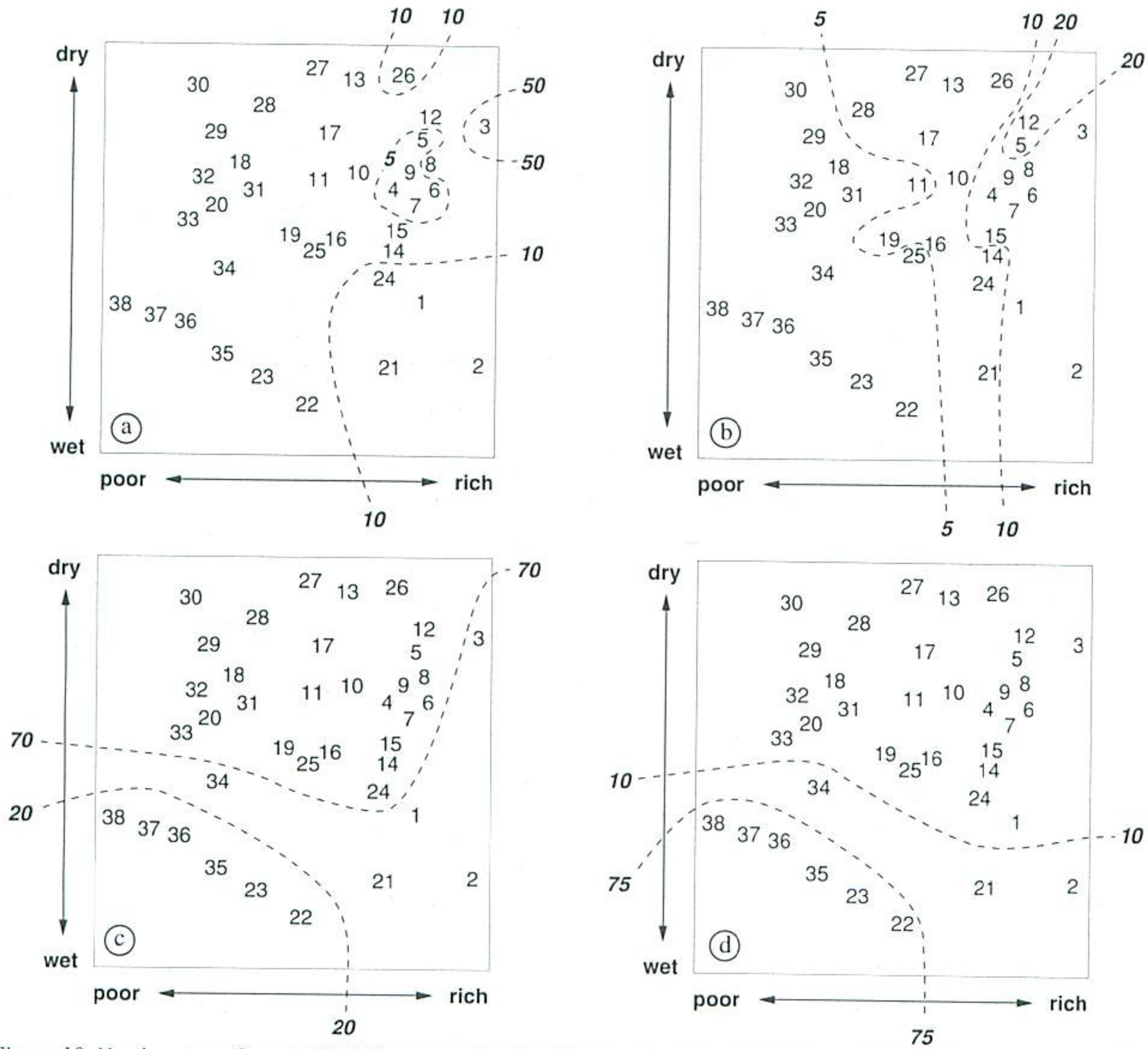


Figure 10. Northwestern Ontario FEC V-types ordination (Sims et al. 1989) overlain with percentage occurrence isolines for (a) mull, *(b)* moder, *(c)* mor, *and (d)* peatymor *humus form orders.*

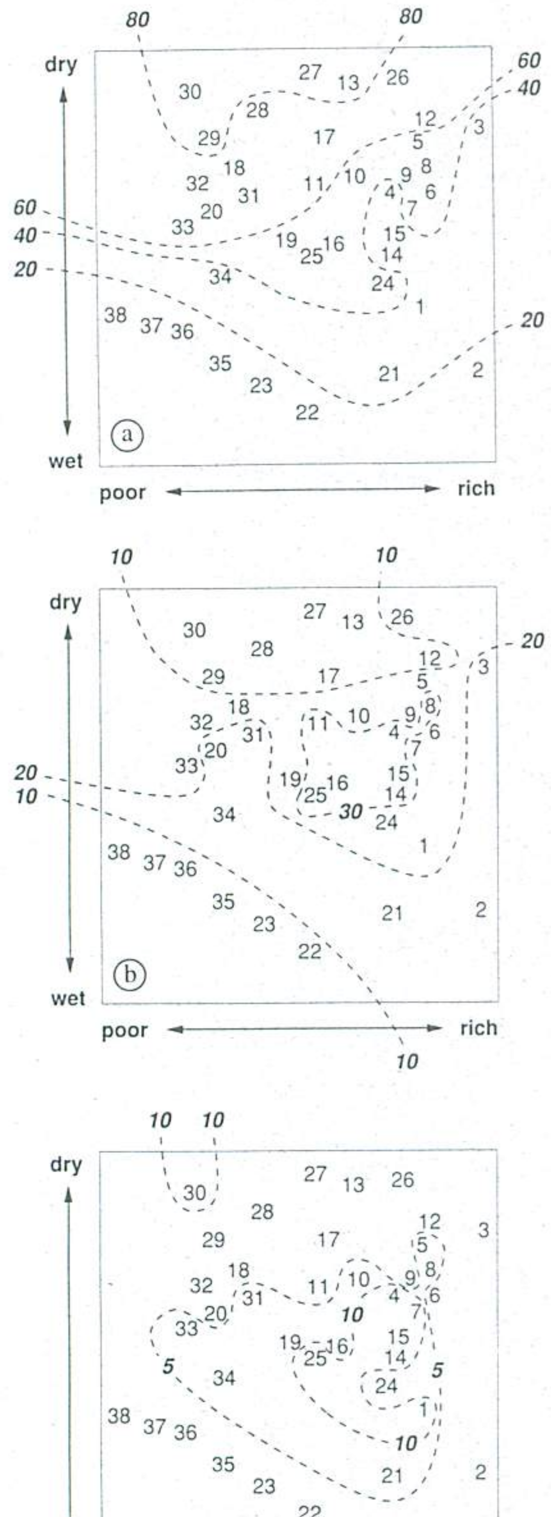


Figure 11. Northwestern Ontario FEC V-types ordination (Sims et al. 1989) overlain with percentage occurrence isolines for (a) fibrimor, *(b)* humifibrimor, *and (c)* humimor *humus form groups.*

