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Studies of Boreal Peatland Ecosystems
in Britain and Newfoundland

by

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A thesis submitted
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy -
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Abstract

Using the Zurich-Montpellier survey methods, 12 peatland associations were determined from Central Newfoundland and positioned along an ombrotrophic-minerotrophic gradient. For the major associations, regional floristic differences are discussed and comparisons made with their analogous vegetation units in Northern Europe. The widespread occurrence of the associations Kalmiето-Sphagnetum_fusci (raised bogs) and Calamagrostiето-Sphagnetum_fusci (fen hummocks), in the study region indicate more continental conditions than experienced elsewhere on the Island.

Analysis of nutrient status and related physical peat characteristics were undertaken for each major peatland type, with results showing a correlation between the underlying peat substrata and species composition of vegetation layer, particularly through total Ca, N, Fe, Mn and available Ca concentrations. The potential of peatland utilization in Newfoundland is discussed, and a field key for detection of associations is provided.

A more intensive site analysis, emphasizing production and mineral distribution within delineated vegetation units was undertaken on Moorthwaite Moss, a small bog in Northwestern England. The vegetation units are described using Z-M techniques, and physio-chemical properties determined from related peat substrata. Production analyses included estimates of peak standing crop from 7 vegetation units. Individual species performance, taken as a measure of one

years growth, was determined for dominant mosses. Because of its dominance, Sphagnum recurvum studies were stressed. It was found that its growth ranged in mean length from 3.5 cm/plant (fen site) to 7.5 cm/plant (bog hollows) and in mean weight from 18.0 mg/plant (fen) to 36.0 mg/plant (bog mat). Estimates of standing crop and/or net annual production were assessed for herbs Narthecium ossifragum, Eriophorum angustifolium, Eriophorum vaginatum and shrubs Calluna vulgaris, Erica tetralix and Vaccinium myrtillus.

Nutrient concentrations within the main plant groups, mosses, herbs and shrubs, were determined. It was found that each group differs greatly in their demands on particular nutrients. It was further noted that a close relationship exists between nutrient content in certain plant tissues and available nutrient supplies in corresponding peat substrata.

To whom it may concern:

I hereby certify that this dissertation, submitted in candidature for the degree of Doctor of Philosophy of the University of Durham, has not been submitted in substance for any degree and is not being submitted for any other degree. This dissertation is the result of my own investigation and any assistance I have received is given in Acknowledgements on the following page.

Frederick C. Platt
..... Candidate

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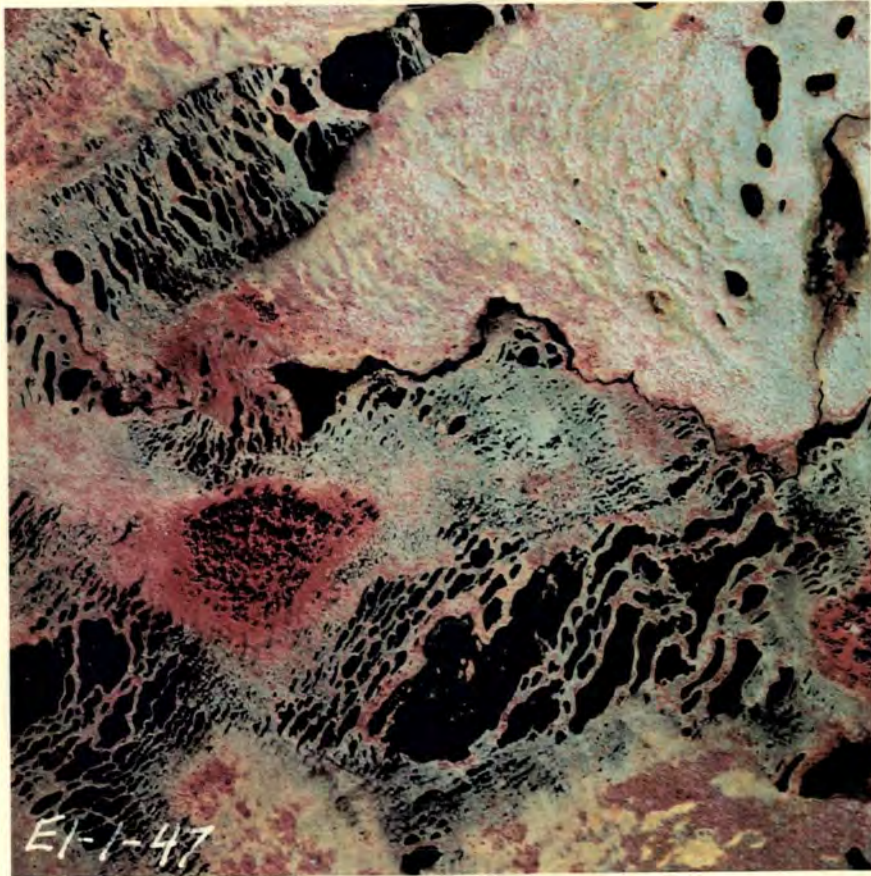
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- B: Tables 3-1 to 3-6: Vegetation tables for Moorthwaite Moss.
- C: Tables 3-8 and 3-9: Physical and chemical properties of peat soils on Moorthwaite Moss.
- D: Tables 3-10 and 3-11: Standing crop and biomass estimates for vegetation units on Moorthwaite Moss.



Ektachrome infrared aerial photograph of bog and fen vegetation in Newfoundland. Scale 1:5,000

On boreal peatlands:

"A biological material, in itself tending to disperse at random, is forced into a pattern of high mechanical precision by the ecological action of external forces and internal transformation."

Hugo Sjors, 1961



SECTION 1
INTRODUCTION

INTRODUCTION

Although extensive peatland research and utilization of peat resources is characteristic of both European and Russian plant ecological schools, the converse is true in North America, where peatland, the dominating northern landform has, until recently, attracted little attention in comparison with other terrestrial ecosystems. Now, with the focus directed toward use of northern resources and the development of more ecologically orientated programmes in forestry and agriculture there is a growing interest in problems revolving around multiple use classification and utilization of peatlands. Yet within the scant knowledge and data obtained to date, any immediate wide scale use of peatland on a 'hit or miss' approach would almost assuredly be disastrous both ecologically and economically.

In Canada there are an estimated 500,000 square miles of peatland (Radforth, 1968), 25 million acres excluding muskeg (Tibbetts, 1970) and in the United States there are an additional 140 million acres (Leake, 1951). The work embodied in this thesis is a broad based study of certain aspects of the ecology of peatlands which is aimed at providing a background for the wide ranging ecological research which is essential if resource potential of these Canadian peatlands is to be realized. The study had three main objectives:



1. To test the Zurich-Montpellier methods for the classification of peatlands which would be adaptable for large scale mapping.
2. To determine the ecological parameters pertinent to the units of classification which could give an insight into most appropriate land use, particularly in relation to forestry.
3. To test methods which might aid in determining the natural potential of a site through measurement of production, standing crop and nutrient contents of species comprising communities.

SITES SELECTED FOR INVESTIGATION:

In Figure 1-1 the study sites are shown. They are wide ranging both in habitat and space, yet linked by bonds common to maritime boreal environment. Newfoundland was selected because it contains a vast peatland expanse of more than 2,500,000 ha (5,000,000 acres), almost entirely virgin; and because of recent interest in using peat resources for peat moss, agricultural and forest based industry. Other than slight drainage near highways, none of the selected sites have been disturbed by man.

Moorthwaite Moss, a small bog in Northwest England was selected for production and nutrient studies. This bog is partially covered by a well developed pine forest which represents the most

recent stage of a hydrosereal succession. Such sites are not found in Newfoundland, where succession of bogs leads to a poorly developed spruce scrub cover. The site was also chosen because it had been previously disturbed by peat harvesting and has been somewhat influenced by local agronomy and nearby industrialization.

Results and discussions are presented in four sections as follows:

Section 1 - Introduction

Section 2 - Classification and nutrient status of the
peatlands in Central Newfoundland

Section 3 - Production and nutrient contents of vegetation
on Moorthwaite Moss

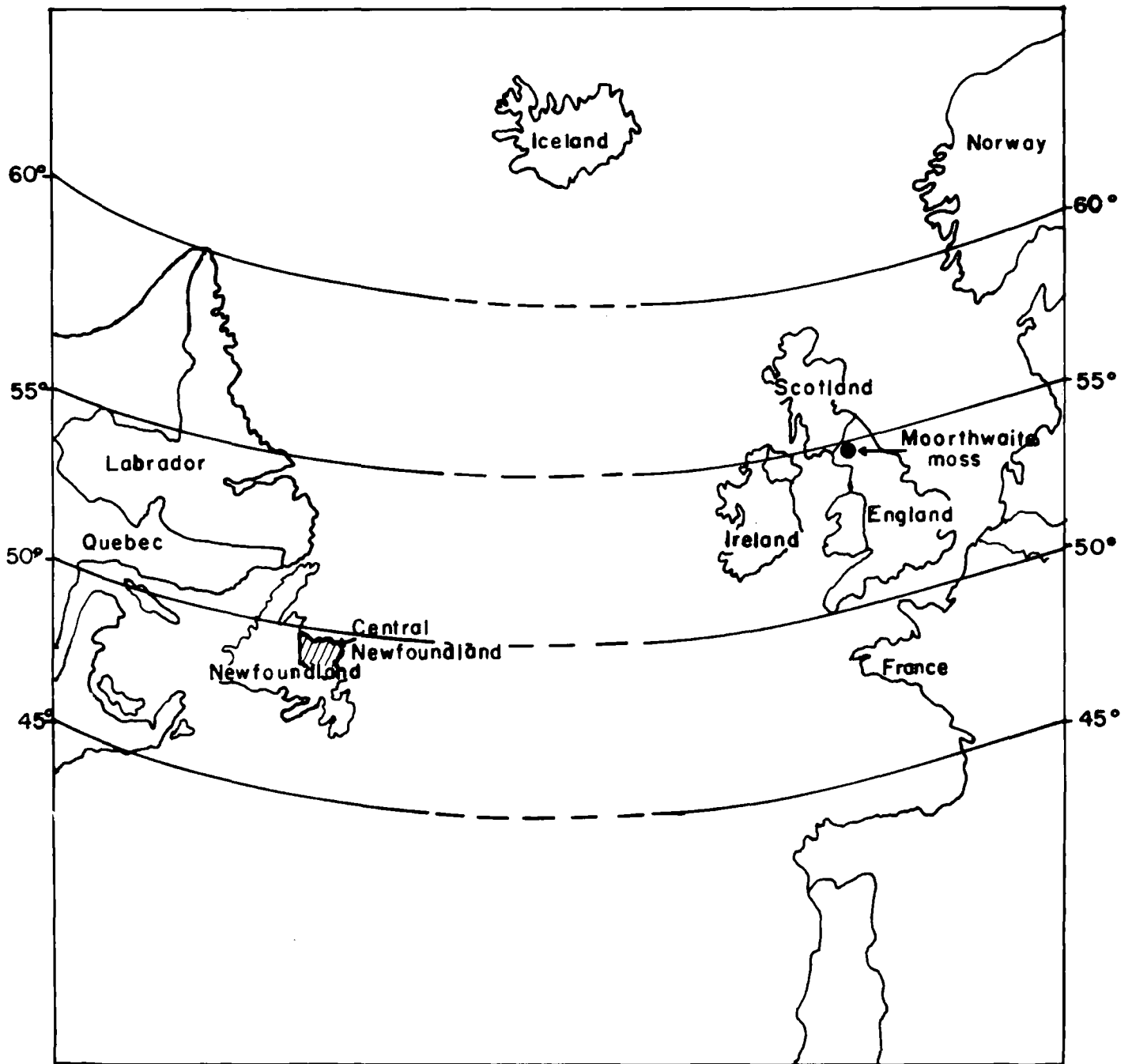
Section 4 - Summary and Conclusions

TERMINOLOGY:

Although the extent of peatland literature is vast, an attempt has been made to "filter out" relevant segments which are pertinent to this research and may provide a background for the scientist and non-specialist who are recently caught in the emerging field of peatland ecology in North America.

One of the primary barriers to transatlantic understanding of peatland ecology is the unsettled state of terminology. Authors in each geographic area have developed their own classification using similar terms to suit their particular purpose. Adoption of terms from one phytogeographic region to another or across disciplines is

Fig. 1-1. Location of study sites in Newfoundland and England.



thus both difficult and generally detrimental to the development of a universal terminology. Consequently, terms used in different classifications evolve within the framework of each classification destroying their potential widespread application.

Furthermore, the literature lacks any standardization for existing terms. For example, 'organic terrain', 'muskeg', and 'peatland' are incorporated into North American literature as meaning - all peat deposits. In Finland 'swamp' is the accepted term; in Sweden and Middle Europe 'mire' is most common. 'Myr', 'moor', 'bog' and 'bogland' are also used in the same context. In this investigation the term 'peatland' is used throughout.

Conversely, many terms are each given numerous definitions. 'Bog' is a prime example defined by Gates (1942) as an invading mat over a body of water. Radforth (1964) defines bog simply as an area of confined organic terrain but does not qualify it from other peatland types. Sjors (1960) and Damman (1964a) emphasize the floristic constituents whereas Pyvachenko (1963) states that both botanical and geological principles should be incorporated into the definition. The researcher must utilize each term in a prescribed context and clarify where ambiguity is probable.

Sjors (1959) having intensively investigated peatland ecosystems in both Northern Europe and North America states: "It would seem worthwhile to try a direct application of concept and terms developed in Europe, notably in Scandinavia, to boreal and subarctic Canadian peatlands." Most of the terms used in the text are based on their European definition. Glossaries compiled by Drury (1956),

Heinselman (1963) and Pollett (1968) are used in much of the peatland research conducted in North America. A glossary by Tuomikoski et al. (1955) is also popular because of its use of four languages.

PEATLAND CLASSIFICATION:

Man's insatiable need to classify transcends many boundaries and peatlands are not excepted. Programmes are currently underway in Canada aimed at indepth classification of land systems through a biological approach (Jurdant 1968, 1969; Zoltai and Adams, 1969; Rowe, 1971). Peatlands comprise an integral portion of the majority of such systems and a need for an adaptable classification suited to such study is evident. To aid this research and to place the present investigation in its proper context the following review on the development of peatland classifications is provided.

In many of the early botanical writings reference is made to peatlands. Dallas (1967) notes that John Leland in 1535 coined the familiar terms 'moor', 'moss', 'marsh' and 'fen'. Furthermore, according to Dallas, Gerard Boate, 1652, presented a classification of Irish bogs. Other historical references in peatland literature are referred to by Gorham (1957).

Although numerous peatland classifications have developed in the past 300 years, there is still no universally accepted system. Indeed, the trend in such classification is based on regional differences and the purpose for its establishment. However, despite inherent differences three basic approaches in peatland classification are evident and underlie much of current peatland research. These approaches are:

Morphological - involving the peatland complex

Phytosociological - involving subunits of the complex

Ecological - the linking theme, involving ecological parameters

In any particular classification more than one approach may be taken, yet the individual units can be related to one system.

Morphological:

Underlying the criteria on which selection of peatland complexes are based is the geomorphological concept of land systems which provides a generic approach to land classification. Cajander (1913) provided the first comprehensive work on peatland complexes with his description of the Finnish 'moorkomplextypen' based on the morphology and surface features of the peatland over wide geographical areas. Four main complexes were proposed, which are as follows:

Raised	}	based on climate
Aapa		
Palsa		
Carelian		based on topography

Auer (1920) extended this to include an important variant of the aapa bog complex formed by fen on hill slopes in Eastern Finland - termed Hill Slope Bog Complex. Ruuhijarvi (1960), in a more comprehensive analysis of the 'moorkomplextypen' subdivided the Aapamoor into three distinct types from north to south on basis of surface patterns. Also, Euroala and Ruuhijarvi (1961) subdivided the raised bogs into three zones; coastal, central and Lapland raised bogs. In general, the Ruuhijarvi (1960) concluded that isothermal lines separated the raised, aapa and palsa zones.

The value of a wide-scale morphological classification is evident in preparation of small scale maps and indeed in ecological interpretation. The Finnish approach has also been used by Drury (1956) in North America and more so in Russia by Boch (1963), Boch and Jurkovskaja (1964) for aapamoor classification and Kats (1962) in raised bog classification in Northern Russia. Nitsenko (1960, 1962) suggested the widespread use of the Finnish 'moorkomplextypen' for Russian peatland classification.

Du Rietz (1954) presented a classification which dealt with the main formation of boreal peatland subdivided into two main units, the bog formation and the fen formation. The bog was further divided into four subtypes: the ledum pine bog and three specific regional peatland complexes.

Tansley (1939) determined four peatland formations for the British Isles: marsh, bog, fen and marsh. The bog formation was further divided into raised, valley and blanket bog. However, unlike more continental classifications, the British system is not clearcut, primarily due to climatic variation and associated hydrotopographic differences. Burnett (1964), commenting on Scottish vegetation, stated that one of the major classification problems was clarification of what constituted swamp, bog, fen and mire. Spence (1964) lumps Tansley's fen, marsh and much of the valley bog into a single fen unit. Ratcliffe (1964) proposed use of bog (raised and blanket bog), mire (soligenous bog), springs and flushes as main morphological units.

For the Irish peatlands the categories raised bog and blanket bog were suggested by Barry (1954) in addition to a montane subtype, the high-level blanket bog. This superceded an earlier

system of Jessen (1949) who had subdivided Irish peatlands into topogenous and paludification bogs based on Von Post's (1937) theories.

Concurrent with Barry's work, Fraser (1954) proposed a new basis for peatland classification aimed at clarification of existing systems and could be used for peatlands in general. The categories proposed were:

Climatic or Zonal Bog - Ombrogenous

- deposits widely distributed zonally in association with wet cool temperate, subarctic maritime or montane climatic zones.

(i) Blanket Bog

- a) of cool temperate regions formed under maritime climate at lower elevations
- b) bogs of hill and montane plateaux
- c) bogs of subarctic climate in Tundra
- d) Arctic alpine bogs

Intrazonal (Topogenic) Bog - Minerotrophic

(i) Basin Bog

- a) lake basin peat and shallow lakes with swamp vegetation
- b) valley bog - typical vegetation of origin
- c) flush bog - mobile waters, slope peat

This system has not gained in popularity and has been critically assessed by Barry (1954) because of its reliance on climatic criteria which is not readily applicable to the Irish peatlands.

Phytosociological:

The phytosociological approach to peatland classification describes and delineates the peat forming communities which are supported by the peatland complex. This approach is based primarily on floristic attributes of the units. In Europe such systems were provided by Cajander (1913), Tansley (1939), Du Rietz (1954), Nordhagen (1936, 1943) and Braun-Blanquet (1932).

Cajander's (1913) treatise describes the phytosociological subunits of the 'moorkomplextypen' and terms them 'moortypen'. In all the 'moortypen' includes four main types each with numerous subdivisions; these are:

Weissmoore - dominated in the field layer by graminaceous plants, while in the bottom layer *Sphagna* and brown mosses dominate.

Braunmoore - similar to weissmoore but indicating a more calcareous influence.

Reisermoore - dominated in the field layer by dwarf shrubs with bottom layer dominated by *Sphagnum*.

Bruchmoore - peatlands having woody (tree) communities.

The underlying criterion of identification is based on the physiognomy of the dominants, however, complexity is found in separation of the more than seventy defined units. Kivinen (1948) and Lukkala-Kotilaisen (1951) closely adhered to Cajander's classification in their

attempt to establish units for agricultural and forestry interpretation. This led to a number of later simplified systems required to increase practicality for industrial purposes (Huikari, 1952, 1958; Heikurainen and Huikari, 1952; Heikurainen, 1960). As a result, four terms were devised to encompass both types and subtypes of the four major 'moortypen' groups.

- Korpi - spruce broad-leaved tree covered peatland or karr
- Rame - peatland dominated by ericaceous shrubs and pine
- Letto - rich treeless fens
- Neva - nutrient poor treeless fens

Lukkala and Kotilainen (1951) and Heikurainen (1960, 1964) have assigned potentials to each type site on the basis of suitability for agriculture and forestry. McEwen (1960) suggests using the Finnish system for industrial surveys in North America, however many of the Finnish units are not applicable to Canadian peatlands. Furthermore, McEwen does not include raised bogs, aapamoor or palsas in his discussion.

The theory of Hult, that plant communities could best be described and classified on the basis of plant physiognomy, led to the development of the well-known Uppsala school (Duffy, 1964). Primary contributions to peatland classification have stemmed from the Uppsala school led by Du Rietz (1949, 1954, 1957, 1964) and his students. Previous to this Swedish peatlands were examined from the botanic aspect only (Oswald, 1923; Malmstrom, 1923). Peatland contributions by some students of the school are those of Thunmark (1942, 1948); Witting (1947, 1949); Oswald (1949); Sjors (1952, 1956, 1961); Malmer (1958, 1962a, 1968); Mornsjo (1969); and Sonesson (1970).

Du Rietz' system divides peatland into bog and fen, as previously discussed, and these form the basis of the highest phytosociological units the Ombrosphagnetea and Sphagno-Drepanocladetea. The bog formation is comprised primarily of two main alliances, the Fuscion of the open bogs and the Parvifolion of the wooded bogs.

FUSCION

- Rubellion (open Komosse)
- Rubellion-Fuscion (open Skagershultmosse)
- Eufuscion (open Ryggmosse)

PARVIFOLION

- Parvifolion (Komosse)
- Ledo-Parvifolion (in other three types)

The alliances are further subdivided into associations and subassociations, in each alliance the hummock vegetation is united into one association and the hollow vegetation into another.

Plant communities of the fen formation have been delimited through differential species lacking in the bog formation and have been termed EUMINEROBIONTEN (Ackenheil, 1944), 'fen plants' (Sjors, 1946, 1948), 'exclusive fen plants' (Du Rietz, 1949, 1950), and 'Mineralbodenwasserzeiger' (Du Rietz, 1954). Thus one can say that bog communities are defined by negative criteria. Westhoff and Den Held (1969) object to this floristic boundary line because precipitation in oceanic areas can be so mineral-rich that ombrotrophic bogs occurring in these regions may show a number of species which are considered 'Mineralbodenwasserzeiger' in more continental climates. Fen formation

is divided on a regional basis each of which is subdivided into two main types:

APICULATION (poor fen)

- Euapiculation (extremely poor)
- Subsecundo-apiculation (moderately poor)

SCORPIDION (rich fen)

- Warstorffio-Scorpidion (moderately rich)
- Euscorpidion (extremely rich)

Malmer (1962a) also discusses the third main Scandinavian classification based on Nordhagen's (1936, 1943) system which is summarized here.

Nordhagen's system is founded principally on mountain peatland types. Other authors using this system are Kolliola (1939) and Persson (1961).

The classification consists of a number of well-defined alliances and their subdivisions. The main alliances are:

Caricion atrofuscae-saxatilis (rich fen)

Schoenion ferruginei (upland and lowland fens)

Caricion canescentis-Goodenowii (fen margin communities)

Stygio-Caricion limosae (communities poor in species
with scattered mosses such as Scorpidium)

Leuco-Scheuchzerion (wet growing vascular plants and sphagna)

- Scirpeto-Eriophorion vaginati (less hygrophilous alliance)

- Cuspidato-Scheuchzerion (strongly hygrophilous alliance)

Nordhagen deals separately with the Sphagnum fuscum hummocks as the Oxycocco-Eupetition hermaphroditum.

The Nordhagen classification like the Cajander system does not take into account the clear-cut difference between ombrotrophic and poor minerotrophic vegetation. Also Sjors (1965) points out that the system does not make full use of the bottom layer as indicator species. As a result of this, Persson (1961) has difficulty in placing his Sphagnum riparium community and Sphagnum warnstorffianum-parvifolium community within the classification. Nordhagen's classification is not widely applied in peatland surveys today.

The Central and Western European countries have developed a classification of peatland based on criteria advanced through the Zurich-Montpellier (Z-M) school of phytosociology (Braun-Blanquet, 1932). This deviates from the Uppsala approach but the differences are probably overrated and direct comparisons can sometimes be made. In accordance with current European opinion the bulk of peatland vegetation is placed into two widely differing classes:

Scheuchzerio-Caricetea nigrae (= fuscae)

((Nordhagen, 1936) R. Tuxen, 1937)*

and

Oxycocco-Sphagnetea (Braun-Blanquet, 1951; Braun-Blanquet and Tuxen, 1952; Tuxen, 1955, 1961; Oberdorfer, 1957)

*References to established Z-M units are according to Westhoff and Den Held (1969).

In addition, by Scandinavian criteria, the classes Molinio-Arrhenatheretea (Oberdorfer, 1957); Vaccinietea uliginosi (Tuxen, 1955) and the alliance Magnocaricion (W. Koch, 1926) contain peatland communities of rich fen as well as wooded varieties of poor fen and bog types. Also the Oxycocco-Sphagnetea includes the wet heath vegetation of the alliance Ericion tetralicis (Schwickerath, 1940).

Duvigneaud (1949) as well as Westhoff (1947) unite the European peatlands into one class, the Sphagno-Caricetea fuscae Duvign. 1949 (= Caricetales uliginosae Br. Bl. and Vlieger, 1937); however, despite having a number of feature species this class is hardly defensible, particularly in Central Europe (Westhoff and Den Held, 1969). Malmer (1962) using this united class, suggests the union of the hummock alliance, Sphagnion europeum (Schwickerath, 1940), the wet heath, Ericion tetralicis and the Scheuchzerietalia palustris (Nordh., 1936) into the order Erico-Sphagnetalia would be comparable to the Ombrosphagnetea + Apiculation of Du Rietz' system with the exception of the Subsecundo-Apiculation. The latter with the Scorpidion would be similar to the Molinio-Caricetalia fuscae making up the remainder of Duvigneaud's Sphagno-Caricetea fuscae. Eventually Malmer (1968) suggested the erection of a separate class Caricetea limosa which would include the Molinietales (W. Koch, 1926) and Tofieldietalia (Preising after Oberd., 1949). In this way the rich fens could be united in a separate class without inclusion of the Scheuchzerietalia palustris.

Westhoff and Den Held (1969) also express dissatisfaction with the order Scheuchzerietalia palustris because it includes communities of the bog hollows in the Rhynchosporion albae (W. Koch, 1926) which are

primarily oligotrophic, in union with the more eutrophic Caricion lasiocarpae (Vanden Berghen, 1952), the latter being a link with the Tofieldietalia and Caricetalia nigrae (W. Koch, 1926). A large part of this union has hardly any class taxa with the exception of a few species of wide ecological tolerance. As a solution Westhoff and Den Held (1969) suggest that the oligotrophic hollow communities be placed in an autonomous class, the Scheuchzerietea, situated between the Parvocaricetea, in which they include the remainder of fens, and the Oxycocco-Sphagnetea. Although this proposed class is closely related to the Central European Parvocaricetea, it is more closely related to the Oxycocco-Sphagnetea in Scandinavian records (Sjors, 1948; Malmer, 1962).

Along with synsystematic changes in the hollow vegetation, the hummock classification is also of interest. The hummocks are divided according to geographical differentiation, but in recent studies on the synecology of the Oxycocco-Sphagnetea, Moore (1968) proposes an attempt be made to revert to an ecological-floristic subdivision of hummocks rather than the more recent geographical subdivisions of Schwickerath (1940). Specifically a change is suggested from the alliances Sphagnion atlanticum (Schwick., 1940) and Sphagnion continentale (Schwick., 1940) to Sphagnion magellanicum and Sphagnion fuscum respectively. Tuxen (1969), however, defends the geographic subdivision and suggests its retention.

The interrelationships of the Du Rietz and Z-M systems in peatland classification is of importance in that each has a vital function. The units within the Swedish system are almost directly

applicable to the present survey and run parallel with nutrient poor - nutrient rich gradient providing a floristic-ecological dichotomy. The Z-M system does not recognize the 'exclusive fen plant limit' and dwells on the floristic similarities. The latter relates well to overall vegetation comparisons and has a more universal applicability as will be discussed later. An example of this can be seen in the Magnocaricion of the class Phragmitetea (Tuxen and Preising, 1942) which is included in the fen vegetation by Du Rietz on environmental criteria but which, according to Westhoff and Den Held (1969) have hardly a single species in common with the nutrient poor fens.

The Z-M methodology today is probably the most universally adopted phytosociological technique used in wide-scale vegetation surveys and its popularity is now extending into anglo-american research (Bridgewater, 1970; Heinselman, 1970).

In the British Isles the phytosociological development within peatland classification was influenced by Tansley who described a number of associations comprising the fen and bog vegetation. The most prominent peatland communities are: Sphagnetum, Rhynchosporietum albae, Schoenetum nigricantis, Eriophoretum vaginati, Eriophoretum angustifolii, Molinietum caruleae, Scirpetum caespitosi and Alnetum glutinosae, all of which are primarily distinguished by their physiologically characterizing species. Tansley's (1939) classification is still used in Britain on restricted sites, but in many areas only with some difficulty (Chapman, 1964; Spence, 1964; Green and Pearson, 1968). Much less quoted is Oswald (1949) who conducted a wide-scale survey of the British peatlands using the Swedish system.

More recently the fen vegetation of Scotland has been described by Spence (1964) and grouped into three alliances:

Phragmitio-Acrocladion (moderately rich - rich fen)

Myrico-Caricion lasiocarpae (poor fen)

Schoenoplecto-Magnocaricion (swamp types)

Spence states that these groups should readily fit into the phytosociological classifications of Nordhagen (1943) and Duvigneaud (1949). The bog, mire, as well as springs and flushes, have been phytosociologically subdivided into six, thirteen and six communities by Ratcliffe (1964).

Both the Du Rietz and Z-M systems are being constantly modified by their proponents. For example, Sjors (1948, 1950, 1961a) suggests the use of 'directions of variation' founded on Tuomikoski's (1942) system to augment the bog and fen classification of Du Rietz. These 'directions' encompass the community types making up the major units and are arranged in series as follows:

For bog:

- (a) wooded hummock - woodless hummock - lawn - carpet - mud bottom

For fen:

- (a) mire expanse - mire margin - spring fen
- (b) hummock - lawn - magnocaricetum - carpet - mud bottom

Sjors does not stress the use of alliances and his delineated associations are arranged in a coordinatic scheme using the 'directions' or series as a framework.

Within the Z-M school as well emphasis has been taken from the use of higher units and placed on the presence of sociological and ecological species groups (Scamoni and Passarge, 1959; Doing, 1962) rather than conventional differential and characteristic species. Damman (1967) in his classification of forest types in Western Newfoundland arranges species according to their site preferences into ecological groups. In defining the floristic characteristics of the vegetation units Damman uses sociological species groups which include species which occur usually together but which do not necessarily have the same ecological amplitude.

Ecological:

Permeating all work on peatlands is the concept of Weber's (1908) Verlandungehypothese which recognizes three basic types (Bellamy, 1967). These types are listed below with their synonyms (after Bellamy, 1967).

Niedermoore ¹	Übergangsmoore	Hochmoore
Low Moor ²	Transition Moor	Highmoor
Flachmoore ³	Zwischenmoore	Hochmoore
Rikkarr ⁴	Karr	Mosse
Rich Fen ⁵	Poor Fen	Moss
Rheophilous Mire ⁶	Transition Mire	Ombrophilous Mire

1. Weber (1908); 2. Tansley (1949); 3. Potonie (1908);
4. Melin (1917); 5. Sjors (1948); 6. Kulczynski (1949).

Kulczynski (1949), on the basis of Weber's hypothesis, classified the peatlands of Poland on the ecological criterion of water movement in conjunction with the changes in vegetation through succession. In contrast, the previous classifications were ecological in reflection of mutual relationships between communities but based solely on natural vegetation. Kulczynski (1949) derived three groups of peatland systems:

A: Ombrophilous - (Hochmoore) - peatlands developing in immobile ground waters, their whole water table supply coming from the rain falling directly on them.

