FOREST FLOOR RECOVERY INDEX

Boreal Mixedwood Field Guide

Natural Resources Canada
Ressources naturelles Canada

Canada

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Hoffman, D.R.; Shaw, C.H.; Kull, S.J.; Voicu, M.F.; McNalty, C. 2019. Forest floor recovery index: Boreal Mixedwood field guide. Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, AB.

Abstract

The Forest Floor Recovery Index (FFRI) aims to assess ecosystem recovery using changes in forest floor properties during stand development following reclamation. Modeled predictions from the Carbon Budget Model of the Canadian Forest Sector were used to generate recommendations for the tree biomass inputs required to build natural forest floors. This FFRI manual presents a simplified forest floor classification system, using photographs and descriptions to illustrate examples of 19 forest floor types, differentiated according to composition and dominant horizons. The manual provides users with guidance in data compilation, determination of an index of recovery through comparison of site data with reference data, and an assessment of the tree biomass inputs needed for natural forest floor development. This approach provides a useful tool for monitoring recovery of forest sites that have been disturbed and subsequently reclaimed following oil sands development activities.

Résumé

L'Indice de rétablissement de la couverture morte (IRCM) vise à évaluer le degré de rétablissement de l'écosystème en mesurant les changements des propriétés de la couverture morte pendant le développement d'un peuplement après la remise en état d'un site. Des prévisions modélisées tirées du Modèle du bilan du carbone du secteur forestier canadien ont été utilisées pour formuler des recommandations quant aux apports requis en biomasse forestière pour le rétablissement de couvertures mortes naturelles. Le présent manuel de l'IRCM expose un système simplifié de classement des couvertures mortes qui s'appuie sur des photos et des descriptions illustrant 19 exemples de types de couvertures mortes différenciés selon leur composition et les horizons dominants. Ce manuel fournit aux utilisateurs de l'orientation pour la compilation des données, pour la détermination d'un indice de rétablissement au moyen d'une comparaison entre les données du site et des données de référence et pour l'évaluation des apports en biomasse ligneuse nécessaires pour le développement d'une couverture morte naturelle. L'approche proposée constitue un outil utile pour faire le suivi du rétablissement de sites forestiers qui ont fait l'objet d'une remise en état à la suite de perturbations occasionnées par des activités d'exploitation des sables bitumineux.

Preface to the Boreal Mixedwood Edition

Through the Canadian Forest Service's Forest and Oil and Gas Sectors Research and Collaboration (FOR-C) initiative, Canadian Forest Service researchers were encouraged to develop projects applying their areas of expertise to the oil sands region. In response to the need for tools to assess forest ecosystem recovery after reclamation, the authors' expertise in forest ecology and soil science related to forest floor development was used to create the Forest Floor Recovery Index (FFRI) manual and app. The FFRI manual presents a simple forest floor classification system for 19 forest floor types and provides users with guidance to determine an index of recovery through comparison of site data with reference data. The original version of the manual was published early in 2017, and it was field tested in the summer and fall of that year to produce an updated 2nd edition of the FFRI manual. The 2nd edition includes changes to the criteria for achieving each index score (1–3), hints for users, and new pages describing the effects of earthworms on forest floors, and characteristics of forest floors on reclaimed well pads. In 2018, further field testing was conducted using the 2nd edition in the Dry Mixedwood subregion to determine if the FFRI could be expanded to a larger area of the Alberta Boreal Mixedwood. This Boreal Mixedwood Edition of the FFRI includes further updates to the index score criteria based on those field results. Woody biomass input guidelines have also been updated in this edition.

The Forest Floor Recovery Index: Boreal Mixedwood Field Guide and the Information Report, Forest Floor Recovery Index: A Tool to Assess Forest Recovery after Reclamation (NOR-X-427) are available from the CFS Publications database at the following links: Field Guide, http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/39494.pdf; Information Report, http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/38992.pdf.

All FFRI documents and the FFRI app are available at the Canadian Institute of Forestry website: http://cif-ifc/forest-floor-recovery-index/
The FFRI app automatically calculates index scores as data is entered.

CONTENTS

BACKGROUND

Motivation

The Alberta Energy Regulator requires that soil organic horizons (L, F, H, and O) be identified and forest floor thickness measured for the predisturbance assessment of sites destined for in situ or surface-mine extraction of bitumen. However, no assessment of the forest floor is required for certification following reclamation. This suggests acknowledgment that the forest floor is an important component of forest ecosystems before disturbance and that its assessment for certification may be absent because no method currently exists to assess post-reclamation forest floors.

In the boreal forest, decaying wood from tree stems and branches constitutes a large portion of the material making up the forest floor but has at times been overlooked in favor of more traditional and nutrient-rich components, such as litter. To meet the reclamation objective of restoring land capability to a state similar to that existing before disturbance, inputs of woody material are required. When this material is absent, it can negatively affect soil nutrient availability and tree growth in the longer term.

The Forest Floor Recovery Index (FFRI) manual provides guidelines for inputs of woody materials that will help to develop natural forest floors and a healthy ecosystem, along with methods to assess forest floor development as an indicator of overall ecosystem recovery.

Objectives

This manual seeks to

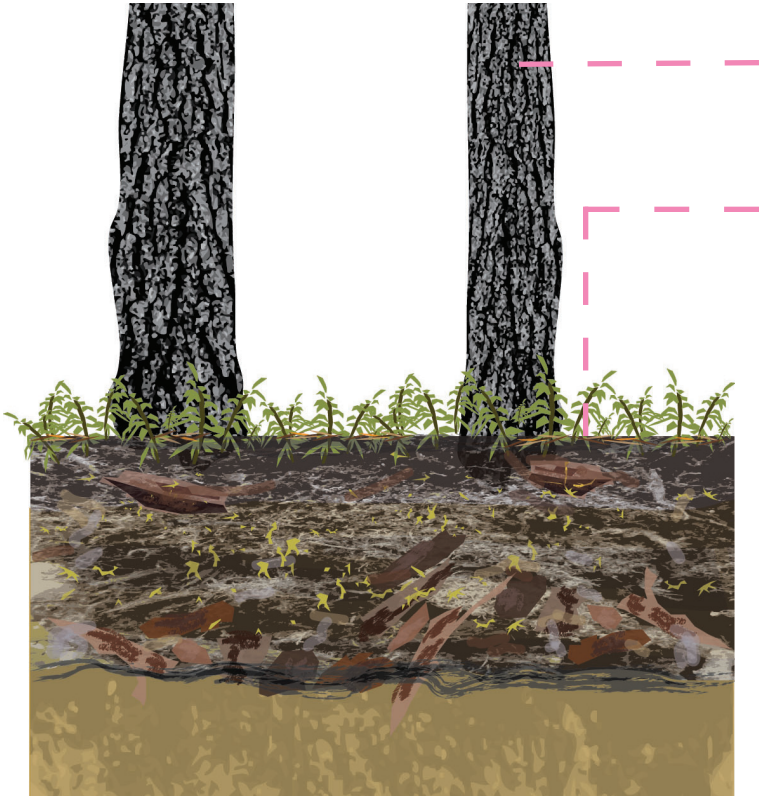
- give users information and images from reference samples to explain how to describe and classify the forest floor;

- allow users to monitor the forest floor as an indicator of ecosystem recovery after reclamation with the FFRI; and,

- provide guidelines for the amount of tree biomass inputs needed to establish forest floors indicative of functional, resilient forest ecosystems on reclaimed sites.

This manual was developed for soils with organic horizons ≤ 40 cm thick overlying mineral soil. It should not be used for organic soils > 40 cm thick, like those found in peatlands.

The forest floor



Trees and other plants provide organic material from foliage, roots, branches, dead moss, and stem wood to build forest floors.

This organic material accumulates at the soil surface in forest ecosystems.

In the boreal forest, decomposition is carried out primarily by fungi. Trees form mutualistic relationships with these fungal networks to better obtain water and nutrients in exchange for organic compounds (carbon and associated nutrients).

Forest floor ecology influences important reclamation metrics, such as nutrient cycling, site index, soil carbon, soil moisture, plant community composition, and resilience to both natural and anthropogenic disturbance.

Mors: forest floors in the boreal forest

The cold climate in the boreal forest results in relatively slow decomposition of organic matter. Plant material tends to accumulate in a compact, matted structure (formed through incomplete fungal decomposition) on top of the mineral soil, with a sharp transition between organic and mineral horizons. **This type of forest floor, which is called a Mor, will be the focus of this manual.** Other forest floor types, Moders and Mulls, are far less common in the boreal forest but may be encountered there. It is important to distinguish between Mors, Moders, and Mulls. Doing so requires an understanding of the organic horizons that make up these different forest floor types.

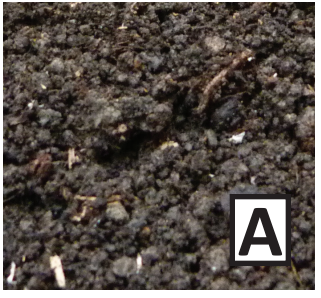
Organic horizons: well-drained sites

Organic horizons are made up of at least 30% organic matter by mass.

L (litter); the least decomposed. L horizons are made up of identifiable materials, such as intact leaves or needles, sitting on the surface of the forest floor.

F (fermented); intermediate decomposition. F horizons are made up of plant residues in which partial structures are still identifiable; the F horizon usually occurs below the L horizon and above the H horizon.

H (humic); the most decomposed. H horizons are made up of fine plant residues that are, for the most part unrecognizable and dark in color.



A (mineral horizon); < 30% organic matter by mass. A horizons are not organic horizons but are sometimes present just below the organic horizons. They are dark in color and often gritty because of mixing of the mineral soil with organic matter.

Organic horizons: poorly drained sites

O horizons occur in areas affected by a high water table for a significant portion of each year. They are often dominated by mosses but may also include significant amounts of woody material.

Of (fibric); a surface O horizon that consists of poorly decomposed, identifiable plant residues. The Of horizon produces relatively clear water when squeezed.

Om (mesic); an O horizon that consists of partly decomposed, mushy plant residues at a stage of decomposition between Of and Oh horizons. The Om horizon produces muddy brown water when squeezed.

Oh (humic); an O horizon that consists of well-decomposed plant residues, which for the most part have been transformed into humic materials (as in H horizons). The Oh horizon produces a dark paste when squeezed, and few recognizable plant structures can be seen.

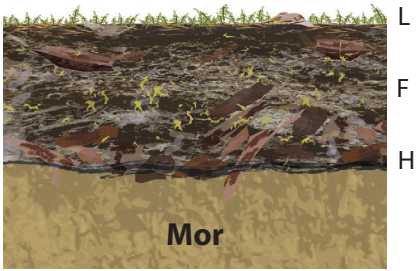
How to identify a Mor forest floor

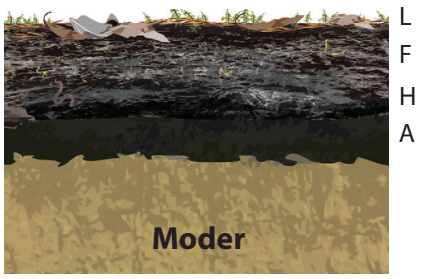
The combined thickness of the F and H horizons in a Mor must be greater than the thickness of the A horizon, if it is present. In L Mors, which may lack F and H horizons, the thickness of an A horizon must be less than the thickness of the L horizon and no more than 2 cm. (See pages 6 and 7 for descriptions of the horizons.)