were related to the right-hand extreme of the richness gradient of the V-types ordination, in association with the richest V-types (Figs. 10a,b). Highest frequencies of occurrence for *mulls*, in descending order, were with vegetation types **V3**, **V24**, **V26**, **V2**, and **V1**. Associated most frequently with *moders* were vegetation types **V12**, **V5**, **V6**, **V9**, and **V1**. *Mors* were extremely widespread, with high percentage occurrences of this humus form order being associated with many of the V-types. Moreover, virtually every V-type supported some proportion of *mor* humus forms (Fig. 10c). *Peatymors* (including both *fibric peatymor* and *mesic/humic peatymor* subgroups) were associated almost exclusively with the wet end of the moisture gradient (Fig. 10d). High percentage occurrences (≥75 percent) of *peatymors* were associated with vegetation types **V22**, **V38**, **V35**, **V37**, **V36**, **V35**, and **V23**; other occurrences at the >10 percent level were associated with vegetation types **V34**, **V2**, and **V21**.

Within the *mor* order, the *fibrimor*, *humifibrimor*, and *humimor* groups exhibited some general affinities for different groups of V-types (Fig. 11). *Fibrimors* occurred in a large proportion of the northwestern Ontario FEC plots, but nonetheless showed a general trend in percentage occurrence relative to the moisture gradient of the V-types ordination (Fig. 11a). In general, higher frequencies of *fibrimors* were associated with the fresh to dry end of this gradient (*see* Fig. 8b); highest percentage occurrences (≥80 percent) of *fibrimors* were associated with vegetation types **V29**, **V27**, **V13**, and **V30** (Fig. 11a). There did not appear to be a significant trend for *fibrimors* along the richness axis of the ordination, but this relationship needs further quantification based upon analyses of soil chemistry data. *Humifibrimors* were not as frequently encountered as *fibrimors* but were also associated with a wide range of V-types (Fig. 11b). The highest percentage occurrences (≥30 percent) of *humifibrimors* were observed within a pocket of V-types (**V16**, **V4**, **V15**, **V14**, **V8**, and **V11**) in the fresh range of the moisture gradient and toward the richer end of the richness gradient of the FEC V-types ordination. Relative to *fibrimors* and *humifibrimors*, *humimors* were infrequently encountered in the northwestern Ontario FEC data set (Fig. 11c). However, like the *humifibrimors*, *humimors* were more common in some fresh and moderately rich V-types, in particular (i.e., with ≥10 percent occurrence) vegetation types **V15**, **V7**, **V1**, **V14**, **V4**, and **V25**.

Within the *fibrimor* subgroups, additional trends were apparent (*see* individual ordinations in Sections 3.6). *Litter fibrimors* were infrequently encountered, but were primarily associated with drier conditions (**V4**, **V12**, **V17**, and **V26–V30**) as well as with **V14** and **V24**. *Mycelial fibrimors* were common. They exhibited a trend of increasing occurrence from right to left on the richness axis of the ordination; greatest frequencies of *mycelial fibrimors* occurred

Figure 12. Trembling aspen–white spruce stand supporting a mull *forest humus form: (a) general stand conditions, (b)* in situ *forest humus form, and (c) extracted divot showing humus form profile.*

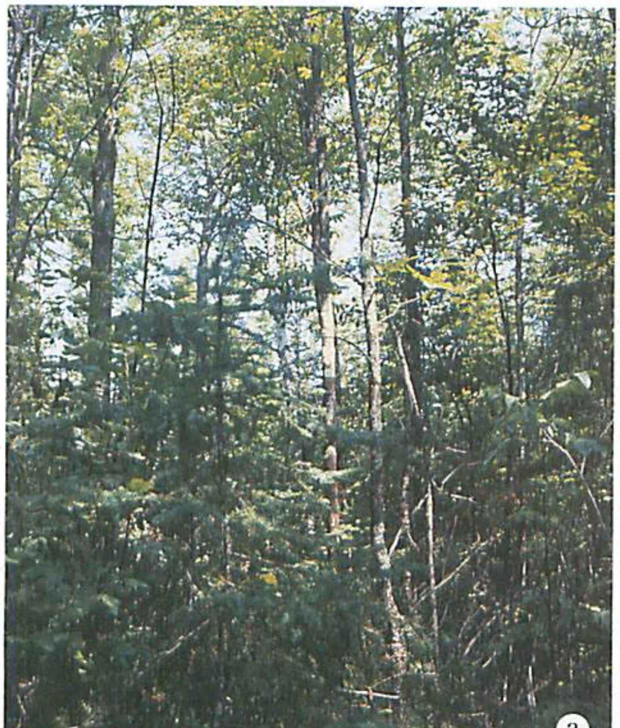


Figure 13. Black ash stand supporting a moder *forest humus form: (a) general stand conditions, (b)* in situ *forest humus form, and (c) extracted divot showing humus form profile.*

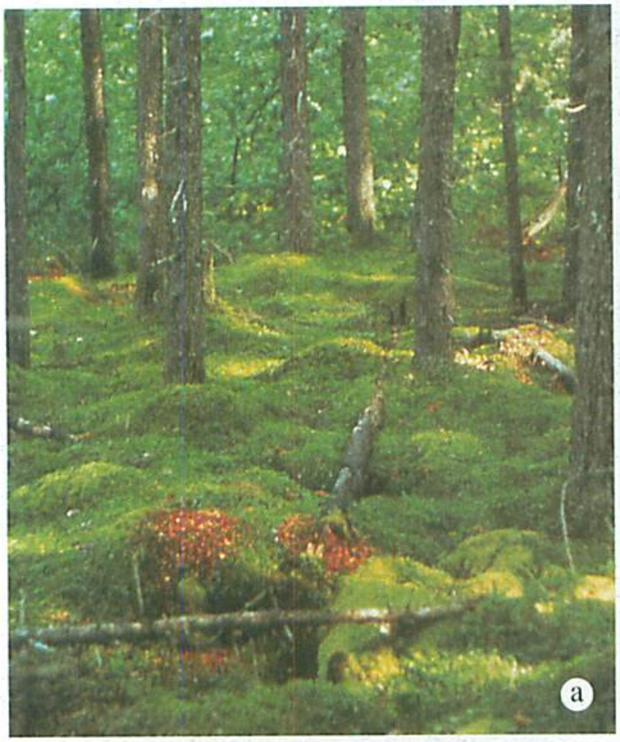


Figure 14. Jack pine–black spruce stand supporting a mor *forest humus form: (a) general stand conditions, (b)* in situ *forest humus form, and (c) extracted divot showing humus form profile.*