_____ Calcareous water limit, (Witting, 1967) _____

B: Transition - (Ubergangsmoore) - either ombrophilous peatlands which have recently changed their rheophilous water economy to an ombrophilous one or rheophilous peatlands with an insufficient terrestrial water supply.

_____ Mineral Soil water limit, (Thunmark, 1942) _____

C: Rheophilous - (Neidermoore) - peatlands developing in mobile ground waters.

Bellamy (1966, 1967, 1968) discusses the successional aspects of the peatland systems and through refinement established the basis of seven hydrological types which is suggested could have a universal distribution. Bellamy (1968) relates these seven hydrological types to Sjors' seven phytosociological peatland types previously determined from floristic and analytical data. Bellamy and Bellamy (1966) further utilize this method to classify the lowland peats of Ireland.

Weber's bog categories of highmoor, low moor, and transition moor have been widely adopted in industrial peatland surveys in Germany (Baden, 1954, 1964) and Russia (Pyvachenko, 1965) and in the United States (Dachnowski-Stokes, 1941; Waksman, 1943). In proposing a classification for the United States, Dachnowski-Stokes carried the ecological classification one step further by equating the terms oligotrophic, mesotrophic and eutrophic with highmoor, transition moor and low moor respectively. These terms have since become widely used in peatland investigations in reference to nutrient conditions. However, Heinselman (1970) presents a critical appraisal of these terms in favor of the Du Rietz' (1954) ecological separation of peatlands into ombrogenous and minerotrophic types.

Peatland Classification in North America:

Whereas the groundwork of peatland classification has long been established in European countries there is not, as yet, a foundation on which to develop a much-needed peatland classification system in North America. Many of the earlier investigations were confined largely to localized sites (Gagnon, 1898; Gates, 1914; Rigg, 1922a) and few works examined peatland on a geographical scale (Rigg, 1937, 1940; Transeau, 1903). Later descriptive monographs by Gates (1942) and Conway (1949) indicated the influence of Tansley (1939) and Clements (1928) through use of associations and their seral development. Most of the studies considered could be termed as morphological, phytosociological and/or ecological in approach. In addition, systems were developed by Radforth (1955, 1958) and Dansereau and Segadas-Vianna (1952) on basis of vegetation structure.

The peatland classifications utilizing primary morphological criteria were established by Radforth (1952, 1955, 1956, 1962, 1968a, 1969), Allington (1961), and Heinselman (1963). Radforth's system is based on the phenomenon of recurrent vegetative cover and the textures produced on aerial photographs taken at different altitudes. Descriptions of air-form patterns are provided using such terms as planoid (lacking textural features), vermiculoid (striated with feature markings tortuous), and polygoid (coarse textured, bearing polygons). Although of valuable use in engineering problems, especially transport, this classification imparts limited ecological information in its present state. Sjors (1963), referring to the Radforth system, states that such patterns cannot in themselves reveal the factors at work forming and arranging the elements of the pattern, and only when the pattern is understood ecologically will it make sense. This understanding could come from relating intensive ground investigation with aerial photography such as used by Allington (1961) and Ruuhijarvi (1960).

Allington (1961) attempted to classify the bogs of Central Labrador - Ungava according to their physiographic characteristics emphasizing the dominant vegetation forms which were related to air-form patterns. Elements of Radforth's (1955), Cajander's (1913) and von Post's (1937) theories were extracted and utilized in the investigation. It was concluded from the study that the bogs of Labrador could mostly be classified into five categories: string bog, closed strings, sedge meadow, spruce muskeg, and tamarack swamp forest.

In 1963, Heinselman developed a tentative classification of the peatland types for the Lake Agassiz Peatlands of Minnesota aimed at definition of classes which could be mapped using aerial photos supplemented by aerial reconnaissance and ground checking. The basis of the system was that each type could be separated on one or more of the following: water movement pattern, physical features, peat characteristics or natural vegetation. Heinselman (1970) recognized seven physical peatland types in the Lake Agassiz region ranging from minerotrophic swamp - string bog - ombrotrophic bog.

Phytosociological investigations of the peatland vegetation in North America are not infrequent in recent years. Sjors (1959, 1961a, 1961b, 1963) conducted an extensive investigation of the Hudson Bay Lowland Peatlands using the Du Rietz classification modified to emphasize Sjors' 'direction of variation' including differentiation between poor and rich fen vegetation. Other studies influenced by Scandinavian phytosociological approaches which have been conducted in North America are those of Auer (1920), Pollett (1967, 1968b), and Heikurainen (1968).

The Z-M methodology has also been used in surveys by Janssen (1967), Damman (1964, 1967), Heinselman (1970), Gauthier (1967), Stanek (1970), and Joyal (1970). Damman (1964, 1967) is primarily a forest classification, however, the associations Alneto-Piceetum and Alnetum rugosae do ally with the richer peatland types in Newfoundland. Janssen (1967) employed a modified approach combining species in sociological groups consisting of species with comparable ecological amplitude.

This is similar to detection of sociological groups by European phytosociologists (Doing, 1962). Janssen's work does lack a utilization of *Sphagna* or other non-vasculars as indicator species which may have aided in his stating that the peatlands conform to the continuum concept with no distinct community discontinuities. Furthermore, Janssen's erection of hierarchical units above the association level is probably premature in lieu of present status of peatland floristic analysis in North America. Heinselman (1970) described seven peatland vegetation types throughout a gradient from rich swamp forest to *Sphagnum* - leatherleaf - *Kalmia* - spruce heath on raised bogs. These units also lack preciseness because of the incomplete use of the bryophytes and lichens as indicator species.

Ecological approach to peatland classification in North America centers around the use of the terms oligotrophic, mesotrophic and eutrophic borrowed from limnology by Dachnowski (1925). According to Heinselman (1970) these terms are falling into disuse with respect to peatlands, however, the present literature survey found little evidence to support this and such terms were found to be useful in ecological site description.

Dansereau and Segadas-Vianna (1952) attempted a new approach to peatland classification of the St. Lawrence Lowlands based on vegetational structure, i.e. on growth forms according to habitat. Such structural investigations provide a work picture and, according to Dansereau (1957), probably rank before composition in description of a landscape. The principal advantage of this system is that little knowledge of the species composition of a site is necessary to produce

a description. Radforth (1961), on basis of this principal, contended that assessment of surface cover, if attempted on a species basis, may lead to bewilderment because too many species transgress micro-environments and consequently differing species or admixtures of species share similar environments. If, however, cover is assessed on a structural basis it characterizes environment. In all, nine classes of vegetative cover are given (MacFarlane, 1958) to depict 'muskeg' vegetation and these classes are combined to form a series of formula to account for any admixture of classes.

One other significant study on peatland in North America was conducted by Drury (1956) who attempted to describe the bogs and fens of Alaska. Although the investigation lacks uniformity because of the direct comparisons with both Du Rietz' and Cajander's systems it ranks high in discussion on the development and possible evolution of peatland types in the area.

PRESENT STUDY:

The peatland studies in North America are often ultra-regional, lacking in preciseness of phytosociological merit or are fragmented. Also little insight is given which might aid in selection of sites with potential for forestry utilization. It was therefore decided to select an area of virgin peatland with a high degree of site diversity and attempt description and classification using the methodology of the Zurich-Montpellier School.

In order to gain a basic knowledge of the ecology of the units recognized, examination of the nutrient status of their peat substrata was undertaken which could possibly provide the required parameters for estimating the site potential for forestry purposes.

The area chosen to test the classification was Central Newfoundland, selected because of its diversity of bog and fen types. In addition, this area has both continental and maritime affinities. Within the region, peatland complexes are common which embody a cross-section of peatland types from ombrotrophic raised bog to rich fen. Using such sites as focal points, conclusions could be attained concerning physical and chemical composition of the peats, which in all probability are pertinent to most bog and fen in the region.

SELECTION OF METHODS:

Today's phytosociologist can be mesmerized by the number of criticisms and refinements of methods available. The basic argument of classification versus ordination (Ramenski, 1930; Curtis and McIntosh, 1951; Bray and Curtis, 1957; McIntosh, 1967) is no longer black and white. Careful analysis of one process in relation to the other show that ordination and classification are not conflicting but rather complementary (van Groenewoud, 1965; Greig-Smith, 1964; Whittaker, 1967; Becking, 1968; Van der Maarel, 1969; Moore et al., 1970). The choice of systematic approach depends on the area investigated and the purpose of the investigation (van Leeuwan, 1966; Van der Maarel et al., 1964). A summary of many available methods and their probable use in phytosociology is given by Bridgewater (1970).

The techniques of the Zurich-Montpellier school of phytosociology are employed in this survey. This was chosen for many reasons. Primary of these was the need of a method that is flexible, adaptable to large scale rapid surveys, and with a high degree of ecological validity. According to Van der Maarel et al. (1964) peatland is susceptible to classificatory techniques. Also although a hierarchical or dendritic system of classification is not so much justified by nature itself, such a system with higher and lower units better answers our needs of speech and thought than a system of units arranged in ecological series or in a system of coordinates (Damman, 1964a; Tuomikoski, 1942). In addition, the Z-M system is primarily an edaphic-ecological classification based on floristic differences. This is in common with other systems, but characteristic for the Z-M system is the consistent use of the floristic criterion throughout the classification even for the separation of higher and highest units.

The main criticisms of the method are its subjectivity (Poore, 1955, 1956) and its non-adaptability to mathematical techniques. Moore et al. (1970) defends against the former by stating that random sampling leads to omission of obvious vegetation types and omission of samples containing conspicuous and fairly common species. A properly trained worker in the Braun-Blanquet school will select areas for description on the basis of two criteria:-

- (a) that the main physlognomic and floristic types of vegetation seen in the area being studied are reasonably sampled;

- (b) that the sample plots seem uniform in regard to vegetation and to obvious ecological features; this is aimed at avoiding the inclusion of two vegetation types in one releve.

Results from Z-M surveys have also been applied successfully to mathematical techniques with success to multivariate analysis and ordination (Bridgewater, 1970), principal component analysis (Orloci, 1966; Kershaw, 1968; Wishart, 1969; Van der Maarel, 1969) and monothetic agglomerative methods (Moore et al., 1970).

The Z-M method is advantageous to methods having results expressed by dendrogram in that the latter have all floristic information jettisoned and one must revert back to field records. Also dendrograms may suffer because of the similarity coefficient chosen which can provide variable results (Moore et al., 1970). A more serious charge is that "numerical taxonomies" (Sneath, 1957 , 1957b) provides a situation that contrasts with that in statistics to such an extent that methods cannot be taken on faith, permitting the biologist to arrive at spurious inferences (Lange et al., 1965).

As modified from Moore et al. (1970) the Z-M method was considered for the following reasons:

- (a) An informal classification based on dominance and physiognomy would be too imprecise a basis for further work in applied and theoretical ecology (with reference to the Uppsala school).

- (b) Strictly quantitative description of vegetation samples is so time consuming that given the limited man power available, it would not be possible to obtain a realistic sample of the vegetation types occurring in a region of such high edaphic and climatic diversity.
- (c) The Z-M method enjoys the distinction of widespread application and may one day be accepted universally.

The disadvantages to such a purely floristic approach are:

- (a) If consistently used it may lead to a classification which cuts through important formation boundaries (Zonneveld, 1960); most of the higher units are defined such that they conform to formation types which is not always true (Doing, 1963).
- (b) Many higher units can be defined more efficiently and clearly on the basis of their structural and physiognomic characteristics than on the basis of their floristic composition and affinities (Damman, 1967 after Ehrendorfer, 1954).

SECTION 2
CLASSIFICATION AND
NUTRIENT STATUS OF
PEATLANDS IN
CENTRAL NEWFOUNDLAND

On peatland investigations:

"Whereas in Europe the study of peatland has been a well developed science for sixty years, there are as yet few important contributions from the New World, where some students of peatland seem reluctant to apply European experience to North American problems."

Hugo Sjors, 1959

On Z-M methodology:

"Seen in its proper perspective and pruned of the scientific "betises" of which it may have been guilty during its development stage, it is a proven method for detecting rapidly, without undue computation, the underlying pattern in a set of samples from vegetation which is now recognized by all who have thought about it to 'fluctuate tantalisingly between the continuous and the discontinuous' (Webb, 1954)."

Moore et al., 1970



Ektachrome oblique showing the bog, fen, heath, and forest patterns typical of central Newfoundland vegetation. A. Bog B. Fen C. Heathland

CLASSIFICATION OF PEATLANDS IN CENTRAL NEWFOUNDLAND

GEOGRAPHIC SETTING:

The area described here as Central Newfoundland includes most of the forest region B28a of the boreal forest region on the forest classification map of Canada (Halliday, 1937; Rowe, 1959). In addition it includes the coastal portions of region B30 near Wesleyville and B29 in Notre Dame Bay. It extends southward in B31 to Bay D'Espoir (Figure 2-1).

TOPOGRAPHY:

According to Damman (1964a) the main part of forest section B28a has an elevation between 250 and 700 feet (90-211 m.) above sea level, with the level of the land rising toward the southwest, south of the region the land is 1200-1600 feet (365-488 m.) with the Annieopsquotch Mountains more than 2000 feet (610 m.). The whole area has an undulating topography with an abundance of lakes and ponds. The general water flow is in a northeasterly direction with the Exploits, Gander and Terra Nova River influencing a major portion of the area. Peatlands inundate the whole region with large fens covering most depressions influenced by water flow. Larger ombrotrophic bogs cover higher plateaux and much of the coastal region.

GEOLOGY:

The geology of the region is complex with sediments and volcanics underlying most of the area with plutonics more restricted in distribution. Intermediate to major volcanic rocks, slate,

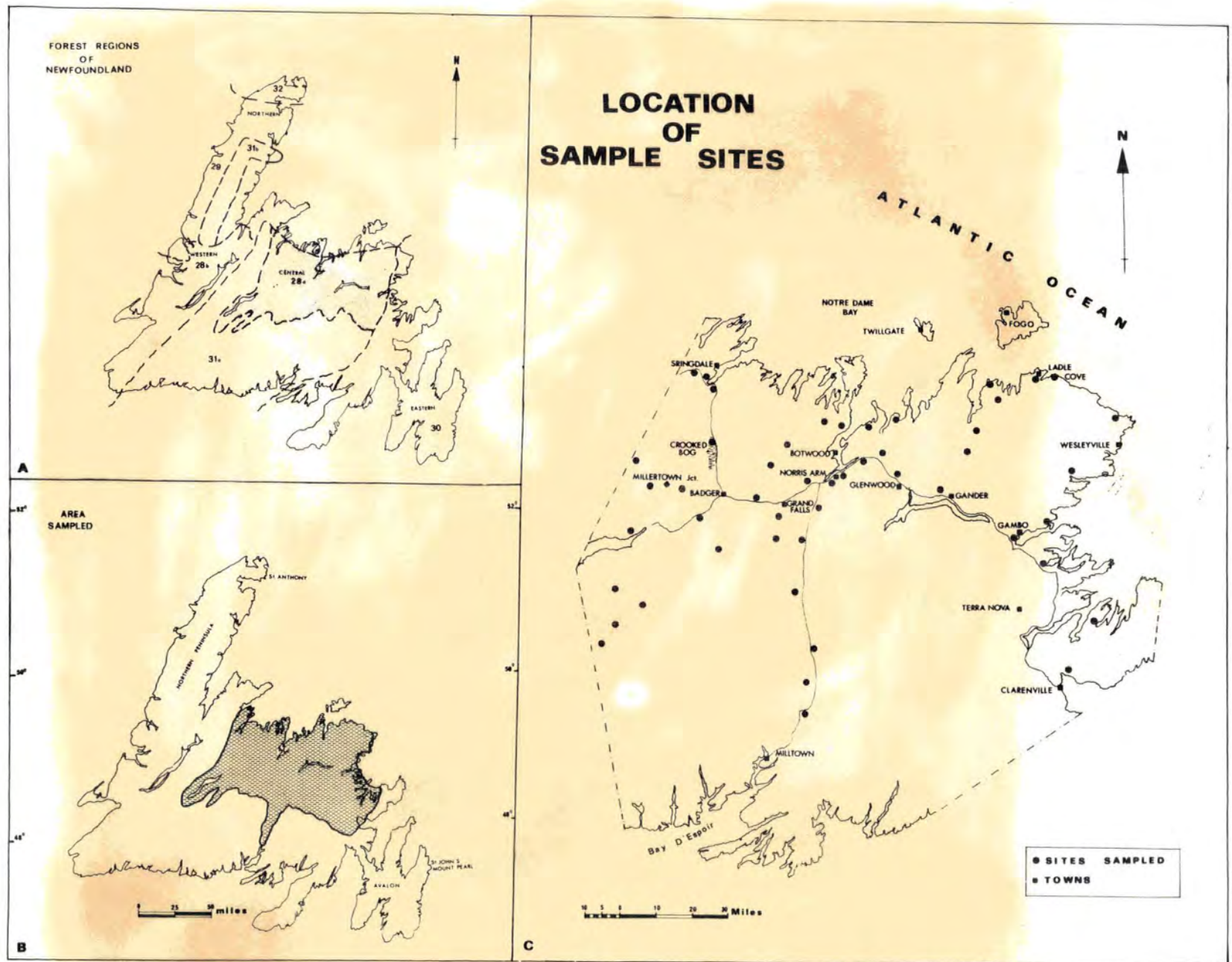


Fig.2-1 A. Division of Newfoundland into forest sections, according to Rowe (1959). B. Extent of region investigated. C. Location of peatland sites visited in Central Newfoundland.

siltstone and conglomerate are common; acidic volcanics are abundant in the Springdale and Botwood areas (GSC Maps 1231A, 1967). Devonian plutonics composed of gabbro, diorite, pyroxenite, quartz diorite and related rocks are mainly concentrated in the Millertown Junction, Norris Arm and Badger areas and seem to have some correlation with the distribution of fens in Central Newfoundland. The Wesleyville area covered by blanket bog is underlain by large granite, granodiorite and quartz diorite intrusives made up primarily of coarse-grained porphyritic biotitic granite (Jenness, 1963). More detailed local geology is described by Hriskevitch (1950), Kalliokoski (1953), Williams (1963), and Neale and Nash (1963).

Little information is available on surficial geology, however considerable variation is evident in bog substrata from clay rich in the Clarendville area, to sandy deltic deposits at Gambo and coarse gravel and granite bedrock near Wesleyville. Overall glacial drift forms an almost continuous localized moraine in which the composition is directly related to rock type (Jenness, 1963). Except for coastal regions the soil is relatively deep in comparison to other parts of the island. Damman (1964a) states that waterlaid soils are rare with the most common being the glaciofluvial sand and gravel deposits occurring in valleys and mouths of larger rivers. Alluvial soils are present along brooks and rivers but are confined to narrow fringes along the drainage channels. Lacustrine deposits are rare.

In general fen peat deposits are found in well mineralized zones having an active water seepage; such soligenous water peats are shallow and composed of well converted woody-sedge, sedge or *Campylium-Equisetum* peats. In comparison to the telmatic deposits, the bogs are mainly deep with some deposits greater than 10 m in depth (Pollett, 1967). These peats underlie ombrotrophic *Sphagnum* dominated communities and are less decomposed (H2-4) *Sphagnum*, sphagnum-sedge layers. The lower layers of these deposits do resemble fen peats in both composition and degree of humification.

CLIMATE:

The Labrador Current and the abundance of arctic ice along the coast are two dominant factors in influencing the climate. As a result spring is late and in most of the region begins about mid-May with the vegetative season being 150 days in length (Hare, 1949; Pollett, 1967, 1968b). The persistence of pack ice and the prevailing southwest winds have a profound effect on the vegetation in the north-east, near Wesleyville, where blanket bog vegetation is completely dominant. The annual average of daily mean temperature ranges from 38°F at Fogo to 39.8°F at Glenwood. The January means vary from 18.2°F at Grand Falls to 22.4°F at Twillingate and July means from 60°F at Fogo (possibly lower at Wesleyville) to 63.0°F at Grand Falls. In comparison to the remainder of the island the central portion of forest section B28a has the highest summer means but a lower annual mean than all regions except the Northern Peninsula.

Precipitation is high throughout Newfoundland with a uniform distribution in all seasons. The range of annual means is from 32.75" (83.2 cm) at St. Anthony to 63.79" (162.0 cm) at Mount Pearl in the east. In the study region the range is 34.12" (86.4 cm) to 40.35" (102.5 cm); potential evapotranspiration is 19.2" (47.9 cm) and water surplus varies from 16.0" (40.0 cm) to 21.0" (52.5 cm) (Pollett, 1968c).

Wind, because of its frequency and velocity is an important climatic factor in Newfoundland with normal means higher than the adjacent mainland. The prevailing wind over most of the island is SW, however in Central Newfoundland percentage frequency of SW and W winds is similar at 21%. Mean wind speed is 14.0 mph (22.4 km/hr) which is higher than in all other regions except the Avalon.

VEGETATIVE COVER:

According to Damman (1964a) forests of balsam fir (Abies balsamea) occupy the major portion of the forest section, although extensive fire stands of black spruce (Picea mariana) occur in the eastern half. Black spruce is also dominant in the coastal areas investigated. Undisturbed forests are primarily balsam fir except for very dry and very wet soils, covered by black spruce stands or older swamps. Hardwood forests restricted here to stands of white birch (Betula papyrifera), trembling aspen (Populus tremuloides) and pin cherry (Prunus pennsylvanica) are always of fire origin (Damman, 1964a). In areas with rich soils, such as parts of the Harpoon River and Noel Paul River watersheds, they cover fairly extensive areas.

Most depressions are occupied by fen types which are interwoven with forest stands; raised bogs are localized but may be extensive. Blanket bog covers much of the higher portions of Central Newfoundland, except drier sites which have a cover of heath dominated by Kalmia angustifolia and Gladonia spp. The coastal areas near Wesleyville are covered by deep ombrotrophic blanket bog.

PEATLAND TYPES IN CENTRAL NEWFOUNDLAND:

This region offers the greatest range of open peatland communities anywhere in Newfoundland, particularly with respect to bog and fen varieties. Wooded peatland or swamps are present only in small quantity and have been provisionally described by Damman (1964a) and are not included in this investigation. The bog and fen peatland have been partially classified by three previous workers, Damman (1964b), Pollett (1968b), and Heikurainen (1968).

Damman suggested the use of the following terms, based on the nutrient balance and general morphology of the deposit.

1. Dwarf shrub bog (dry, nutrient poor vegetation, dominated by ericaceous shrubs)
2. Oligotrophic bog (wet, very nutrient poor)
3. Mesotrophic bog (moderately poor, wet)
4. Mesotrophic fen (moderately poor, with meadow-like vegetation)

5. Eutrophic fen (nutrient rich vegetation with more exacting species)
6. Marsh (rich vegetation covered with a high vegetation of sedges and grasses; vegetation of periodically flooded alluvial soils)

Pollett used this classification and added species lists for the first five types. Heikurainen also provided six types based on species composition and relationship to nutrient status.

1. Dwarf shrub bog (*Kalmia-Sphagnum fuscum* bog)
2. Small sedge bog (*Sphagnum-Scirpus cespitosus* bog)
3. Sedge bog (*Carex oligosperma* bog)
4. Herb rich sedge bog (*Sphagnum recurvum-Carex-Herbaceae* bog)
5. Sphagnum fen (*Sphagnum warnstorffii* fen)
6. Brown moss fen (*Campylium stellatum-Scirpus* fen)

THE STUDY:

In all, 137 sites were visited in the study region covering the range of peatland types described in the existing classifications. The 307 releves obtained were subjected to analysis and synthesis sensu Braun-Blanquet (Appendix II) and results presented in Tables 2-1 to 2-14 (Vol. 2). Twelve vegetational taxa were recognized and are given in the text as provisional associations. The main floristic units delimited were possible to recognize from recurrent patterns on

aerial photographs and a key was devised (Appendix I) on basis of species composition to aid in checking the associations in associated ground surveys.

It was attempted to correlate the associations with, among other factors, the nutrient status of the underlying peat substrata. In this way each unit could be assessed in terms of its forestry and agricultural utilization.

Description of the associations are given in an ecological framework based on Du Rietz' (1954) peatland classes. Du Rietz suggested a division of peatlands into two main types: the 'ombrotrophic' and 'minerotrophic' which can be used as the first dichotomy in classification. The ombrotrophic vegetation includes all bogs whereas the minerotrophic would include the weakly minerotrophic fen, euminerotrophic fen and marsh vegetation. The term marsh refers to those areas dominated by large sedges e.g. (Carex rostrata) with a poorly developed moss layer and little or no peat deposition. The water table is above or at the surface.

A: OMBROTROPHIC PEATLAND

1. BOGS

1-1. Vaccinieto-Cladonietum boryi (Table 2-1*; Figure 2-2)

Differential species of the association are:

Vaccinium vitis-idaea var minus

Vaccinium uliginosum var alpinum

Stereocaulon paschale

Cladonia boryi

*Phytosociologic tables 2-1 to 2-14 are included in Volume II.

Rhacomitrium lanuginosum

Ochrolechia frigida

Rubus chamaemorus

Empetrum nigrum

Morphologically the association is extremely distinct occurring as typical 'blanket bog' covering the whole area with peat to 6.0 m in depth. The peat surface is undulating with hummocks formed by Rhacomitrium lanuginosum with associated lichen species. These hummocks are characteristically recognizable as the Alectoria nigricans variant, since that species and less frequently Alectoria ochroleuca occur there exclusively. These hummocks, especially near the coastline, often have Carex limosa associated with them.

There is another variant closely correlated with very dry exposed situations with only ericaceous shrubs and Rubus chamaemorus present. The height of the vegetation mat in these sites is little over 10 cm. This variant is invariably formed on well drained edges of the bog where the blanket peat meets the sea (Figure 2-2).

In terms of distribution for the study region the association is very restricted occurring only in the coastal areas near Wesleyville (Figure 2-1). It is, however, quite extensive covering almost the whole portion of the northeast coastline in the Wesleyville area. The mean July temperature is between 55°-60°F (Pollett, 1968a) and the climate is similar to that of the Northern Peninsula. Phytogeographically therefore, this is perhaps the southernmost extension of a much more widespread, northerly vegetation.

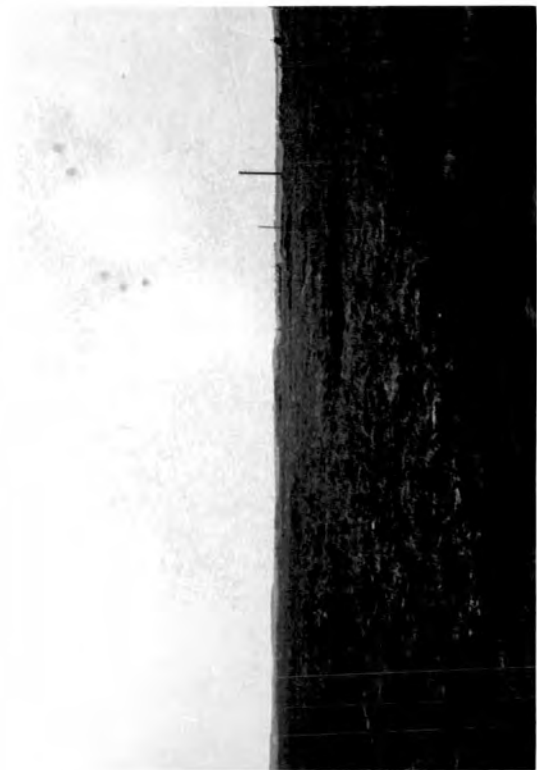




Fig. 2-2. Blanket bog (*Vaccinieto-Cladonietum boryi*) extending to coast near Wesleyville.



Fig. 2-3. Infilling of a flasket by *Sphagnum cuspidatum* in an oligotrophic bog.

The underlying peat layer indicates that an active growing Sphagnum vegetation preceded the present vegetation with both Sphagnum fuscum and Sphagnum imbricatum remains evident. The peats are not uniform with lenses of well decomposed ericaceous remains throughout. This change in the present development of the coastal bogs may be resultant from fires experienced in the region which encourage development of Rhacomitrium lanuginosum hummocks (Pollett, 1968a).

1-2. Kalmieto-Sphagnetum fusci (Table 2-2)

Characteristic species of the association:

Kalmia angustifolia, Vaccinium angustifolium

Cladonia mitis, Cladonia sylvatica

Cladonia rangiferina, Cetraria islandica

Rubus chamaemorus, Empetrum nigrum

Differential species of the subassociation:

Scirpietosum, Scirpus caespitosus

This association includes the categories 'dwarf shrub bog' and 'oligotrophic bog' (Pollett, 1968b) and is one of the most extensive peatland associations in the whole of Newfoundland. Morphologically this type occurs as "oceanic raised bog" which has a structure of dry Sphagnum fuscum hummocks intermixed with open ponds (flashets) and all stages of infilling between (Figure 2-3).





Fig. 2-4. Oceanic raised bog (*Kalmieto-Sphagnetum fusci*) on a peatland complex in Central Newfoundland.

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The other subassociation, Scirpietosum, is more characteristic of the 'oligotrophic bog' type habitat, and is much wetter. Besides the presence of Scirpus cespitosus this is also differentiated by increase in frequency of Sphagnum rubellum. There is an Eriophorum spissum variant indicating extremely wet conditions such as filled flashets. Rubus chamaemorus, though common throughout most of the bog vegetation, is rare in this variant.

There are also moist areas on the sloping edges of the bog which have some water movement in comparison to more stagnant water conditions over most of the surface. These edges are identified by the Carex oligosperma subvariant of the Eriophorum spissum variant, differentiated by the presence of the more exacting species Carex oligosperma.

Links between this association and the Vaccinieto-Cladonietum boryi can be seen in releves DW 17, 69-17B and 69-18C (Table 2-2). DW 11 was taken at the extreme seaward edge of peatland at Dark Cove, geographically just outside the Wesleyville region. Although in a typical Kalmiето-Sphagnetum fusci bog the presence of Stereocaulon paschale and Vaccinium vitis-idaea var minus show the edge of the northern influence. The other two releves are both taken from a large bog at Ladle Cove (Figure 2-1). Morphologically this peatland is similar to Wesleyville region, although floristically it has stronger ties with the Kalmiето-Sphagnetum fusci. The marginal aspect of this peatland type is further shown by the presence of Stereocaulon paschale, Cladonia boryi and Rhacomitrium lanuginosum together with an

increased cover of Empetrum nigrum. A more detailed study of the peatland in this area is needed to clarify the position of these anomalous forms.

B: MINEROTROPHIC PEATLAND

2. FEN

The fen vegetation is divided into two categories according to the degree of minerotrophy, weakly minerotrophic and euminerotrophic.

WEAKLY MINEROTROPHIC FEN

2-1. Calamagrosti-Sphagnetum fuscum (Table 2-3)

Differential species:

Calamagrostis inexpansa, Pyrus floribunda,
Solidago uliginosa, Carex exilis, Carex
oligosperma, Sanguisorba canadensis, Scirpus
cespitosus, Juniperus communis, Juniperus
horizontalis, Sphagnum fuscum, Coptis
groenlandica.

This association which has a greater species diversity than the other taxa occurs as hummocks in the fen mat. Many fen species are found at the junction of hummock and fen matrix but also occur over the hummock surface. In the investigation the transitional edges were not included in observations made.

There are two subassociations, Typicum and Kalmietosum. Differential species for the Kalmietosum are: Kalmia angustifolia, Cladonia rangiferina, Empetrum nigrum and Picea mariana seedlings. This subassociation most commonly occurs in the 'poor fen mat', that is in areas fed by nutrient deficient mineral waters or sites with very slight drainage and characteristic low pH balance. Such sites are often referred to as 'mesotrophic' bog or fen. In contrast the Typicum is found in more minerotrophic fen.

The Kalmietosum hummocks are illustrated in Figure 6 in comparison with a hummock from the 'oceanic raised bog', in addition to the differentiation in floristics the fen hummock is often characterized by higher sedge peat content which is relatively decomposed below the surface layer.