The F horizon in a Mor usually has a matted structure due to the presence of fungal hyphae and roots. The sharp transition between organic and mineral horizons is a result of the rarity or absence of soil fauna that mix organic and mineral horizons as they move through the mineral soil and forest floor in Mulls or Moders.

- If the combined thickness of the F and H horizons is < 2 cm, and they overlie a mineral A horizon > 2 cm thick, the humus form is a **Mull**.

- If the humus form does not meet the requirements of a Mull, and the F horizon is significantly altered by the action of soil fauna, such as earthworms, the humus form is a **Moder**. Moders have properties that are transitional between those of Mors and Mulls.





FOREST FLOOR CLASSIFICATION

Horizon groups: well-drained sites

In this manual, the forest floor is classified by identifying and combining horizon groups and material groups. Horizon groups are defined by the dominant horizon(s).

L Mor

The L horizon accounts for at least 70% of the L, F, and H combined thickness.

If a sample does not meet the requirements to be designated an L Mor, the thickness of the L horizon is not taken into account when determining whether the sample is an F Mor, FH Mor, or H Mor, as defined below.

F Mor

The F horizon accounts for at least 70% of F and H combined thickness.

FH Mor

The F and H horizons each account for between 30% and 70% of F and H combined thickness, or the F and H horizons may be mixed together; there is no dominance between F and H horizons.

H Mor

The H horizon accounts for at least 70% of F and H combined thickness. **It is often difficult to distinguish between different material groups in H Mors because H horizons are so well decomposed. Extra hints are provided for distinguishing Ordinary and Woody H Mors in the Reference Examples section (pages 37 and 38).**

Horizon groups: poorly drained sites

Total forest floor thickness must be ≤ 40 cm. Otherwise, the sample is classified as an organic soil, like those found in peatlands, and this manual does not apply.

Hydromor

The F and H horizons account for at least 50% of L, F, H, and O combined thickness; poorly aerated because of saturated conditions in part of the profile for a portion of the year, sometimes resulting in O horizon(s) in the lower part of the profile. Often, much of the O horizon(s) is formed from dead moss.

O Hydromor

The O horizon(s) accounts for at least 50% of L, F, H, and O combined thickness; very poorly aerated, with at least part of the profile being permanently saturated. L, F, and H horizons may form above O horizons. Often, much of the O horizon(s) is formed from dead moss.

Material groups

Material groups are defined by the dominant organic material making up the forest floor or part of the forest floor.

Ordinary Partially or well-decomposed tree litter makes up at least 50% of the organic material, so neither wood nor moss dominates.

New The forest floor is made up of undecomposed tree litter (needles or leaves).

Woody The dominant horizon is made up of at least 50% decaying wood. Most of this wood originates from coarse (≥ 7 cm diameter) woody debris.

Mixed The dominant horizon contains a mixture of recognizable plant residues (small wood fragments < 7 cm diameter, roots, bark, needles, cones) with yellow, brown, or red colors.

Mossy The dominant horizon is made up almost entirely of dead moss. The surface of the forest floor may be mostly live moss (live moss is not measured when determining the thickness of the forest floor, although some litter material may be mixed in with the live moss).

Fungal The dominant horizon is made up of at least 50% yellow or white fungal hyphae. If this condition is met, the Fungal designation overrides the material in which it is growing (e.g., mossy, woody).

Effects of earthworms

Earthworms are invasive species that are spreading into the Canadian boreal forest. Initially, these populations are small and do not drastically change the forest floor, but when populations increase they have the ability to consume large amounts of organic matter, sometimes mixing organic horizons with mineral soil, forming A horizons (see page 6). The bioturbation can cause a shift from a Mor forest floor to a Moder or Mull, destruction of fungal mycelia, dispersion of bacteria resulting in more rapid decomposition, and reduced forest floor thickness.

Some of the reference sites used to develop the FFRI have been affected by earthworms. Their presence alone will likely not affect the results of an assessment using this manual, but users should note when earthworms are encountered at a site.

Forest floors on reclaimed well pads

Forest floors on reclaimed well pads will vary greatly depending on the amount of time that has passed since reclamation was completed, and the vegetation that has been established on the site.

On sites where no trees have been established and no wood has been added, generally, there will be no forest floor. Instead, a layer of grass roots – living, dead, and decomposing – will usually be present.

Where trees have established and wood was added to a site, the forest floor development should be similar to a stand originating from natural disturbances, and these sites are more likely to achieve successful index scores in the FFRI.

A mixture of soil and peat is often used in reclamation and might be difficult to distinguish from an H horizon in a developing forest floor. **Be careful to distinguish between the reclamation soil and the organic horizons**.

SAMPLING AND RECORDING DATA

Sampling

With knowledge of the key properties of forest floor horizons, horizon groups, and material groups, you can begin sampling. To be able to calculate the FFRI, you will first need to know the target ecosite type ("a" to "h", see pages 51-59) and how many years have passed since reclamation.

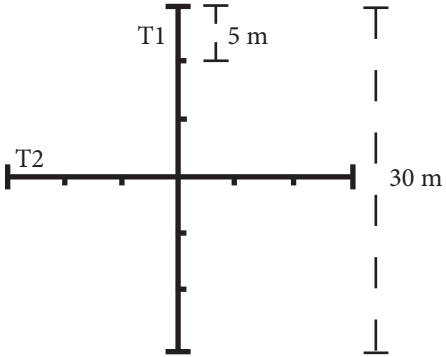
We recommend the following sampling supplies:

- Hori hori knife or flat-edged shovel
- Clippers
- Ruler or measuring tape
- Meter tape for measuring transects
- Data sheets **(may use copy of data sheet on page 21)** or FFRI app (**link in preface**)

The forest floor varies in thickness from 0 to 40 cm. If the organic horizons are thicker than 40 cm, the sample is classified as an organic soil, like those found in peatlands, and this manual does not apply.

Sampling design

1. Before sampling, record your target ecosite ("a" to "h") and years since reclamation.
2. Establish two perpendicular transects 30 m long, as illustrated in the diagram.
3. Sample at 5-m intervals starting at the beginning of the first transect (T1).
4. Sample at 5-m intervals starting at the beginning of the second transect (T2), with the exception of the middle sampling point, which was already sampled on T1.



For large sites, you may want to sample at greater intervals along longer transects. For example, on a 1-ha site, sampling every 15 m may be appropriate. Depending on the layout of the site, a single straight transect can substitute for two perpendicular ones.

How to sample and record data

1. Use your knife or shovel to remove a 20 cm × 20 cm forest floor sample (you may want to take a smaller sample where the forest floor is thin), including up to 10 cm of the mineral soil. To maintain the structure of the sample, use your clippers to cut any roots that were not severed by the knife or shovel.

2. You may want to expand the sampling area you have created, to better observe the forest floor, especially if it is thick.

3. Measure and record the thickness (cm) of the forest floor.

4. Determine the origins of the materials in your sample (see pages 12 and 13 for material group descriptions and the photographs and descriptions provided in the "Reference Examples" section starting on page 23). Material may differ between horizons, and you may need to pull apart your sample to identify each material. Record the material group.

5. Observe the organic horizons, L, F, H, and O. Determine the horizon group that your sample represents according to the relative thicknesses of the horizons (see pages 6 and 7 for horizon descriptions and pages 10 and 11 for horizon group descriptions). Record the horizon group.

6. Include any additional notes about the sample and site in the comments column of the data sheet (e.g., did you see evidence of earthworms or other disturbance?).

Site name:

Ecosite: Years since reclaimed: Surveyor(s): Date: dd mm yy

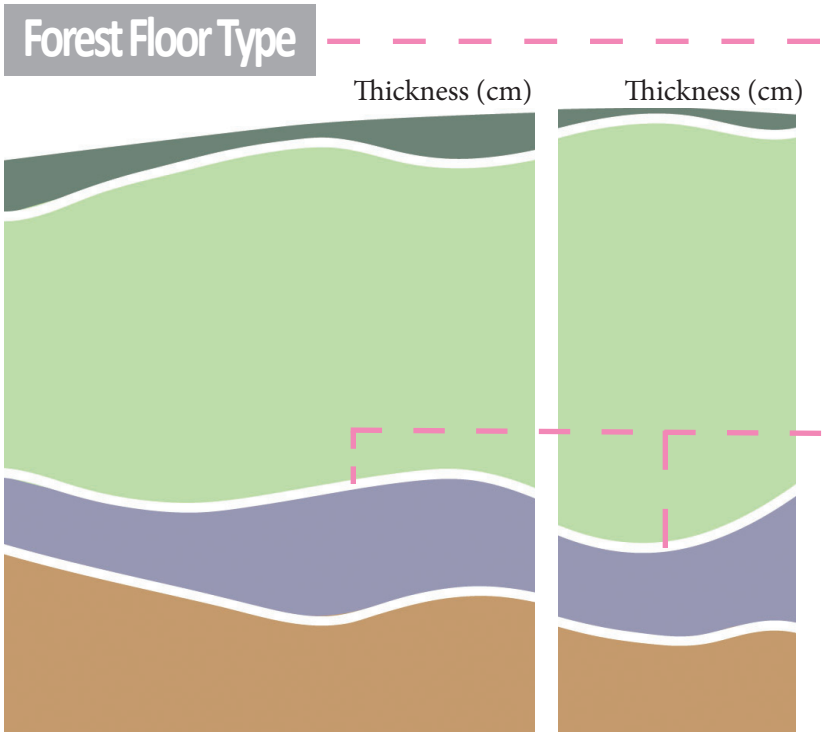
Material group, Horizon group	Thickness (cm)	Comments

Average thickness: Percent woody and mixed: Percent F: Percent FH: Percent H:

REFERENCE EXAMPLES

When using the reference examples, **do not rely on the images alone**. Read descriptions and carefully examine your sample.

How to interpret reference examples



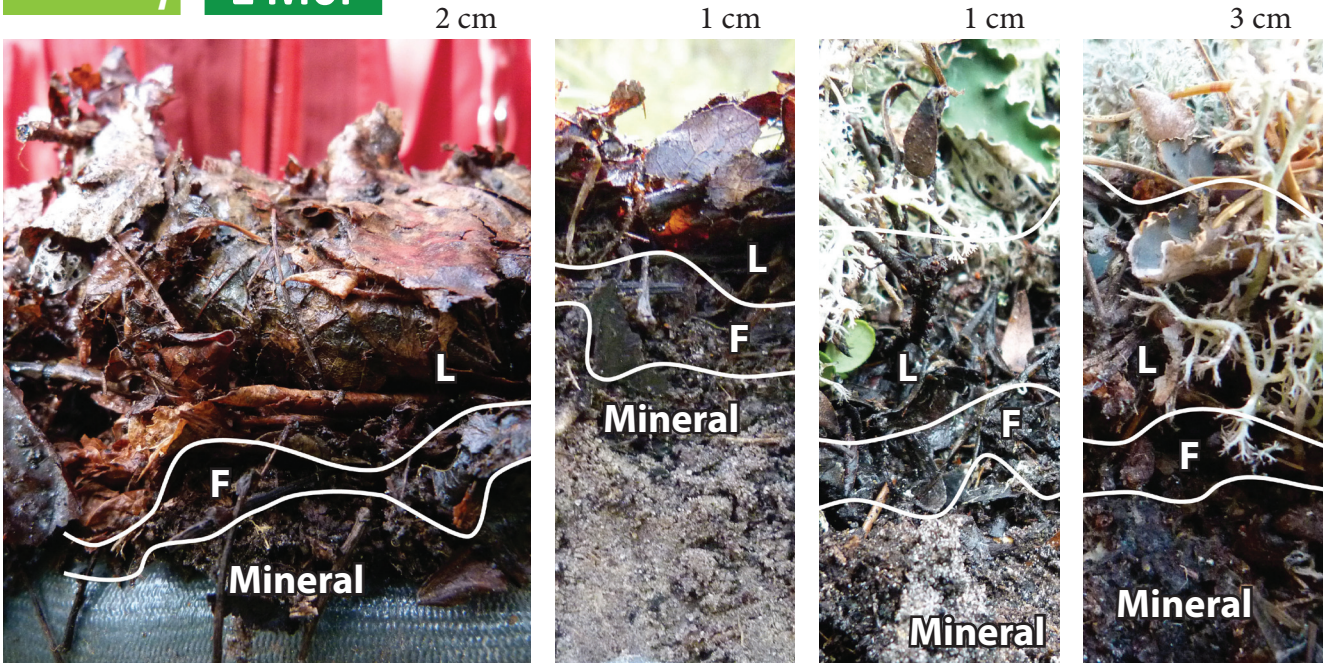
The name of each forest floor type (material group, horizon group) is shown in the upper left-hand corner.