Figure 15. Black spruce stand supporting a peatymor *forest humus form: (a) general stand conditions, (b)* in situ *forest humus form, and (c) extracted divot showing humus form profile.*

in association with V-types at the poor end of the richness gradient, where feathermoss and lichen cover was generally high (e.g., **V20**, **V29–V34**). *Typical fibrimors* were also frequently encountered. They showed a reverse trend to the *mycelial fibrimors*, occurring with greatest frequency in association with V-types at the rich end of the richness axis of the ordination (e.g, **V4–V10**, **V12–V17**). *Subhumic fibrimors* occurred in association with a large number of V-types, but were most common in a band corresponding to the center of the ordination's moisture axis, representing intermediate moisture conditions (fresh, moist). *Humic fibrimors* were rarely encountered in the FEC data set, so their distribution in relation to FEC V-types is not clear; they would be expected to be more abundant in association with moist, poor to intermediate V-types such as **V20**, or **V31–V34**.

4.2. Humus Forms in Relation to Soil and Site Features

There are general relationships among the four humus form orders and FEC soil types. As expected, *peatymors* were most frequently observed in association with wet organic soils, in particular **S11**, **S12F**, **S12S**, and **SS9**. *Mulls* were most frequently encountered on **S4–S6, S8, S10**, and **SS8** soil types. *Moders* were most commonly associated with soil types **S1–S10**, **SS2**, **SS4**, and **SS8**. *Mors* occurred widely on all S-types, but those most frequently associated were **S1**, **S2**, **S7**, **S8**, **SS5**, and **SS6**. Group and subgroup levels of the northwestern Ontario forest humus form classification were associated more specifically with individual S-types, as summarized in Section 3.6.

Based upon examinations of the field data from FEC plots, it was possible to describe some generalized relationships between soil/site features and humus form conditions in northwestern Ontario. Figure 16 provides a comparison of several soil variables (soil moisture regime, soil drainage class, seepage class, surface and **C** horizon texture, coarse fragment content, and organic layer thickness class) in relation to the six main forest humus form groups and orders found in northwestern Ontario. Based upon the analysis of trends in tabular summaries of the FEC data, these relationships are useful in making general interpretations. For example, while *peatymors* are associated with wet or moist soil moisture regime classes (*see* Section 3.5), the remainder of the groups are associated with predominantly dry, fresh, or moist SMRs. Only *peatymors* and *humimors* tend to develop thick (>15 cm) organic layers. *Moders, mulls, humimors,* and *peatymors* are commonly associated with poor to very poor drainage classes and clayey surface and **C** horizon textures (Fig. 16).

Comparing the same soil/site characteristics for the five *fibrimor* subgroups (Fig. 17) resulted in elucidation of some additional trends. Wet SMRs were not associated with the *fibrimor* group, but *humic fibrimors* and, to a lesser extent, *subhumic fibrimors* were commonly associated with moist soils. In addition, although soil drainage class was very rapid to imperfect for *fibrimors* in general (Fig. 16), *humic fibrimors* tended to occur under poor drainage conditions (Fig. 17). All of the *fibrimors* were associated with sandy or coarse loamy soils (Fig. 16). However, *mycelial fibrimors* and *typical fibrimors* were also found over clayey surface or **C** horizon soil textures (Fig. 17); *typical fibrimors, subhumic fibrimors,* and *humic fibrimors* were also common on silty or fine loamy soils. Relative to the other *fibrimors*, only *humic fibrimors* occasionally developed thick (>15 cm) organic layers; *litter fibrimors* were most common in association with thin (<7.5 cm) organic layers (Fig. 17).

Although other parameters such as soil calcareousness, forest floor cover, **A** horizon thickness, and northwestern Ontario FEC S-type were also investigated, they showed no significant relationships with northwestern Ontario humus forms, and were not included in Figures 16 and 17.

Several geographic trends in the distribution of some forest humus forms were observed during the analysis of the northwestern Ontario FEC data. Upland, terrestrial humus forms (especially *mors*) were typically less decomposed in the western half of the study area. *Fibrimors* were, by far, the prevailing humus form group on dry/fresh mineral soils (**S1–S6**, **SS1–SS7**) throughout northwestern Ontario. *Humifibrimors* were more common in the eastern half of the study area (especially **S5–S10**, **SS5–SS8**), while *humimors* were rare everywhere. Similarly, for semiterrestrial *peatymors*, the proportion of more highly decomposed *mesic* and *humic peatymors* was noted to be higher in the eastern half of the study area (especially **S12F** and **S12S**). In large part, these trends may be attributed to reduced biological activity in the boreal portions of the western half of the study area, due to a generally drier and warmer climate during the growing season.

According to the northwestern Ontario FEC system, treatment units (TUs) were defined as aggregates of vegetation and soil types that could be used to "organize forest management practices on a management unit in an ecologically relevant manner" (Racey et al. 1989, Sims et al. 1989). Treatment units are less precise in describing soil/site and vegetational characteristics than is the original northwestern Ontario FEC system, but they are appropriate to apply in cases where broader level management decisions are being considered for a given site. Eleven TUs and some subdivisions, referred to as TU phases (determined on the basis of moisture status), were defined and described by Sims et al. (1989) (*see* Fig. 7).

Treatment units and treatment unit phases may also be related to humus form groups. Figure 18 summarizes FEC