The Typicum has two variants, the Sphagnum papillosum variant occurring in the Scirpeto-Sphagnetum papillosum and the Potentilla fruticosa variant found in more Potentilleto-Campylietum stellatae fens. The Sphagnum papillosum variant has a subvariant differentiated by Sphagnum magellanicum and Sphagnum pulchrum, found in rather wetter mat areas with poor drainage. Growth form of the hummocks in the more minerotrophic fen areas is often much flatter than those in more ombrotrophic sites.

An unusual form of the association is found in the Ladle Cove area. In this form Sphagnum fuscum is virtually absent; and the main hummock forming sphagna are Sphagnum imbricatum and Sphagnum rubellum. Carex limosa also occurs rather frequently on such hummocks.

The combination of fen mat hummock is rather common and widespread throughout the central region of Newfoundland and can be detected on aerial photographs by a uniform dotted texture. The fen mat that accompanies the Calamagrostieto-Sphagnetum fusci is formed by vegetation of all fen associations.

Both the fen hummock and oceanic raised bog associations are characterized by the presence of Ledum groenlandicum, Kalmia polifolia, Rubus chamaemorus, Vaccinium oxycoccus, Sarracenia purpurea, Andromeda glaucophylla, Drosera rotundifolia and Chamaedaphne calyculata.

2-2. Scirpieto-Sphagnetum papilloi (Table 2-4)

Differential species of the association:

Sphagnum papillosum, Mylia anomala, Chephalozia connivens, Lepidozia reptans, Calamagrostis inexpansa, Carex exilis, Sphagnum plumulosum, Larix laricina.

This comparatively species poor association corresponds closely to the 'mesotrophic bog' of Damman (1964b) and Pollett (1968b). It is typically formed on sites having a flat or only slightly sloping surface with a water table near or at the surface. There is no evidence of the complex hummock-hollow relationship seen in the vegetation of the raised bog nor are there many fen hummocks present. Physiognomically these areas are not unlike gently rolling fields with sedges and grasses set in a Sphagnum mat. In many areas Larix laricina is sporadically distributed throughout (Figure 7).

The association is characterized by several species more usually recognized as 'fen' species than 'bog' species. Calamagrostis inexpansa, Solidago uliginosa, Carex exilis as well as species typically from bogs; Cephalozia connivens, Lepidozia reptans. Vegetation which it forms therefore may be regarded as intermediate between bog and fen. Although fairly widespread the association is usually found in juxtaposition to either or both the Kalmieto-Sphagnetum fusci and Potentilleteo-Campylletum stellatae.

2-3. Caricetum exilii (Table 2-5)

Differential species of the association:

Carex exilis

This rather ill-defined association contains few sedges with Carex exilis excepted. It can be termed a mud-bottom vegetation in the poor fen sites having an incomplete vegetation cover, usually about 70%.

A Betula michauxii variant is distinguished (differentiated in addition by Drosera intermedia) located in slightly wetter sites. Extreme wet areas are defined by the presence of an Aster nemoralis variant.

2-4. Caricetum lividae (Table 2-6)

Characteristic species of the association:

Carex livida, Carex lasiocarpa

An association morphologically similar to the Caricetum exilii is found in more minerotrophic areas. In addition to the

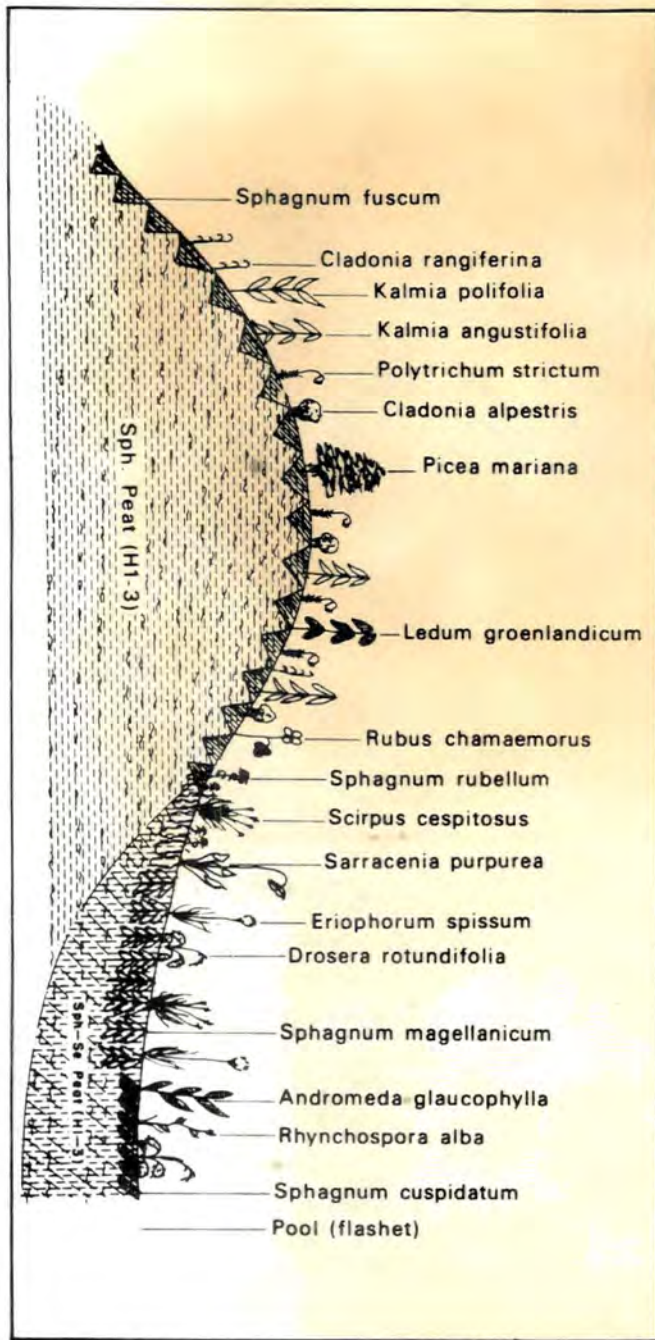


Fig 2-5 Profile of oligotrophic hummock of the oceanic raised bog 'Typicum' showing distribution of commonly occurring species from top of hummock to bog mat. Decomposition (H values) is used according to the von Post scale (Pollett, 1968b).

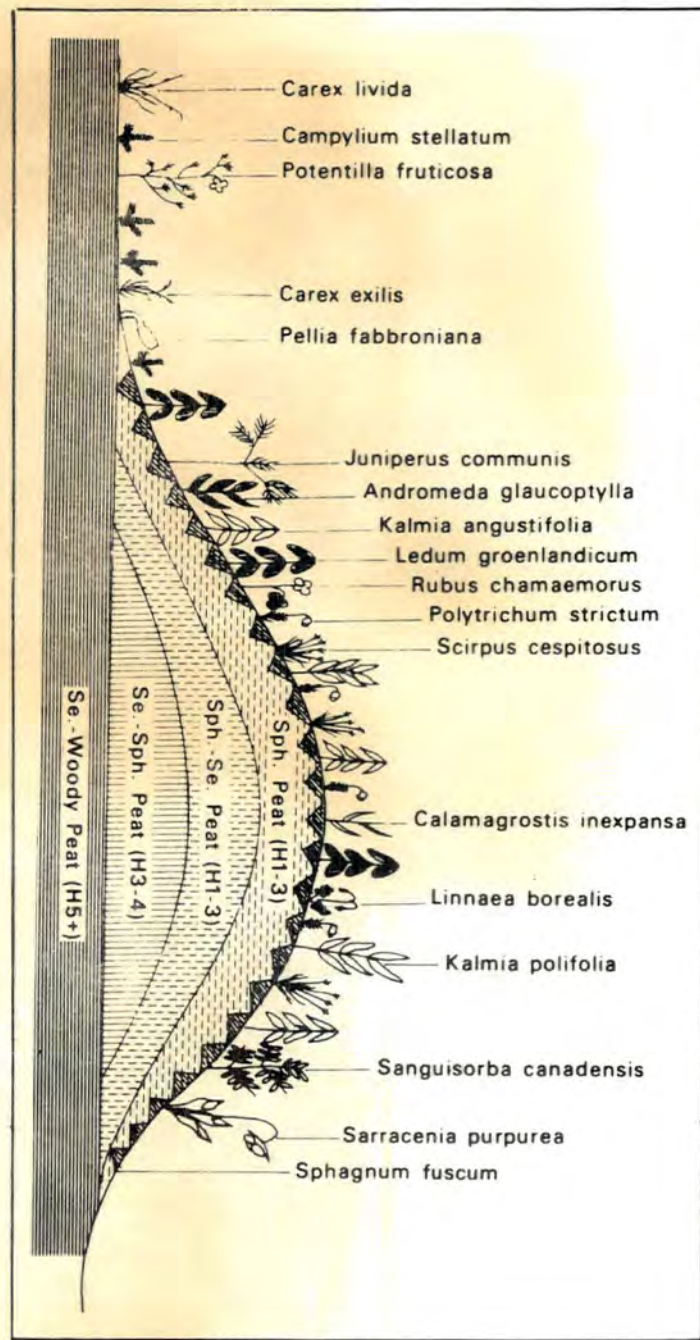


Fig 2-6 Profile of oligotrophic hummock of the fen sub-association 'Kalmietosum' showing distribution of species from top of hummock to the fen mat. Peat underlying this type of hummock is well decomposed below the surface layer.



Fig. 2-7. *Scirpus cespitosus* - *Sphagnum papillosum* bog north of Crooked Bog (*Scirpieto-Sphagnetum fusci*).



Fig. 2-8. Portion of rich fen in Central Newfoundland (*Potentilleteo-Campylietum stellatae*).

characteristic species, the dwarf shrubs Andromeda glaucophylla, Myrica gale and Chamaedaphne calyculata are frequently present. The Ledum groenlandicum variant also differentiated by Betula michauxii represents the driest form of this association.

2-5. Caricieto-Droseretum intermediae (Table 2-7)

Characteristic species of the association:

Carex livida, Carex exilis, Drosera intermedia,
Betula michauxii, Myrica gale, Pyrus floribunda,
Epilobium palustre.

This association represents a very open vegetation cover with vascular plants rarely covering more than 50% of the area. Although dwarf shrubs are characteristic of the species complement they rarely develop to their full potential. The surface of the peat is wet, but dries rapidly in summer to a hard crust. The range of the association seems to be confined to the fens of the Northern Coastal area of the Central Newfoundland Region.

2-6. Lycopodiето-Sphagnetum pylaesii (Table 2-8)

Characteristic species of the association:

Sphagnum pylaesii, Lycopodium inundatum,
Drosera intermedia.

The wet open areas in the fen mat are occupied by this association. Sphagnum pylaesii usually forms a dense mat with other

species growing in it. The fern, Schizaea pusilla occurs in such areas. Geographically the association has not been found outside the central portion of the region.

2-7. Eriocaulum septangulare (Table 2-9)

Characteristic species of the association:

Eriocaulon septangulare, Utricularia intermedia.

Found in the pools of the fen mat and occasionally those of the oligotrophic bog, this association is always submerged. Vegetation cover varies between 30-70% becoming highest where there is emergent vegetation. A Carex lasiocarpa variant, differentiated in addition by Menyanthes trifolia is found in the pools and has these species as emergent vegetation. Other pools with few species and no emergent vegetation are characterized by a variation with Eriocaulon septangulare only, associated with a species of freshwater sponge, Spongella lacustris.

EUMINEROTROPHIC PEATLAND

Damman (1964a) describes the fens as 'meadow-like vegetation', composed of low sedges and few sphagna spp. These peatlands are, in Newfoundland, only extensive in the central region in areas covered by the main forest belt. The vegetation has a high species diversity and form the greater number of peatland associations described. Such associations are often found as a mosaic in the fen complex, indicating changes along moisture and/or nutrient gradients.

2-8. Betuleto-Campylietum stellatae (Table 2-10)

Characteristic species of the association:

Betula michauxii, Campylium stellatum,
Calliergon stramineum.

This association, together with the Potentillieto-Campylietum stellatae form the vegetation type described as 'eutrophic fen' by Damman (1964b). The wetter sites are characterized by this association, which is relatively species poor. An unusual form of this group was noted in the south of the region with species Cirsium muticum, Deschampsia caespitosa var glauca and Dulichium arundinaceum present. The site is subject to periodic inundation from nearby pools.

2-9. Potentilleto-Campylietum stellatae (Table 2-11)

Characteristic species of the association:

Campylium stellatum, Potentilla fruticosa,
Selaginella selaginoides, Muhlenbergia glomerata,
Thalictrum polygamum, Scirpus cespitosus.

This association occupies highly minerotrophic sites in the fen category and has two subassociations, the Sphagnetosum and Typicum, the latter, rather species poor, occupying drier, possibly poorer areas.

Differential species of the subassociation Sphagnetosum:

Sphagnum warnstorffianum, Pellia fabbroniana, Senecio pauperculus, Rosa nitida and Rubus acaulis.

The Sphagnetosum has a well defined Rhinanthus crista-galli variant which is extremely diverse in species composition and is found in areas with pH 5.2-5.4. Differential species are: Rhinanthus crista-galli, Pyrus floribunda, Juniperus horizontalis and Sphagnum papillosum. Two subvariants can be further distinguished, the first differentiated by Carex flava, Calliergon stramineum and Betula michauxii is of restricted distribution, found rarely outside the centre portion of the region. Typically this develops in mat flushets on a gently sloping fen mat.

In contrast, in rather dry areas, usually associated with fast-flowing streams, the second subvariant develops. The water table depth is low (50 cm or more) and the stream bed covered by rocks. The differential species of the subvariant are: Eriophorum viridi-carinatum, Sphagnum strictum, Sieglingia decumbens, Pleurozium schreberi, Viola cucullata, Lonicera villosa, Thalictrum alpinum, Eriophorum virginicum, Drepanocladus intermedius. In addition to these differential species, others found in vegetation of this subvariant are Primula mistassinica, Pyrola rotundifolia, and Tomenthypnum nitens.

A further possible variant of this subassociation is the Fissidens adiantoides variant. The locality is believed to be rich in calcium, supported by the presence of abundant Chara foetida in the streams and pools of the fen.

Apart from the differential and characteristic species for each association, all the 'fen' type usually are distinguished by the presence of Andromeda glaucophylla, Chamaedaphne calyculata,

Vaccinium oxycoccus and Sarracenia purpurea. Figure 8 illustrates the physiognomic aspect of the Potentilleto-Campylietum stellatae.

C: MARSH

As stated by Damman (1964b) this type of peatland is rather rare in Newfoundland; its main area of distribution is on the southern edge of the region and scattered points elsewhere. Favourite habitat conditions for its development are at the edge of lakes and ponds and on alluvial flats as well as on areas of alluvial soil in the forest belt (typically Abietum balsameae, Damman 1964a).

3-1. Myricieto-Caricetum rostratae (Table 2-12)

Differential species of the association:

Myrica gale, Carex rostrata.

In its typical form the vegetation is dominated by Carex rostrata near the edge of drainage channels and surrounded by a tight cover of Alnus rugosa or Picea mariana. There are three variants of the association. The Carex limosa variant occurs usually as part of a peatland complex, usually bordering larger streams or ponds. Geographically this variant is confined to the northern coastal portion of the region.

The Carex aquatilis variant was found only in the central portion of the study region. Near the edge of a small lake the variant forms dense swards of sedge meadow (Figure 10) composed more





Fig. 2-9. Eutrophic marsh filling in a shallow pond in the southern portion of the study region.



Fig. 2-10. Carex aquatilis variant found only in the central portion of the study region, south of Bishop's Falls.

or less equally of Carex rostrata and Carex aquatilis. The meadow has small, poorly developed ombrotrophic hummocks with Sphagnum fuscum, Sphagnum rubellum and Sphagnum papillosum as main hummock formers. Tomenthypnum nitens invariably occur on these hummocks. One rather unusual feature of the variant is the presence of Vaccinium uliginosum in the 'meadow'. This is the only peatland site where this species was recorded.

Marshes associated with wet alluvial pockets in forest are of the Glyceria canadensis variant. A rich subvariant differentiated by Scirpus atrovirens, Aster puniceus, Rhynchospora alba and Solidago rugosa (Figure 11). A fourth variant, denoted by one releve is the Geum rivale usually found at wet woodland edges where Abies balsamea overshadows the marsh.

D: UNDEFINED COMMUNITIES

Three releves were taken in extreme wet situations, all characterized by the presence of Rhynchospora alba, Myrica gale and Sphagnum cuspidatum (Table 2-13). There is insufficient detail, however, to produce an association from these releves at present.

Two rather aberrant communities occur in the Ladle Cove area. One, obviously influenced by the sea, has Carex paleacea, normally occurring in salt marshes, present with Carex limosa and Iris versicolor. This community was growing about 10 m from high water mark. Another marshy spot near Ladle Cove supports a community with Hypericum virginicum, Campylium stellatum and



Fig. 2-11. Rich variant of the association *Myriciето-Caricetum rostratae*.



Sphagnum pulchrum as its three main species. This community was not detected elsewhere.

SUMMARY OF VEGETATION UNITS:

The peatlands of the central region of Newfoundland (Forest Section B28a) have been classified into 12 associations. The major floristic differences are summarized in Table 2-14.

Although each association can be found growing as a separate vegetation type, or distinct peatland type, the juxtaposition, in a large peatland complex of many of these types is most frequently encountered. For example ombrotrophic bog and fens of various minerotrophic status rarely occur separately, more usually they are linked by a complete drainage system. Currently, work is being undertaken which may lead to an understanding of the origins of these complexes and their present internal relationships.

A provisional key for field determination of associations through differential species is given in Appendix 1. This key will enable types to be selected for possible industrial utilization. From current and past investigations the peatlands have been categorized into the broad heading ombrotrophic, weakly minerotrophic, euminerotrophic and marsh. These are arranged below in approximating order of increasing minerotrophy.

1. OMBROTROPHIC PEATLAND

1-1 Vaccinieto-Cladonietum boryi

1-2 Kalmieto-Sphagnetum fusci

S.A. Scirpietosum

2. MINEROTROPHIC PEATLAND

(Weakly minerotrophic)

- 2-1 Calamagrostieto-Sphagnetum fusci
S.A. Kalmietosum
- 2-2 Scirpieto-Sphagnetum papillosum
S.A. Sphagnetosum
- 2-3 Caricetum exilis
- 2-4 Caricetum lividae
- 2-5 Caricieto-Droseretum intermediae
- 2-6 Lycopodieto-Sphagnetum pylaesii
- 2-7 Eriocaulletum septangulare
- 2-8 Betuleto-Campylietum stellatae
- 2-9 Potentillieto-Campylietum stellatae

3. MARSH

(Alluvial soils)

- 3-1 Myriciето-Caricetum rostratae

DISCUSSION:

The peatland associations described for Central Newfoundland are made up of a cross section of peatland types from open ombrotrophic bogs to extremely rich fens which are characteristically found in boreal, subarctic and north temperate regions. Nevertheless each geographical region has its own uniqueness both in floristic composition and morphological structure of the peatlands.

Comparison of these associations with other surveys and classifications can better place the vegetation in proper perspective.

Similar vegetation units described for the bogs of Newfoundland are generally included in the Oxycocco-Sphagnetea (continental European) or Ombrosphagnetea (Du Rietz' system). Although the Kalmiето-Sphagnetum_fusci is analogous to raised bog associations within these classes, the Vacciniето-Cladonietum_boryi and Calamagrostiето-Sphagnum_fusci would be more difficult to place.

The Vacciniето-Cladonietum_boryi, the blanket bog covering exposed coastal areas, is lacking in Sphagnum species, but in north-eastern Newfoundland is underlain by Sphagnum peat, to depths up to 6 m. This vegetation is allied to other exposed coastal peatlands in Newfoundland including the Typicum subassociation of the Rubeto-Empetretum_nigrae on the Northern Peninsula Coastal Plain and the Cornetosum subassociation of the Vacciniето-Cladonietum_boryi on the southwest, south and east coasts of Newfoundland (Pollett, unpublished data). The regions referred to in the discussion are given in Fig. 2-12 and summary tables for the units are provided in Table 2-15.

In contrast to exposed blanket bogs in the Wesleyville region, coastal peats in other areas are shallow. Furthermore, the southwestern and eastern exposed blanket peats are weakly minerotrophic whereas central and northern sites are ombrotrophic. This

Table 2-15. Summary Table of Differential Species in
Exposed Blanket Peatlands in Newfoundland

	<u>Central</u>	<u>Northern</u>	<u>Western</u>	<u>Eastern</u>
<i>Alectoria nigricans</i>	II			
<i>Vaccinium vitis idaea</i> var <i>minus</i>	V	III	IV	V
<i>Vaccinium uliginosum</i> var <i>alpinum</i>	IV	V	III	V
<i>Cornicularia aculeata</i>	II	I	II	III
<i>Stereocaulon paschale</i>	III	V	II	I
<i>Rhacomitrium lanuginosum</i>	IV	III	IV	IV
<i>Cladonia boryi</i>	IV	III	III	IV
<i>Ochrolechia frigida</i>	III	V	I	IV
<i>Vaccinium angustifolium</i>	III	II	IV	V
<i>Cetraria islandica</i>	III	V	II	III
<i>Cladonia sylvatica</i>	III	IV	IV	V
<i>Cladonia alpestris</i>	III	V	III	III
<i>Cladonia rangiferina</i>	IV	V	IV	V
<i>Kalmia angustifolia</i>	IV	IV	V	IV
<i>Empetrum nigrum</i>	V	V	IV	IV
<i>Dicranum spurium</i>	I	IV	I	I
<i>Rubus chamaemorus</i>	IV	V	II	
<i>Cetraria nivalis</i>		III	I	II
<i>Potentilla tridentata</i>			III	V
<i>Cornus suecica</i>			IV	II
<i>Deschampsia flexuosa</i>				IV

is indicated by the dominance of Rubus chamaemorus in the ombrotrophic vegetation and its absence in eastern sites. This is not a geographical variant in that Rubus chamaemorus is commonly occurring on other bogs in the Forest Section B30 (Figure 2-1A). The minerotrophic blanket peat is also differentiated by the presence of Potentilla tridentata, Cornus suecica and an abundance of Calamagrostis inexpansa. Geographically, Deschampsia flexuosa is found throughout exposed blanket bogs and heath in eastern Newfoundland but not recorded elsewhere. Damman (1967) includes one occurrence of Deschampsia flexuosa for the dwarf shrub heath Kalmietum from the west coast.

The northern form of blanket peat is closely related to the acidic Wesleyville peats and is characterized by active erosion. Both Dicranum spurium and Cetraria nivalis are more common. The latter has been associated with wind-swept areas of low snow accumulation by Sjors (1959) and in Newfoundland this species was only recorded from such sites in northern and eastern regions. Physiognomically the northern vegetation is characterized by large Racomitrium lanuginosum hummocks in which the moss is dead and decayed. This is probably similar to areas described by Oswald (1949) for western Scotland.

In addition to the Vaccineto-Cladonietum boryi, the Kalmieto-Sphagnetum fusci represents the remainder of ombrotrophic peatlands including the oceanic raised bogs. This association, however, is found in both western and eastern Newfoundland where it forms blanket bogs. The morphology of these deposits differs

between regions in that the Kalmieto-Sphagnetum fusci on the west coast includes the extensive, uniform blanket peats covering carboniferous sandstones of the coastal plain. Comparatively the association represents the more topographically confined 'dwarf shrub' bogs of the east coast as well as the wetter more extensive bogs intermixed with barrens on the Avalon and Burin Peninsulas. The association varies floristically in that the coastal bogs are marginally more nutrient rich because of the higher and more salt laden precipitation. West coast blanket bogs have an abundance of shrubs such as Pyrus floribunda, Rhododendron canadense, Nemopanthus mucronata, Gaylussacia dumosa and the herb Cornus canadensis. The eastern bogs also have a higher complement of these species with exception of Rhododendron canadense, than do the Kalmieto-Sphagnetum fusci in the study region.

The species Calamagrostis inexpansa, Trientalis borealis, Solidago uliginosa and Myrica gale which are mineral water indicators in central Newfoundland are not infrequently found on the coastal bogs. In addition Carex rostrata occurs on the slopes of the bogs in the eastern region.

Although the association does not extend onto the Northern Peninsula the Pyrus floribunda subvariant of the Rubeto-Empetretum nigrae is also differentiated by the group Pyrus floribunda, Cornus canadensis and Gaylussacia dumosa relating it to the western blanket bog.

Oswald (1949) notes that the main difference between Scandinavian bogs and those in Britain is that the bogs in Scandinavia are primarily of a raised variety but in Britain they are of the blanket bog type. Furthermore he notes that the hummocks and depressions become less pronounced coastward and that in Ireland the raised bogs of the Central Irish Plain are replaced westward by a 'rather uniform type of vegetation in which only occasional deep wet depressions and high, dry hummocks occur'. Also the British bogs have a richer flora than the Swedish bogs which according to Westhoff and Den Held (1969) is not unexpected in comparison of maritime and continental bogs because of the more nutrient rich precipitation in oceanic areas. As previously discussed both the morphological and floristic differentiation noted between inland and coastal bogs have been recorded within the Kalmiето-Sphagnetum fusci in Newfoundland.

The fen hummock association, Calamagrostiето-Sphagnetum fusci, although widespread in the central region is rarely found in coastal locations and like the fen mat associations is a more continental vegetation. These hummocks are dominated by Sphagnum fuscum but would not place in Du Rietz' main alliance Fuscion because of the high incidence of exclusive 'fen plants' such as Lonicera villosa and Sanguisorba canadensis. The vegetation would more probably comprise subunits within the Apiculation and Scorpidion alliances according to the degree of minerotrophy indicated.

In contrast to Du Rietz' approach the Z-M system does not recognize the 'exclusive fen plant limit' and such hummocks could be phytosociologically combined with true bog hummocks. This is true, for example, of the Sphagnion fusci of Braun-Blanquet (1949) and Nordhagen's Oxycocco-Empetrium hermaphroditum. The fen hummocks do contain a strong complement of both bog and fen differentials. In the present survey these hummocks have been grouped with the weakly minerotrophic vegetation as part of the fen complex.

A number of other weakly minerotrophic peatland associations were described including the Scirpieto-Sphagnetum papillosum, Caricetum exilis, Caricieto-Droseretum intermediae, Caricetum lividae, Lycopodieto-Sphagnetum pylaesii and Eriocauletum septangulare. These vegetations characterized peatlands with a restricted or nutrient-deficient minerotrophic water supply and would be termed by many as 'transition bog or fen'. Only the Scirpieto-Sphagnetum papillosum vegetation covers large areas and may be likened to the poor sloping fen described by Sjors (1965) as having the appearance of an 'almost smooth lawn-like vegetation with Trichorophorum cespitosum (Scirpus cespitosus) and Molinia caerulea co-dominant'. The remaining associations comprise 'mud-bottom' and pool vegetation all of which have to date only been recorded from the central region. Much of this vegetation is similar to poor fens of the Euapiculation, Subsecundo-Apiculation in the Swedish classification as well as Nordhagen's Caricion canescentis-Goodenoiivii. In the Z-M hierarchy the poor fen

vegetation occurs in the order Scheuchzerietalia palustris which also includes the more ombrotrophic bog hollow vegetation. The problems involved with this have been previously discussed. Similarly, the pool vegetations lend synsystematic problems to the continental phytosociologist. In indepth discussion of both pool and hollow development in boreal peatlands and agents acting on their vegetation cover is given by Sjors (1963).

Euminerotrophic fen vegetation, sometimes termed 'eutrophic fen' or 'rich fen' is widespread only in the central region of Newfoundland. Where it does occur in western and eastern Newfoundland the sites are localized and usually of small area. Two associations, the Betuleto-Campylietum stellatae and Potentilieto-Campylietum stellatae, comprise the rich fen with the latter more prevalent. On the west coast the Potentilieto-Campylietum is restricted to alluvial and outwash sites of calcium (limestone) or magnesium (serpentine) rich soils. Eastern occurrences of this association are rare and usually part of a larger fen complex occupying slopes flushed by continual seepage waters from uplands. An allied association occurs along the coastal plain of the Northern Peninsula covering areas underlain by ordovician limestones. This association, the Thalictrieto-Potentilletum fruticosae (Pollett, unpublished data) is the dominant vegetation of these limestone sites.

Floristically there is a hard core of differential species from the Potentilieto-Campylietum stellatae and Thalictrieto-Potentilletum fruticosae (Table 2-16) comprised of Campylietum stellatum, Selaginella selaginoides, Potentilla fruticosa, Thalicrum

Table 2-16. Summary Table of Presence for Differential Species
in Euminerotrophic Fen Vegetation of Newfoundland

	C	W(Se)	E	N
<i>Sphagnum warnstorffianum</i>	III		I	
<i>Muhlenbergia glomerata</i>	III			
<i>Smilacina trifolia</i>	III			
<i>Aulacomnium palustre</i>	II			
<i>Thalictrum polygamum</i>	III	III	IV	
<i>Campylium stellatum</i>	V	V	II	II
<i>Selaginella selaginoides</i>	III	V	I	IV
<i>Potentilla fruticosa</i>	IV	V	II	V
<i>Thalictrum alpinum</i>	II	IV		V
<i>Scirpus cespitosus</i>	V	V	V	V
<i>Habenaria dilatata</i>	I	V	IV	
<i>Triglochin maritima</i>	I	IV		II
<i>Tofieldia glutinosa</i>	I	III		I
<i>Drepanocladus sendtneri</i>		I		IV
<i>Carex capillaris</i>		I		III
<i>Betula pumila</i>	I	I		IV
<i>Carex scirpoidea</i>				III
<i>Tortella tortuosa</i>				III

polygamum and Thalictrum alpinum. The northern fens, however, lack Thalictrum polygamum and the eastern fens have an absence of Thalictrum alpinum. Furthermore the slightly poorer central fens have Sphagnum warnstorffianum, Muhlenbergia glomerata and Smilacina trifolia; whereas the richer western fens have a high frequency of Habenaria dilata, Triglochin maritima and Tofieldia glutinosa as well as dominance of Drepanocladus revolvens in the moss layer. The eastern fens have a high frequency and abundance of Sphagnum strictum in the moss layer. Geographical differentials of the Northern Peninsula rich fens are Drepanocladus sendtneri, Carex capillaris, Betula pumila, Carex scirpoidea and Tortella tortuosa.

In comparison with Scandinavian classifications the rich fens described here are comparable to the Warnstorffio-Scorpidion and Euscrocpidion of Du Rietz. In the continental classification the fens are within a number of widely separated units with the majority in the Molinio-Caricetalis fuscae. Malmer (1965) in describing the rich fens of Southern Sweden refers to the importance of Campylium-Drepanocladus in the moss layer and describes a number of sites similar to those found in central and western Newfoundland.

In the current survey, the association Myriceto-Caricetum rostratae has been categorized as 'marsh' vegetation, however, environmentally it is closely allied to the fens. Continental European phytosociologists place this type of vegetation into the alliance Mognocaricion of the Phragmitetalia (Koch, 1926; Oberdorfer, 1957) but Swedish researchers include it with the fen

vegetation. Sjors (1965) refers to the 'marsh' as Carex fens dominated largely by such species as Carex lasiocarpa and Carex rostrata in poorer sites and Carex aquatilis in better developed fens near streams and lake shores. Sjors' description is suitable for Newfoundland 'marsh' with Carex rostrata dominant in poorer sites and a Carex aquatilis variant occurring on richer alluvial soils. On the Northern Peninsula Carex aquatilis is the dominant species in 'marsh' vegetation and is the defining taxon of the association Caricetum aquatilis (Pollett, unpublished data).

Although the units have been described here using the Z-M methodology they can possibly be related to the units of Du Rietz' system because of the environment similarities of the peatland habitats, and to a lesser degree, their floristic composition. It is also recognized that on a continental basis Du Rietz' classification loses a degree of validity outside local environmental conditions whereas the Z-M classification because of its abstracted approach can better account for such problems. Thus in order to structure the peatland units into higher syntaxa on a national basis for Canada, and to make it compatible with other vegetation surveys now undertaken in different vegetation types, this classification is given. It is recommended that, at present, the association level should remain the highest units such that many future synsystematic problems, previously experienced in Europe, may be partially avoided.