Images of the forest floor type over a range of ages and ecosites are presented for reference. Sample thickness (cm) is presented above each image.

In each image, white lines separate organic horizons from one another, and from mineral horizons if present. Horizons are labeled.

Other details include the common horizon sequence and a description of the forest floor type based on the relative thickness of horizons and which organic materials are dominant.

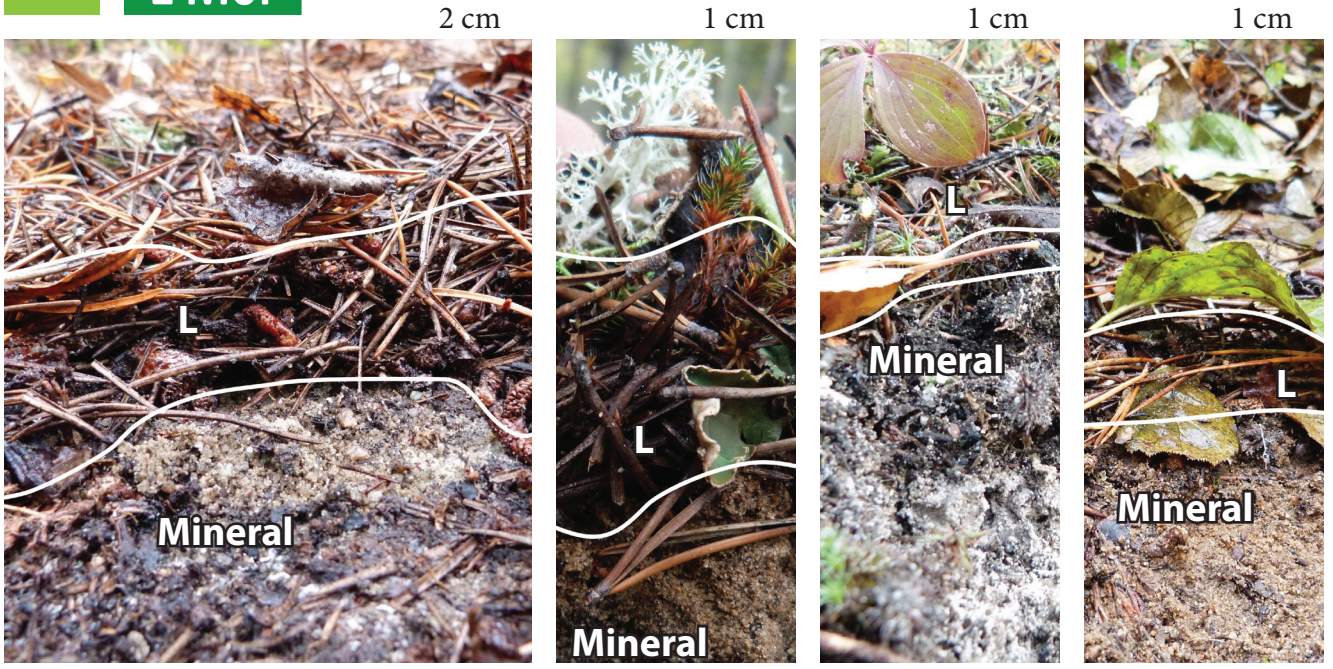
Ordinary L Mor



Horizon sequence: **L** **F**

The L horizon accounts for at least 70% of the L, F, and H combined thickness. Ordinary L Mors have a thin F horizon accounting for less than 30% of the total thickness of the combined organic horizons, and tree litter makes up a significant portion of the organic material.

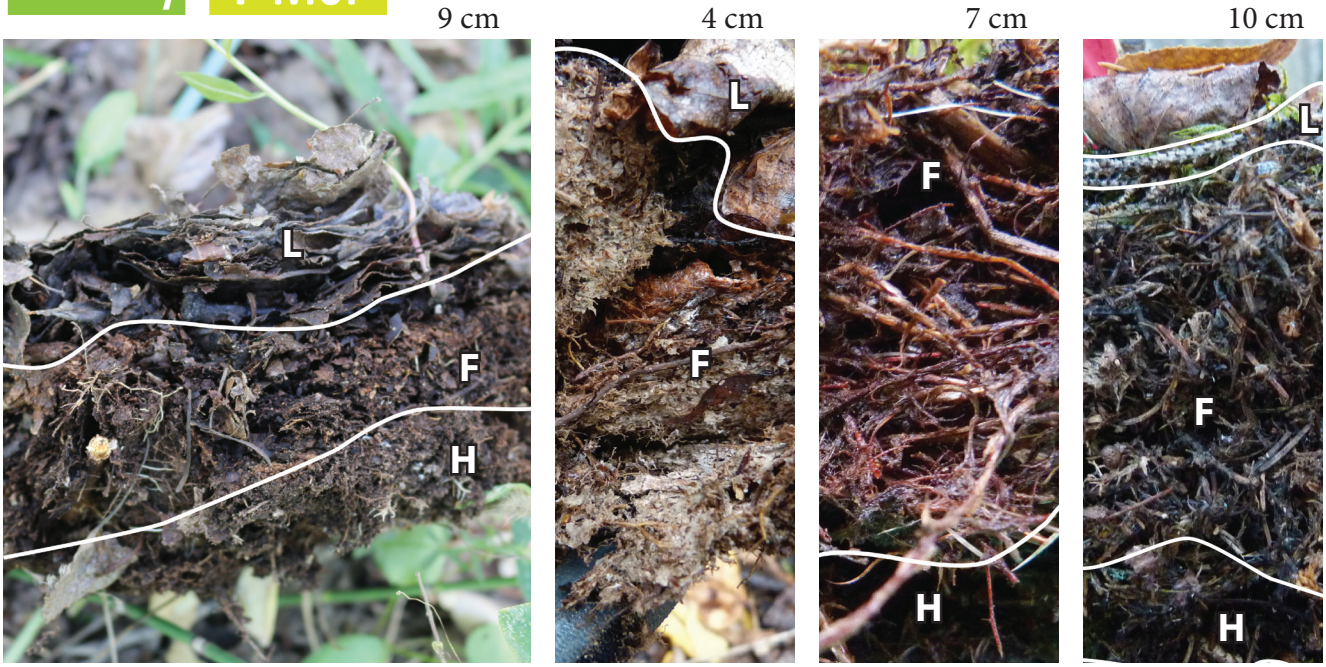
New L Mor



Horizon sequence: **L**

The L horizon accounts for nearly 100% of the L, F, and H combined thickness. New L Mors are made up of undecomposed tree litter (needles or leaves).

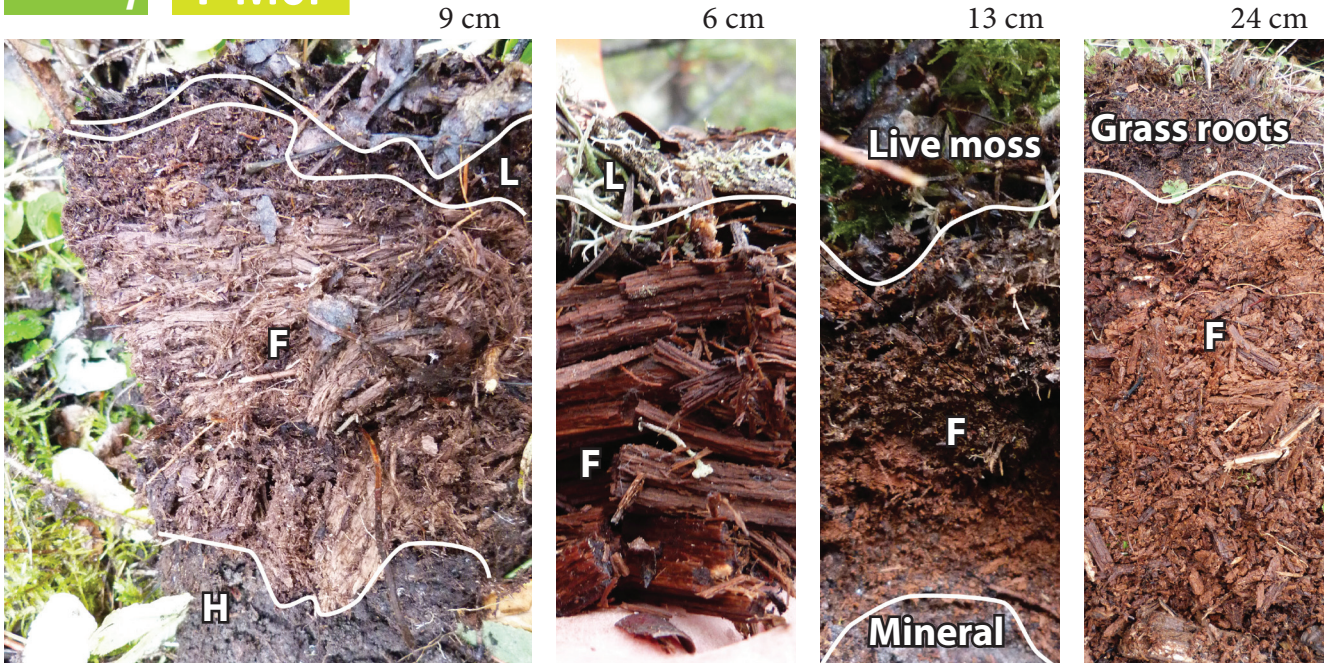
Ordinary F Mor



Horizon sequence: L F (H)

The F horizon accounts for at least 70% of F and H combined thickness. In Ordinary F Mors, partially or well-decomposed tree litter makes up at least 50% of the organic material.