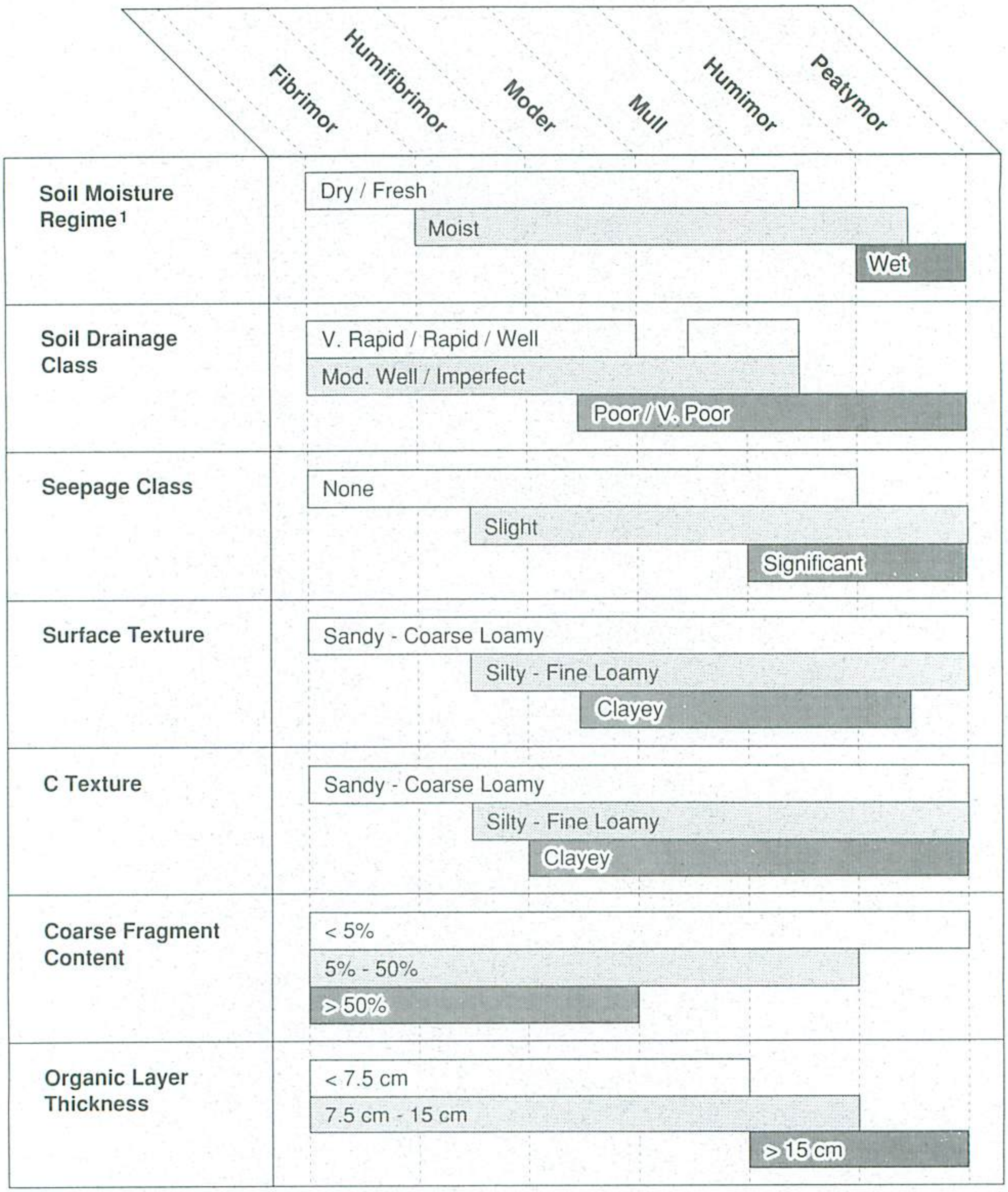


Figure 16. Comparison of characteristics of six main forest humus form orders and groups found in northwestern Ontario: fibrimor, humifibrimor, moder, mull, humimor, and peatymor.

[1] As defined by the Ontario Institute of Pedology (1985) and Sims et al. (1989).

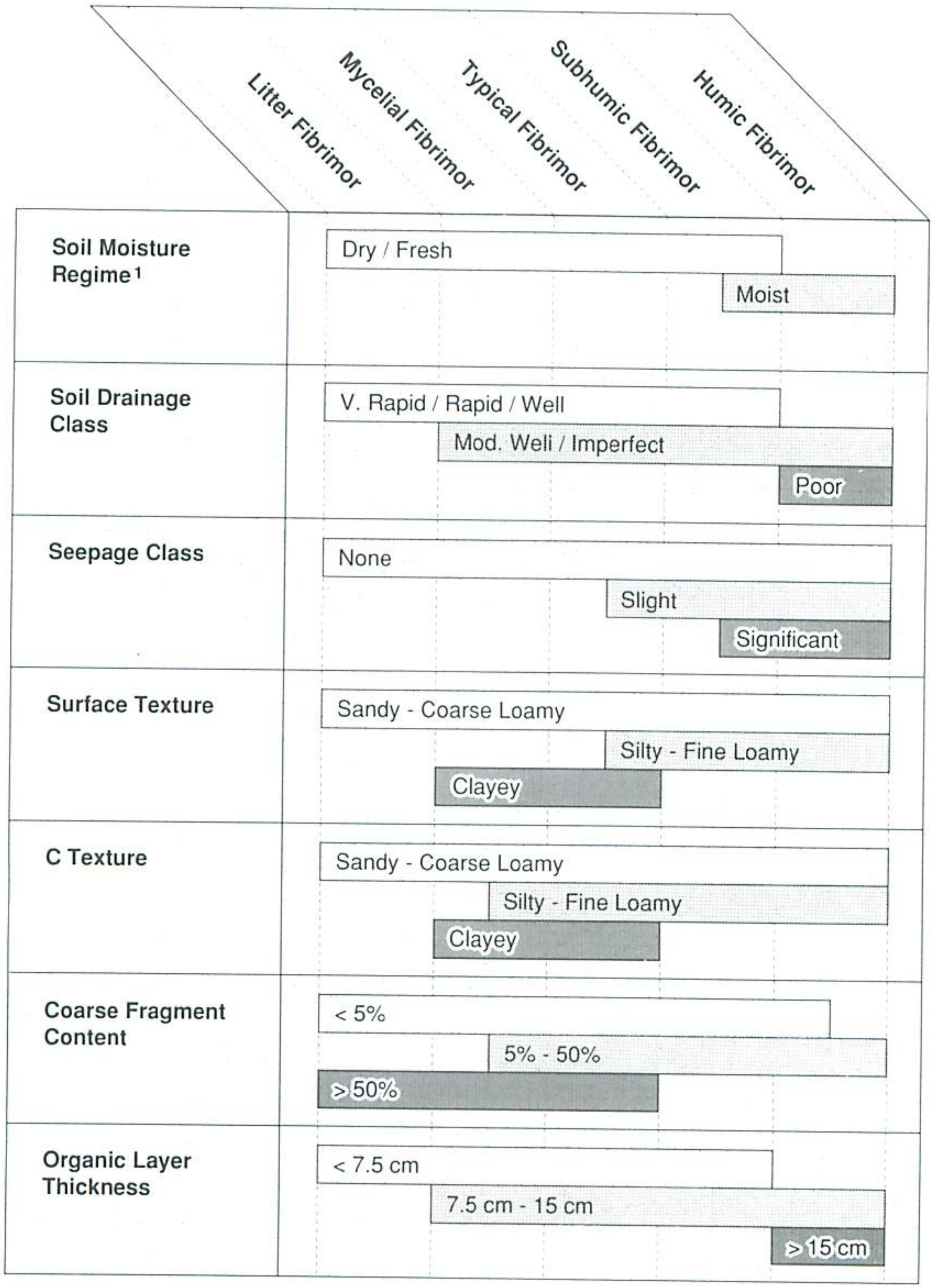


Figure 17. Comparison of characteristics of five fibrimor *subgroups recognized in the northwestern Ontario forest humus form classification:* litter fibrimor, mycelial fibrimor, typical fibrimor, subhumic fibrimor, and humic fibrimor.