LEGEND

- E**... EASTERN
- C**... CENTRAL
- S**... SOUTHERN
- Se**... SERPENTINE
- Na**... NORTHERN ALPINE
- Nc**... NORTHERN COASTAL
- W**... WESTERN

SCALE

0 25 50 75 MILES

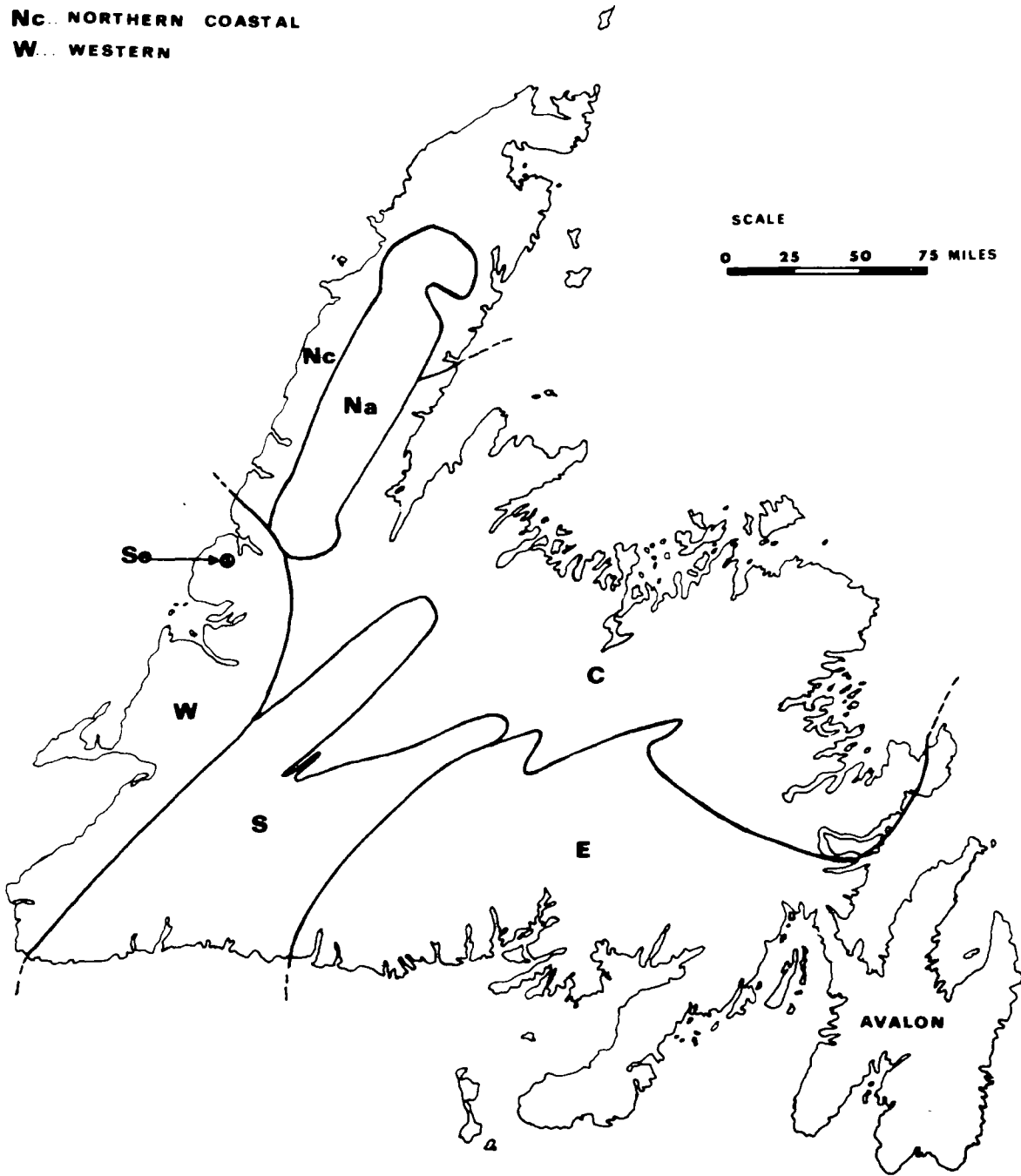


Figure 2-12 Regional subdivision of Newfoundland for peatland classification; modified from Damman (1967).

NUTRIENT STATUS OF PEATLANDS
IN CENTRAL NEWFOUNDLAND

Each peatland association described for the central region of Newfoundland has been determined on basis of its floristic composition and categorized according to hydrotopographic conditions. To provide additional criteria for industrial site selection an investigation of peat substrata was undertaken from 8 associations emphasizing their present nutrient status.

ENVIRONMENTAL RELATIONSHIP:

Three important environmental influences affecting both floristic composition and productivity of peatland ecosystems are pH, moisture and nutrition. Other factors may predominate in localized areas, for example, periodic flooding in alder swamps, water table fluctuations in mud-bottom communities and exposure in coastal blanket peat formation.

Under normal circumstances change in nutrient status or moisture regime is gradual and subsequent change in vegetation cover follows suit. Nevertheless, transitions related to drier, wetter, richer or poorer types can be noted which are expressed by 'lines of variation' (Sjors, 1950), 'ecological series' (Sukachev, 1960) or 'co-ordinate system' (de Vries, 1954). Additionally various ordination systems also express variation but without delimitation of principal units (Whittaker, 1967).

The preceding vegetation analysis presents the vegetational units according to their source and degree of nutrition. In this study this degree of minerotrophy will be assessed quantitatively for selected associations along the ombrotrophic-minerotrophic gradient. Although soil analysis provides a basis for determining site nutrient status, difficulties of interpretation associated with the variety of forms in which the nutrients can occur and their availabilities to plants are well known (Loach, 1964).

CHEMICAL AND PHYSICAL PROPERTIES OF SELECTED PEAT SOILS :

Peat soils have been frequently analyzed and under various conditions have been found locally deficient in many nutrients including nitrogen (McVean, 1963; Gore, 1963), phosphorus (Binns, 1959; Fraser, 1933; Zehetmaeyer, 1954; MacDonald, 1954; Wright, 1959), potassium (Horawski, 1965; Brown et al., 1964), calcium (Lucas and Davis, 1961), copper (Gyori, 1967; Liwski, 1963), boron (Kurki, 1962), molybdenum (Lucas and Davis, 1961), etc. The majority of such analyses, however, have been concentrated on the more acid peats.

Overall accounts of mineral and nitrogen contents and their role in peatland ecosystems are given by Malmer and Sjors (1955), Sjors (1950), Malmer (1958, 1962b), Holmen (1964), Puustjarvi (1956, 1957), Pyavchenko (1960), Gore and Allen (1956), Gorham (1967), and Lucas and Davis (1959, 1961).

DATA PRESENTATION:

A cross section of sites from bog and fen were sampled and examined for comparison of both total and available N, P, K, Ca, Mg, Mn, Na, Fe and Zn. In addition, bulk density (g/cc) taken as an expression of soil dry weight in wet volume (Paivanen, 1969) was determined for each sample to enable volumetric expression of nutrient content. Decomposition values (von Post, 1924), water content (% of wet weight), pH and peat types were also recorded. Unless otherwise stated all values given are means of three or more samples. Nutrient contents are expressed by weight in mg/g and/or volume in mg/cc. Sampling techniques and analytical methodology are presented in Appendix II.

To avoid frequent repetition of hierarchial nomenclature the various associations and subassociations are categorized into three series on the basis of preliminary pH analysis. The abbreviations by which each unit will be designated are given in brackets:

Ombrotrophic (O):

Vaccinieto-Cladonietum boryi (VCb)

Kalmieto-Sphagnetum fusci Scirpetosum (KSfS)

Kalmieto-Sphagnetum fusci Typicum (KSfT)

Minerotrophic:

Weakly Minerotrophic (WM):

Calamagrostieto-Sphagnetum fusci Kalmietosum (CSfK)

Scirpieto-Sphagnetum papillosoi Sphagnetosum (SSpS)

Scirpieto-Sphagnetum papillosum Typicum (SSpT)

Caricetum exilis (Ce)

Hypericum virginicum Community (Hv)

Caricieto-Droseretum intermediae (CDi)

Caricetum-lividae (Cl)

Lycopodieto-Sphagnetum pylaesi (LSp)

Eriocauletum Septangulare (ES)

Euminerotrophic (Eu):

Calamagrostiето-Sphagnetum fusci Typicum (CSFT)

Betuleto-Campylietum stellatae (BCs)

Potentilieto-Campylietum stellatae Typicum (PCsT)

Potentilieto-Campylietum stellatae Sphagnetosum (PCsS)

Myriciето-Caricetum rostratae (MGr)

One association, Calamagrostiето-Sphagnetum fusci could logically be separated into weakly minerotrophic and euminerotrophic subdivisions. The Kalmietosum being comprised of more elevated hummocks belongs to the former whereas the much flatter hummocks of the Typicum are euminerotrophic.

PHYSICAL CHARACTERISTICS AND PH OF PEAT SOILS:*

In Table 2-17 the pH and bulk density (BD) ranges are given for the various peatland types showing pronounced differences from ombrotrophic through euminerotrophic groups. Overall range for pH is 3.2-6.5 and for BD 0.03-0.26; furthermore all peats examined

*All peat sampling was restricted to the top 30 cm of the deposits, which is considered to be the maximum rooting depth for most species in undrained bog and fen (Heikurainen, 1953; Fraser, 1954; Boggie and Knight, 1962; Holmen, 1964; Paavilainen, 1967).

TABLE 2-17. BULK DENSITY, pH, WATER CONTENT AND DECOMPOSITION
VALUES FOR PEATLAND TYPES IN CENTRAL NEWFOUNDLAND

Group	Unit	BD	pH	H ₂ O%	H*	No. of samples
O	KSfS	.03 - .08	3.2 - 4.2	90 - 97	2 - 4	9
	KSfT	.04 - .08	3.2 - 4.0	90 - 97	2 - 4	15
WM	CSfK	.05 - .08	4.0 - 6.0	90 - 95	2 - 6	4
	SSpS	.04 - .09	3.8 - 4.3	90 - 95	2 - 5	12
	SSpT	.04 - .13	4.2 - 5.2	89 - 95	3 - 6	12
	Hv	.08 - .11	4.0 - 4.2	85 - 90	5 - 7	3
	CDi	.08 - .13	4.8 - 4.9	87 - 95	6+	3
	Cl	.05 - .11	4.6 - 4.9	87 - 93	6+	3
	ES	.11 - .18	5.0 - 5.5	80 - 88	6+	3
Eu	CSfT	.08 - .14	4.6 - 6.0	84 - 95	3 - 8	12
	PCsS	.09 - .26	4.8 - 6.5	80 - 87	4 - 9	12
	MCr	.10 - .25	5.0 - 6.0	80 - 85	8+	6

*von Post (1924) humification scale

contained more than 80% water on a wet weight basis. Decomposition is low in the sphagnum peats and high in the sedge dominated fens.

CHEMICAL PROPERTIES OF PEAT:*

TOTAL NUTRIENTS:

Nitrogen

Nitrogen (N) is often used to indicate potential fertility of peat sites because of its distinct differentiation from poor bogs to rich fens. In addition the N content has been shown to correlate with other habitat factors such as pH, calcium, phosphorus, ash content and bulk density (Holmen, 1964). Expected range of N values falls between a low of 3 mg/g in very ombrotrophic peats (Heikurainen, 1968) and 50 mg/g in eutrophic fen peats (Sjors, 1961b; Persson, 1962). Malmer (1962b) reports a range of 6-29 mg/g for peats of bog and fen sites and Holmen (1964) from 7.5 to 47 mg/g from a similar survey.

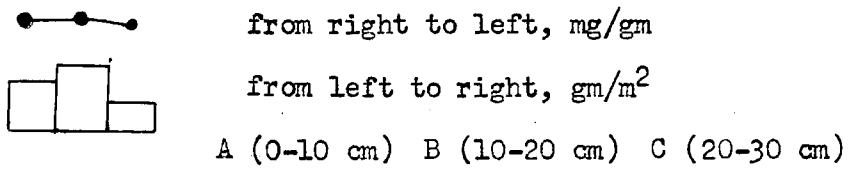
In the central Newfoundland peats variation extends from 3.3-31.6 mg/g with the Kalmieto-Sphagnetosum fusci Scirpetosum and Potentilletto-Campylietum stellatae Sphagnetosum having peats of low and high values respectively.

In Figure 2-13a, N values are presented on both volumetric and weight basis for surface (0-10 cm), middle (10-20 cm), and lower (20-30 cm) peat layers. Reading left to right the ombrotrophic series have low N contents in all layers whereas the mesotrophic (weakly

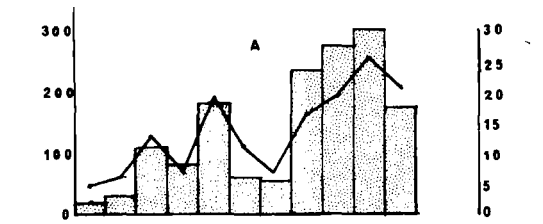
*All peat sampling was restricted to the top 30 cm of the deposits, which is considered to be the maximum rooting depth for most species in undrained bog and fen (Heikurainen, 1953; Fraser, 1954; Boggie and Knight, 1962; Holmen, 1964; Paavilainen, 1967).

Fig. 2-13. Total nutrient contents of peat soils from the Central Newfoundland peatland associations.

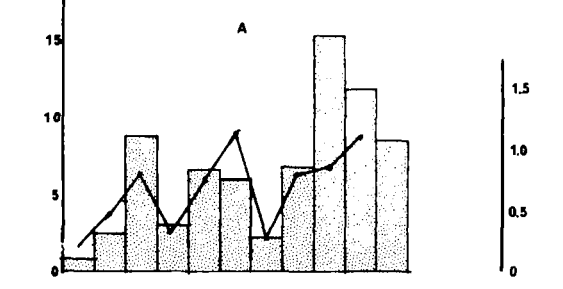
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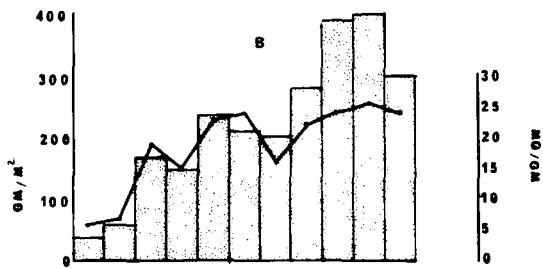
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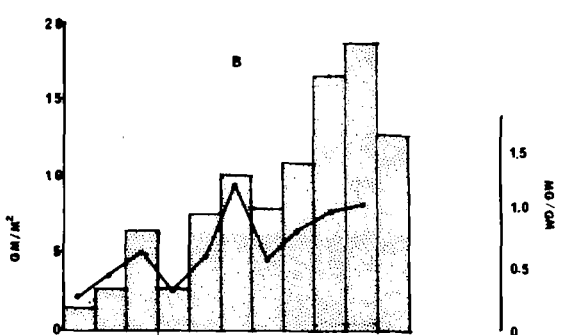
P



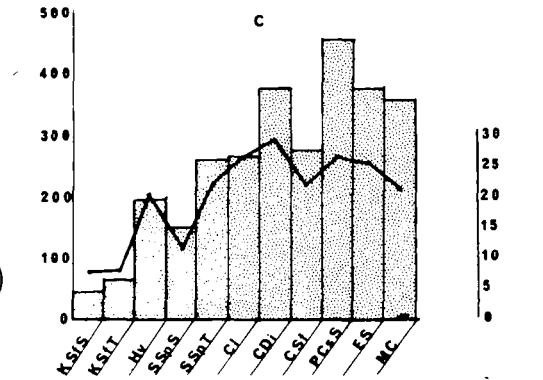
B



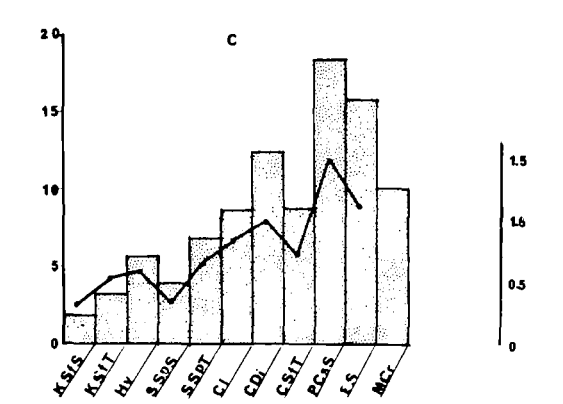
B



C



C

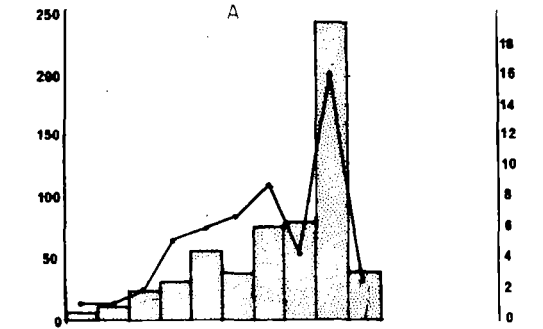


(a)

(b)

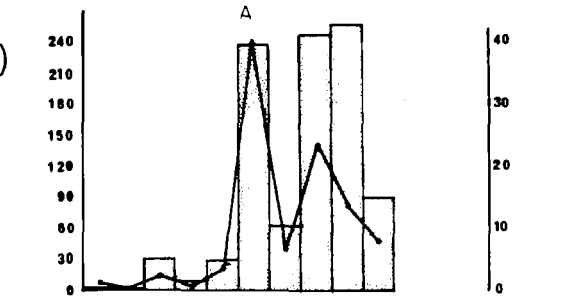
Ca

A

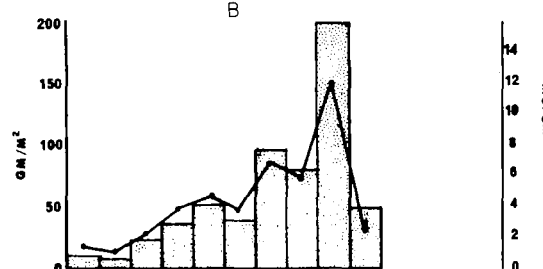


Fe

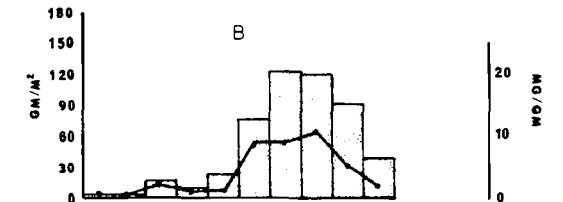
A



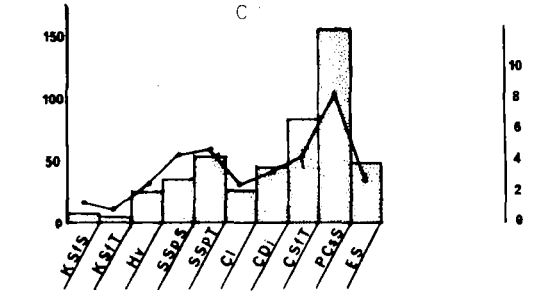
B



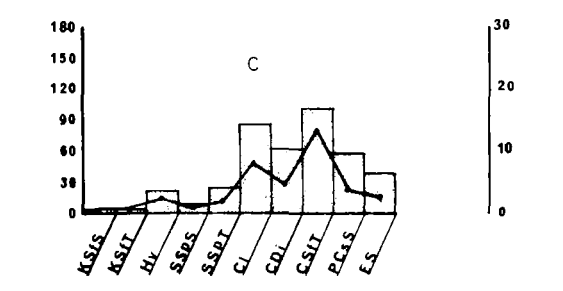
B



C



C



(c)

(d)

minerotrophic) peats have values generally relating to the poorer peats in the surface layer but are more closely allied to the richer fen peats in the middle and lower layers. Within the mesotrophic units the well defined SSpS and SSpT show some stability with increasing depth, however the more open vegetation exhibited by the associations C1 and CDi show rather dramatic change in N concentration with depth. This fluctuation may be associated with the role of these units as transition communities between ombrotrophic and eutrophic conditions.

There is a general increase of N with depth for all sites, however this is not always true as Holmen (1964) and Koulter-Anderson (1960) recorded wide variation of N with depth.

Phosphorus (Fig. 2-13b)

Results of total phosphorus (P) analyses from Newfoundland peat soils are within the range reported for organic soils by Davis and Lucas (1959) and Lines and Neustein (1966) with trends from ombrotrophic to eutrophic peats similar to that of N. Only the CDi association peats are anomalous, with low content in the surface layer and a levelling off in the middle and lower layers. On a weight basis, the C1 peat has the highest P values for the surface (1.14 mg/g) and middle (1.15 mg/g) layers. Volumetrically, the PCsS subassociation peats have the highest values in all layers, including highest weight value (1.4 mg/g) in the bottom layer. Fig. 2-13b shows the variation of peat phosphorus content within vegetation units.

Variation of P with depth is not pronounced and except for the CDi peat there is little significant difference. Holmen (1964) states that phosphorus decreases with increasing depth to 30-40 cm below the surface. Conversely Kaila (1956b) indicates a tendency for P content to increase with depth in more acid peats with opposite behaviour in richer sites. On all sites investigated in central Newfoundland there was no indication of P decreasing with depth to 30 cm.

Calcium (Fig. 2-13c)

Calcium (Ca) is a very good indicator of rich and poor sites and may be correlated with other soil properties such as pH, ash content, and bulk density. Also Ca/Mg ratios have been used to distinguish peat formed under minerotrophic conditions from peats formed under ombrotrophic conditions (Mattson and Koutler-Anderson, 1954; Olausson, 1957; Chapman, 1964; and Mornsjo, 1968). Within the ombrotrophic and mesotrophic sites Ca is most frequently low in weight and volume content. Again the CDi unit is anomalous having rather high values in the upper 20 cm.

One site from the CSfK subassociation showed a sharp cutoff from the upper to middle layer with the following values:

0 - 10 cm	-	4.65 mg/g	(pH 4.1)
10 - 20 cm	-	24.00 mg/g	(pH 6.0)

This may be partially explained by the changes of the subassociation with succession from fen conditions to ombrotrophic conditions within

the hummock (Bellamy and Rieley, 1967). Other disparities of the CSfK are its high Fe, Mn, ACa, and AMn contents as well as its low AP content in the lower layers. This site is defined by releve 69-12 and can be seen to have a strong complement of both the more minerotrophic defining species such as Calamagrostis inexpansa and Lonicera villosa as well as more ombrotrophic indicators Cladonia rangiferina and Kalmia angustifolia. According to Bellamy and Rieley (1967) the presence of the hummock only 10 cm high can close off all effect of the mobile base rich ground water.

In the more eutrophic association PCs, Ca content is significantly higher in the upper layers with recorded means of 17.9 mg/g in the Sphagnetosum. Additionally, taken on a volumetric basis contrasts are more pronounced with poorer sites having 5-50 g/m² whereas the PCs has peat with a mean value of 250 g/m².

Holmen (1964) shows a marked increase in Ca content with increased depth on sites from southwest Sweden. Conversely Mornsjo (1968) shows a decrease with depth. In central Newfoundland the peats show little variation of Ca content from 0-30 cm with the exception of fen hummocks in the CSfK.

Iron (Fig. 2-13d)

Iron, like Ca, shows a large differential between sites with values ranging from 1 mg/g to 45 mg/g. The lower values for ombrotrophic peat are comparable with results published by Efimov (1961, 1962) and Mornsjo (1968), however, the values obtained

from fen samples are very high, reaching the upper portion of the expected range of 0.2 - 45.0 mg/g for organic soils (Lucas and Davis, 1959).

There is a general decrease of Fe with depth, except for the CSfK sample previously discussed; values obtained for this site are as follows:

0 - 10 cm	0.98 mg/g
10 - 20 cm	7.50 "
20 - 30 cm	42.50 "

This increase may be resultant from the shallow nature of the peat and the influence of topogenous and soligenous water percolants from surrounding iron rich soils. Furthermore, the peats underlying the CSfT have high iron contents in the upper layers indicating some horizontal movement from the fen peats below. This may be due to a filtering effect by the undecomposed hummocks peat during periods of high water conditions. Iron concentration seems to be a factor of localized conditions as supported by the variation within each of the minerotrophic associations. For example, in the upper layers of the CSfT concentration ranges from 36.84 to 218.7 g/m².

Puustjarvi (1952) extensively investigated the relation of iron precipitation to fertility of the peat soils and stated that 'iron precipitates can be regarded as indicators of the tillability of the mires' with all sites having such precipitates having high productivity potential. He also stated that 'oily'

surface films (ferrous hydroxide) occur on rimpis when the ionized iron is in the precipitated stage and pH is from 6.2 - 6.6. In the study region iron precipitates were noted in the Caricetum lividae which has a partial plant cover but with pH 4.6 - 4.9. 'Oily' films are common also in wetter sites of the same association, as well as portions of the eutrophic fens. In the Thalictrum alpinum subvariant of the PCs the peat has a high iron concentration and in exposed areas has a characteristic rusty colour. Analysis shows the surface peats of the C1 to have the highest recorded value (45 mg/g). On a volumetric basis the PCsS has the highest concentration (264 g/m²). Such high Fe concentrations must affect the vegetation complement of these associations either directly or indirectly through interaction with other nutrients, especially available quantities of phosphorus which may be bound as iron phosphate. The recorded pH values for Newfoundland sites are somewhat less than those reported by Puusjarvi (1952), however, this may be due to the methods used (Puusjarvi, 1957). Overall, Fe concentration can be used as a quick analysis to separate poor and rich peats and is thus a useful parameter for site selection in industry.

Manganese (Fig. 2-13e)

Manganese, like Fe and Ca, clearly differentiates between sites, however, like Fe, there is considerable variation within each site type. For example, the range of values recorded for the surface layers of the PCsS is 0.27 - 0.95 mg/g and for KSfT, 0.02 - 0.11 mg/g. Range of values for all sites is 0.005 - 0.980 mg/g.

There is a definite decrease in Mn concentration with depths in all peats except for the CSfK sample for which the following values were obtained:

0 - 10 cm	0.445 mg/g
10 - 20 cm	0.950 "
20 - 30 cm	0.980 "

This behaviour is probably due to similar causes as discussed for Fe.

Little information is available on Mn concentration in peats other than in available form. Values for the poorer sites, however, do compare with values given by Mornsjö (1968) and in richer sites substantiated by Maksimov et al. (1960). In terms of distribution within peats of the units, values are slightly high in all samples of the KSfS (range 0.250 to 0.375 mg/g) which is consistently higher than in the Typicum of the same association. Highest mean values were recorded for the CSf in the surface (0.90 mg/g) and bottom layers (0.28 mg/g); the CDi which has peats of high manganese content has the maximum values for the middle layer (0.32 mg/g).

One factor linked with manganese concentration is the flushing of these areas with soligenous waters.

Zinc (Fig. 2-13f)

Distribution of Zn in the upper layer is interesting in that the poorer peats have, in general, less than the richer peats. This is more pronounced volumetrically than by weight basis.

The reverse is true for the bottom layer in which all samples of the ombrotrophic peats had higher concentrations than any of the fen areas. Maximum weight values are found in the Cl (0.067 mg/g) and SSpT (0.062 mg/g) in the surface layer and in the PCsS (0.63 g/m²) volumetrically. In the lower layer the KSfS (0.023 mg/g) and KSfT (0.027 mg/g) have the maximum values. The SSpS has low values throughout.

With depth there is a Zn decrease in the richer peats, however the peat samples from more ombrotrophic sites reflect rather stable conditions.

Magnesium (Fig. 2-13g)

Magnesium has seemingly little relation to the distribution of the peatland associations described and only fluctuate widely in terms of geographical location of the peat sample. For example, all samples of the SSpS and SSpT were taken well inland under little influence of the sea which is reflected by their having the lowest recorded values both volumetrically and by weight. The Hv community and CDi association are found primarily in areas influenced by the sea and have the maximum values.

Sodium (Fig. 2-13h)

Sodium behaves in a similar nature to magnesium, but exceptionally high values were recorded from the peats of the Hv community. This area is virtually on the shoreline and the vegetation indicates these factors by including Carex palacea and Hypericum virginicum; both species common to salt marsh habitats.

Potassium

Total K contents measured were discarded because of problems encountered with the analytical procedures (see methods - Appendix II).

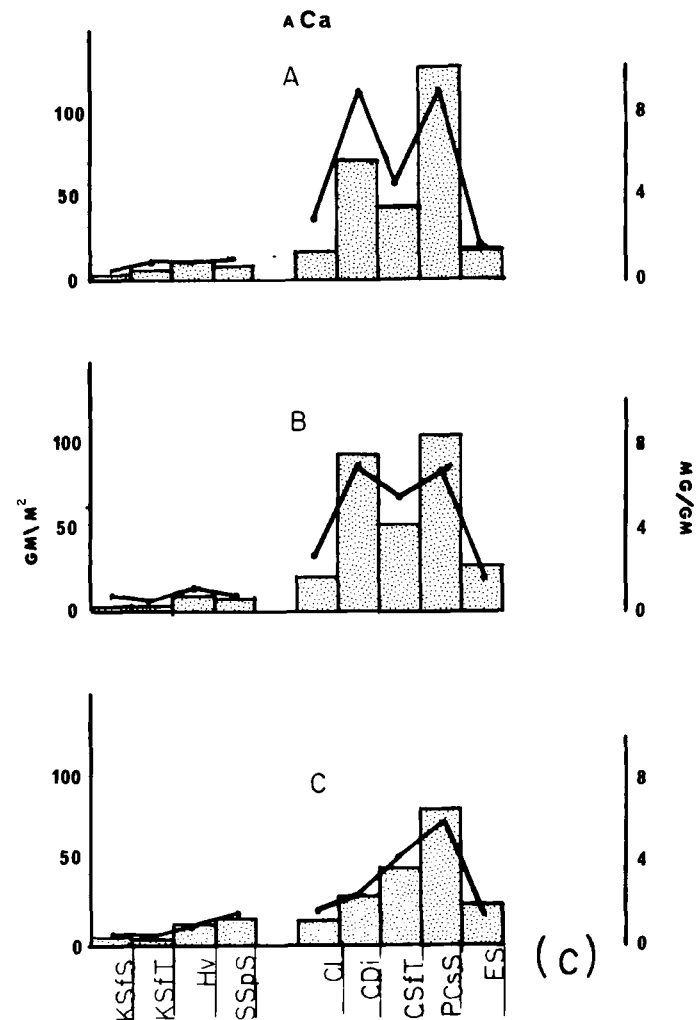
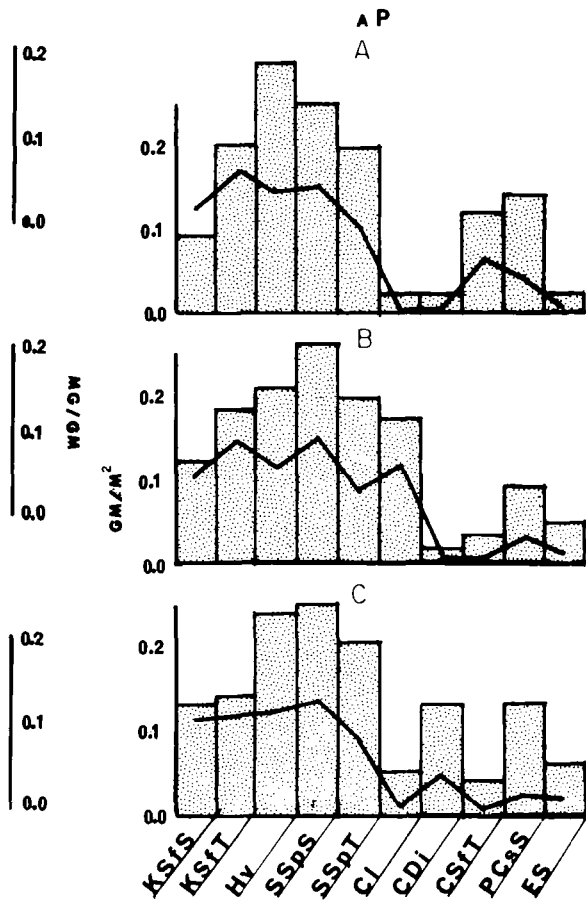
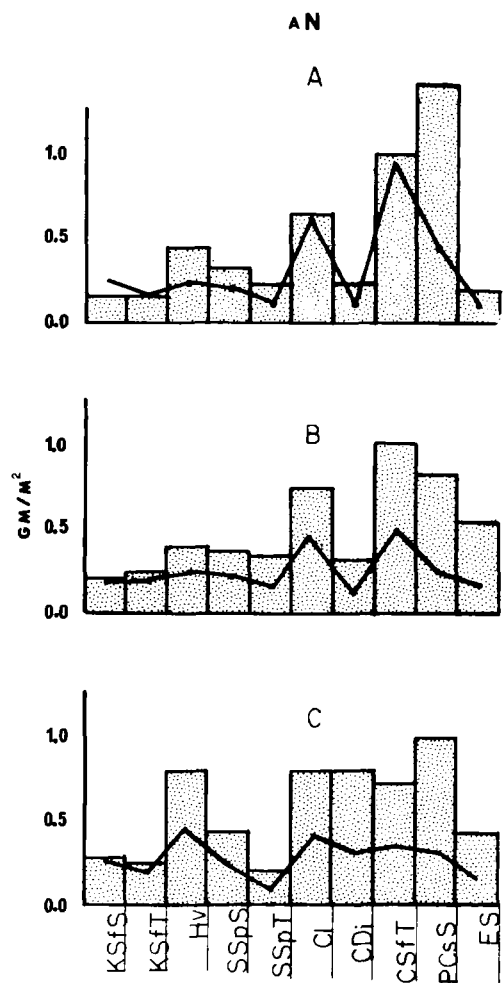
AVAILABLE NUTRIENTS:

For purposes of site classification and selection, the total nutrient contents of the peats have a high diagnostic value. Yet, by itself total nutrient concentration does not permit accurate interpretation of site nutrient dynamics and potential in that it does not measure the availability of the nutrient to the vegetation. Site 'richness' is possibly better evaluated through measurement of the available fraction of each nutrient. This consists of nutrients present in the soil solution and some portion of the nutrients in solid phase. In many peat soils the characteristic low pH has a profound effect on the availabilities of certain nutrients (Lucas and Davis, 1961). Furthermore, in wet areas waterlogging affects solubility of particular nutrients and indirectly affects concentration through causing anaerobic site conditions.