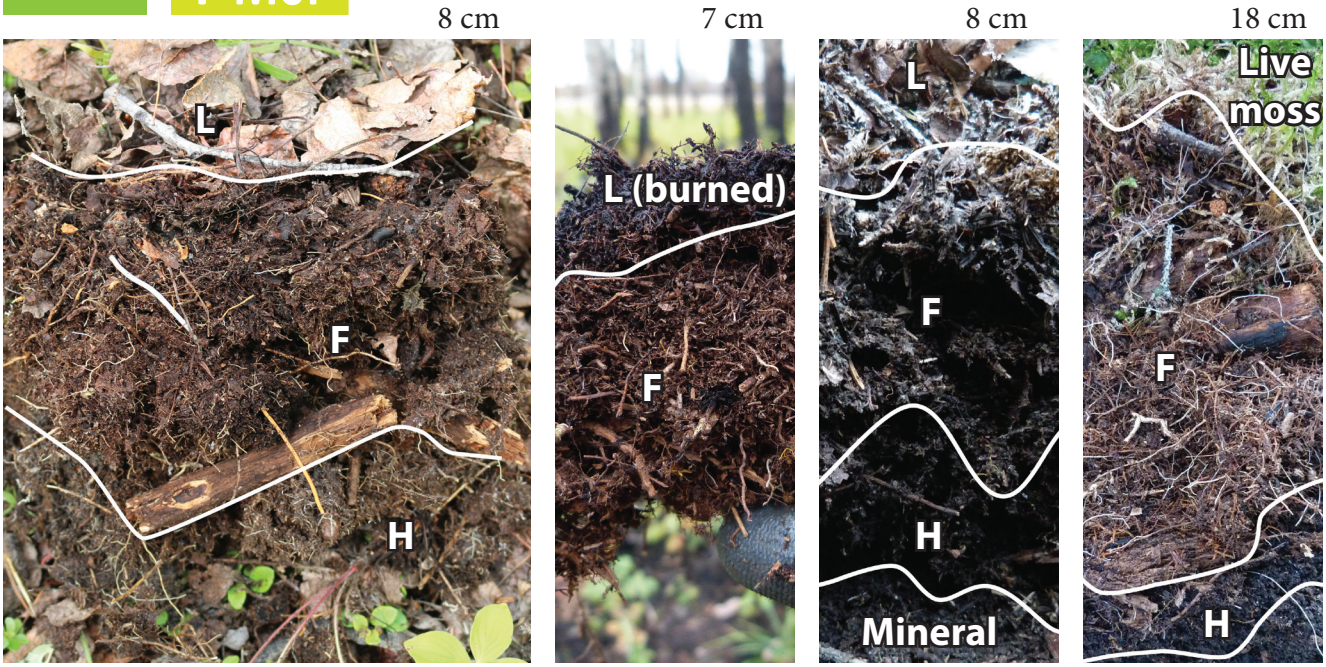
Woody F Mor



Horizon sequence: L F (H)

The F horizon accounts for at least 70% of F and H combined thickness. Woody F Mors have F horizons made up of at least 50% decaying wood. Most of this wood originates from coarse (≥ 7 cm diameter) woody debris.

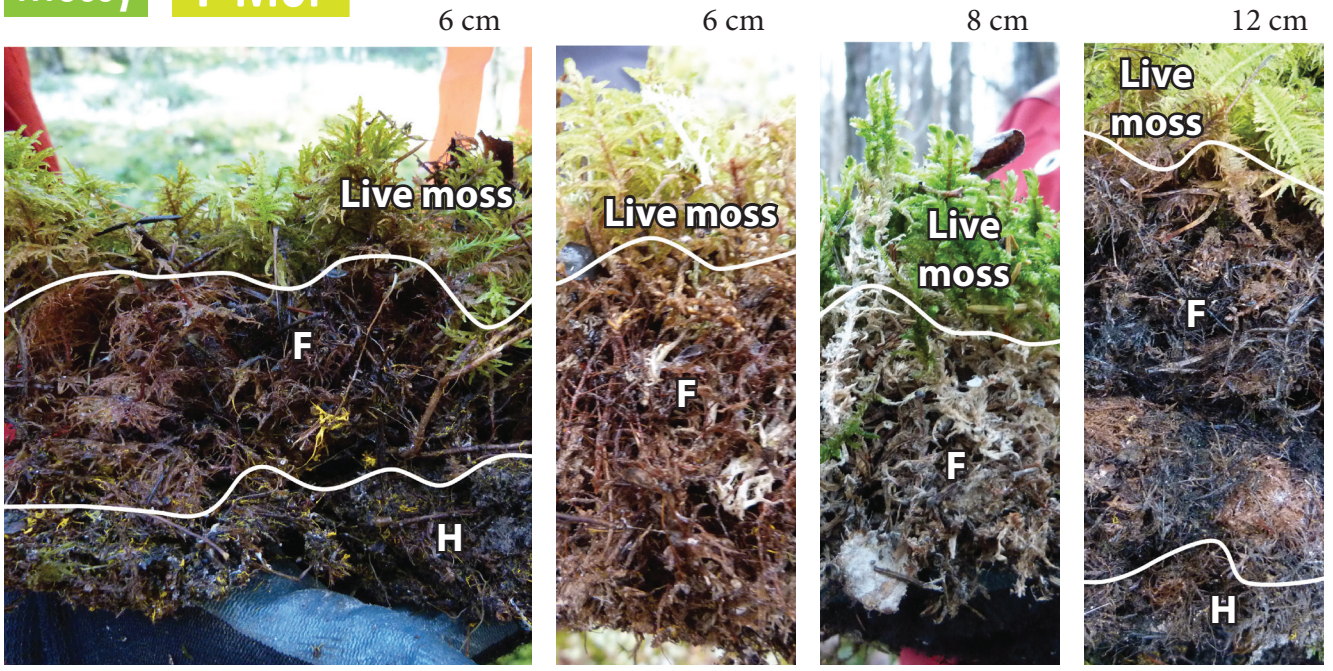
Mixed F Mor



Horizon sequence: L F (H)

The F horizon accounts for at least 70% of F and H combined thickness. Mixed F Mors contain a mixture of recognizable plant residues (small wood fragments < 7 cm diameter, roots, bark, needles, cones) with yellow, brown, or red colors.

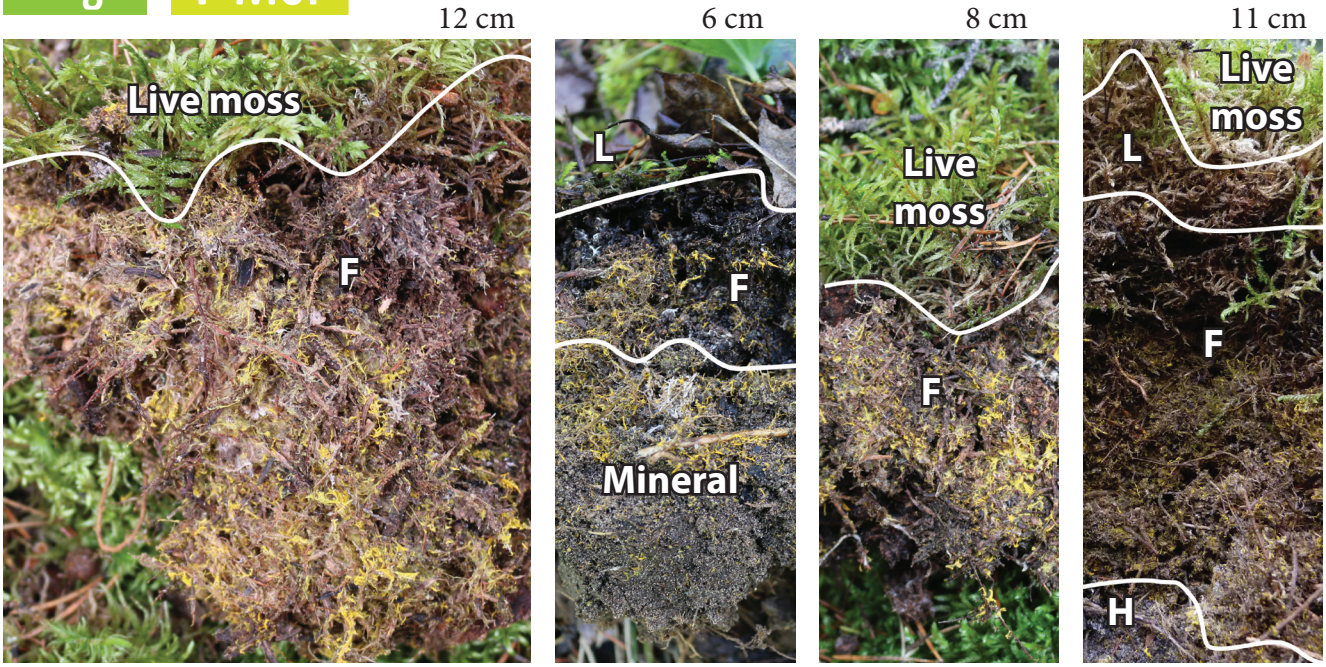
Mossy F Mor



Horizon sequence: L F (H)

The F horizon accounts for at least 70% of F and H combined thickness. Mossy F Mors have an F horizon made up almost entirely of dead moss. The surface of the forest floor may be mostly live moss.

Fungal F Mor



Horizon sequence: L F (H)

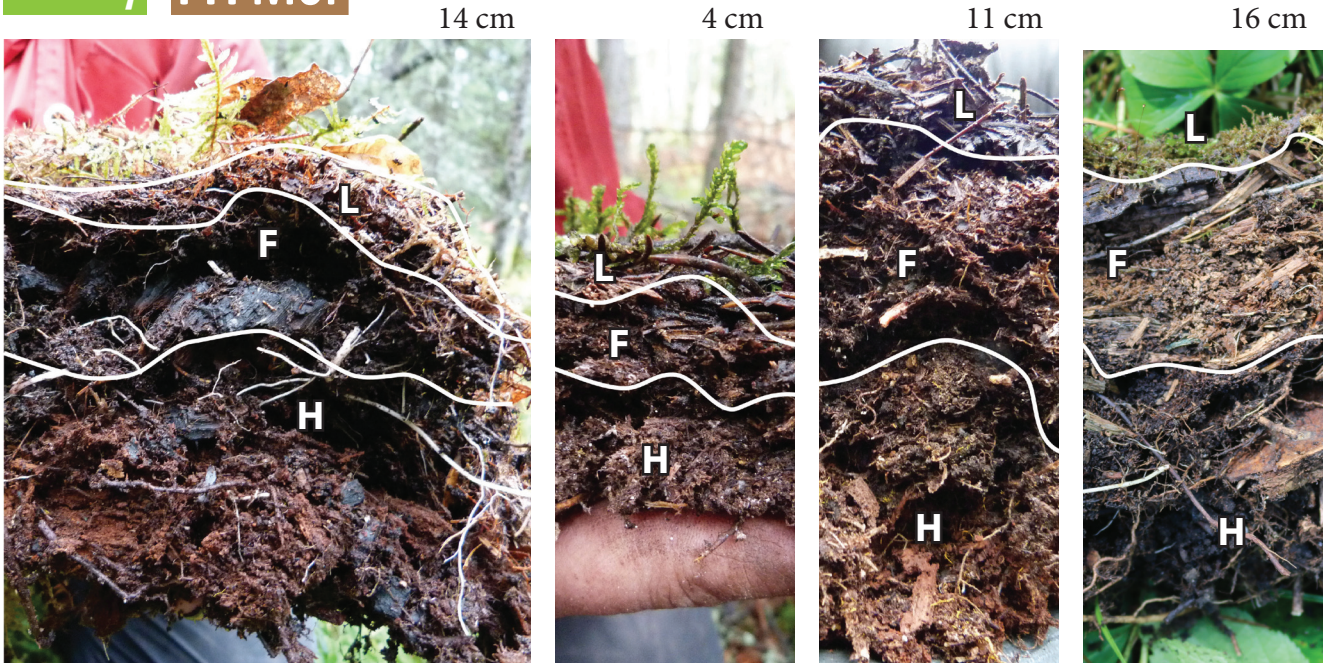
The F horizon accounts for at least 70% of F and H combined thickness. Fungal F Mors have an F horizon made up of at least 50% yellow or white fungal hyphae.