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[1] As defined by the Ontario Institute of Pedology (1985) and Sims et al. (1989).

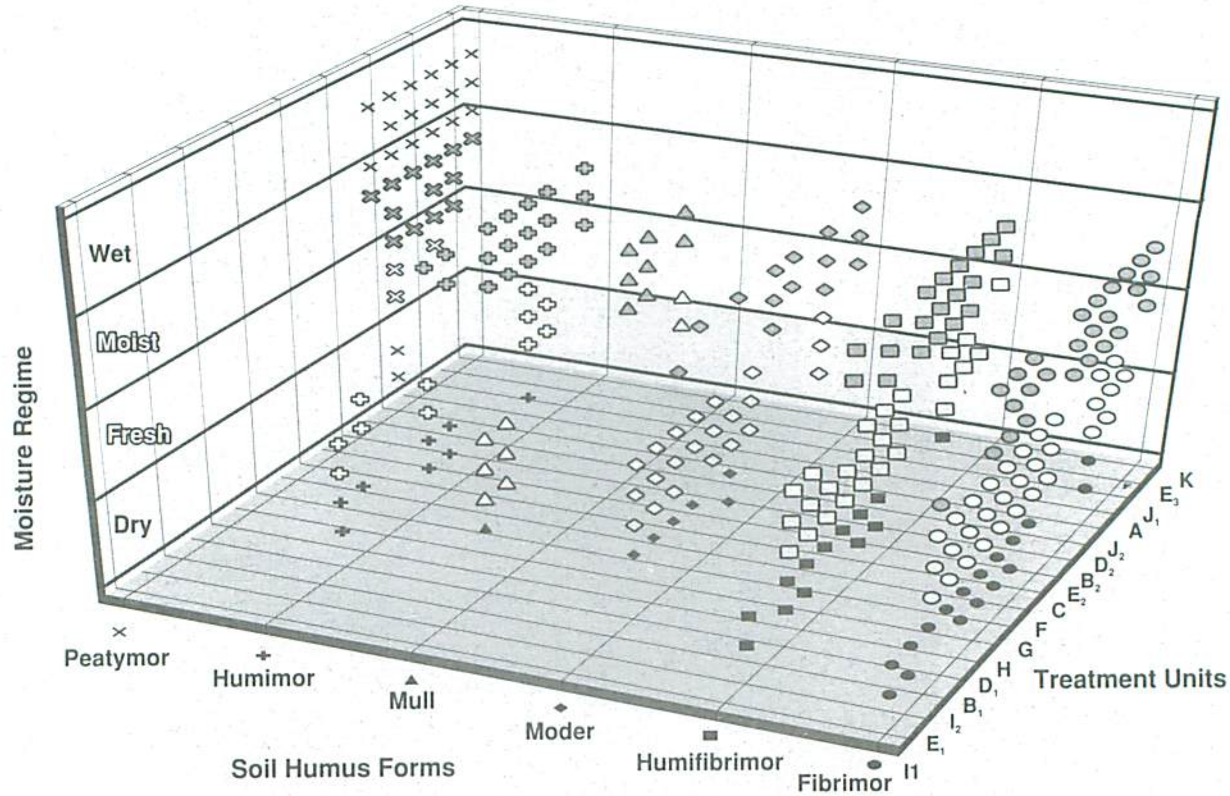

Figure 18. Three-dimensional graph relating soil moisture regime (vertical axis) to FEC treatment units (right-hand margin) and humus form orders and groups (across front). Arrays of points are coded (from left to right) as follows: peatymor (×), humimor (+), mull (▲), moder (◆), humifibrimor (■), *and* fibrimor (●). *The graph is based upon 2 167 plots, although multiple plots that fall at the same x,y,z coordinates are not indicated on the graph. The 11-class soil moisture regime* (see *Ontario Institute of Pedology 1985) is abbreviated on the vertical axis into four groupings (dry, fresh, moist, and wet), as defined in Section 3.5.*

field data as arrays of points in three dimensions: 1) treatment units, ranked artificially according to an approximate soil moisture gradient; 2) soil moisture regime, from dry to wet, according to the 11-class SMR scale (*see* Section 3.5); and 3) the six main humus form orders and groups. From Figure 18, it is evident that *peatymors* and, to a large extent, *humimors* are associated with the moist to wet SMRs, as well as with the "wetter end" TUs (i.e., **J2**, **A**, **J1**, **E3**, **K**). *Fibrimors* and *humifibrimors* are associated with virtually all of the TUs and all SMR classes for mineral soils (dry to moist). *Mulls* and *moders* are also found in the dry to fresh SMR range, but occur in association with a restricted selection of TUs .

4.3. Humus Forms in Relation to Regional Climate

To investigate the relationships between climate and humus forms, a unique approach was employed.[4,5] A meso-scale climate model was used to generate estimates of long-term mean monthly climatic variables at the locations of each of the 2 167 northwestern Ontario FEC plots. The climate model consisted of mathematical interpolation surfaces fitted to the provincial network of 475 long-term weather stations. The interpolation procedure used thin plate smoothing splines as developed by Hutchinson (1988) (*see also* Nix 1986, Mackey 1993). Independent variables for the interpolated surfaces were the longitude (x), latitude (y), and elevation (z) of each weather station.

[4] Mackey, B.G.; McKenney, D.W.; Yin-qian, Y.; McMahon, J.P.; Hutchinson, M.F. Site regions revisited: A climatic analysis of Hills' site regions of Ontario using a parametric method. Can. J. For. Res. (In press)

[5] Sims, R.A.; Mackey, B.G.; Baldwin, K.A. Stand and landscape level applications of a forest ecosystem classification for northwestern Ontario, Canada. Ann. Sci. For. (In press)

Hence, estimates of selected climatic variables could be generated at any locations for which the x,y,z geocodes were known.