Available Nitrogen (Fig. 2-14a)

Distribution of AN within the peat substrata shows that only a slight correlation exists with its concentration and that of total nitrogen (N). In general the more ombrotrophic peats have less AN by weight (0.01 - 0.05 mg/g) and volume (0.1 - 0.25 g/m²) than mesotrophic and eutrophic peats (.05 - 0.140 mg/g) and

Fig. 2-14. Available nutrient contents of peat soils from the Central Newfoundland peatland associations (for legend see Fig. 2-13).



(a)

(b)

(c)

(0.1 - 1.38 g/m²). One anomalous fact is that samples from the ES association have little AN in comparison to total N indicating a degree of anaerobism underneath the pond waters.

In acid peat under boreal conditions there is little activity of nitrifying bacteria and a corresponding deficiency results in nitrate nitrogen and often in ammonium nitrogen (Rommell, 1954; Russel, 1961). Nitrogen deficiencies have been recorded on Calluna peats where it causes growth check in spruce (Weatherhall, 1953). In Newfoundland the Kalmia heath has a similar effect on black spruce (Damman, 1967). Acid peats may also be deficient in AN because of a low rate of nitrification (McVean, 1963; Gore, 1963).

Mineralization of peat soils have been undertaken to increase AN (Maciak, 1963; Sakayanagi and Akatsuka, 1963) by cultivation and liming. Lucas and Davis (1961) state that little improvement is attained in availability when pH is above 5.2. The favourable pH range for AN in peat is given as 1 to 1.5 units below that of mineral soils.

Available Phosphorus (Fig. 2-14b)

Phosphorus is probably the most critical element in peatland interpretation because of its key role in production. It is generally deficient in all more ombrotrophic peatlands and in many richer sites as well (Holmen, 1964; Kaila, 1956a, 1956b; Binns, 1959).

In Central Newfoundland peats AP shows a trend reversed to most other properties in that the higher values are recorded for the KSfT and SSpS and lower values are characteristic of all the richer sites. This phenomenon holds for all three depths measured. These differences are great enough to show up on a volume basis as well.

Reasons for this trend are twofold. Firstly, much of the AP is bound by Fe and Al to form iron and aluminum phosphates and secondly, there are greater demands made on AP supply by vegetation in most of the richer associations. According to Kaila (1958) chemical determinations on air-dry samples (used in this study) may be lower in AP than under natural conditions because of tendency to fix P.

Available Calcium (Fig. 2-14c)

Available calcium is almost identical in distribution pattern to total Ca with pronounced differentiation between poorer and richer peats. Values obtained from all samples fall within the range 0.17 - 14.20 mg/g. Excluding the rich fen the range is 0.17 - 8.10 mg/g which is comparable to values recorded by Malmer and Sjors (1955) for poor fens and bogs (0.72 - 3.9 mg/g) and by Holmen (1964) ranging from 0.12 - 4.12 mg/g for similar sites.

Puustjarvi (1957) carried out extensive analysis on exchangeable cations for various peat types and his Ca results are summarized below.

Bryales - sedge peat	2.0 - 16.0 mg/g
Eutrophic sphagnum - Carex peat	4.6 - 20.2 "
Carex peat	0.4 - 9.2 "
Sphagnum - Carex peat	0.04 - 6.8 "
Carex - Sphagnum peat	0.10 - 6.0 "
forest - Sphagnum peat	0.30 - 12.0 "

In Finland the determination of exchangeable Ca is used to characterize the base status of the peat soil and is used exclusively, for instance, in fertility investigations (Puustjarvi, 1957).

Available Manganese (Fig. 2-14d)

Results obtained from AMn analysis show influences other than the degree of eutrophication in its distribution. Most noticeable are the high weight and volume concentrations in the units KSfS, Cl and CDi in the upper layer:

	Vol. g/m	Wt. mg/g
KSfS	0.63	0.177
Cl	0.75	0.144
CDi	1.13	0.134

In comparison the subassociation KSfT has much less AMn.

KSfT	0.16	0.03
------	------	------

Lucas and Davis (1961) state that AMn is influenced more by soil reactions than any other plant nutrient with pH rather crucial in

that availability decreases above pH 5.5. Snider (1943) correlates high manganese concentration due to its increased solubility at a low pH.

Differences in AMn concentration of KSfS and KSfT are not accounted for by pH but rather may be due to waterlogging. The Cl and CDi units both experience high water tables (at the surface) which may increase solubility in conjunction with low pH.

Range of values for poor peats has been listed below:

Malmer and Sjors (1955)	0.02 - 0.15 mg/g
Heilman (1968)	0.004 - 0.07 "
Mornsjo (1968)	0.004 - 0.02 "
(C. Nfld.)	0.002 - 0.19 "

Available Iron (Fig. 2-11e)

Distribution of AFe in the peats is similar to AMn in that it too is affected by waterlogging (Pearsall, 1950). The highest values throughout all three layers are found in the Cl and CDi peats. Also KSfS and other poorer sites have higher AFe concentration in the surface layer than the eutrophic fen PCsS (on a weight basis only). One oddity is the drop in AFe in the CSf which has the highest total Fe content. This may be due to the drier conditions associated with these hummocks.

Available Zinc (Fig. 2-11f)

Analyses for AZn show that the poorer peats have higher content in the upper layer and that KSfS has the higher mean values in all layers.

Heilman (1968) reports values of 10-92 ppm exchangeable Zn whereas in the samples from central Newfoundland the range is 1-11 ppm. This difference may be due to localized conditions.

Available Magnesium, Sodium and Potassium (Fig. 2-14g, h, i)

There is little evidence of correlation between the peatland types and the distribution of AMg, ANa, or AK other than providing an index of proximity to the sea. The available fractions for Mg and Na seem to be directly related to their corresponding totals.

DISCUSSION:

Analysis of the nutrient status of the Central Newfoundland peatlands reveals that the degree of differentiation afforded by the Z-M classification is reflected in the concentration of nutrients in the underlying peats. This is best demonstrated by total values of nitrogen, calcium and iron as well as available calcium. Indeed, as a quick measure of site nutrient status, calcium would probably yield most informative results.

In addition to substantiating the ecological validity of the classification system the nutrient analysis could provide valuable data enabling more controlled selection and successful manipulation of peatlands for afforestation purposes. In Newfoundland, due to the heavy industrial demand placed on upland stands, accompanied by the deterioration of additional areas through erosion, insect infestation and disease, there is a need to evaluate the use of peatland to provide the raw products for existing and new operations.

The present survey shows that the poorer bogs of the Kalmiето-Sphagnetum fusci have

300 - 1000 kg/ha	N
30 - 50 kg/ha	P
50 kg/ha	K (Heikurainen, 1968)

and the Potentilieto-Campylietum stellatae

4000 - 7000 kg/ha	N
200 - 350 kg/ha	P
182 kg/ha	K (Heikurainen, 1968)

In Newfoundland where fertile mineral soils are limited, the future of agriculture relies on utilization of peatlands (Rayment and Chancey, 1966). As yet this utilization has been primarily restricted to the poorer sites because of their uninterrupted expanse and ease of tillability. The real future, however, may lie in the utilization of fens which may be more economic to the Island than their use in forest-based industry.

In selection of sites amenable to afforestation the division of bog and fen is very important in that the bog associations are usually one extensive area whereas fen vegetation is often a mosaic of poor and eutrophic sites interspersed with fen hummocks. Such mosaics could only be considered as a unit. The most extensive fen associations are the Scirpeto-Sphagnetum papillosoi and the Potentilieto-Campylietum stellatae.

The Central Newfoundland region is the only part of the Island with extensive fens, the favoured vegetation type for such trials in Finland, where more than 1,500,000 hectares have been drained for forestry purposes. Unfortunately direct comparisons cannot be made between Finland and Newfoundland because of differences in natural succession. Whereas many Finnish 'swamps' have a natural tree cover (Cajander, 1913), in Newfoundland naturally forested peatlands are rare. One can, however, derive a great amount of information regarding the ecological changes through amelioration of such sites which could be applied to local situations.

As previously discussed, the peatlands of western Sweden have close similarity with those of Central Newfoundland and more direct comparison is more feasible. In Sweden more than 700,000 hectares have been drained with the eutrophic fens used for agriculture (Holmen, 1964). The minimum nutrient supplies in the upper layer of 20 cm for sustaining forest growth on deep peatlands in Sweden are calculated as:

2000 - 3000 kg/ha	N
150 - 200 kg/ha	P
100 - 125 kg/ha	K

The fen areas have the required nutrients and are not fertilized, whereas an application of NPK is used on most deep peats, although N may be omitted where the surface peats are fairly well decomposed.

Understandably nutrient content is the most important criterion in site selection, however in amelioration other ecological problems centered about the hydrological regime including ditch spacing, water table fluctuations, peat shrinkage, nutrient leaching, and increased mineralization, will increase in importance. Also unique problems in site management, vegetational succession, windblow, insect and disease infestations and thermal regime of peats will be encountered. One new factor to be considered is the demands on the environment, in that the peatland habitat in many areas will be virtually destroyed and may disrupt surrounding ecosystems through its upsetting watershed dynamics. Also the habitat, once taken, is not replaceable for many years hence, if at all. If areas are to be used in this manner foresight in planning is a primary need to ensure any degree of success.

SECTION 3
PRODUCTION AND NUTRIENT DISTRIBUTION
WITHIN A PEATLAND ECOSYSTEM
IN NORTHWESTERN BRITAIN

"Techniques and tools for study of dynamic equilibria and changes in ecosystems are lacking. The technique which adapts itself best to this dynamic approach is the study of ecosystems, which measures rates of mineral cycling and biomass productivity."

Becking, 1968

INTRODUCTION

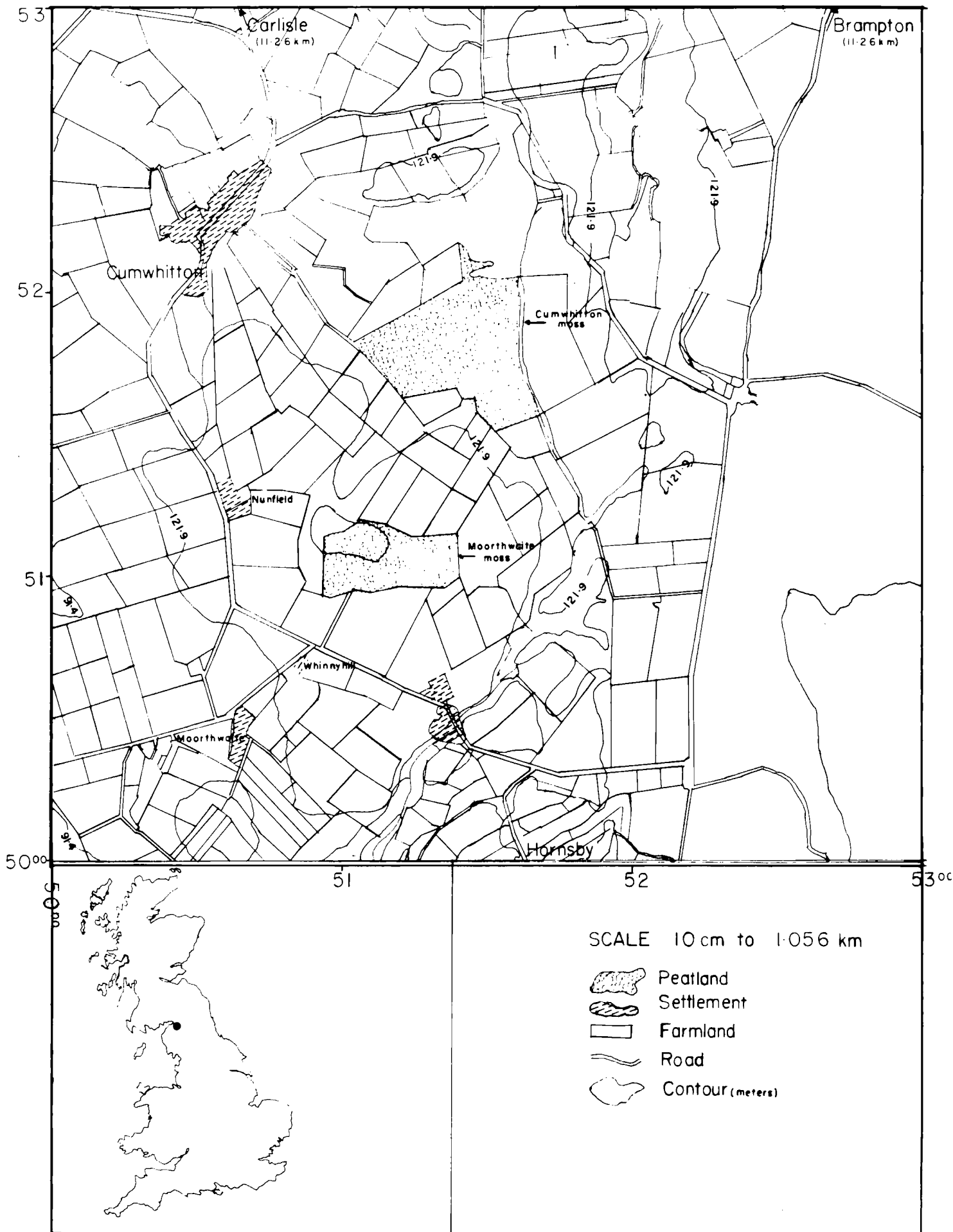
The scope of this thesis has included the classification of peatlands in central Newfoundland, laying the groundwork for a more extensive classification of peatlands throughout the Island and nearby mainland of Canada. In addition the nutrient status of the types have been measured which will enable sites to be selected and appropriate amelioration measures undertaken to help rectify nutrient deficiencies. Yet to gain an understanding of the production and nutrient dynamics within units, rates of production for selected species and their related mineral contents have to be analyzed.

To conduct an analysis of units within a peatland ecosystem a small bog, Moorthwaite Moss, located in county Cumberland, north-west England, was chosen (Figure 3-1). This site was selected for the following reasons:

- (i) It is a boreal peatland with a well developed forest cover encroaching from the margin, yet with a central portion being open approximating to true bog conditions.
- (ii) The site is accessible year around and free from long frost periods, thus enabling samples to be collected for production analyses.



Fig. 3-1. Location of Moorthwaite Moss.



- (iii) It has an environmental gradient from nutrient poor to fairly nutrient rich conditions, as well as wet to dry habitats within a small area.
- (iv) The bog was within a two-hour journey from the university, allowing for frequent visits as required.

The aim of this investigation was to establish methods of measuring production for selected species and to assess the variation of nutrients within species having a wide ecological tolerance. There is extensive documentation of literature dealing with productivity and mineral analysis of plant systems which limits the need for an extensive literature review. Wherever required in the text any references pertinent to particular aspects of the investigation are given.

Botanical sources used are Chapman, Tutin and Warburg (1962) for the vascular plants, Watson (1963) for the bryophytes and the sources for lichens are Gladonia impexa Horm.; Gladonia arbuscula (Wallr.) Rabenh. and Parmelia physodes (L.) Ach.

SITE DESCRIPTION

The geography, stratigraphy and ecological development of Moorthwaite Moss have been intensively discussed by Walker (1966) and the following description is primarily summarized from that work.

TOPOGRAPHY AND GEOGRAPHY:

Moorthwaite Moss, at an elevation of 120 m, occupies an elongated kettle hole at the top of a rise approximately 1.5 km from the Eden River, 11.5 km southeast of Carlisle and 1.5 km southeast of Cumwhitton. Grid reference for the site is 510510 (Figure 3-1). The moss is relatively flat, with gentle slopes from the northeast and southeast toward the centre with the lower portion of the bog in the western and northwestern areas. The only drainage outlet is provided by ditching at the northwestern corner of the site. Moorthwaite Moss is surrounded by farmland involved with a variety of pasture and crop production. The highest portion of this surrounding land is approximately 9 m above the bog surface and drainage from the slopes influences the species composition of the marginal zone.

The hill on which the kettle hole was formed is composed mainly of a sandy boulder clay with the eastern flank covered by an outwash sand from the K and M stages in the retreat of the Main Glaciation ice. An extension of this drift forms an ose train around the northern edge (Trotter, 1929). Bedrock geology in this area shows the hill to be underlain by St. Bees Sandstone (Ordnance Survey, 1967).

STRATIGRAPHY AND ECOLOGICAL DEVELOPMENT:

Walker's (1966) account of the bog stratigraphy, as well as the pollen diagrams and chronology show that the site underwent a true hydrosere development. Figure 3-2 shows a cross section of the peat layers in Moorthwaite Moss. The peat deposit is underlain by red sand and gravel with silt predominant at the centre. Overlying this is a grey silty clay mud with coarse sand, topped by a coarser gravel which in turn is covered by nekton mud containing remains of aquatic plants. Sedge leaves, Nymphaea alba seeds and Potamogeton spp. fruit stones are common above this succeeded by a more organic layer with Carex spp., Phragmites communis and Sphagnum remains common.

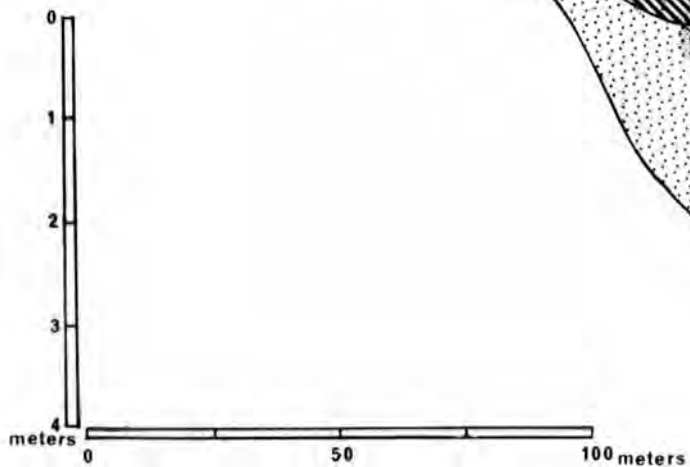
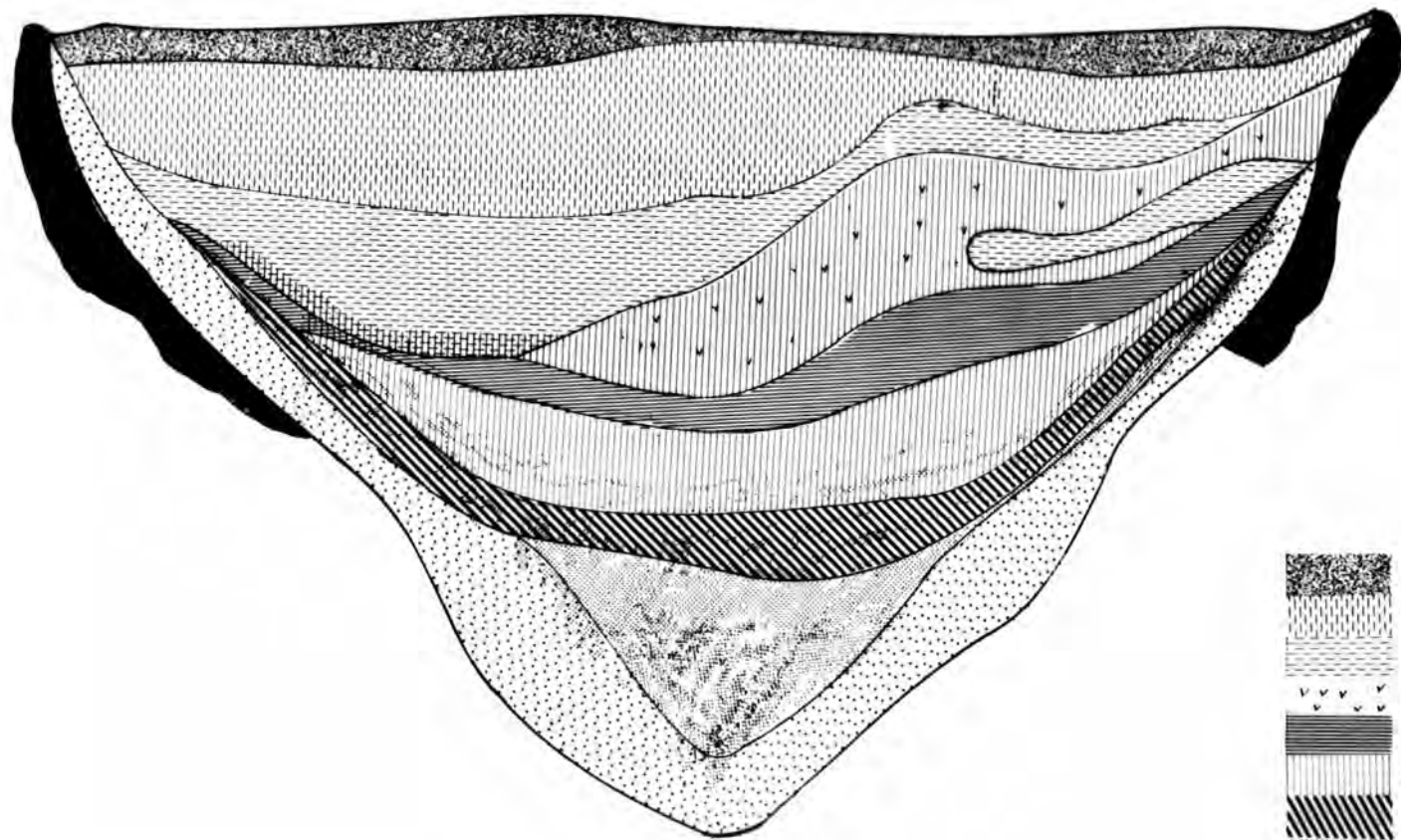
Sphagnum peat overlies the mud layer with depths to 2.5 m and humification (H 5-7). In certain areas this layer is rich in wood fragments of Betula and Alnus. The uppermost layer is composed of Sphagnum peat with occasional woody fragments and frequent remains of Eriophorum vaginatum. In places the surface has been cut for peat fuel disturbing the deposits. Baulks of peat, which we shall term 'dry knolls' are left between old cuttings and constitute the drier portions of the bog. In open areas these are dominated by Calluna vulgaris with Vaccinium myrtillus more common in shaded sections. Such 'dry knolls' have a surface layer of heavy mor peat, black in color with frequent woody remains. Such peat is well decomposed rating 6 or above on the von Post scale.

Walker (1966) provides a detailed chronological analysis of the site describing its ecological development to present. In

Fig. 3-2. Cross section of stratigraphy on Moorthwaite Moss.
(Modified from Walker 1966).

MOORTHWAITE MOSS

STRATIGRAPHY



-  DISTURBED PEAT
-  SPHAGNUM - SEDGE PEAT
-  SPHAGNUM PEAT
-  WOODY FRAGMENTS
-  FINE ORGANIC DETRITUS
-  COURSE ORGANIC DETRITUS
-  CLAY
-  SILT
-  SAND
-  GRAVEL

general the early vegetation was comprised of Myriophyllum alterniflorum which flourished in oligotrophic conditions. Sparganium spp. and Nymphaea alba were also sparsely represented. The fringing fen was characterized by Thalictrum sp. and Filipendula ulmaria. Accompanying organic deposition Myriophyllum declined in abundance and Ranunculus sect. Batrachium succeeded with sedges replacing grasses in the fen. The fen encroached on the lake from the northern margin and acidification began. The initial colonizing communities were of the swamp-carr type. While this carr developed in the northern portion a Sphagnum bog predominated southward and eventually replaced the carr. The Sphagnum bog gradually covered most of the site and indication is that Moorthwaite Moss was probably an ombrogenous raised bog.

As previously noted, the site was used for peat fuel and evidence of old cuttings is present between the drier knolls. Sphagnum recurvum, Sphagnum cuspidatum and Narthecium ossifragum have recolonized these areas in the ombrogenous bog and Juncus bulbosus is common in the fen cut-away. In recent times only has the area become covered by Pinus sylvestris with an admixture of Betula pubescens in some parts; both species of which are regenerating. These may have spread inward from an old plantation near the southern margin of the bog. At present the anthropogenic factor is of increasing importance in that the bog border is used as a dumping ground for disused machinery. Additionally there is evidence of recent fire damage in the western bog. Other influences are tree

cutting, hunting, and of undetermined importance are the wind-blown fertilizers and soil particles deposited on the surface from the surrounding farmland.

CLIMATE:

The nearest climatological records were obtained from Castle Carrock (NY(35)545551) however only precipitation values were available. This shows an annual mean of 785 mm. More complete records from nearby Carlisle have a mean annual precipitation of 853 mm. Newton Rigg (NY(35)493310) is at an altitude of 165 m and is probably the closest station with similar climate conditions. The mean annual precipitation is 872 mm with a variance of 164 mm from 1940-1968. The mean annual temperature is 8.3°C with July mean of 14.7°C and January mean 2.4°C.

PRESENT VEGETATION:

The interrelations of past peat exploitation, nearby agronomy practices, and recent metal deposition have created a rather complex vegetation pattern surrounding the ombrotrophic central portion of Moorthwaite Moss. Only this open central portion is relatively undisturbed, probably because it was the last remnant of the infilling process and consequently was too wet for exploitation until recent solidification of the Sphagnum mat. The site is subdivided into six physiognomic types each interspersed and grading with another. Approximate boundaries have been established for each type from ground survey in conjunction with point plotting on the

Fig. 3-3. Physiographic-vegetation units comprising Moorthwaite Moss (scale 1 cm = 40 m).

established grid. The areal portion of the site covered by each type is shown in Figure 3-3. Furthermore, where type mixing or disturbance is intense it has been indicated. Aerial photographs, taken in 1945, can be used to illustrate this variation, however forest development has since led to further encroachment over the center. The physiographic types referred to in the text are as follows:

OMBROTROPHIC

- I Open Bog
- II Dry Knoll
- III Open Forested Bog
- IV Closed Forested Bog

MESOTROPHIC

- V Marginal Fen and Edge
- VI Soligenous Fen

Descriptions of these types are given with their corresponding vegetation units throughout the text. In most cases such vegetation units correspond in distribution with these zones. The units have been derived through use of the Zurich Montpellier (Z-M) techniques and emphasis is placed on the ombrotrophic bog and forest vegetation which have been subjected to investigations concerning species production and mineral store. The major units of vegetation comprising Moorthwaite Moss are:

OMBROTROPHIC VEGETATION:

A. Wet Ombrotrophic Bog (Table 3-1)*

This vegetation typifies the bog mat of the open bog and forest zones and rather limited areas of the ombrotrophic closed forest which are in more wet, relatively shade-free, locations. The differential species group is made up of:

<u>Drosera rotundifolia</u>	<u>Andromeda polifolia</u>
<u>Cephalozia connivens</u>	<u>Sphagnum magellanicum</u>

Physiognomically this vegetation unit is relatively flat, interrupted with low Sphagnum rubellum hummocks and less often with Polytrichum commune hummock development. Also there are scattered pine (Pinus sylvestris) trees. The wetter portion of the open bog zone has an abundance of pine seedlings, 1-10 years in age, indicating favourable regeneration conditions. There are no open pools remaining in the ombrotrophic bog, however, the water table is at or near the surface in most areas.

The variants within the open bog mat align a moisture gradient from extreme wet to moderately dry conditions. Sphagnum cuspidatum differentiates the wettest variant which is characterized by a 'floating mat', being the locations of the last open pools. This variant is lacking in species diversity because of its pioneer status. In other areas, wet troughs consist of an almost complete Sphagnum recurvum cover (Figure 3-4). Such areas are usually

*All phytosociologic tables included in Volume II.

'infilled cut-aways' and will be referred to as 'infilled pools'. On an areal basis these extreme wet variants are rather insignificant.

A less wet variant is differentiated by Narthecium ossifragum and although confined to small areas is commonly found within the open bog zone. This variant has greater species diversity and is physiognomically distinct because of its differential species (Figure 3-5). Less clearly defined is the Sphagnum rubellum variant associated with Narthecium vegetation. This is only in very open parts of the bog. Releve 4 indicates that Sphagnum rubellum can form an almost complete cover; such areas are drier than others previously discussed.

The typicum portion of the ombrotrophic bog is represented by releves 38-69 (Table 3-1)* and is dominated by Sphagnum magellanicum and a heavy cover of Eriophorum angustifolium. This vegetation unit varies from a wet, dense Sphagnum magellanicum carpet to a drier less dense cover admixed with Sphagnum recurvum and Aulacomnium palustre. The driest variant of the ombrotrophic wet bog is the Aulacomnium palustre variant which is further differentiated by Empetrum nigrum and Pleurozium schreberi. Figure 3-6 shows the aspect of the open bog zone with abundant Eriophorum angustifolium.

B. Hummocks, Dry Knoll and Forest (Table 3-2)

This unit comprises the drier vegetation on Moorthwaite Moss made up of the natural regeneration hummocks scattered over the open bog, the dry knoll (peat baulks) underlain

*Tables 3-1 to 3-6 included in Vol. II.



Fig. 3-4. Infilled pool showing sward of Sphagnum recurvum.