Ordinary FH Mor

Horizon sequence: **L** **F** **H**

There is no dominance of either the F or H horizon, each horizon accounting for between 30% and 70% of their combined thickness. In Ordinary FH Mors, partially or well-decomposed tree litter makes up at least 50% of the organic material.

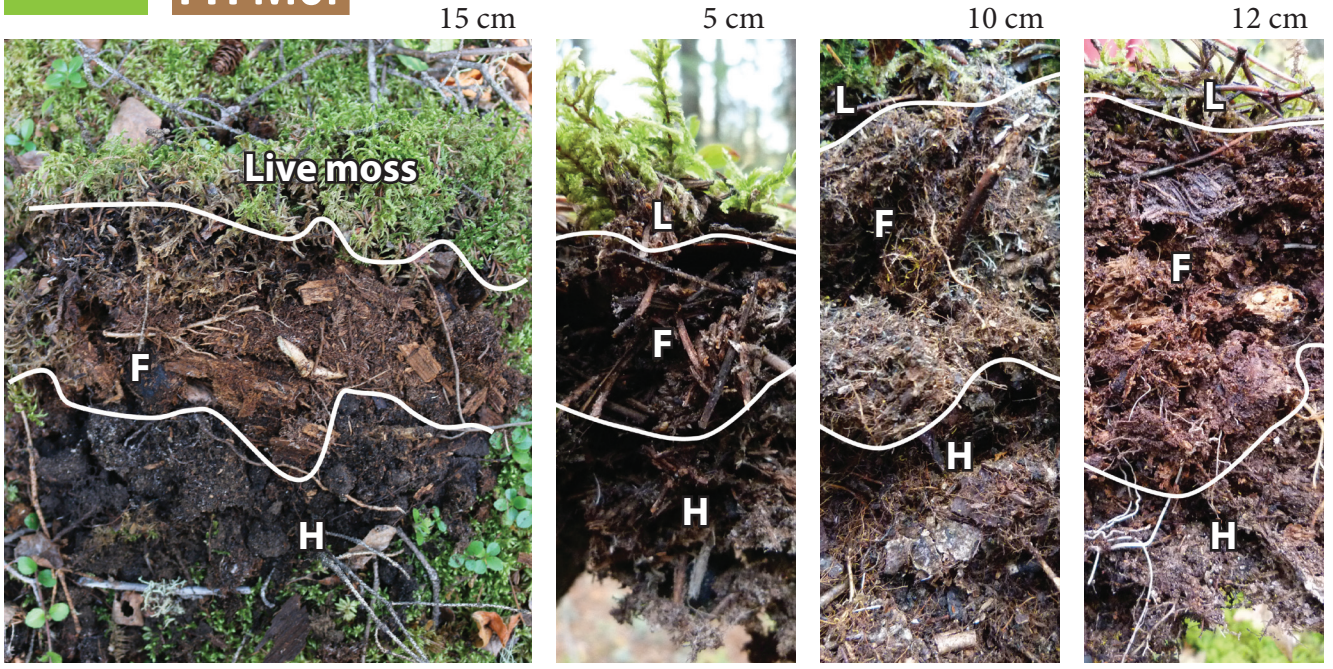
Woody FH Mor



Horizon sequence: L F H

There is no dominance of either the F or H horizon, each horizon accounting for between 30% and 70% of their combined thickness. Woody FH Mors have F and H horizons made up of at least 50% decaying wood. Most of this wood originates from coarse (≥ 7 cm diameter) woody debris.

Mixed FH Mor



Horizon sequence: L F H

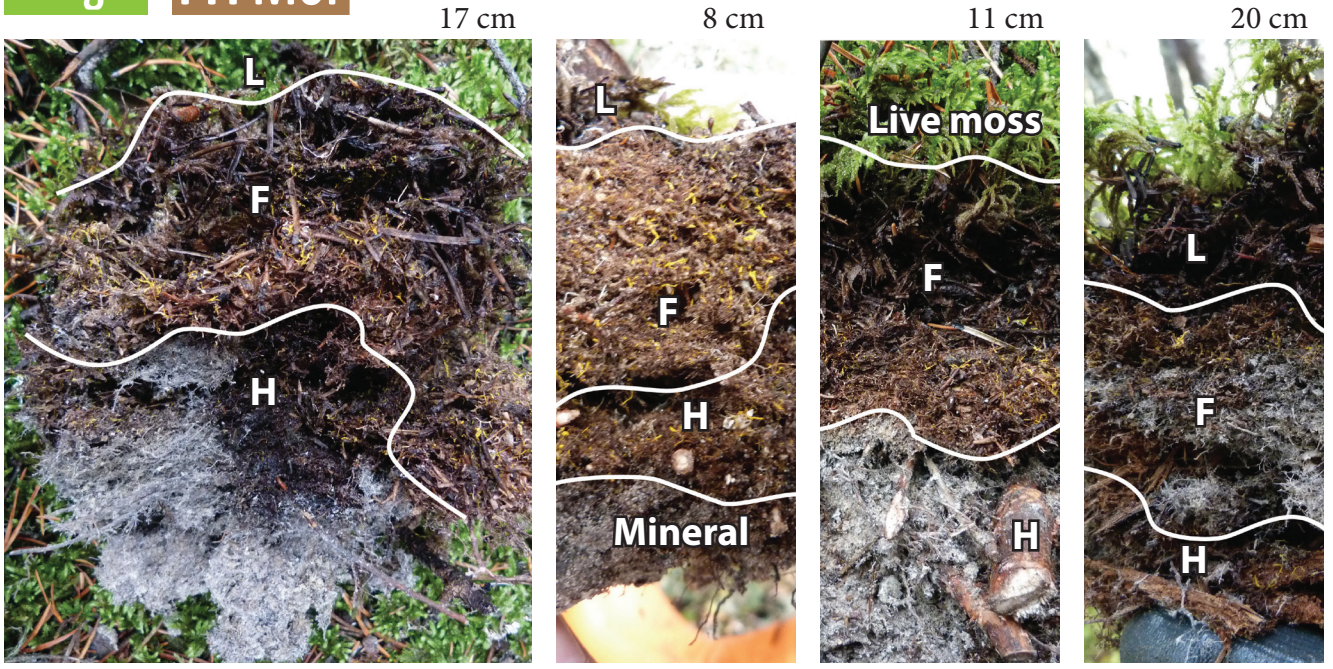
There is no dominance of either the F or H horizon, each horizon accounting for between 30% and 70% of their combined thickness. Mixed FH Mors contain a mixture of recognizable plant residues (small wood fragments < 7 cm diameter, roots, bark, needles, cones) with yellow, brown, or red colors.

Mossy FH Mor

Horizon sequence: L F H

There is no dominance of either the F or H horizon, each horizon accounting for between 30% and 70% of their combined thickness. Mossy FH Mors have F and H horizons made up almost entirely of moss. The surface of the forest floor may be mostly live moss.

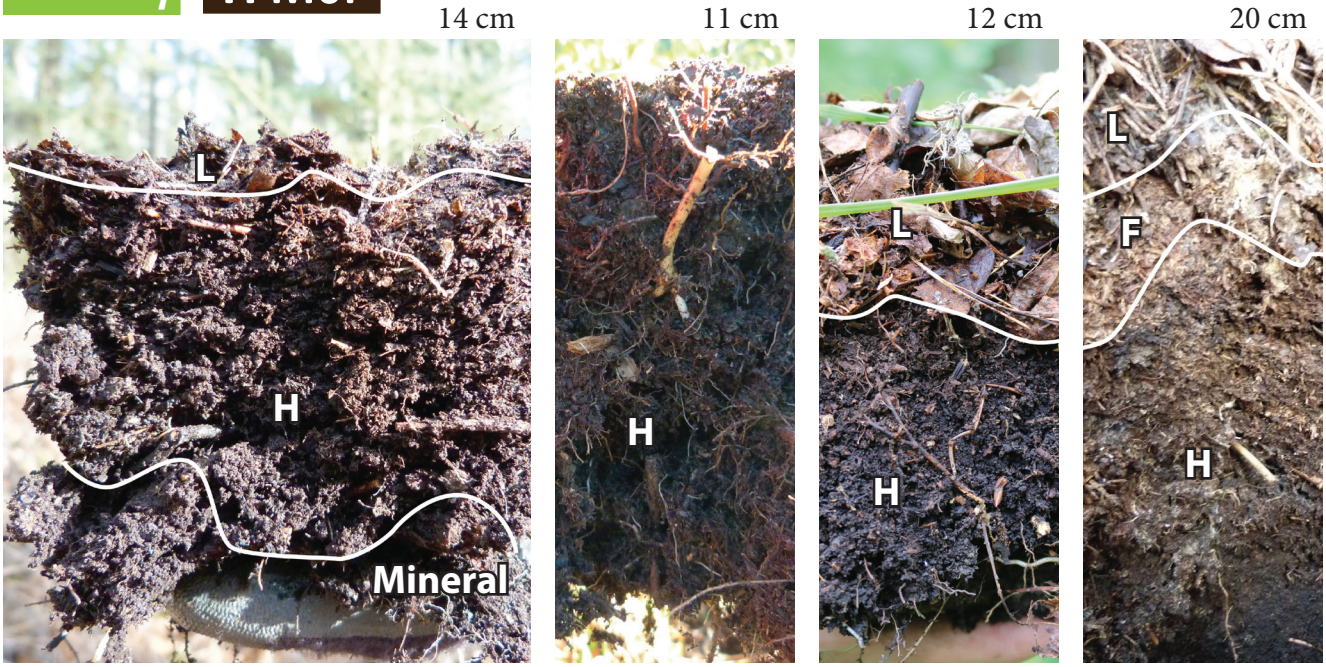
Fungal FH Mor



Horizon sequence: **L** **F** **H**

There is no dominance of either the F or H horizon, each horizon accounting for between 30% and 70% of their combined thickness. Fungal FH Mors have F and/or H horizons made up of at least 50% yellow or white fungal hyphae.