Climate surfaces were produced earlier for several variables across Ontario: including, minimum temperature, maximum temperature, total precipitation, potential evaporation, and radiation[6,7] (Mackey et al. 1994). These data were further analyzed to produce a sequence of long-term mean daily minimum and maximum temperatures. The growing season (GS) was then defined as follows: 1) GS starts on the first day after March 31 when the minimum temperature is greater than 5°C; and 2) GS ends on the first day after August 1 when the minimum temperature is less than -2°C. By taking a base temperature of 5°C it was possible to generate, at the location of each northwestern Ontario FEC plot, an estimate of growing degree-days (GDD) for the growing season.

As indicated earlier, the characteristic forest humus form was originally recorded at each northwestern Ontario FEC plot using the terminology and approach of Bernier (1968). Humus forms were subsequently reclassified using the northwestern Ontario forest humus form classification described in this report. Using data from all of the 2 167 FEC plots, the cumulative percentage occurrences of each of the six main humus form orders and groups were plotted against two climatic variables, growing degree-days (Fig. 19) and growing season precipitation (Fig. 20). Figures 19 and 20 each display a set of characteristic response curves that illustrate relative relationships of the six humus form classes along the respective climatic gradients.

Figure 19 shows the relationships of the six humus form orders and groups to growing degree-days. The curves associated with colder conditions include those for *humimors, humifibrimors*, and *peatymors*. The fiftieth percentile for these groups was reached, respectively, at approximately 1 200, 1 250, and 1 300 GDD (Fig. 19). The curve associated with the warmest growing season condition represented *mulls*, where recruitment of plots was not initiated until 1 200 GDD. Fifty percent of the plots containing *mulls* had been added to the curve by about 1 575 GDD. The *fibrimor* and *moder* curves occupied intermediate positions between the curves for *peatymors* and *mulls*. To some extent, these curves overlap; this may reflect the limited number of *moder* sites in the FEC plot network, perhaps resulting in less accuracy for the *moder* curve. The results of the GDD analysis suggest that *humimors* are associated with the coldest site locations in northwestern Ontario, while *mulls*, the most biologically active humus form, occur on the warmest site locations. Other humus forms occur across intermediate GDD conditions, but are generally separable, from colder to warmer, as *humifibrimor, peatymor, fibrimor,* and *moder*. These rankings (Fig. 19) are consistent with the generally expected levels of biological activity, as reflected in the decomposition characteristics of each of these forest humus form orders and groups.

The relationships of the six main humus form orders and groups to total precipitation during the growing season are presented in Figure 20. It is evident that there is little distinction among the humus form classes that can be attributed to growing season precipitation. *Moders,* on the right, are associated with marginally higher precipitation; the fiftieth percentile for this group occurs at about 480 mm, compared to the other curves where the fiftieth percentiles are in the 460 mm to 470 mm range. Differences among the other curves are not apparent, suggesting that growing season precipitation is less influential in humus form genesis and development than is the growing season temperature regime, as expressed by GDDs. Certainly, based upon these preliminary findings, further investigations into the relationships between humus forms and climatic variables are warranted.

4.4. Some Considerations for Applying the Forest Humus Form Classification for Northwestern Ontario

The forest humus form classification for northwestern Ontario was tested in an operational setting during two summers of field data collection at the Rinker Lake Research Area (*cf.* Sims and Mackey 1994), as well as in other areas of northwestern Ontario. In general, the system worked very well under field conditions, and proved to be accurate, repeatable, and robust. As with similar classification systems, once the field key has been used to indicate a given endpoint (humus form order, group, or subgroup), the corresponding factsheet description (Section 3.6) must be checked in order to ensure that no misassignment was made during the keying process.

In applying the classification operationally, there were some inconsistencies with the identification of the boundary between the litter (L) and **living moss** layers. This problem has particular implications when attempting to discriminate between *typical* and *mycelial fibrimors.* In

[6]Mackey, B.G.; McKenney, D.W.; Yin-Qian, Y.; McMahon, J.P.; Hutchinson, M.F. Site regions revisited: A climate analysis of Hills' site regions of Ontario using a parametric method. Can. J. For. Res. (In press)

[7]Sims, R.A.; Mackey, B.G.; Baldwin, K.A. Stand and landscape level applications of a forest ecosystem classification for northwestern Ontario, Canada. Ann. Sci. For. (In press)

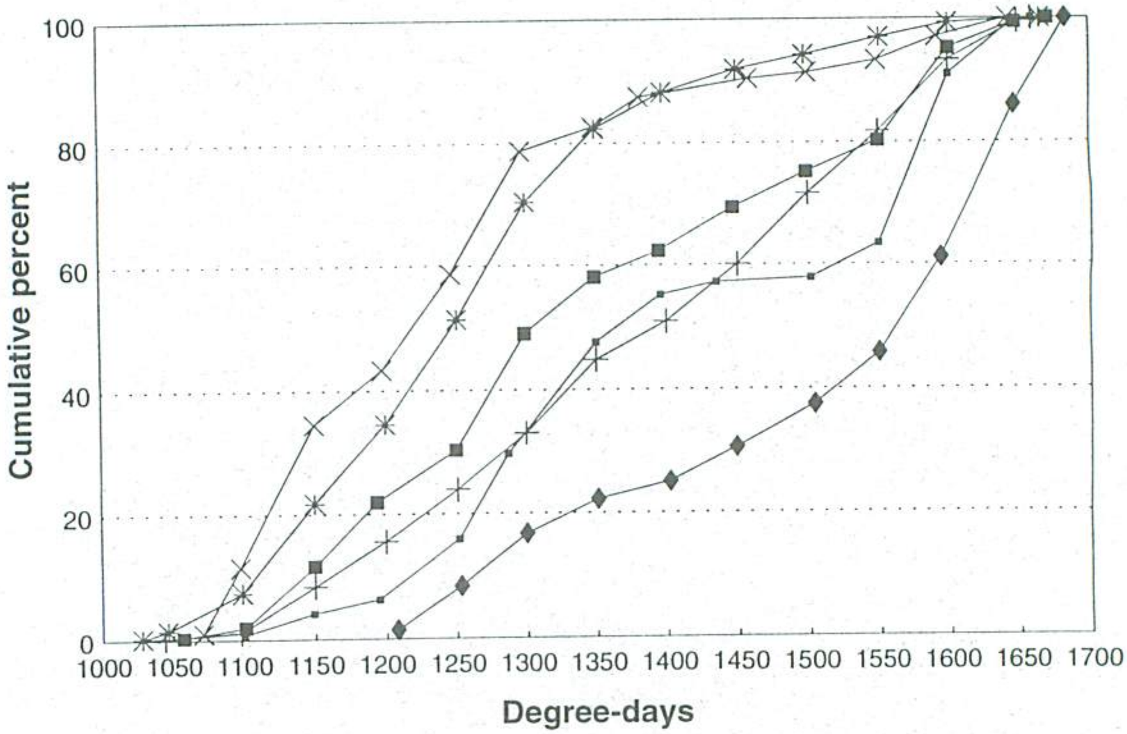

Figure 19. Cumulative percentage occurrences of northwestern Ontario FEC plots supporting six forest humus form orders and groups, according to growing degree-days (^oC). Arrays of points are coded (from left to right) as follows: humimor *(X),* humifibrimor *(※),* peatymor *(■),* fibrimor *(+),* moder *(▪), and* mull *(◆).*