Fig. 3-5. Narthecium ossifragum variant within the ombrotrophic wet bog vegetation.

by mor peats and those areas influenced by a more complete tree cover within the more ombrotrophic portions of the bog. Differential species of the unit are:

<u>Eriophorum vaginatum</u>	<u>Pleurozium schreberi</u>
<u>Sphagnum palustre</u>	<u>Calluna vulgaris</u>
<u>Dicranum scorparium</u>	

The hummocks of the open bog mat and the dry knoll vegetation are partially delineated by the Cladonia impexa variant representing the drier parts of the bog. This variant is subdivided into the Aulacomnium palustre hummocks (Figure 3-7) and the Sphagnum rubellum hummocks. The former are restricted to the open bog and represent the drier extension of the Aulacomnium palustre mat. In such areas the moss is more impact and of a smaller variety than on the mat.

A second hummock type is characterized by the subvariant of the Cladonia impexa variant differentiated by:

<u>Sphagnum rubellum</u>	<u>Empetrum nigrum</u>
<u>Sphagnum magellanicum</u>	<u>Calypogeia sphagnicola</u>

which is found as well developed hummocks in areas having a high Pinus sylvestris seedling density, as well as the wetter parts of the Calluna dry knoll.

The driest portion of the ombrotrophic zones are the dry knolls (Figures 3-8, 3-9) left from peat exploitation. There are two main vegetation types within the category. Firstly, the open



Fig. 3-6. The open bog vegetation showing the high density of Eriophorum angustifolium in the herb layer.



Fig. 3-7. Hummocks in the open bog mat, with Aulacomnium palustre and Cladonia impexa dominant.



Fig. 3-8. Vaccinium myrtillus dry knoll in the open forest zone.



Fig. 3-9. The Calluna vulgaris dry knoll showing the open aspect of the shrub cover.

or slightly shaded baulks covered by Calluna vulgaris in association with Eriophorum vaginatum, Pleurozium schreberi and Gladonia impexa. This vegetation is easily identified by its physiognomy, being dominated by Calluna vulgaris with a height of approximately 50 cm. The second knoll is termed the 'Vaccinium knoll' which is also on a dense mor peat but generally in more shaded areas of the open forest. It is almost wholly dominated in the understory layer by Vaccinium myrtillus. The peat soils underlying the vegetation is slightly less acidic than on the Calluna knoll, however, it is equally deficient in nutrient content. The 'Vaccinium knoll' vegetation is not extensive, being mainly confined to a small area south of the open center.

Occasionally there occurs a hummock type differentiated by the Polytrichum commune variant. This is found both on the open bog mat and in the marginal fen. Such hummocks are the driest vegetation and are associated with Pinus sylvestris seedlings, however, such seedlings are not rooting in the crown part of such hummocks. On an areal basis the Polytrichum commune variant is of little importance.

The remaining dry variant of the ombrotrophic vegetation is the forested portion representing the largest physiognomic zone yet of a very uniform structure with a well developed tree cover underlain by an almost unbroken cover of Erica tetralix in association with Eriophorum vaginatum and Vaccinium myrtillus. The moss layer has an increased cover of Sphagnum palustre with Pleurozium schreberi common in some areas. The tree layer is characterized by a mixed age stand of Pinus sylvestris with many standing dead of the same species.

Betula pubescens is scattered throughout, more commonly present as seedlings.

MESOTROPHIC VEGETATION:

The vegetation of the more nutrient rich areas only underwent cursory examination such that the whole site could be assessed with relation to the effect of such areas on the more nutrient poor portion of Moorthwaite Moss.

C. Edge (Table 3-3)

That part of the site termed 'edge' is the portion bordering on the ombrotrophic forest zone representing extremely dry conditions but still rather poor in nutrient content. In structure it is like the dry knolls of the ombrotrophic zone. In addition it includes a wetter, seemingly more nutrient rich vegetation found within the ombrotrophic closed forest near the open central area. This latter vegetation denoted by releves 33, 34 is differentiated by:

Carex nigra Narthecium ossifragum

It is found in only two small areas in which Carex nigra forms a dense sward. Also Narthecium ossifragum is much larger than in the open bog Narthecium but is almost flaccid compared to the erect open bog plants. Such areas are possibly small 'soaks' (Sjors, 1963) within the otherwise ombrotrophic bog.

At the northern and western bog borders are dry sites occupied by two different vegetations, the first in slightly

moister conditions is the Dryopteris spinulosa variant differentiated by the species group:

<u>Lophocolea bidentata</u>	<u>Dryopteris spinulosa</u>
<u>Anthoxanthum odoratum</u>	<u>Erica cinerea</u>

The driest areas have the Epilobium angustifolium variant with:

<u>Digitalis purpurea</u>	<u>Epilobium angustifolium</u>
<u>Deschampsia flexuosa</u>	

The 'edge' vegetation reflects possible anthropogenic influences and the area has been disturbed by ditching, fire and rubbish dumping.

D. Marginal Fen (Table 3-4)

The marginal fen vegetation approximates the lagg of true bog development. This fen is influenced by drainage from nearby farmland and is also the recipient of wind-blown fertilizers. Species diversity is greater in the marginal fen than the other zones with the exception of wet areas where plant cover is less than complete.

Differential species for the fen are:

<u>Carex nigra</u>	<u>Sphagnum palustre</u> var <u>squarrulosum</u>
<u>Mnium hornum</u>	<u>Plagiothecium undulatum</u>
<u>Agrostis tenuis</u>	

The wet troughs, left from peat cutting in the fen, often have only partial plant cover and comprise the Juncus bulbosus variant with species group:

<u>Juncus bulbosus</u>	<u>Carex curta</u>
<u>Cardaminae amara</u>	<u>Carex echinata</u>

The closed fen vegetation is characterized by the Holcus lanatus variant commonly occurring in shaded, flat, mineral flushed areas downslope from the surrounding mineral soils. A wetter seemingly more nutrient rich subvariant is differentiated by Potentilla erecta, Molinia caerulea and Juncus effusus. Figure 3-11 shows the complexity of the fen vegetation with its dominant herb layer. Areally this vegetation is significant, however distribution is confined to the extreme outer portion of Moorthwaite Moss (Figure 3-3).

E. Soligenous Fen (Table 3-5)

This vegetation is restricted to the north-eastern area and receives inflow directly from adjacent mineral soils. Unlike the marginal fen it juts into the bog proper. Furthermore its physiognomy is quite different in that the Pinus tree layer is replaced by an admixture of Salix aurita, Salix cinerea atrocinerea and Betula pubescens (Figure 3-12).

A series of releves were obtained from the inner bog bordering to the adjoining mineral soil vegetation. The moderately rich areas have a near surface water table and are differentiated



Fig. 3-10. Erica tetralix understory within the forested bog zone.



Fig. 3-11. Physiognomic aspect of the marginal fen vegetation.



Fig. 3-12. Soligenous fen vegetation showing the dense Salix-Betula cover.



Fig. 3-13. Open pool vegetation bordering the soligenous fen, with heavy Potamogeton natans cover.

from the eutrophic fen and ombrotrophic bog by Carex rostrata and Salix aurita, whereas true fen conditions are characterized by the presence of Rhytidiadelphus squarrosus. The species composition is complex and only a detailed micro-environmental analysis could clarify the intricate differentiation. Such areas are not unlike the alder swamps described for Central Newfoundland.

F. Pools (Table 3-6)

The open pool vegetation (Figure 3-13) on Moorthwaite Moss is only found near the soligenous fen and are few in number usually less than 3 m in length. The pool surface is covered in summer by Potamogeton spp.

G. Disturbed Areas

Apart from the anthropogenic factors previously discussed, the northern section of the bog has been severely disturbed by windblow, causing the toppling of many large trees. On bog soils the rooting is relatively shallow and well spread such that large sections of the site have been torn away (Figure 3-14). Pteridium aquilinum covers much of this area.

GROUP ANALYSIS

For comparison of the classification given here using the Z-M methods, an objective approach was used for separation of units. Because of time pressure only the group analysis (Crawford and Wishart, 1967) was used. This technique requires less computer



Fig. 3-14. Root mass of Pinus sylvestris toppled by strong winds.

work than other multivariate techniques such as nodal analysis (Lambert and Williams, 1962).

To test the data, sampling was conducted only within the ombrotrophic vegetation from which 27 randomly selected quadrats, each 2 sq. m, were recorded and analyzed. The level of Group Coefficient used to determine the groups was 0.70. In all, nine groups of quadrats were produced (Figure 4-15).

The species dividing the data initially is Calluna vulgaris (A - with; a - without). If we consider first quadrats without Calluna (a) we have a division on Pinus sylvestris (b, B). Quadrats with Pinus sylvestris make up segments of open bog vegetation (Group 7) and closed forest vegetation (Group 6) which are subdivided on Eriophorum vaginatum (g, G) with the closed forest having the species. The two remaining quadrats without Pinus sylvestris were subdivided manually into Groups 8 and 9 because of obvious differences. Group 8 is from the wet open bog whereas 9 is on a dry vegetation with incomplete cover.

The quadrats with Calluna vulgaris (A) divided on Eriophorum angustifolium (d, D) which firstly define Group 1 (without Eriophorum angustifolium) which represents the hummocks and dry knoll vegetation are given in Table 3-2. Quadrats with Eriophorum angustifolium are subdivided on Cladonia impexa (c, C). Quadrats with Cladonia impexa subdivide further on Odontoschisma sphagni (e, E) with the positive Group 4 representing the wet bog and open bog hummocks, and the negative Group 5 also representing the open bog mat and associated hummocks. These bog sites are described in our Z-M discussed as

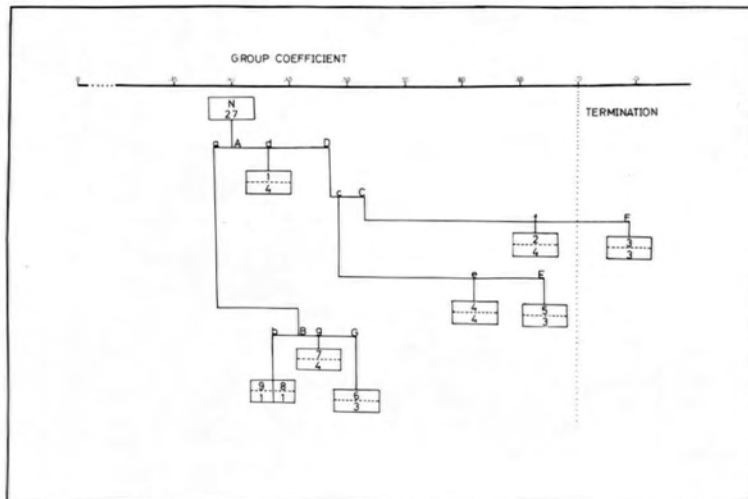


Fig. 3

the Narthecium ossifragum variant and the typicum Sphagnum magellanicum mat. The hummocks are included in both because of the differences in sampling procedure.

The remaining quadrats, without Cladonia impexa subdivided on Narthecium ossifragum again with the positive Group 3 representing wet open bog vegetation and Group 2 without Narthecium ossifragum made up of hummock and forest vegetation.

These results poorly show the differentiation of units from open bog to forest vegetation. This is due in part to the species used to divide the data which is selected on the basis of species gregarity rather than vegetational homogeneity. Bog vegetation is sparse in species number but the species present are particularly social or gregarious.

In general the groups can be positioned along ecological gradients (Table 3-7), however, the influences of one environmental factor in relation to another is difficult to discern. Primary gradients on the site are from wet to dry and open to shaded conditions. Group 4 has elements of wet open bog and drier hummock development. Also the division of Group 1 (without Eriophorum angustifolium) is of dubious merit when assessed with Table 3-2. This approach could possibly be applied to bog vegetation with some success, but is seemingly more applicable to areas of heterogenous vegetation such as investigated by the originators of the method (Crawford and Wishart, 1967).

Table 3-7. Ecological species groups determined by group analysis for ombrotrophic vegetation on Moorthwaite Moss.

	Group Number								
	8	7	3	4	5	2	1	6	9
<i>Rhynchospora alba</i>	+								
<i>Narthecium ossifragum</i>	+	+	+	+					
<i>Andromeda polifolia</i>	+	+	+	+					
<i>Drosera rotundifolia</i>	+	+	+	+					
<i>Cephalozia connivens</i>	+	+							
<i>Polytrichum strictum</i>		+							
<i>Sphagnum cuspidatum</i>		+							
<i>Sphagnum rubellum</i>	+	+		+	+				
<i>Sphagnum magellanicum</i>		+	+		+	+			
<i>Sphagnum tenellum</i>		+							
<i>Empetrum nigrum</i>				+	+	+			
<i>Dicranum scoparium</i>				+					
<i>Odontoschisma sphagni</i>					+				
<i>Hypnum cupressiforme</i>					+				
<i>Dicranum bonjeani</i>						+			
<i>Calluna vulgaris</i>			+	+	+	+	+		
<i>Calyptogeia sphagnicola</i>				+	+		+		
<i>Cladonia impexa</i>				+	+		+		
<i>Cladonia sylvatica</i>							+		
<i>Sphagnum palustre</i>						+	+	+	
<i>Betula pubescens</i>								+	
<i>Vaccinium myrtillus</i>				+		+	+	+	
<i>Pleurozium schreberi</i>				+	+	+	+	+	
<i>Eriophorum vaginatum</i>				+	+		+	+	+
<i>Mylia anomala</i>		+	+	+	+	+	+		
<i>Pinus sylvestris</i>		+	+	+	+	+	+	+	
<i>Sphagnum recurvum</i>		+	+	+	+	+	+	+	
<i>Pamelia physodes</i>		+	+		+	+	+	+	+
<i>Eriophorum angustifolium</i>	+	+	+	+	+	+		+	+
<i>Aulacomnium palustre</i>	+	+	+	+	+	+	+	+	
<i>Oxycoccus palustris</i>	+	+	+	+	+	+	+	+	+
<i>Erica tetralix</i>	+	+	+	+	+	+	+	+	+

Open _____ Shaded

Wet _____ Dry

SUMMARY OF VEGETATION SURVEY:

The vegetation of Moorthwaite Moss has been described according to the Z-M methodology with emphasis placed on the more ombrotrophic sections of the vegetation. Unlike the Newfoundland sites for which no established hierarchy has been determined, the ombrotrophic bog described here can be classified as follows (from Moore, 1964):

CLASS: Oxycocco-Sphagnetea Br-B1 et Tx 1943
 ORDER: Sphagnetalia magellanici Moore 1964
 ALLIANCE: Erico-Sphagnion Moore 1964
 ASSOCIATION: Erico-Sphagnetum magellanici Moore 1964
 SYN: Sphagnetum imbricati Schwick. 1940
 Sphagnetum papilloso Schwick. 1940
 Sphagnetum rubelli Schwick. 1940
 Sphagnetum medii Kastner et al. 1933

Sub-Atlantic Race

The Sub-Atlantic Race takes in areas of England, as well as coastal areas of Holland and Niedersachsen. In this unit, Narthecium ossifragum is relatively common and Sphagnum recurvum is present, often in quantity. Both species are commonly found on Moorthwaite Moss.

PHYSICAL AND CHEMICAL PROPERTIES
OF PEAT SUBSTRATA ON MOORTHWAITE MOSS

Variation in the surface vegetation of peatland is often associated with differences in physical and chemical properties of their peat substrata (Sjors, 1952). This has already been demonstrated for the peatland associations of Newfoundland, however, on Moorthwaite conditions are radically different in that there is an admixture of vegetation within a very small area across moisture, shade and nutrient gradients. To assess the site peat characteristics a series of samples were taken from each of the major vegetation zones. Methods used in analysis are appended (App. II) and the results obtained are given in Tables 3-8 and 3-9 (Vol. II).

PEAT TYPES:

The botanical composition of the sample layer, the upper 30 cm, varies greatly. In the open bog and underneath bog hummocks Sphagnum (Sph) peats admixed with Eriophorum (Se) peat is common. Similarly the soligenous fen areas have a sedge - Sphagnum peat, with sedge dominant, largely comprised of Carex rostrata and Eriophorum angustifolium remains. In the soligenous fen peats woody fragments, of Salix and Betula origin, are frequently found.

The forested bog and marginal fen have peats with a high wood and in places Se and Sph content. Their peats are often more decomposed and less wet than the open bog peat. The dry knolls are characterized by a dark colored, dense, dry mor peat soil, which is rather decomposed. The woody peat made up primarily of heath litter

is of two varieties: the Calluna vulgaris peats in open areas, and the Vaccinium myrtillus - Pinus sylvestris peat in shaded dry knolls. In addition sand particles have been found in this peat and is attributed to loess material. This was not noticed in any of the other peat substrata examined.

BULK DENSITY:

The bulk density (BD) of the peat is an important measure of soil porosity as well as enabling nutrient calculation for volumetric expression of data. On Moorthwaite Moss this is a strong criterion for separation of peat types varying from the lightweight Sphagnum peats of the open bog and fen areas with range from 0.04 - 0.11 g/cc to the forest peats 0.10 - 0.29 g/cc and the heavy dry knoll peat (0.14 - 0.52 g/cc). The bulk density is closely related to other physical phenomena in peats such as its decomposition and water contents (Paivanen, 1969).

DECOMPOSITION AND WATER CONTENT:

The degree of decomposition of peat soils is as yet difficult to clearly define and quantify. In this study the von Post (1924) scale is used even though it is a qualitative measure. Attempts have been made by Kaila (1956), Goetzke (1963) and Farnham and Finney (1965) to establish quantitative techniques for measuring decomposition based on bulk density and fiber size. Numerous investigators use decomposition for comparison with other more quantitatively measured physical properties such as water retention,

ash content and humus content (Kuntze, 1965); hydraulic conductivity (Eggelsmann, 1964); water content (Boelter, 1966); and bulk density (Paivanen, 1969).

On Moorthwaite decomposition is least in the wet Sph - Se, Sph and Se - Sph peats, the range is H 2.5 - 5.0 normally, but in localized areas higher values are recorded up to H 7. The forest peats have a wider range from the least decomposed Sph - w peats (H 3.5) to the almost wholly decomposed w peat (H 9+). The woody peats are generally more decomposed and have a lower water content and higher bulk density.

Water contents in peat have been recorded primarily by engineers or hydrologists (Boelter, 1966, 1969; Boelter and Blake, 1964; Bay, 1967a, 1967b) or researchers interested in peat exploitation (Heikurainen, 1964; Kaila, 1956b). Peatland ecologists could make more use of such studies than indicated in current literature.

Water contents are often presented on an oven dry weight basis, that is ratio of weight of water to oven dry weight of peat (MacFarlane, 1969). Less frequently, yet meaningful for peat comparisons, the water content is expressed as per cent volume for a given volume of peat. Also used is the per cent of water in total wet weight. Boelter (1966) illustrates the differences in each method.

In this survey water contents are expressed as per cent of wet weight. Because the oven dry weight per unit volume of peat in the field is very low compared with mineral soil, and varies considerably for different peat types there is no basis for comparing their water contents when calculated as a weight per unit weight.

The open bog, soligenous fen and marginal fen peats all have water contents between 92-96% by wet weight. Additionally those peats within the forest and the dry knoll which have a high sphagnum content have comparable water contents ranging from 88.8 - 94.5%. The drier peats of the forested bog have values of 81 and 77% which is reflected in their high densities of 0.28 and 0.29 respectively. The dry knoll peats indicate very dry conditions for peat soils with the Calluna vulgaris heath having 88.8% in its wet Sphagnum rubellum variant and 80.2% under its typicum. The very dry Vaccinium myrtillus heath and the dry edge Erica cinerea heath have 64.7 and 67.9% water content respectively. This again is indicative of its high bulk density 0.52 and 0.51.

PH:

The determination of pH is often a useful complement to other analyses and may be the most valuable. It is often correlated with other habitat factors such as nutrient availability (Lucas and Davis, 1961), ash content and total calcium (Holmen, 1964). Holmen (1964) states that there is an increase in acidity of soil when it is dried and rewetted before measuring; however, this change is slight with the less acid sedge peats more affected than the Sphagnum peats. Also pH can change throughout the year as shown by Malmer (1962b), for water samples taken from bog hollows. Yet for peats the seasonal change is less pronounced and if taken under similar conditions within a short span of time comparative values are easily obtained.

On Moorthwaite Moss the pH can be used as a defining character for peat types even though the range throughout the site is fairly narrow. The dry knoll peats are highly acidic with the Calluna and Erica cinerea knolls having a pH of 2.90 - 2.92. Slightly less acidic is the Vaccinium myrtillus knoll which has a value of 3.30 which is compatible with ombrotrophic forest conditions (3.15 - 3.31). These sites are both acid because of the mor aspect of peat accumulation with heath plants and Pinus sylvestris needles the primary peat contributors.

The open bog and hummock peats are higher than the heath dominated sites with pH varying from 3.45 to 3.78. This range is expected for such sites with many similar values given for such peats. The marginal fen has a pH 4.10 - 4.30 enabling a number of its species components to exist in such areas. Still higher in pH is the soligenous fen peats with values 4.72 and 5.10.

NUTRIENT CONTENTS:

The variation of nutrient content within peats has been discussed in Section 2 and its use to augment or substantiate vegetation classification has been shown. Moorthwaite Moss, however, offers a different problem in that it is one small site and emphasis is placed on separation of its vegetation on a more localized level. Because of this the differences in nutrient contents are not as clear-cut as are the physical peat characteristics previously discussed. In Tables 3-8, 3-9 the recorded values are given in both weight and volumetric terms, which differ according to the bulk densities of the peat types.

(A) By Weight:

On a weight basis the open bog Sphagnum peats have the lowest concentrations of total nitrogen, with a more even distribution throughout the remaining peats. These peat nitrogen contents (5.20 - 13.80 mg/g) are low in comparison to values obtained for the peat soils in Newfoundland. The available nitrogen is more randomly distributed with lowest content in the dry knoll peat. The ombrotrophic forest peats have a uniform concentration whereas the open bog peats have a wide range comparable with the low levels in the dry knoll to the high level in the marginal fen areas.

Phosphorus, both total and available, is also evenly distributed throughout all peats with slightly lower concentration in the dry knoll. Potassium is also lower in the dry knoll peats.

Calcium is the most significant nutrient measure on the site, showing a strong correlation with pH. Again the dry knoll peats have the least concentration with ombrotrophic forest, open bog and hummocks, marginal fen and soligenous fen following suit. The available calcium has a similar pattern of distribution. Magnesium, total and available, is highest in the marginal fen, followed by open bog, ombrotrophic forest and dry knoll.

Manganese, unlike the other nutrients, has its highest concentration in open bog peats, followed by fen, forest and dry knoll. The latter two sites are significantly lower in available manganese. This differentiation can be attributed to wetness of the peat. Zinc has the same pattern as manganese.

Iron, which plays an important role in separation of nutrient poor-nutrient rich peat types, does not have the same significance in Moorthwaite where contents are low and rather uniform throughout. This is probably due to the lack of iron concentration in the surrounding mineral soils. In Newfoundland, with the development of iron pans, drainage received by fens from surrounding podzols is usually high in iron concentration.

Sodium is also evenly distributed on the site, however, in its available form the dry knoll has significantly lower concentration.

On a weight basis, the Sphagnum peats of the open bog are distinguished by low nitrogen and high manganese and zinc concentration. The reasons for these high micronutrient values are not clear in that manganese is usually very low in bog peats. In comparison to the Newfoundland peats the total nutrient contents are lower in the Moorthwaite peat soils whereas available nitrogen, phosphorus, calcium and potassium are similar or higher than their Newfoundland counterparts. This may be due to the addition of wind-blown fertilizers from nearby farmland.

(B) By Volume:

By using the volumetric measure the relationships between peat and nutrient contents change, such that layers believed to be deficient in some nutrients have equal or greater supplies than the corresponding rich peats as categorized by weight. In Table 3-9 all nutrients are expressed in terms of gm/m² for a depth

of 30 cm. This depth was selected because it is taken as the maximum rooting depth in peat soils.

The nitrogen content is lowest in open bog peats and rather evenly distributed in other peats on a weight basis. This disparity is even greater volumetrically with the dry knoll and woody peats having high nitrogen storage up to 1600 g/m^2 . This is not uncommon in heath soils, which are characterized by the low release of soluble nitrogen. Damman (1967) gives the amount of nitrogen in the humus layer of *Kalmia* heath as 2230 g/m^2 . Gimingham (1960) states that Calluna mors are extremely poor in nitrifying ability and vegetation in such areas often indicate a nitrogen deficiency. The Erica cinerea edge vegetation has the highest total and available nitrogen concentrations.

In addition on volumetric comparison phosphorus is found to be low in the open bog and fen peats, with higher concentrations in forested bog and dry knoll; this is also true for magnesium, iron and sodium contents. Zinc has little correlation with peats and is high in localized areas with units, possibly as a result of metal dumping. Manganese and calcium express similar patterns volumetrically as by weight, with available manganese high in the open bog and fen peats, an opposite trend than obtained in the central Newfoundland peats. This however is due to the variation in moisture contents. Overall the available manganese is much lower in the Moorthwaite peat soils than for any peats examined in Newfoundland.

PRODUCTION ANALYSIS

The description of Moorthwaite Moss consisting of its vegetational patterns and peat characteristics does not in itself explain the dynamics of that system. There are at present few investigations undertaken in which neither the study of dynamic equilibria nor description of floristic composition lack preciseness and definition.

Production ecology is not a new field of research and has been widely and successfully utilized in forestry and agricultural practices for many years. In terms of its use as a tool in many ecosystem investigations, however, it is an emergent field of study which has received recent impetus through such organizations as UNESCO and IBP.

Recent reviews on production ecology are lacking with Westlake's (1963) account most familiar. Other works which provide a knowledge of recent developments in methodology are Ovington (1962), Odum (1960), Bliss (1960), Pollard (1966), Milner et al. (1968), Newbould (1963, 1968), Rodin and Bazilevich (1967), Eckardt (1968); Whittaker (1961, 1963, 1966). Other specialized works are discussed in the text.

The aspect of ecosystem investigation is a new innovation in production ecology as opposed to studies on isolated species. According to Eckardt (1968) this reflects the growing awareness

among biologists of the dynamic interrelationships between all physical and biotic components of the biosphere. When assessing the significance of the structural and functional features in living organisms, it must be remembered that these organisms constitute part of a whole which has evolved as a whole. Odum (1960), Bliss (1960), Wiegert and Evans (1964) use this approach. Watt (1955), in addition, emphasizes a need to focus on the dominant species to understand the processes of a community, because of its importance in the formation of community structure.

In this investigation stress is placed on the production of dominants in each of the major vegetation units of the ombrotrophic bog and forest as delineated by the Z-M analysis. Production studies of associations based on this phytosociologic system have been conducted by Smirnov and Semenova (1969) on Piceetum myrtilloso sub-association Sphagnetosum and Mathe, Precsenyi and Lolgomi (1968) on Galatello-Quericetum Polygonatetosum latifolii. Other studies by Rajchel (1965) and Traczyk (1967) focus on the herb layer production in a number of forest associations.

INVESTIGATION FORMAT:

In most peatland associations the dominant layer is the moss layer with *Sphagna* species contributing the bulk of the biomass and lichens and liverworts playing a minor part in production. On many hummock varieties the herb and shrub layers are dominant or co-dominant and in the heathland the shrub layer is dominant. The dominance of vegetation within each unit has been discussed for

Moorthwaite, however, it must be noted that the most important factor affecting overall production is the tree layer which is quite variable in density of individuals per unit area, and in growth form of these individuals.

The investigation is designed primarily to provide an estimate of biomass within the major vegetation types and secondly to determine primary production of component species within selected units. This is confined primarily to the moss, herb and shrub layers. Only a rough measure of the tree layer was feasible within the scope of the investigation. From the results obtained a measure of production within vegetation units can be provided. The methods used in this study are given in Appendix II.

Many terms used in productivity studies contract new meanings with particular authors. The terms used in the text follow definitions provided by Westlake (1963). All measurement of yield are expressed in terms of dry weight measured in metric units.

ESTIMATE OF PEAK STANDING CROP:

Through use of direct cropping techniques the standing crop was estimated for seven vegetation units, in each area two monoliths were taken and dissected. The units sampled were as follows:

- A: Narthecium ossifragum variant of open bog (Table 3-1)
- B: Sphagnum magellanicum mat of open bog (Table 3-1)
- C: Aulacomnium palustre mat of open bog (Table 3-1)
- D: Sphagnum palustre hummock of open forest (Table 3-2)
- E: Calluna vulgaris dry knoll (Table 4-2)

F: Vaccinium myrtillus dry knoll (Table 3-2)

G: Erica tetralix understory in closed forest (Table 3-2)

The results obtained are given in Tables 3-10 and 3-11 (Vol. II) and Figures 3-16 and 3-17.

A: Narthecium ossifragum variant

The area investigated was characterized by a heavy Narthecium cover and was under an open canopy with above 5-10% cover. The water table is near surface and did not go below 2 cm during the growing season. The peat substrata is primarily Sphagnum peat H 1-3 with a great quantity of Narthecium root. Analysis indicates that the aerial standing crop is $\approx 567 \text{ gm/m}^2$ with Sphagnum cuspidatum contributing $\approx 30\%$ and Sphagnum recurvum $\approx 26\%$ of the total dry weight. The other two major producers are Narthecium $\approx 13\%$ and Oxycoccus palustris $\approx 12\%$.

The underground biomass, however, shows that Narthecium roots constitute $\approx 75\%$ and Oxycoccus palustris $\approx 14\%$ of the total. One difficulty, which is elaborated in the discussion, is the separation of live and dead root material, especially for Narthecium in which the roots can remain intact within Sphagnum peat long after they become non-functional. Thus there is a good probability that this can lead to an overestimate. Figure 3-16 shows the root dry matter content of the peat substrate with the greatest root concentration restricted to the upper 10 cm.

Fig. 3-16. Standing crop in open bog and open forest vegetation units A. Nartheceium ossifragum variant, B. Sphagnum magellanicum mat, C. Aulacomnium palustre mat, and D. Sphagnum palustre hummock.