Ordinary H Mor



Horizon sequence: L (F) H

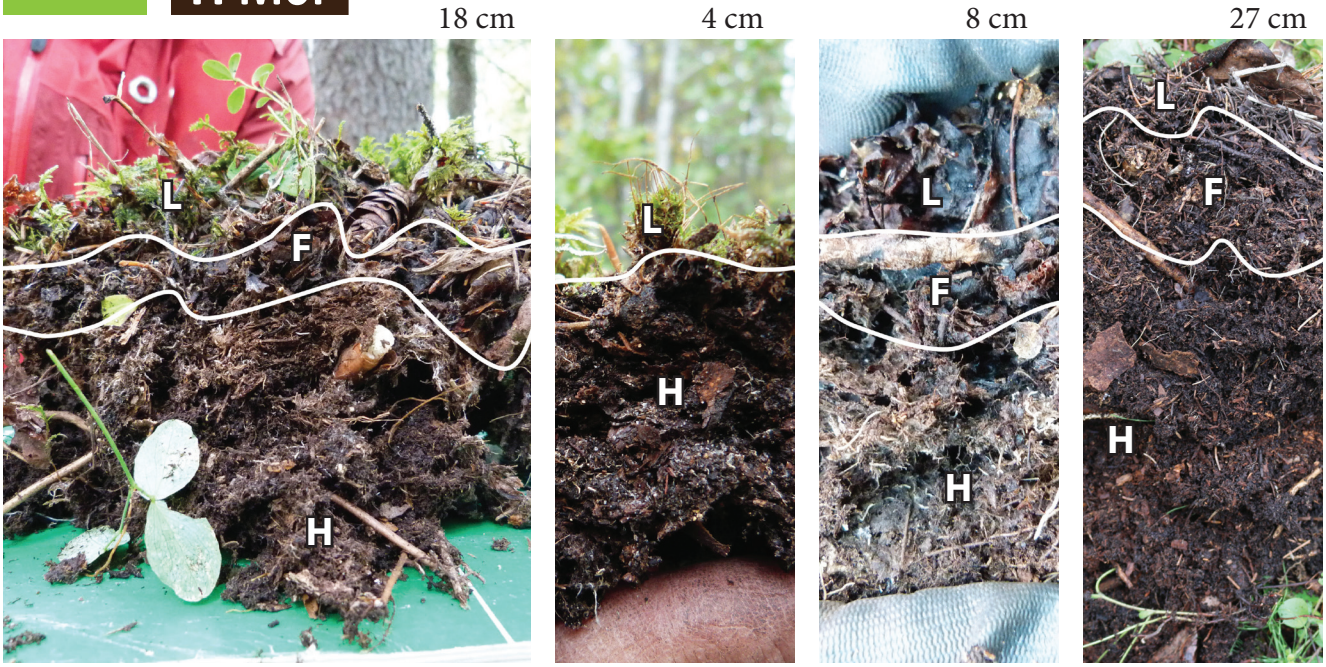
The H horizon accounts for at least 70% of F and H combined thickness. In Ordinary H Mors, partially or well-decomposed tree litter makes up at least 50% of the organic material. **Hint: the H horizon will usually be very dark in color and may be more loosely held together than a Woody H Mor.**

Woody H Mor

Horizon sequence: L (F) H

The H horizon accounts for at least 70% of F and H combined thickness. Woody H Mors have an H horizon made up of at least 50% decaying wood. Most of this wood originates from coarse (≥ 7 cm diameter) woody debris. **Hint: look for very small wood fragments and a bread-like consistency in the H horizon.**

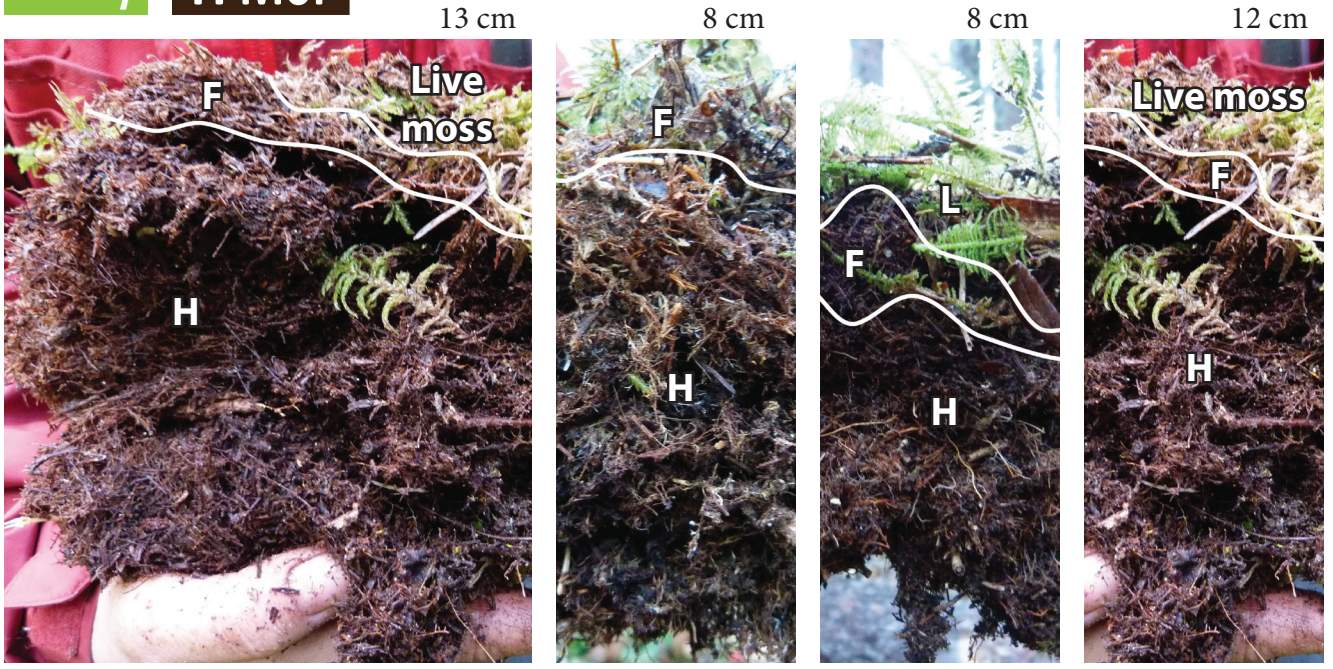
Mixed H Mor



Horizon sequence: L (F) H

The H horizon accounts for at least 70% of F and H combined thickness. Mixed H Mors contain a mixture of recognizable plant residues (small wood fragments < 7 cm diameter, roots, bark, needles, cones) with yellow, brown, or red colors.

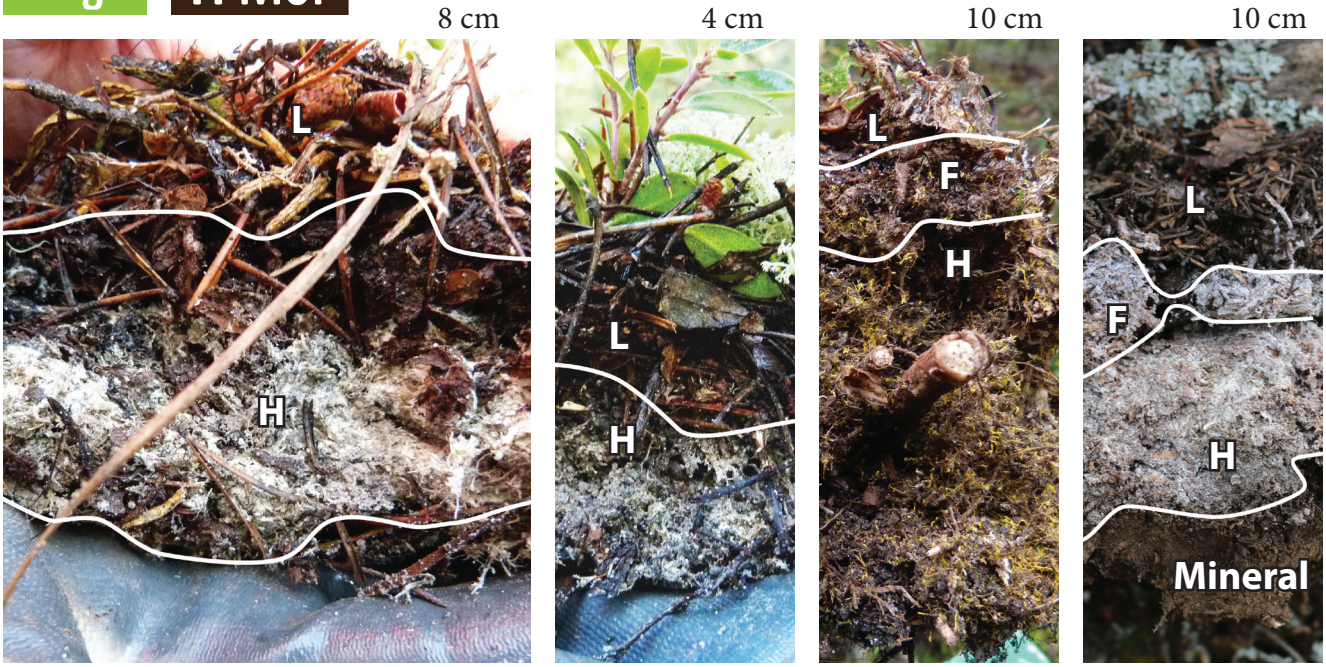
Mossy H Mor



Horizon sequence: L (F) H

The H horizon accounts for at least 70% of F and H combined thickness. Mossy H Mors have an H horizon made up almost entirely of decomposed moss. The surface of the forest floor may be mostly live moss.

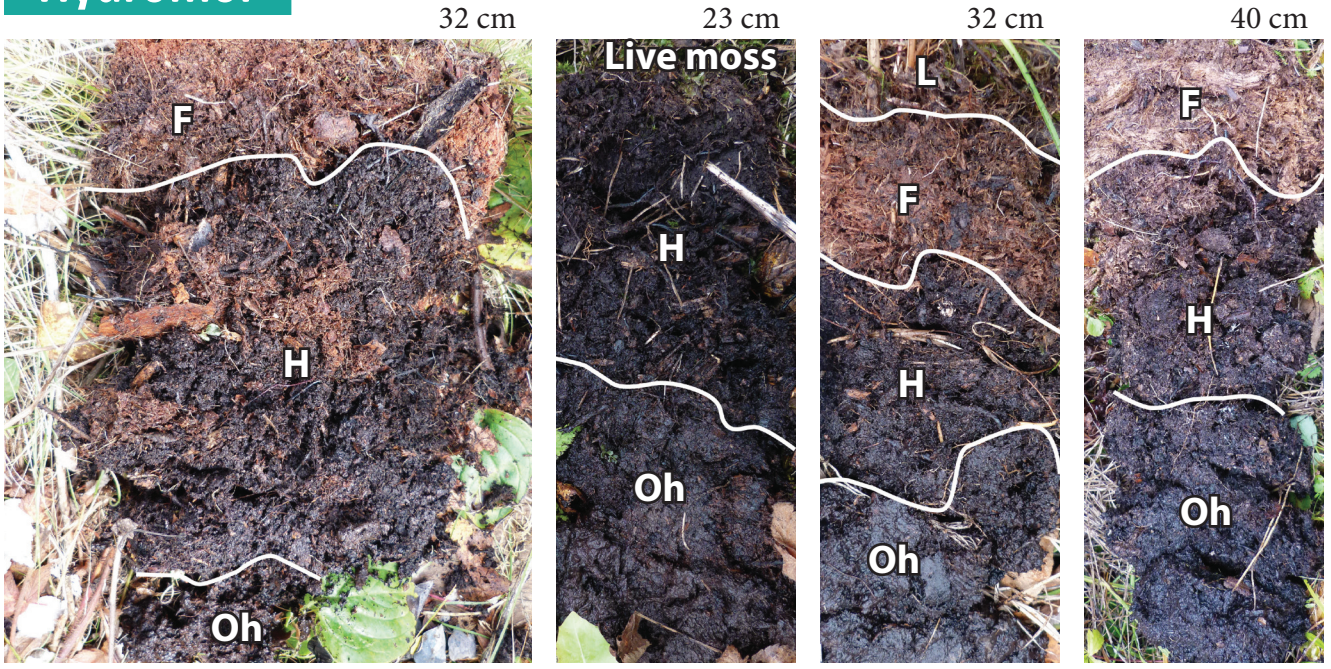
Fungal H Mor



Horizon sequence: L (F) H

The H horizon accounts for at least 70% of the total thickness of F and H horizons. Fungal H Mors have an H horizon made up of at least 50% yellow or white fungal hyphae.