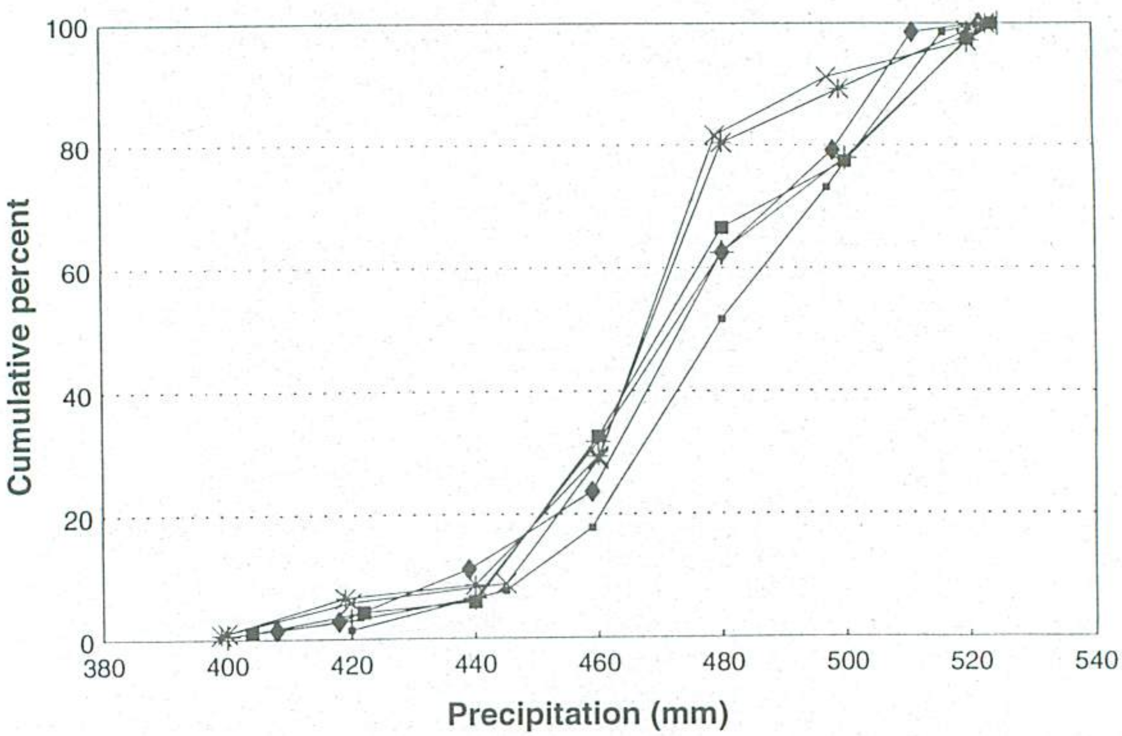

Figure 20. Cumulative percentage occurrences of northwestern Ontario FEC plots supporting six forest humus form orders and groups, according to precipitation during the growing season (mm). Arrays of points are coded as follows: humimor *(X),* humifibrimor *(※),* peatymor *(■),* fibrimor *(+),* moder *(▪), and* mull *(◆).*

addition, some practitioners experienced difficulties recognizing a combined **FH** layer, where it occurred instead of distinct and separable **F** or **H** horizons. In both cases, careful interpretation of the criteria for naming these layers (*see* Section 2.1.1), as well as some field experience with the system, should resolve such problems.

The classification takes only a few minutes to apply in the field, and can be employed without special equipment or tools. It was derived for use within closed forest stands, but experience has indicated that it also can be readily used to describe humus forms in areas where the forest has been disturbed, if there is some residual intact forest floor. While changing microclimatic conditions may lead to some desiccation or compression of the forest floor layers, it may be possible to estimate the "predisturbance humus form" for a period of up to 3 years following disturbance. In general, then, the system could be applied during the snow-free period in mature stands or recently disturbed forest areas.

One portion of the northwestern Ontario forest humus form classification involves the determination of von Post decomposition class. To separate *fibric peatymors* and *mesic/humic peatymors*, it is necessary to determine the dominant decomposition class of the organic profile. This is not an onerous task, but the existing system for determining von Post decomposition classes (Ontario Institute of Pedology 1985) involves a look-up table (*see* Table 2) that requires some degree of familiarity to be used with confidence. To alleviate this difficulty, a hierarchical classification scheme for determination in the field of von Post decomposition classes is presented here (Fig. 21). Preliminary testing has indicated that this decision-tree approach is accurate and quicker to apply than is the conventional version of the von Post system.

5. HUMUS FORMS AND FOREST MANAGEMENT IN NORTHWESTERN ONTARIO

Humus forms are integral components of forest ecosystems in northwestern Ontario, and they must receive due consideration during harvest planning and silvicultural operations. To preserve soil nutrient status; maintain moisture, structure and biological activity in the soil; and control erosion and runoff normally requires minimizing the level of humus form disturbance. However, given the