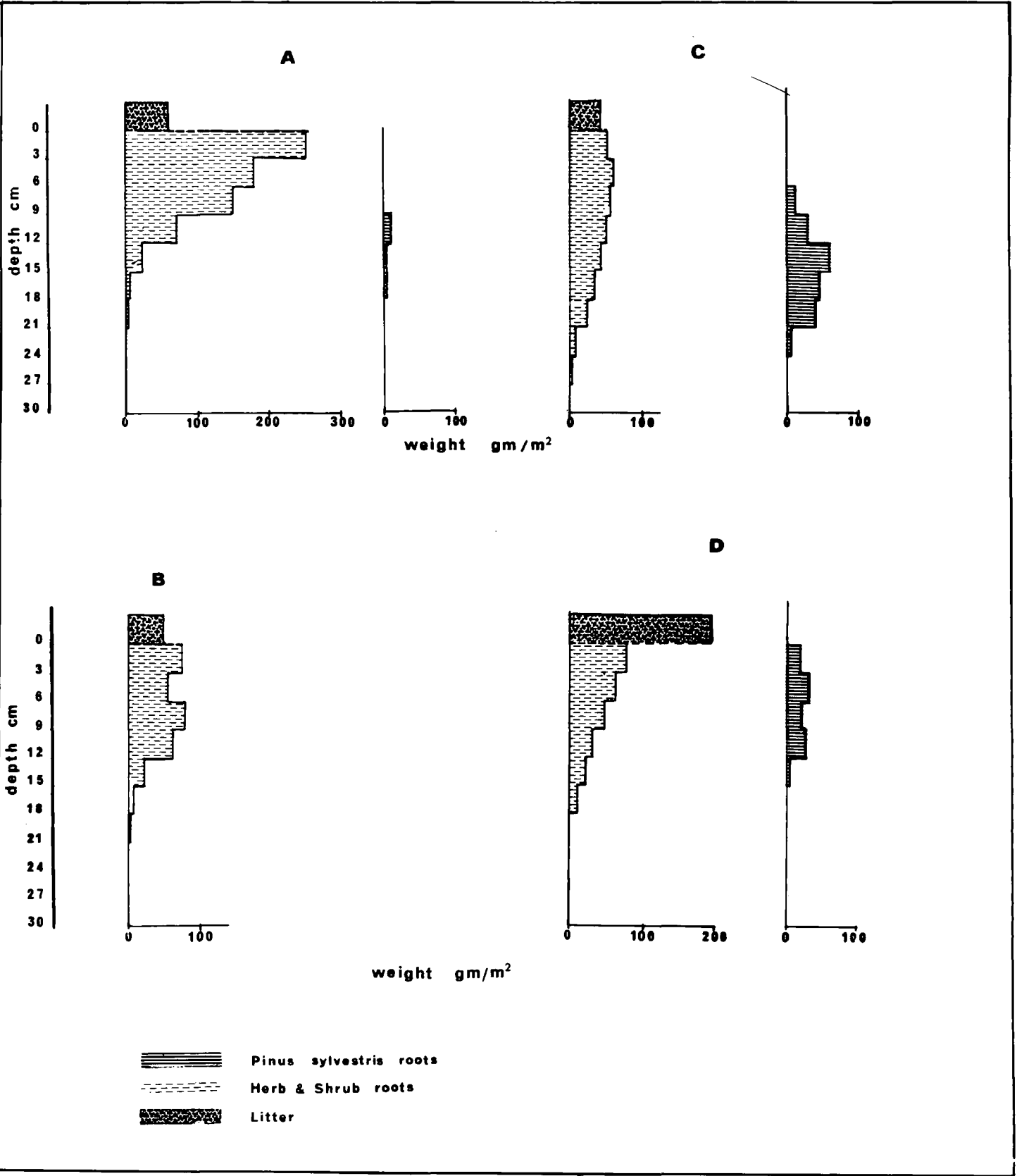
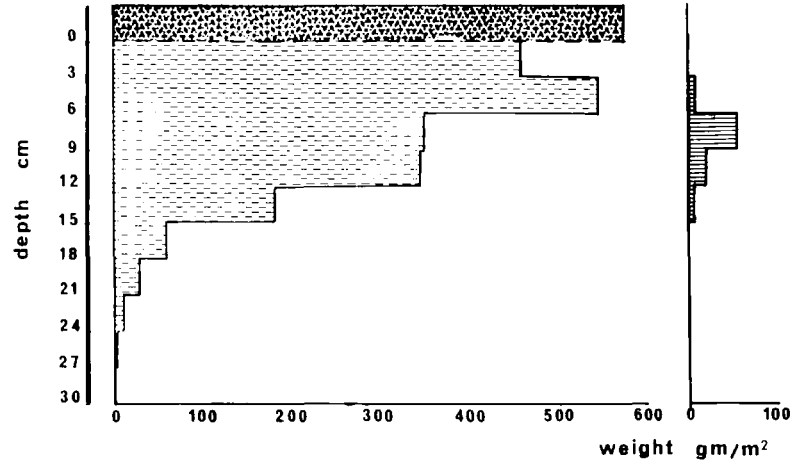
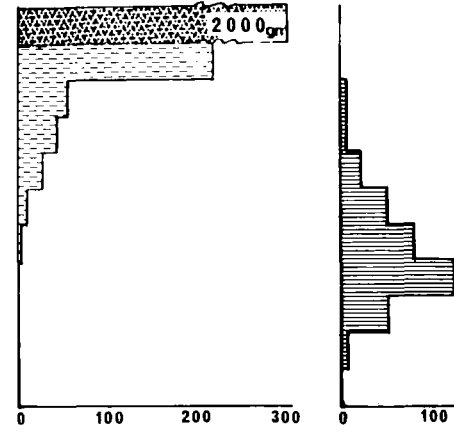


Fig. 3-17. Standing crop in dwarf shrub vegetation on Moorthwaite Moss. E. Calluna vulgaris dry knoll, F. Vaccinium myrtillus dry knoll, and G. Erica tetralix understory. (For legend see Fig. 3-16.)

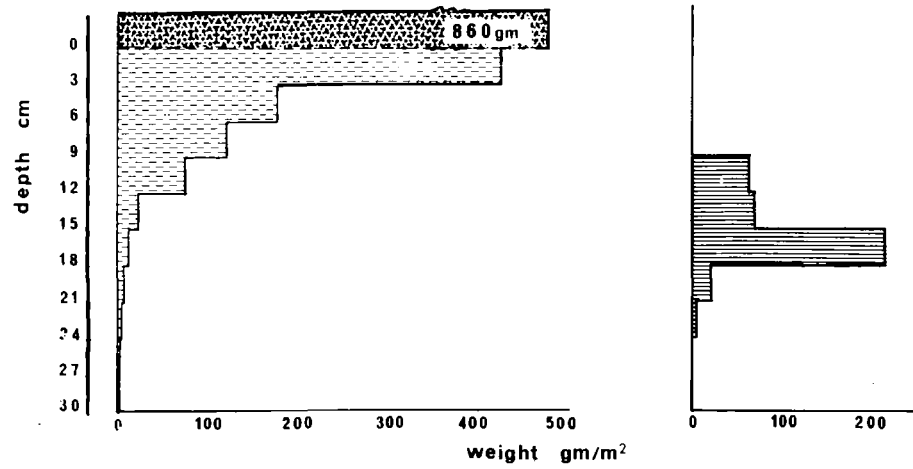
E



G



F



B: Sphagnum magellanicum mat

This mat is dominated by sphagna, Sphagnum recurvum $\approx 30\%$ and Sphagnum magellanicum $\approx 17\%$ with Aulacomnium palustre $\approx 16\%$ and Oxycoccus palustris $\approx 17\%$ is also important. This area is characterized by moderately wet conditions with a water table near surface but falling off to 5-10 cm during drier parts of the summer. It is a flat area which is typical of much of the open bog.

In terms of aerial biomass this area has a higher dry matter content than the Narthecium area but less than the drier portion of the same mat. Total biomass, however, shows that with a low root content, made up primarily of Oxycoccus palustris (72%) the site has the lowest recorded biomass for any of the ground vegetation units.

C: Aulacomnium palustre mat

This sample area is the drier part of the open bog mat and is quite commonly found on Moorthwaite Moss. Aulacomnium constitutes $\approx 41\%$ of the dry matter content of the standing crop Sphagnum magellanicum $\approx 17\%$ and surprisingly Mylia anomala $\approx 18\%$. Oxycoccus palustris ($\approx 12\%$) is a less important producer of aerial dry matter in this unit. The standing crop of the Aulacomnium mat is greater than the wetter ombrotrophic vegetation on an aerial basis but approximates the other open sites when including the underground portion. The presence of Pinus sylvestris roots in the peat augment this biomass more so than in any other open sites.

D: Sphagnum palustre hummock

This sample area is located near the border of the ombrotrophic open bog and closed forest and is typical of much of the actively growing sites in this zone. More so than in any of the other samples one species, Sphagnum palustre, dominates the standing crop content, making up $\approx 72\%$ of the dry matter. Subdominants are Sphagnum recurvum $\approx 13\%$ and Oxycoccus palustris $\approx 8\%$. Root content is primarily supplied by three species, Eriophorum angustifolium $\approx 30\%$, Oxycoccus palustris $\approx 27\%$ and Pinus sylvestris $\approx 35\%$. This unit has the lowest root content of all areas sampled and closely approximates other open sites in total biomass.

E: Calluna vulgaris dry knoll

Unlike the other areas the Calluna dry knoll is a heath rather than bog vegetation. The area has its own physiognomy and is elevated from the surrounding bog vegetation because of old peat cuttings. In general this is a dry area with the water table about 10-15 cm below the surface and up to 25 cm in the summer season. Additionally the peat is of a black well decomposed mor type with little or no Sphagnum to a depth of 30 cm.

This heath vegetation is characterized by a standing crop of $\approx 1400 \text{ gm/m}^2$ aerially and $\approx 1860 \text{ gm/m}^2$ below surface. One problem in such an estimate is to determine where the below-ground material begins. For example, in the loose litter mold there are 400 gm/m^2 of woody stem which has been grouped with the roots but may be as readily put with the aerial crop.

Calluna makes up $\approx 72\%$ of the dry matter, with Cladonia impexa $\approx 17\%$. Similarly Calluna roots make up $\approx 81\%$ of the underground biomass and Eriophorum vaginatum $\approx 14\%$, the latter, however are difficult to separate in live and dead components.

F: Vaccinium myrtillus dry knoll

This site is similar to the previous in morphology and peat structure but dominated by Vaccinium myrtillus which constitutes $\approx 78\%$ of the dry matter, aurally, with Pleurozium schreberi $\approx 11\%$ the most important moss. The root context is influenced by the presence of Pinus sylvestris $\approx 23\%$ of the total with Vaccinium roots $\approx 73\%$ of the total dry matter. In total biomass this vegetation is intermediate between the Calluna heath, and open bog sites, this is probably due to the high density of forest cover in the area which influences understory production.

G: Erica tetralix understory

This sample area typifies the Pinus sylvestris understory in all but the dry knolls. The aerial standing crop for the understory is lowest in this sample with Erica tetralix comprising $\approx 89\%$ of the total. As expected Pinus sylvestris roots are dominant in the below-ground biomass with $\approx 49\%$ of the total and Erica second with $\approx 45\%$.

ROOT DISTRIBUTION:

Figures 3-16 and 3-17 show the distribution of roots in the upper 30 cm of peat in each of the seven sample sites. This indicates that the root mass is restricted to this depth and in communities

dominated by herbaceous or woody plants more than 90% of the total is within the upper 15 cm. The Pinus sylvestris roots are found below this concentration of herb and shrub roots, however, in most areas sampled only a minor part of the lateral root system of Pinus sylvestris was encountered.

SPECIES PERFORMANCE WITHIN VEGETATION UNITS

The estimates of standing crop give a picture of dry matter distribution within the ombrotrophic ground vegetation on Moorthwaite Moss, but explain little of species performance. The next phase of investigation therefore attempts to measure species performance in terms of primary production. Although the species diversity is limited on Moorthwaite, the vegetation is complex in that it reflects a variety of ecological types. Any effort to investigate fully the growth dynamics of all species would require a team approach and a long-term project. Thus limitations are placed on the study, however, the methods will be described which could make such a study possible.

The vegetation is subdivided into four groups: mosses, herbs, shrubs and trees, and the production by individual species within each group is estimated.

MOSSES:

According to Clymo (1970) any attempt to account for the rate of peat formation in bogs and fens is likely to require information on the rate of Sphagnum growth. On Moorthwaite Moss with its mixed open and closed canopy two other mosses, Pleurozium schreberi and Aulacomnium palustre, are also important in site succession.

Unique problems are associated with moss production when there is no clear division between live and dead plant and peat.

In such cases the terms 'standing crop' and 'biomass' have little useful meaning. Nevertheless, there have been many investigations involving growth measurement of mosses.

Cyclic fluctuations are often used to measure growth of mosses. Tamm (1953, 1964) used this method on Hylocomium splendens, Ptilium crista-castrensis, and Pleurozium schreberi; Tallis (1964) on Rhacomitrium lanuginosum, and Streeter (1965) on Acrocladium cuspidatum. Cyclic growth pattern is rather conspicuous on Polytrichum commune and to a lesser extent Aulacomnium palustre, both of which are present on Moorthwaite. Longton and Greene (1969) estimated the growth of Pleurozium schreberi by the position of the inflorescences which they correlated with seasonal growth.

Clymo (1970) lists the disadvantages of this type of measurement; firstly it is only suitable for a long time interval and secondly, in the English climate the cyclic changes in growth pattern are not sufficiently marked for clear separation of segments. Additionally, extension growth and cyclic change in morphology may be more closely related to environmental change within seasons (Hagerup and Peterson, 1960).

Other methods used to estimate moss production are few and have yielded rather questionable estimates. Overbeck and Happach (1956) used cylinders of celluloid with Sphagnum cut to a known length. The plants were removed at intervals, measured, cut back to known length and replaced. In the present survey a similar trial was carried out first using a net designed from a 'hair net' and secondly using 'hair rollers' which are plastic, well perforated and easy to handle. It was found, however, that the frequent

removal of plants and the trampling of the sample site attributed to poor results and subsequent abandonment of the method. Chapman (1965) also used plants cut to a known length for Sphagnum production estimates.

The use of an outside marker as proposed by Clymo (1970) was also used with little success. These markers were cranked wires placed in four Sphagnum recurvum sites. In all cases growth was estimated according to growth upwards from a known initial point marked on the wire. Unfortunately, this was used late in the growing season and the measured growth was negligible. This method may have an advantage for long term growth estimates. Leisman (1957) used the same principal to measure growth of a bog mat in Minnesota.

Clymo (1970) uses two new methods for measuring Sphagnum growth. The first is through direct estimate of weight change by first weighing the plant under water, then a second weighing is taken at harvest, again under water; after which the plant is dried and weighed a third time. This method yielded accurate results but is not suited to field conditions and has not been used here. The second method, the 'capitulum correction method', is used in the present investigation. This method is explained fully in Appendix II. It was used because of its applicability to field conditions and because it enabled measuring growth without excess handling of the plants involved.

GROWTH OF SPHAGNUM SPECIES

A: Sphagnum recurvum

Sphagnum recurvum is the most common species of the understory vegetation on Moorthwaite Moss and is found at

most points along the wet to dry and open to shaded gradients. Furthermore it is also found within both nutrient poor and nutrient rich areas. To obtain a measure of comparative performance for the species four sites were selected, all with a well developed Sphagnum recurvum carpet. These sample areas were as follows:

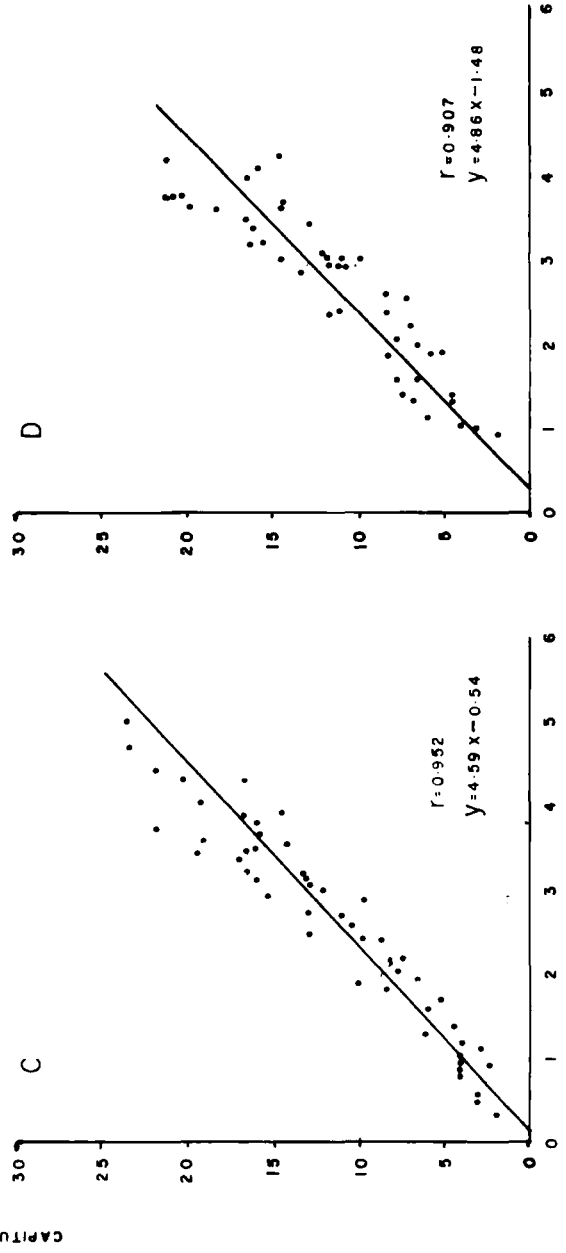
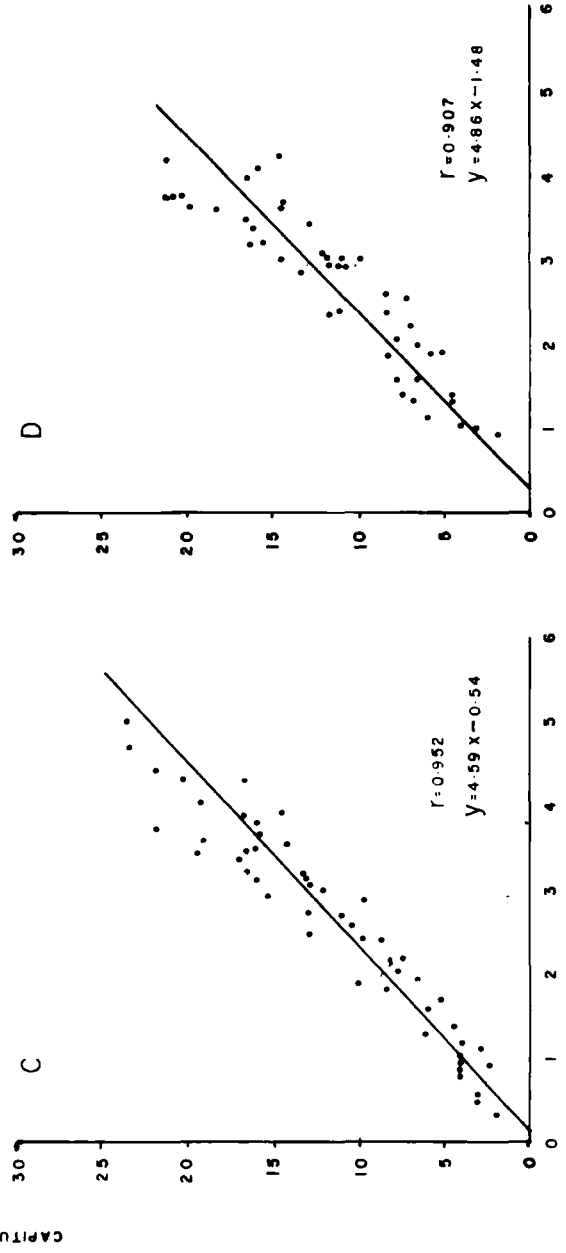
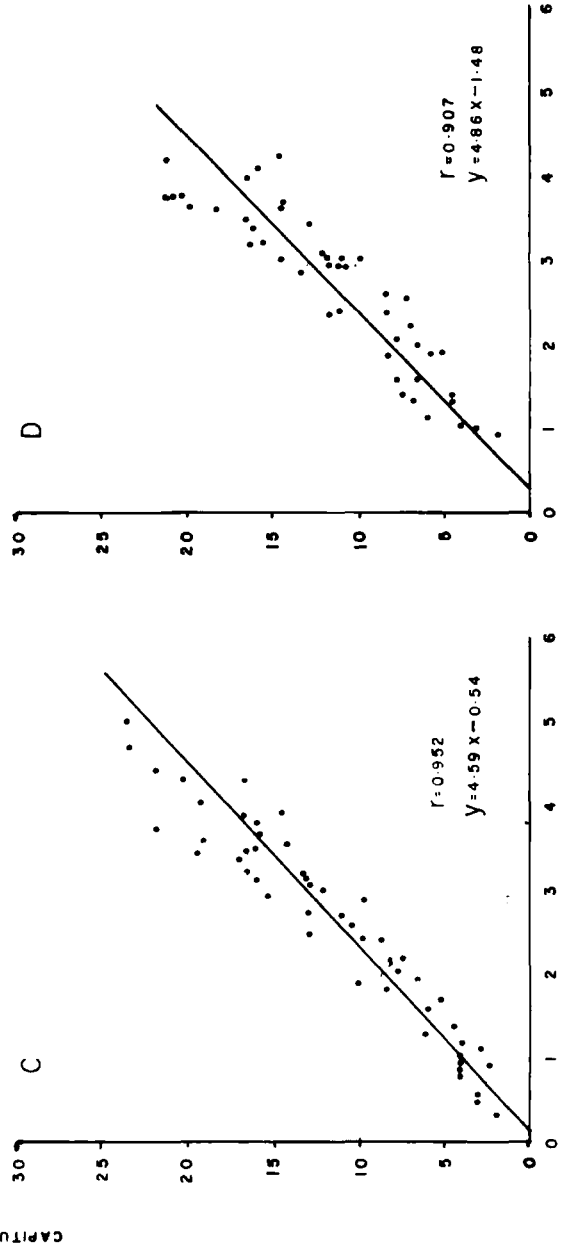
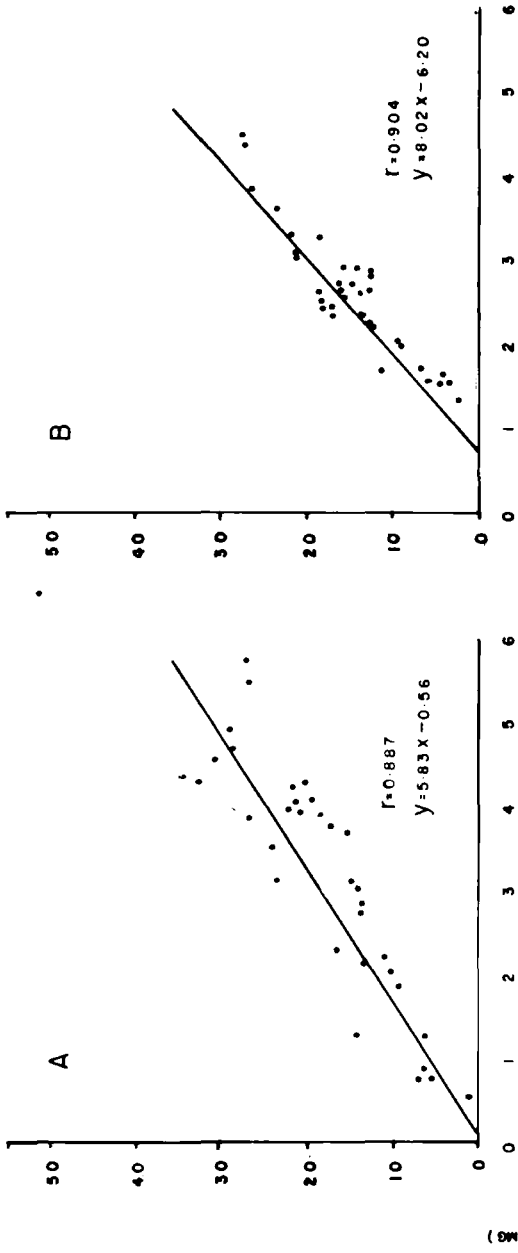
- (i) an old peat cutting infilling with Sphagnum cuspidatum and Sphagnum recurvum, in the open ombrotrophic zone (infilled pool)
- (ii) part of the open ombrotrophic lawn with equal cover of Sphagnum magellanicum (lawn)
- (iii) a small carpeted area on the Calluna vulgaris dry knoll (dry knoll)
- (iv) portion of the marginal fen in a well shaded location, complete Sphagnum recurvum carpet (marginal fen)

Use of the 'capitulum correction' method required the determination of the relationship between the dry weight of capitulum to that of 3 cm of stem (Clymo, 1970). Figure 3-18 shows that there is a strong correlation between capitulum and stem in all four habitats.

Nine collections were obtained from the 'infilled pool' and lawn and eight collections were taken from the dry knoll and marginal fen vegetation. The latter two sites were not sampled in April because of difficulty in measurement of the small growth increase of

Fig. 3-18. Relationships of dry weight of capitulum to that of 3 cm of stem for Sphagnum recurvum sampled from A. infilled pool, B. lawn, C. dry knoll, and D. marginal fen. Each point represents a value for individual plants taken from the sample site. The calculated straight line of best fit is shown.

SPHAGNUM RECURVUM



DRY WEIGHT OF 3CM OF STEM (MG)

many plants. Also sampling was omitted in November and January due to lack of sampling material and levelling off of growth.

The growth curves calculated for Sphagnum recurvum are presented in Figure 3-19 for length and Figure 3-20 for weight. There is a large standard deviation in many samples due to the size variation within the plot and no effort was made to select plants of similar robustness or growth form. In all cases plants were randomly selected. Secondly, under field conditions some of the marked plants were detrimentally affected by shading from adjacent larger individuals. This increases the chance of large standard deviation within a sample, especially toward the end of the growing season. In approximately 3% of the sample population two apices grew from a single marked stem. In all cases this growth is treated as the increase of a single plant. The standard error of the sample means are plotted for each collection as a measure of variance.

Plants from the infilled pool had the greatest increase in length with a maximum growth of 10.0 cm in individual plants (Figure 3-19). The annual length increase for the site was 7.5 cm with a uniform increase from April to July with about 0.8 cm added in length/month. From July to September growth was more rapid with 2.0 cm/month followed by no significant increase from September throughout the winter. Clymo (1970) records a growth of 8.3 cm for Sphagnum cuspidatum in pools and Overbeck and Happach (1956) record a maximum growth of 44.0 cm for one Sphagnum cuspidatum plant. There is a similar length increase in the lawn plants with 1.0 cm added in early spring 0.6 cm/month May-July 2.0 cm from July-August

Fig. 3-19. Growth in length during one growing season measured for Sphagnum recurvum from 4 habitats. Standard errors are plotted with the means.