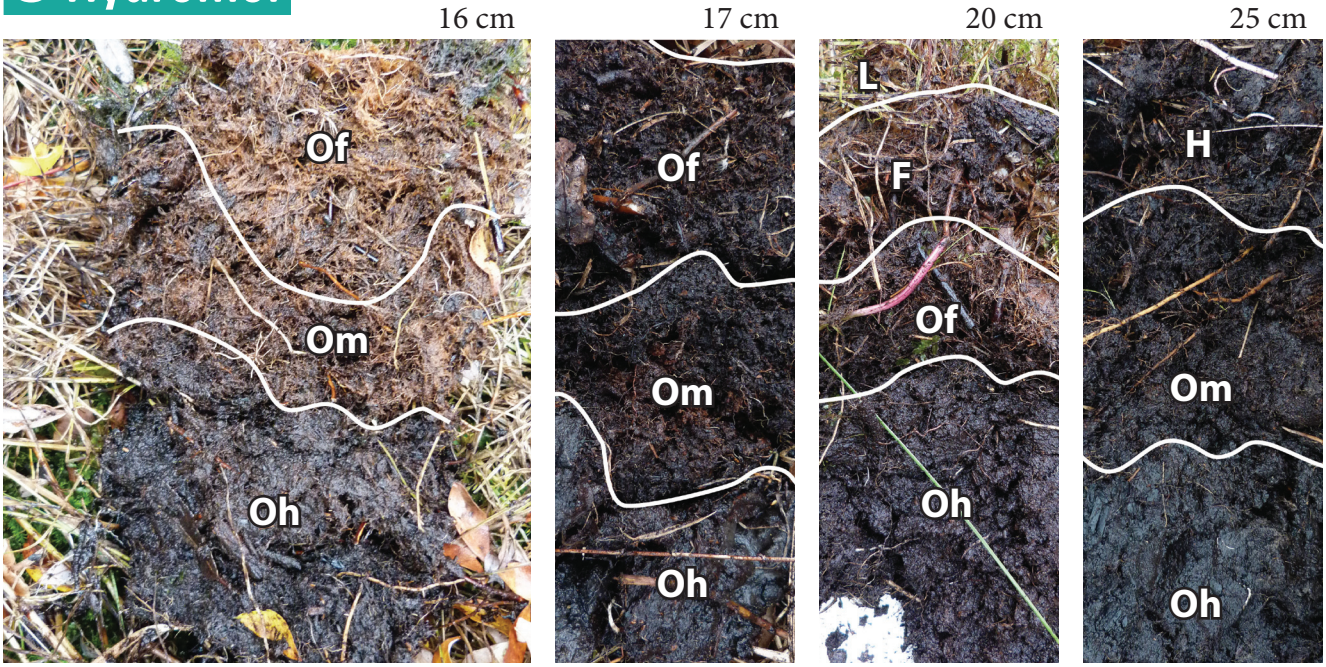
Hydromor



Horizon sequence: L F H (Of Om Oh)

Developed under prolonged but not permanent saturation of at least a portion of the profile, with F and H horizons accounting for at least 50% of the total thickness of organic horizons. **Material groups are not shown in these examples, but they should be recorded for Hydromors.**

O Hydromor



Horizon sequence: (L F H) Of Om Oh

Developed under permanent saturation of at least a portion of the profile, resulting in poor aeration, with the O horizons accounting for at least 50% of the total thickness of organic horizons. **Material groups are not shown in these examples, but they should be recorded for O Hydromors.**

FOREST FLOOR RECOVERY INDEX

Purpose of the FFRI

The FFRI is simple to calculate and uses reference data that allow reclamation sites to be compared with natural sites with regard to dominant materials (indicating whether organic material inputs are similar), dominant horizons (indicating whether rates of decomposition and nutrient cycling are similar), and thickness (indicating whether the balances of accumulation and decomposition are similar).

How to summarize site data

This manual provides FFRI tables for the most commonly occurring ecosites in the Boreal Mixedwood, with information about the percentage of wood-dominated samples, the percentages of F and H Mors, and the average thickness of samples at reference sites.

The FFRI allows users to compare data from their reclamation sites with data from forest stands initiated by natural disturbance. To summarize data for comparison with the index tables, users must complete the following steps:

1. Complete the data sheet (a blank data sheet can be found on page 21).
2. Calculate the average thickness of the forest floor at the reclamation site.
3. Calculate the percentage of woody and mixed material groups.
4. Calculate the percentage for each of the F Mors, FH Mors, and H Mors.

An FFRI app is also available (URL on page vi). As each sample is entered into the app, an index score and woody biomass input guidelines are calculated automatically.

Site name: Example Site

Ecosite: a Years since reclaimed: 14 Surveyor(s): AB Date (dd mm yy): 24-09-16

Material group, Horizon group	Thickness (cm)	Comments
Woody F Mor	5	lichen and moss
New L Mor	2	
Woody FH Mor	7	
Woody H Mor	7	
Woody FH Mor	5	
Ordinary H Mor	8	old stumps - burned, charcoal
Woody F Mor	7	
Woody FH Mor	6	exposed roots
Mixed H Mor	4	
Ordinary L Mor	2	
Woody F Mor	5	
Woody F Mor	7	
Woody H Mor	7	

Average thickness: 5.5cm Percent woody and mixed: 77 Percent F: 31 Percent FH: 23 Percent H: 31

How to use the FFRI tables

A separate index table was developed for each ecosite. Each index table is organized into columns by forest stand age class (0–5 years through 76–100 years), corresponding to the number of years since reclamation, and into rows according to index score. A site may be assigned an index score of 1 (meeting forest floor recovery objectives), 2 (somewhat meeting forest floor recovery objectives), or 3 (not meeting forest floor recovery objectives).

The values in each cell represent the minimum requirements that must be met or exceeded to obtain the corresponding index score.

- The first value, **Woody and Mixed**, is the minimum **percentage** of woody and mixed samples calculated for your site (see pages 47 and 48).

- The second, paired values, **F** and **H**, are the minimum **percentages** of F Mors and H Mors calculated for your site. **The percentage of FH Mors on your site can be added to the percentages of F Mors or H Mors to help meet the minimum requirements.**

- The third value, thickness in centimeters (**cm**), is the minimum **average thickness** of the samples, calculated for your site.

Steps in determining an index score

1. Select the table for your target ecosite and identify the age-class column matching the number of years since reclamation of your site. For the example on page 48 of an "a" ecosite 14 years after reclamation, we use the "a - lichen" index table and the "6–15 years" column.

2. Compare your calculated percent woody and mixed, percent F, and percent H values to those in the index table (remember that the percent FH can be added to the percent F and/or percent H). Compare your calculated average thickness value to the thickness presented in the index table.

3. If all of your calculated values are equal to or greater than the values corresponding to a score of 1, that is your score. If your values are less than the values required for a score of 1, but equal to or greater than the values for a score of 2, that is your score. If any of your values are less than those corresponding to a score of 2, your score is 3.

The example on page 48 has an average thickness of 5.5 cm, percent woody and mixed of 77%, percent F of 31%, and percent H of 31%. The example meets the requirements for a score of 1.

Score	0–5 years	6–15 years	16–40 years	41–75 years	76–100 years
1	0% Woody and Mixed 0% F, 0% H 1 cm	35% Woody and Mixed 0% F, 30% H 2 cm	20% Woody and Mixed 20% F, 0% H 4 cm	15% Woody and Mixed 10% F, 0% H 3 cm	15% Woody and Mixed 35% F, 0% H 4 cm

"a - lichen" index table

"a" ecosites (lichen) have jack pine as the leading species. Commonly encountered species in the understory include reindeer lichen, Schreber's moss, and blueberry. Sites are xeric or subxeric with poor nutrient regimes and sandy textured, rapid- to well-drained soils (Beckingham and Archibald 1996).

Score	0–5 years	6–15 years	16–40 years	41–75 years	76–100 years
1	0% Woody and Mixed 0% F, 0% H 1 cm	35% Woody and Mixed 0% F, 30% H 2 cm	20% Woody and Mixed 20% F, 0% H 4 cm	15% Woody and Mixed 10% F, 0% H 3 cm	15% Woody and Mixed 35% F, 0% H 4 cm
2	Site does not meet the criteria to obtain a score of 1.	15% Woody and Mixed 15% F and H 1 cm	10% Woody and Mixed 10% F and H 2 cm	5% Woody and Mixed 5% F and H 1 cm	5% Woody and Mixed 15% F and H 2 cm
3	A score of 3 does not apply to this age-class for "a" ecosites.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.

"b - blueberry" index table

"b" ecosites (blueberry) tend to have aspen as the leading species but may have white spruce or jack pine as a coleading or leading species. Commonly encountered species in the understory include blueberry, bearberry, and Schreber's moss. Sites are subxeric or submesic with poor or medium nutrient regimes and sandy or sandy loam textured, well-drained soils (Beckingham and Archibald 1996).

Score	0–5 years	6–15 years	16–40 years	41–75 years	76–100 years
1	25% Woody and Mixed 0% F, 0% H 5 cm	15% Woody and Mixed 15% F, 5% H 3 cm	20% Woody and Mixed 0% F, 0% H 2 cm	5% Woody and Mixed 0% F, 0% H 4 cm	30% Woody and Mixed 15% F, 15% H 8 cm
2	10% Woody and Mixed 0% F and H 2 cm	5% Woody and Mixed 10% F and H 1 cm	10% Woody and Mixed 0% F and H 1 cm	0% Woody and Mixed 0% F and H 2 cm	15% Woody and Mixed 15% F and H 4 cm
3	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.

"c - Labrador tea–mesic" index table

"c" ecosites (Labrador tea) have jack pine as the leading species and have a secondary canopy of black spruce. Commonly encountered species in the understory include Schreber's moss, Labrador tea, and bog cranberry. Sites are mesic or submesic with poor nutrient regimes and sandy to loamy textured, well-drained soils (Beckingham and Archibald 1996).

Score	0–5 years	6–15 years	16–40 years	41–75 years	76–100 years
1	25% Woody and Mixed 0% F, 0% H 5 cm	45% Woody and Mixed 35% F, 35% H 5 cm	35% Woody and Mixed 20%F, 15% H 5 cm	30% Woody and Mixed 5% F, 0% H 5 cm	20% Woody and Mixed 30% F, 0% H 5 cm
2	10% Woody and Mixed 0% F and H 2 cm	20% Woody and Mixed 35% F and H 2 cm	15% Woody and Mixed 15% F and H 2 cm	15% Woody and Mixed 0% F and H 2 cm	10% Woody and Mixed 15% F and H 2 cm
3	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.

"d1 - low-bush cranberry Aw" index table

"d1" ecosites (low-bush cranberry Aw) have aspen as the leading species. Commonly encountered species in the understory include prickly rose, low-bush cranberry, and marsh reed grass. Sites are mesic with medium nutrient regimes and fine-textured, moderately well-drained soils (Beckingham and Archibald 1996).

Score	0–5 years	6–15 years	16–40 years	41–75 years	76–100 years
1	0% Woody and Mixed 0% F, 35% H 3 cm	5% Woody and Mixed 0% F, 0% H 3 cm	0% Woody and Mixed 0% F, 0% H 2 cm	30% Woody and Mixed 0% F, 0% H 5 cm	45% Woody and Mixed 15% F, 50% H 11 cm
2	0% Woody and Mixed 15% F and H 1 cm	0% Woody and Mixed 0% F and H 1 cm	0% Woody and Mixed 0% F and H 1 cm	15% Woody and Mixed 0% F and H 2 cm	20% Woody and Mixed 30% F and H 5 cm
3	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.

"d2 - low-bush cranberry Aw-Sw" index table

"d2" ecosites (low-bush cranberry Aw-Sw) have aspen as the leading species with white spruce as a secondary canopy. Commonly encountered species in the understory include stair-step moss, low-bush cranberry, and prickly rose. Sites are mesic with medium nutrient regimes and fine-textured to loamy, moderately well-drained soils (Beckingham and Archibald 1996).