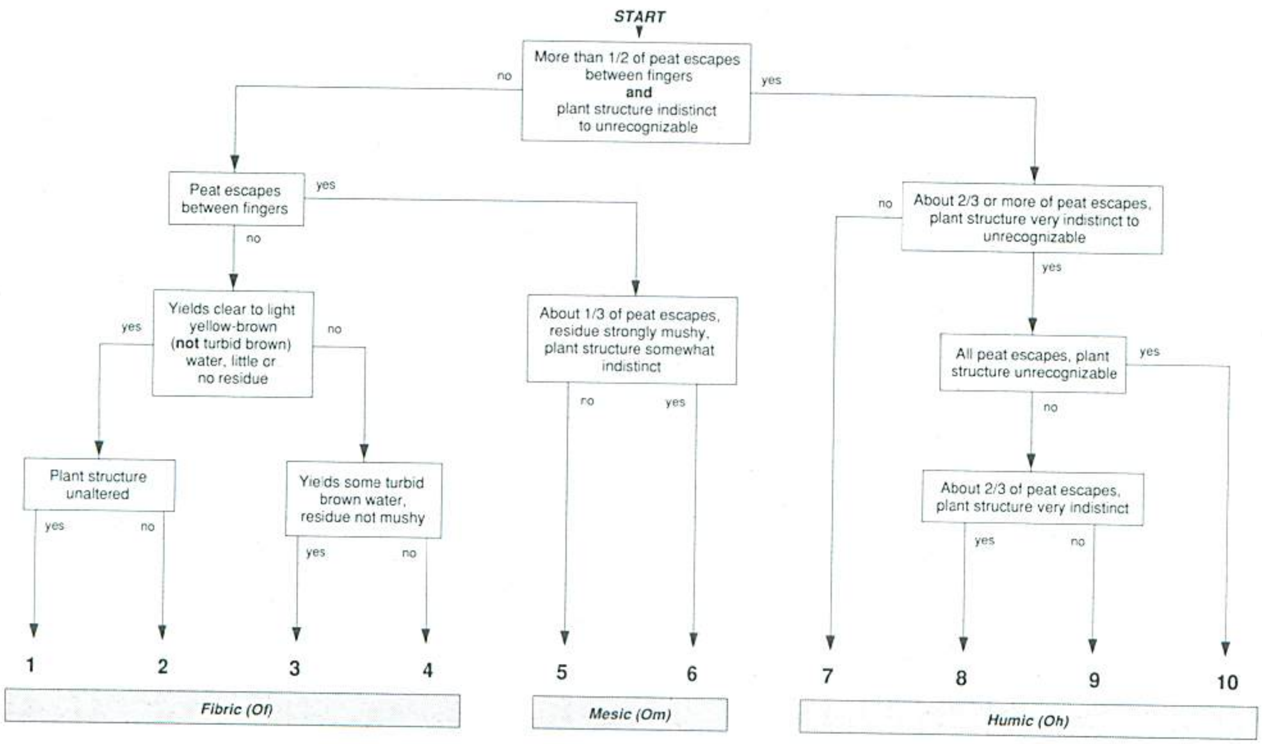

Figure 21. Field estimation of the degree of decomposition of organic soil materials is accomplished using von Post's ten-class scale of decomposition (Ontario Institute of Pedology 1985). The procedure is as follows: first, gently squeeze a small sample (about 100 cc.) of organic material within a closed hand to remove excess water. Then, squeeze the sample a second time and observe: 1) the distinctness of the plant structure in the material after it is squeezed; 2) the color of the solution that is expressed from the sample; 3) the proportion of the original sample that extrudes between the fingers; and 4) the nature of the residual organic materials left on the hand.

range of humus form characteristics summarized in Section 3.6, some humus forms will be inherently more susceptible to mechanical disturbances than will others. Many investigators have recently advocated the need for better consideration of the humus form condition during planning phases of forest management activities (*see* Klima and Grunda 1989, Nakamura 1990, von der Gönna 1992, Jeglum and Kennington 1993).

Some controlled research studies that investigate the on-site effects of mechanical disturbances on forest humus forms are needed. In the interim, Table 6 summarizes some preliminary "proposed best practices" that could be assigned to the six main forest humus form orders and groups. The modal humus form descriptions from Section 3.6 were used to develop: 1) some general guidelines for preferred season of operation, 2) an estimate of the competition potential following harvesting, 3) the most appropriate modes for on-site regeneration of both hardwoods or softwoods, 4) the potential for site degradation due to compaction, rutting, or erosion, and 5) the potential for the site to provide non-woody surface fuel complex (for the planning of prescribed burns).

The preliminary interpretations presented here (Table 6) should be applied with care; they require field validation and revision with time. Certainly, additional or more detailed interpretations need to be developed, including ones that deal specifically with the *fibrimor* subgroups.

There is also a need for considerable future research associated with forest humus form classes. Biological and chemical relationships associated with various forest humus forms are poorly studied in the boreal forest, and in particular, very little data exists for northwestern Ontario. Dynamic processes associated with forest humus forms, including patterns of response to vegetational successional patterns over time, or following forest fires, are not well understood. Spatial distribution of forest humus forms in relation to toposequences or patterns of soil moisture regime have not been well described within boreal environments. Effects following harvesting (e.g, the identification or description of postharvest humus form "sequences") or other forest management activities in relation to various forest humus forms are likewise poorly documented.

Table 6. Some proposed best practices associated with defined forest humus form orders and groups in northwestern Ontario.

	Mull	Moder	Mor			Peatymor
			Fibrimor	Humifibrimor	Humimor	
Operability season	W	A	A	A	A	W
Competition	H to M	H to M	L	M	H to M	H
Regeneration	N/P*	N/P, N	N/S, P, N	N/S, P	N/P	–/N, P
Site degradation	F/C*, R	F/C, R	F	F	C/R	R/C
Prescribed burn	L	L to M	H	M to H	L to M	L to H

LEGEND:

Operability season
W- winter only (i.e., frozen ground)
S - summer only (i.e., not frozen ground)
A - no limitations for harvesting

Regeneration [hardwood/conifer]
N - natural regeneration
P - planting
S - seeding

Competition
L - low
M - moderate
H - high

Site degradation
F - few limitations
C - compaction
R - rutting
E - erosion

Prescribed burn [ability to provide non-woody surface fuel complex]
L - low
M - medium
H - high

* "/" is used to separate suggested regeneration treatments and expected site degradation effects, for hardwood-dominated versus conifer-dominated stand conditions respectively; e.g., N/P indicates natural regeneration on hardwood-dominated sites but planting on conifer-dominated sites.

6. SUMMARY

This report provides an overview of forest humus form classification, as it applies to the Boreal and Great Lakes–St. Lawrence forest regions of northwestern Ontario. Methodologies and approaches for humus form recognition in the field are briefly discussed, and important terms and humus form units are defined and presented.

Based upon forest humus form data from a network of some 2 167 Forest Ecosystem Classification field plots in northwestern Ontario, four orders (*mulls*, *moders*, *mors*, and *peatymors*), five groups, and five new subgroups are defined and described in the northwestern Ontario forest humus form classification. A first approximation classification system and field key are provided for the identification of forest humus forms in northwestern Ontario. Some background on the field use of this hierarchical system is provided. Each of the humus form classes is described in a one-page factsheet summary.

Ecological information derived from the FEC data set is summarized in relation to the humus form classes. These summaries support the segregation of humus form orders, groups, and subgroups according to ecological attributes such as soil moisture regime, soil texture class, and organic layer thickness. Interpolation of climatic data, using an approach described elsewhere,[8] provides evidence that the six main humus form orders and groups can be separated on the basis of response curves along a gradient of growing degree-days.

Forest humus forms in relation to forest management practices in northwestern Ontario are also briefly considered. Some preliminary guidelines are presented for incorporating information about humus forms into some aspects of harvest and silvicultural planning. Operational testing and field research into these matters are warranted.

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