Score	0–5 years	6–15 years	16–40 years	41–75 years	76–100 years
1	15% Woody and Mixed 5% F, 5% H 2 cm	35% Woody and Mixed 0% F, 50% H 12 cm	50% Woody and Mixed 30% F, 30% H 5 cm	50% Woody and Mixed 0% F, 30% H 4 cm	50% Woody and Mixed 0% F, 25% H 8 cm
2	5% Woody and Mixed 5% F and H 1 cm	15% Woody and Mixed 25% F and H 6 cm	25% Woody and Mixed 30% F and H 2 cm	25% Woody and Mixed 15% F and H 2 cm	25% Woody and Mixed 10% F and H 4 cm
3	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.

"d3 - low-bush cranberry Sw" index table

"d3" ecosites (low-bush cranberry Sw) have white spruce as the leading species. Commonly encountered species in the understory include stair-step moss, Schreber's moss, and twin-flower. Sites are mesic or subhygric with medium nutrient regimes and fine-textured, moderately well to well-drained soils (Beckingham and Archibald 1996).

Score	0–5 years	6–15 years	16–40 years	41–75 years	76–100 years
1	15% Woody and Mixed 5% F, 15% H 3 cm	65% Woody and Mixed 0% F, 45% H 10 cm	65% Woody and Mixed 30% F, 30% H 11 cm	55% Woody and Mixed 0% F, 15% H 9 cm	50% Woody and Mixed 5% F, 20% H 11 cm
2	5% Woody and Mixed 10% F and H 1 cm	35% Woody and Mixed 25% F and H 5 cm	30% Woody and Mixed 30% F and H 5 cm	25% Woody and Mixed 5% F and H 4 cm	25% Woody and Mixed 15% F and H 5 cm
3	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.

"e - dogwood" index table

"e" ecosites (dogwood) have balsam poplar, aspen, and/or white spruce as the leading, coleading, or secondary canopy species. Commonly encountered species in the understory include dogwood, prickly rose, and low-bush cranberry. Sites are subhygric with rich nutrient regimes and fine-textured, imperfectly drained soils (Beckingham and Archibald 1996).

Score	0–5 years	6–15 years	16–40 years	41–75 years	76–100 years
1	30% Woody and Mixed 0% F, 30% H 2 cm	45% Woody and Mixed 0% F, 65% H 6 cm	45% Woody and Mixed 5% F, 5% H 5 cm	30% Woody and Mixed 0% F, 30% H 7 cm	45% Woody and Mixed 0% F, 30% H 7 cm
2	15% Woody and Mixed 15% F and H 1 cm	20% Woody and Mixed 30% F and H 3 cm	20% Woody and Mixed 5% F and H 2 cm	15% Woody and Mixed 15% F and H 3 cm	20% Woody and Mixed 30% F and H 3 cm
3	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.

"f - horsetail" index table

"f" ecosites (horsetail) have white spruce, balsam poplar, and/or aspen as the leading, coleading, or secondary canopy species. Commonly encountered species in the understory include horsetail (common and meadow), stair-step moss, and marsh reed grass. Sites are hygric with rich to very rich nutrient regimes and fine-textured, imperfectly drained soils (Beckingham and Archibald 1996).

Score	0–5 years	6–15 years	16–40 years	41–75 years	76–100 years
1	55% Woody and Mixed 5% F, 40% H 17 cm	65% Woody and Mixed 25% F, 35% H 11 cm	20% Woody and Mixed 0% F, 5% H 14 cm	30% Woody and Mixed 5% F, 0% H 10 cm	30% Woody and Mixed 0% F, 0% H 27 cm
2	25% Woody and Mixed 20% F and H 8 cm	30% Woody and Mixed 25% F and H 5 cm	10% Woody and Mixed 0% F and H 7 cm	15% Woody and Mixed 0% F and H 5 cm	15% Woody and Mixed 0% F and H 13 cm
3	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.

"h - Labrador tea/horsetail" index table

"h" ecosites (Labrador tea/horsetail) have white spruce as the leading species and have a secondary canopy of black spruce. Commonly encountered species in the understory include moss (stair-step and Schreber's), Labrador tea, and horsetail (common, meadow, and woodland). Sites are hygric with rich to very rich nutrient regimes and fine-textured, imperfectly drained soils (Beckingham and Archibald 1996).

Score	0–5 years	6–15 years	16–40 years	41–75 years	76–100 years
1	55% Woody and Mixed 0% F, 5% H 20 cm	45% Woody and Mixed 0% F, 45% H 21 cm	35% Woody and Mixed 0% F, 20% H 19 cm	20% Woody and Mixed 0% F, 0% H 17 cm	0% Woody and Mixed 0% F, 0% H 12cm
2	25% Woody and Mixed 0% F and H 10 cm	20% Woody and Mixed 20% F and H 10 cm	15% Woody and Mixed 10% F and H 9 cm	10% Woody and Mixed 0% F and H 8 cm	0% Woody and Mixed 0% F and H 6 cm
3	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.	Site does not meet the criteria to obtain a score of 1 or 2.

WOODY BIOMASS INPUT GUIDELINES

Why woody inputs?

The forest floor develops through the accumulation of organic material from foliage, roots, branches, dead moss, and stem wood from trees and other plants. Its structure and decomposition depend on both the relative amounts of these inputs and the functioning of the decomposer community residing in the forest floor.

In the boreal forest, decomposition is generally slow, productivity relatively low, and disturbance frequent. This combination results in significant amounts of woody material accumulating in the forest floor, which influences temperature, moisture, biodiversity (aboveground and belowground), and carbon storage. To restore reclamation sites to a state similar to that of natural sites, additions of woody material at rates similar to those of natural sites are necessary. **We used the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3, Kurz et al. 2009) to estimate tree biomass inputs required to build natural forest floors. Our recommendations in this section are not based on field data.**

Woody biomass inputs: definitions

CBM-CFS3: The Carbon Budget Model of the Canadian Forest Sector is a stand- and landscape-level modeling framework that simulates the dynamics of forest carbon stocks. The following definitions are consistent with the usage of terms in the CBM-CFS3.

Living woody biomass: All woody material contained in standing live trees.

Merchantable wood: Live tree stem wood with a diameter ≥ 9 cm. This becomes coarse woody debris (defined below) when a tree dies.

Other wood: Living branches, bark, and smaller woody material (diameter < 9 cm). This becomes small and fine woody debris (defined below) when a tree dies or parts of a tree fall to the ground.

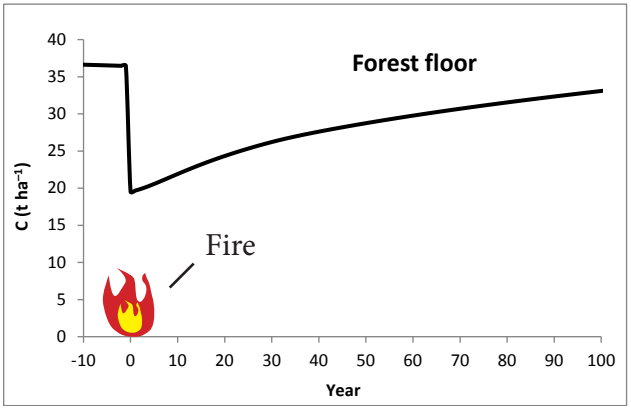
Dead wood: Any woody material that is no longer living. In this section, dead wood refers specifically to dead woody material, either fallen to the ground or standing as snags.

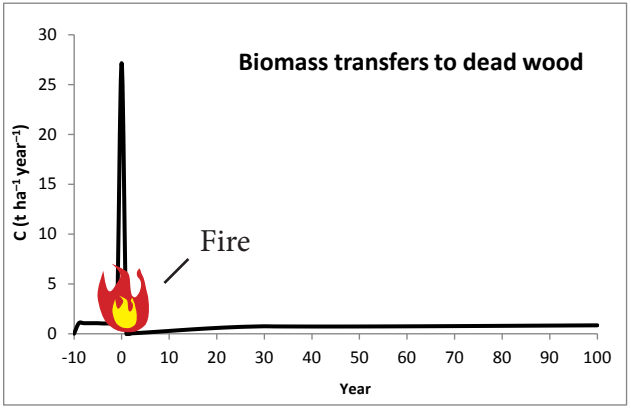
Coarse woody debris (CWD): Dead merchantable wood on the ground.

Small/Fine woody debris (SFWD): Dead branches, bark, and smaller woody material (corresponding to other wood) on the ground.

Input volume per hectare: The volumes per hectare ($m^3\ ha^{-1}$) of coarse woody debris and small/fine woody debris needed to build a forest floor.

Forest floor and woody biomass dynamics after fire





Transfers of carbon from live to dead woody biomass were modeled using the CBM-CFS3 for 0 to 100 years after fire disturbance.

Modeled values were used to calculate the volumes per hectare ($m^3\ ha^{-1}$) of merchantable and other woody material contributing CWD and SFWD to the forest floor.

The graph on the upper left shows how carbon accumulates in the forest floor over 100 years after fire disturbance. The graph on the lower left shows the transfers of carbon from live to dead wood in the forest floor over the same period.

How to read the woody biomass input guidelines table

The woody biomass input guidelines table (page 66) presents four values for each ecosite.

- The **volume coarse wood** columns contain values of CWD ($m^3\ ha^{-1}$) needed to simulate natural carbon transfers from live to dead wood in the merchantable wood pool.

- The **volume small/fine wood** columns contain values of SFWD ($m^3\ ha^{-1}$) needed to simulate natural carbon transfers from live to dead wood in the other wood pool.

Woody biomass input guidelines table

Ecosite	Volume coarse wood ($m^3\ ha^{-1}$)	Volume small/fine wood ($m^3\ ha^{-1}$)
a	76	46
b	98	56
c	75	46
d1	116	71
d2	114	66
d3	23	23
e	58	46
f	59	47
h	24	24

How to calculate input volumes according to index score

The woody biomass input guidelines table presents recommended input volumes per hectare for the range of ecosites covered in the FFRI.

We recommend that coarse and small/fine woody debris be added to all sites during reclamation according to the "volume coarse wood" and "volume fine wood" in the woody biomass input guideline table. Use the values appropriate to the target ecosite.

Recommendations for further additions of coarse and fine woody debris depend on a site's index score.

- **For sites with an index score of 1,** no further additions are necessary.

- **For sites with an index score of 2,** we recommend further additions of coarse and small/fine woody debris between 25% and 50% of values in the columns for both "volume coarse wood" and "volume small/fine wood."

- **For sites with an index score of 3,** we recommend further additions of coarse and small/fine woody debris greater than 50% of values in the columns for both "volume coarse wood" and "volume small/fine wood."

Examples of input volumes per hectare

These images may be used as a visual guide for woody debris application rates.

Source: Pyper, M.; Vinge, T. 2013. A visual guide to handling woody materials for forested land reclamation. University of Alberta, School of Energy and the Environment, Oil Sands Research and Information Network, Edmonton, AB. Rep. No. TR-31. 10 pp. Used with permission.

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ACKNOWLEDGMENTS

This project was funded by the Program of Energy Research and Development and supported with inventory data provided by Alberta-Pacific Forest Industries Inc. We acknowledge COSIA (Canada's Oil Sands Innovation Alliance) for their contribution to this project. We thank Ruth Errington, Ken Baldwin and Murray Riddell for reviewing an earlier draft of the manual. We thank Brenda Laishley for encouraging us to produce a second edition and for guidance on all aspects of the manual and app production.