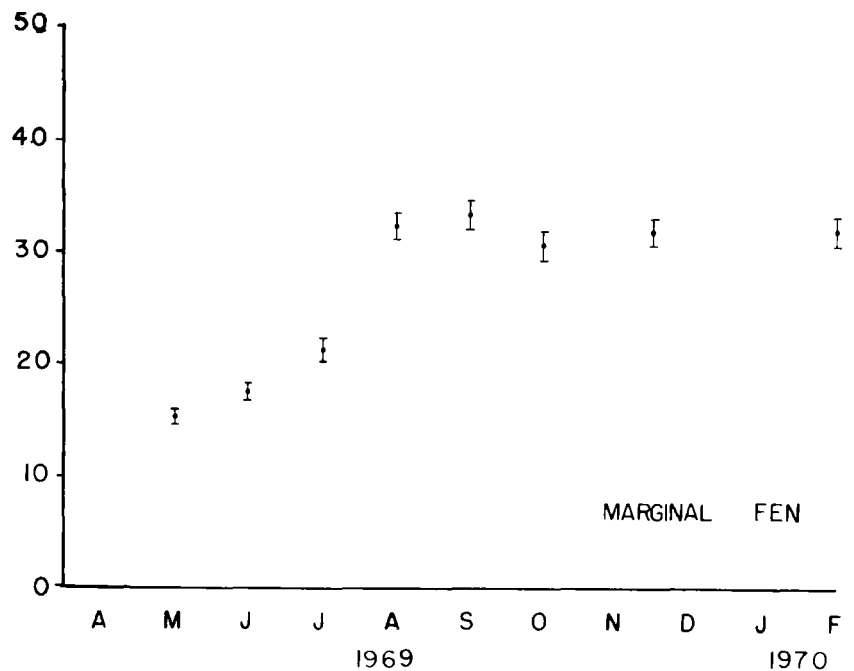
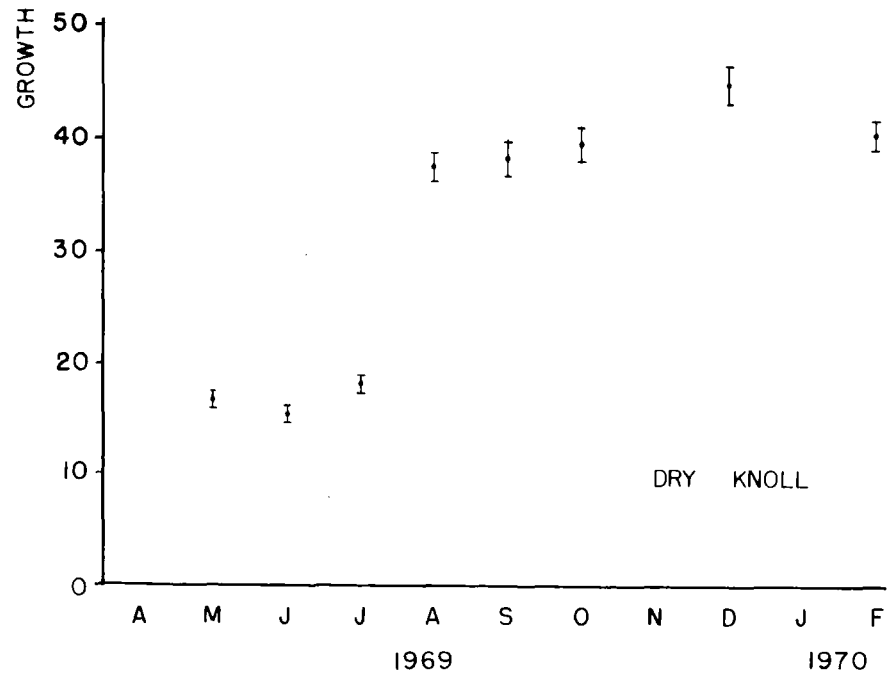
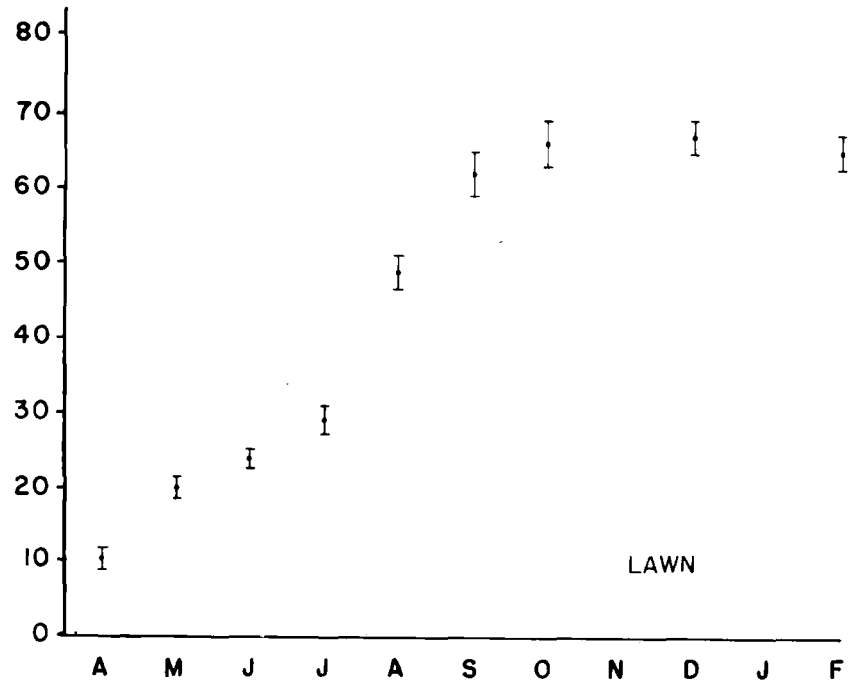
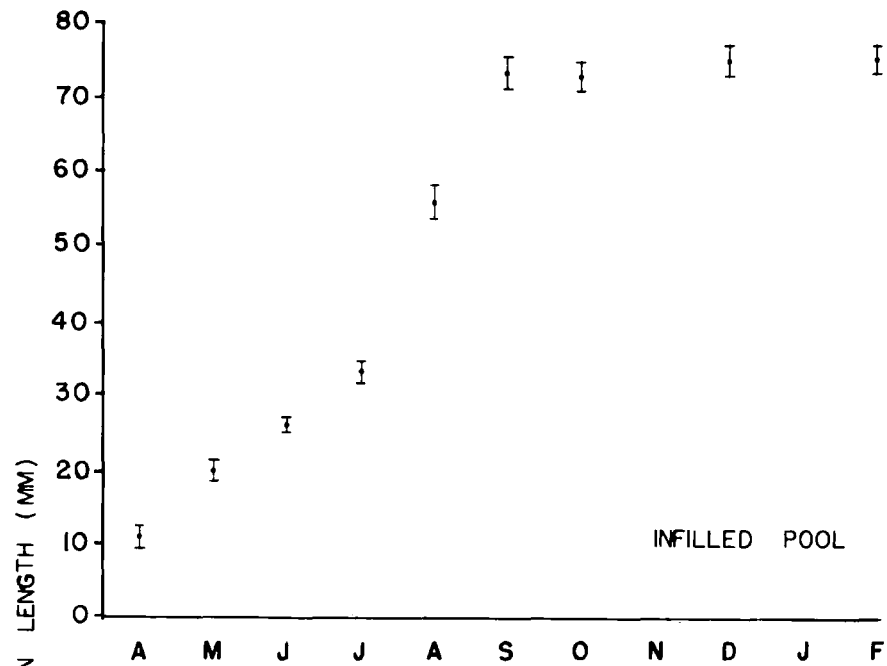
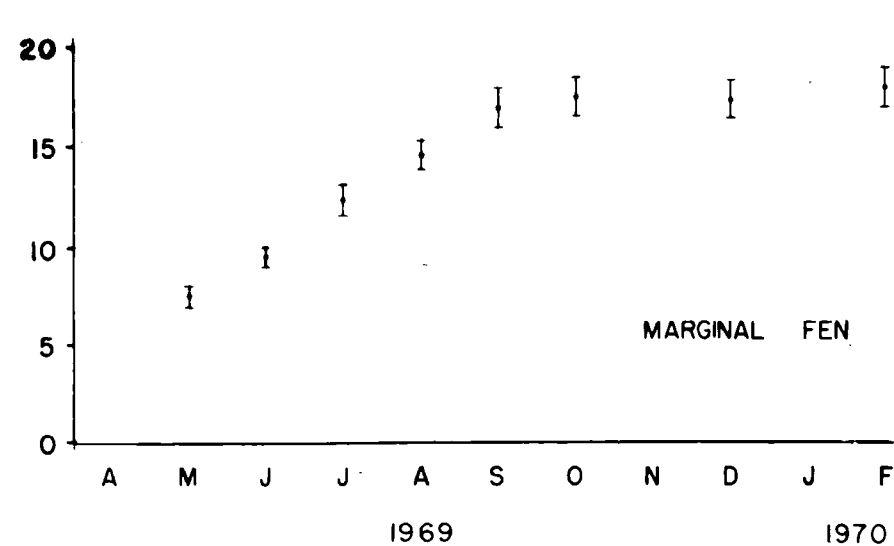
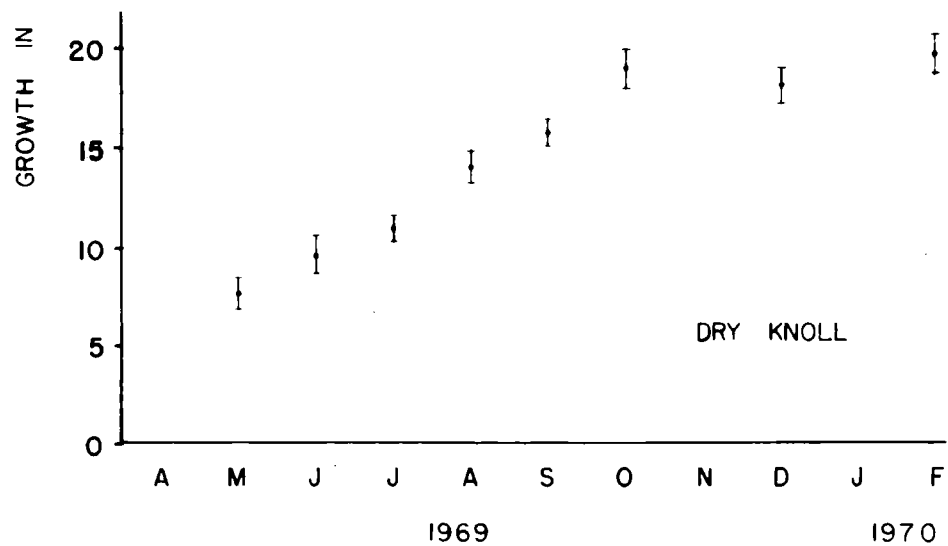
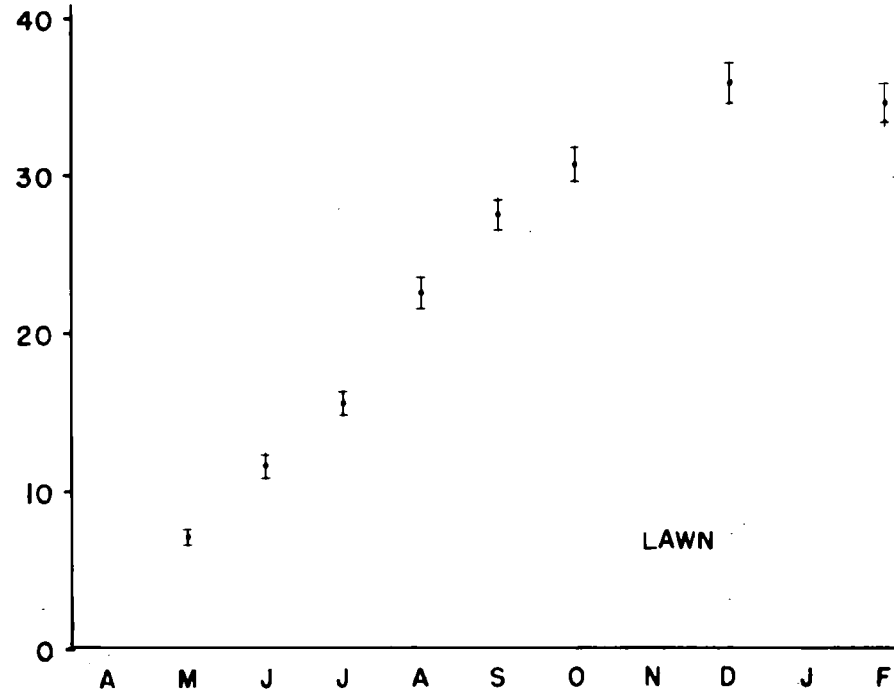
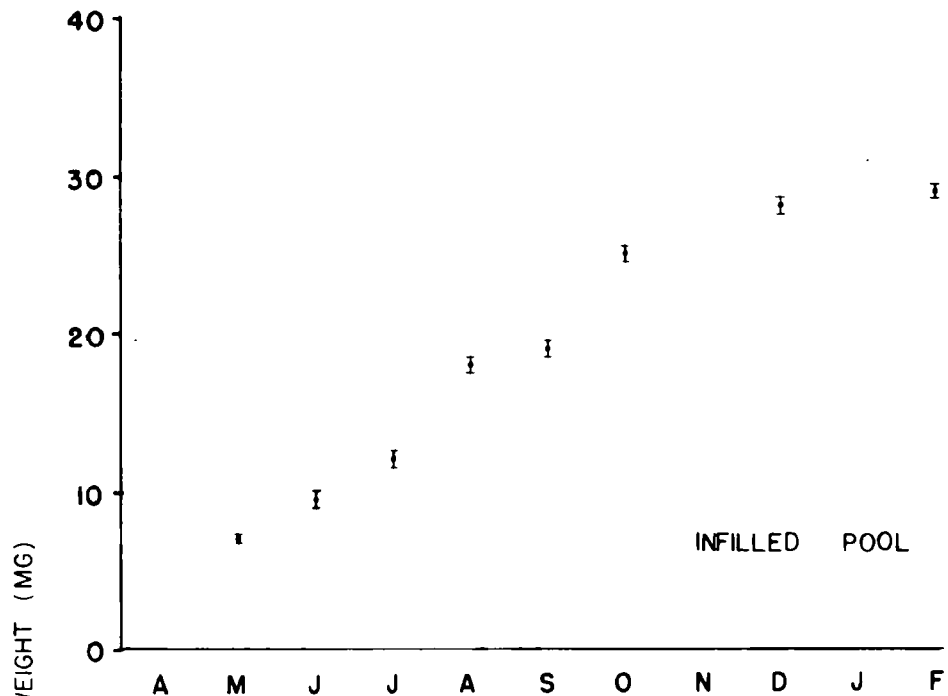


Fig. 3-20. Growth in weight during one growing season measured for Sphagnum recurvum from 4 habitats. Standard error is plotted for each sample.



and 1.3 cm from August to September. Annual increase for the population was 7.3 cm. Length increase in the dry knoll vegetation shows no significant increase until July, after which 1.9 cm is added in one month; this increase is rather dubious in that the standard deviations of the July and August samples have no overlap. The subsequent measurements for later months indicate that this increase has taken place, however, more growth may be attributed to the earlier portion of the growing season. Growth in length of Sphagnum recurvum in the marginal fen substantiates the pattern of growth in the other habitats with moderate increase to July; July to August 1.7 cm increase with little increase in subsequent samples. There is a drop in mean growth between September and October samples which may be attributed to the variation in population between sub-plots. Length increase is greatest in open wet habitats in ombrotrophic conditions and least in the well shaded marginal fen.

Growth in weight (mg/plant) shows that the pool plants have a mean increase of 28.5 mg, however the lawn plants show the greatest increase of 36.0 mg. In both populations growth is moderate in the spring with greatest increase indicated in the August sample. Whereas there is an increase of 10.0 mg in the September lawn sample, there is no recorded increase in the September pool sample. Whereas length increase was negligible after September the weight increase is recorded in the October samples. The dry knoll and marginal fen habitats have a uniform weight increase with a slight addition in the July-August period, but not proportional to the length increase during that period. The reason for this

discrepancy is not explained. Overall, there is continual growth in all habitats and there is no midsummer 'rest period' as reported by Overbeck and Happach (1956).

These results for Sphagnum recurvum are comparable to those of Clymo (1970), however, in this experiment there is little indication of substantial growth after October as recorded by Clymo (1970). In all, the lawn habitat seems most favourable for species dry matter production with the pool, dry knoll and marginal fen following in order. The efficiency of the species in habitat, however, is different in that the marginal fen and lawn plants have a higher weight per unit length than do the dry knolls and infilled pool plants (Table 3-12).

B: Sphagnum magellanicum (Figures 3-22, 3-23)

The Sphagnum magellanicum sample population was chosen in the wet ombrotrophic bog near the center of the undisturbed portion. This site was difficult to sample because of the trampling effect on the quaking surface. Only one population was measured due to apparent similarity of growth of the species in different habitats. Figure 3-21 shows the high correlation of sampled populations for capitulum correction tests.

Growth in length for Sphagnum magellanicum differs from that of Sphagnum recurvum in that the former has a greater increase in spring and less in summer. In both species there is a significant increase in August. Growth in weight shows an increase up to August, however, there is no increase in weight to correspond with the last

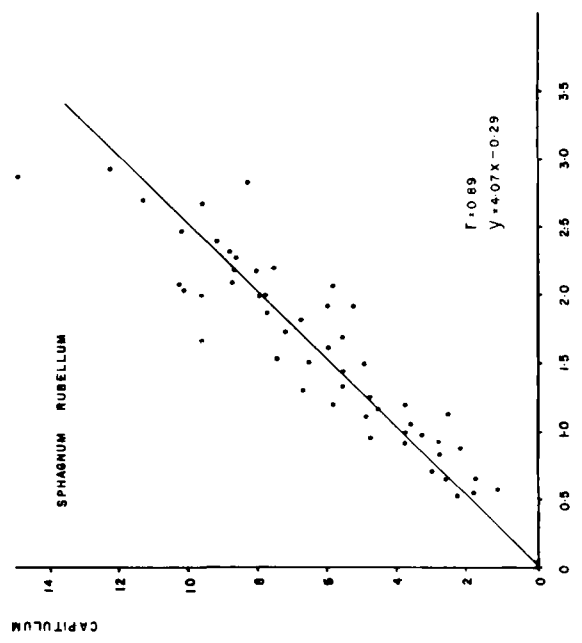
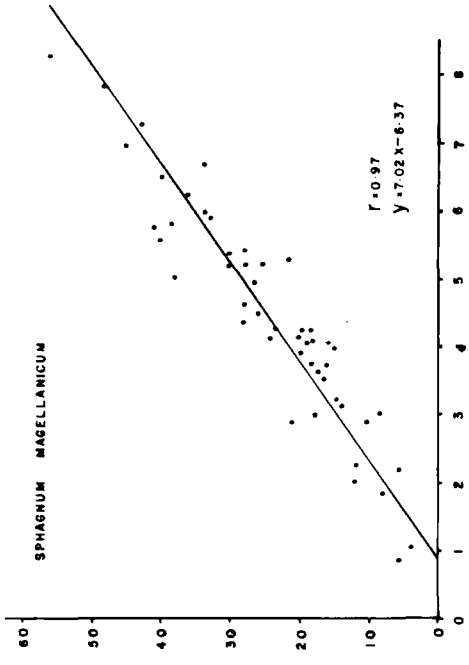
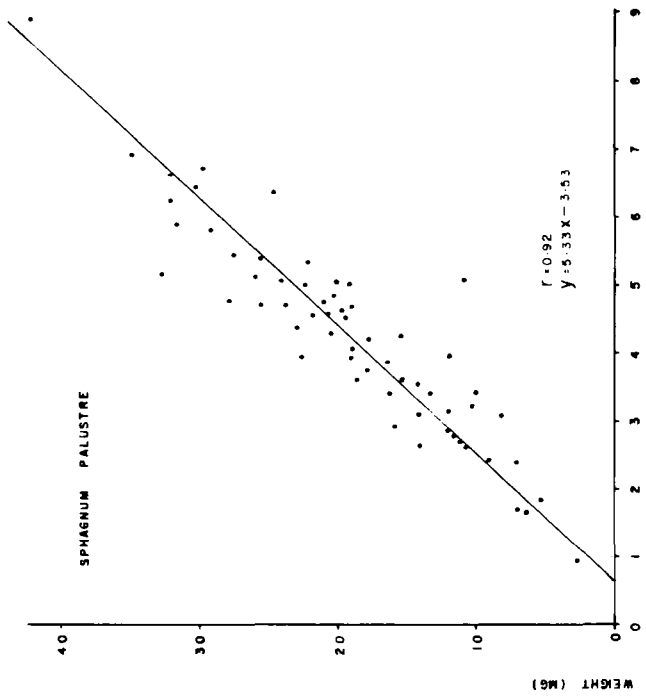
added length. Generally there is a time lag in mass accumulated after length, but none is recorded until December. This has been attributed to an error in sampling or weighing procedure.

The species has a mean length increase of 4.4 cm and mean weight increase of 36 mg/plant. In relation to Sphagnum recurvum from lawn habitat the latter acquired 2.9 cm more in length however, weight increase was similar (Table 3-12).

C: Sphagnum palustre

Sphagnum palustre was also investigated from one habitat, the hummock development near the edge of the open ombrotrophic bog in relatively shaded conditions, which approximates forested conditions as indicated in Table 3-2. The correlation between 3 cm stem and capitulum is high ($r = 0.92$) for sampled populations (Figure 3-21). Increase in length (Figure 3-22) indicates good growth in April with less in May. Greatest addition occurs in June and July, with small increase throughout the winter months. This winter increase is not significant, however, may have some relationship with the lesser degree of frost in the understory than in the more open wetter conditions. Conversely, this area retains frost to a later date than the more open vegetation because of shaded conditions. The time lag in mass increase is evident (Figure 3-23) with greatest increase in July and August. There is a recorded mass loss in the winter samples offsetting length increase measured in Figure 3-22b.

Fig. 3-21. Relationship of capitulum dry weight to that of 3 cm of stem for Sphagnum species sampled from ombrotrophic vegetation on Moorthwaite Moss.



DRY WEIGHT OF 3CM OF STEM (MG)

CAPITULUM DRY WEIGHT (MG)

Fig. 3-22. Growth in length during one growing season for Sphagnum magellanicum from lawn, Sphagnum palustre from bog hummock and Sphagnum rubellum from two habitats, wet hollow and bog hummock. Standard error is plotted for each sample.

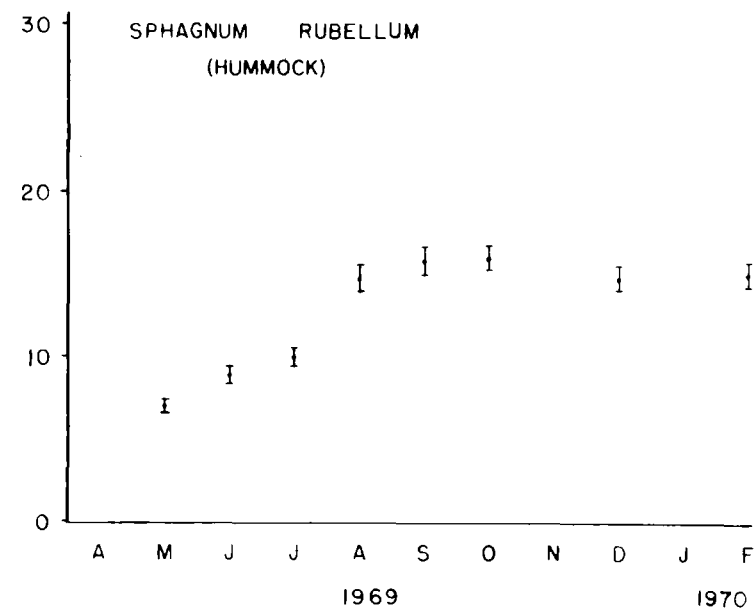
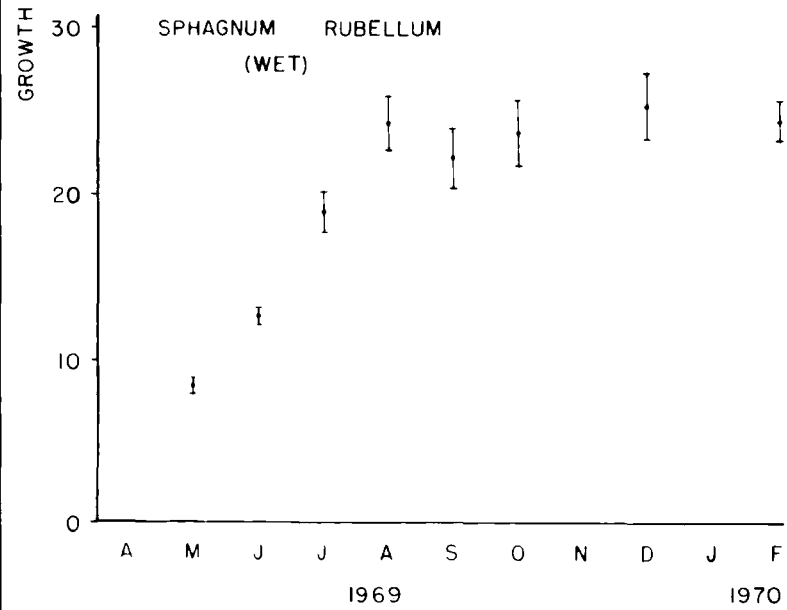
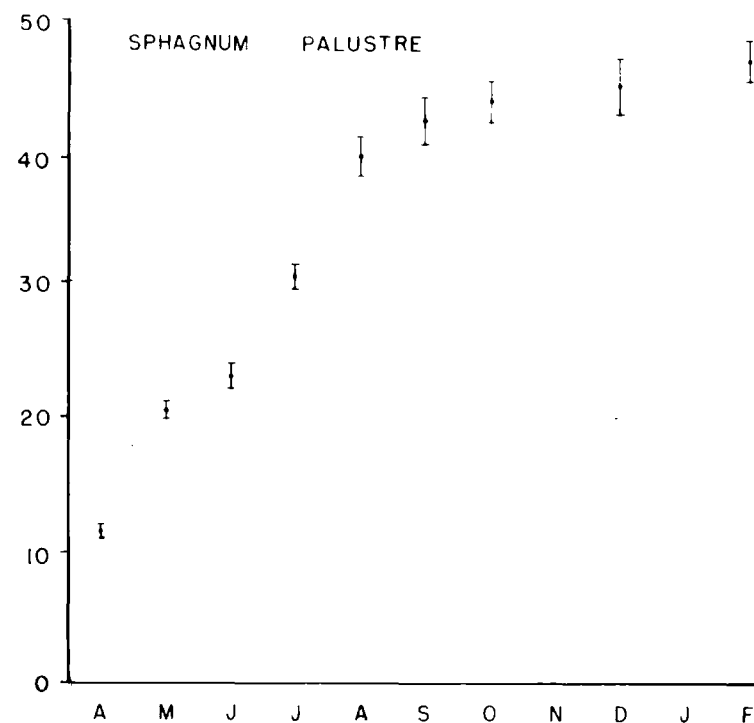
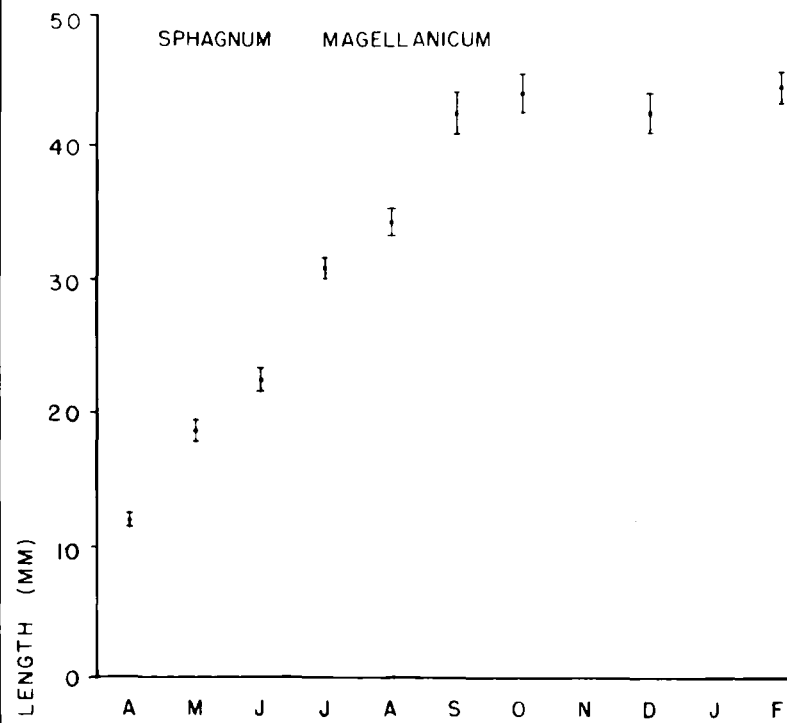
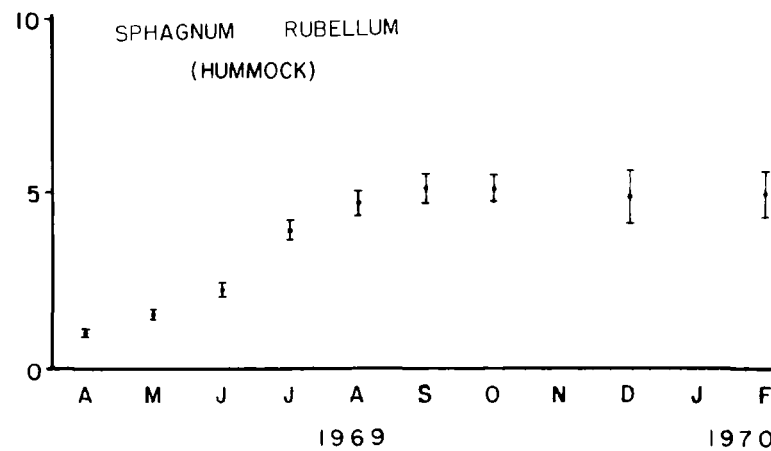
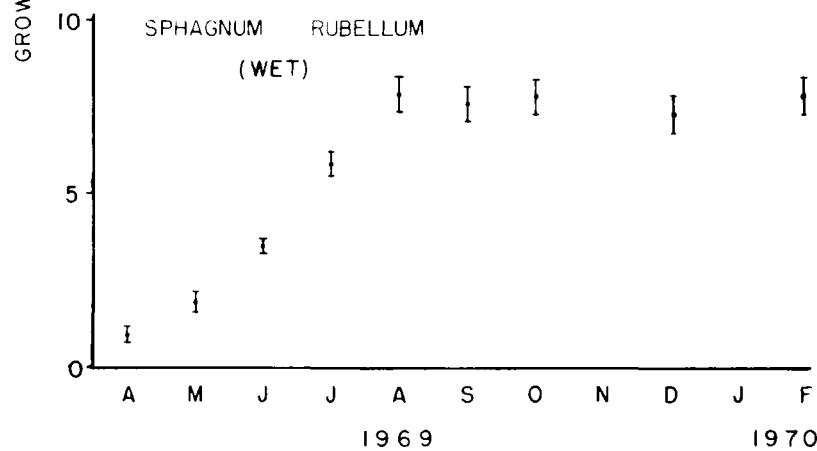
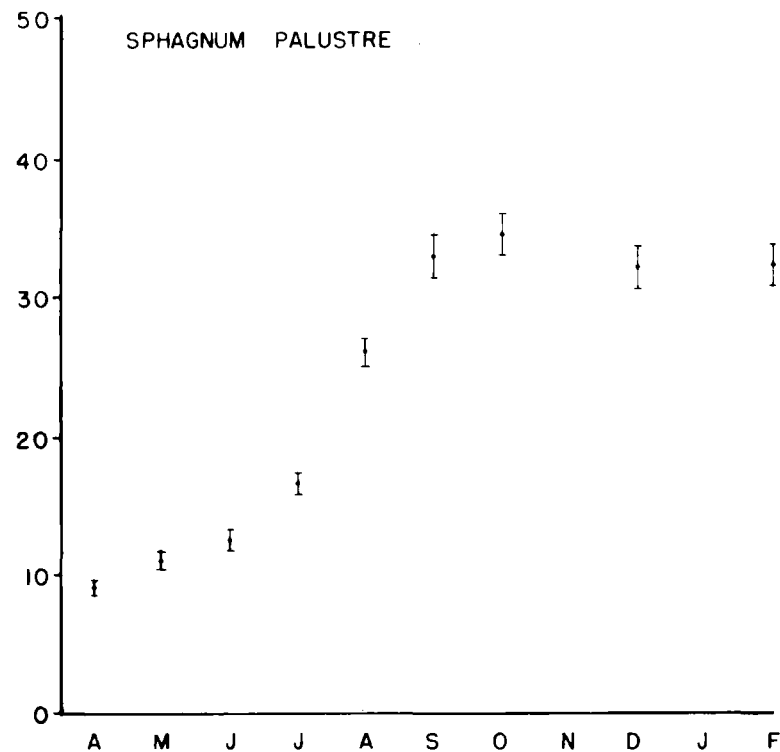
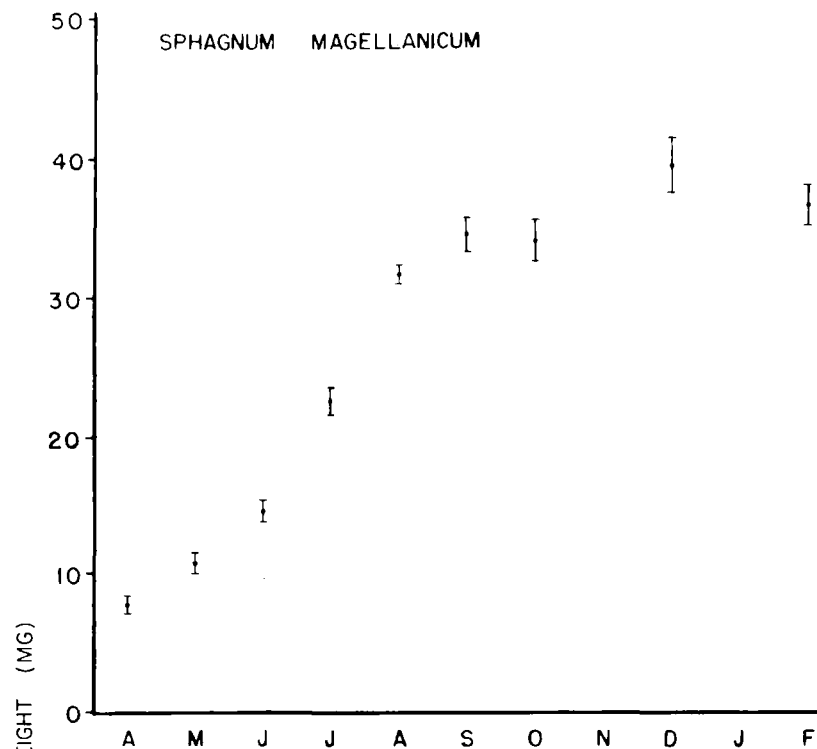


Fig. 3-23. Growth in weight, dry matter, during one growing season for Sphagnum magellanicum (lawn); Sphagnum palustre (hummock) and Sphagnum rubellum (wet hollow and hummock). Standard error is plotted for each sample.



In comparison to other Sphagna, Sphagnum palustre is of similar robustness as Sphagnum magellanicum (Figure 3-2) with a mean length increase of 4.6 cm/plant and a mean weight increase of 34 mg/plant.

D: Sphagnum rubellum

Unlike the other Sphagnum species investigated, Sphagnum rubellum is a much smaller plant with less length and weight increase per individual. Two sites were investigated to attempt detection of growth variation on hummocks (Table 3-2) and in hollows (Table 3-1 - releves 19, 21, 4). One capitulum correction graph was calculated for both sites because of small variation in populations plotted (Figure 3-21).

The hollow conditions yielded plants with a mean increase in length of 2.5 cm (Figure 3-22) and in weight 8 mg (Figure 3-23), whereas the hummock plants had a mean increase of 1.6 cm in length and 5.1 mg in weight. This growth is much less than the other species on an individual basis, however, on areal basis these populations are much greater in number/unit area. This relationship will be elaborated in the discussion on production per unit area.

OTHER MOSSES:

Two mosses other than Sphagnum which play an important role in the productivity of Moorthwaite Moss are Pleurozium schreberi and Aulacomnium palustre. In both, sampling involved separation of new growth through use of the cyclic growth pattern (Tamm, 1953, 1964).

Table 3-12. Mean annual growth increment of Sphagnum species from selected habitats on Moorthwaite Moss. Growth is expressed per plant in length (cm), weight (mg), and weight/unit length.

Species	Habitat	Length	Weight	Weight/Length
Sphagnum recurvum	Infilled pool	7.5	28.5	3.80
	Lawn	7.3	36.0	4.93
	Dry knoll	4.4	19.0	4.32
	Marginal fen	3.5	18.0	5.14
Sphagnum magellanicum	Lawn	4.4	36.0	8.18
Sphagnum palustre	Hummock	4.6	34.0	7.39
Sphagnum rubellum	Hollow	2.5	8.0	3.20
	Hummock	1.6	5.1	3.19

E: Pleurozium schreberi

Two populations were sampled in determination of growth of Pleurozium schreberi. The first occurs on the dry knoll and the second on well-shaded hummocks in ombrotrophic forest conditions. Results of the experiment are expressed in Figure 3-24 for mean length and Figure 3-25 for mean weight.

In all, 10 collections were obtained from each site for the period March-February. As with the Sphagnum where two apices grew from one they were treated as a single plant.

The plants growing in the moist forested zone had a greater increase in both length and weight; this site had more light reaching the surface than did the dry knoll carpet under a Calluna and Eriophorum cover. Increase in length on the dry knoll was 2.9 cm and on the hummock 3.3 cm whereas corresponding weight increases were 9.0 and 9.6 mg. This growth pattern for Pleurozium is similar to Sphagnum with greatest length increment in summer with weight increase lagging behind. Anomalous data were recorded for the October sample on the hummock and the December samples from both sites. This may be in part attributed to the difficulty of determining new growth late in the growing season. In most cases an underestimate was possibly made in the Pleurozium experiment because of the difficulty in determining any growth other than apical in origin.

F: Aulacomnium palustre

Aulacomnium palustre is commonly found both in open hummock and mat conditions. Shade is seemingly the most important factor influencing its distribution on Moorthwaite Moss. Only one site was sampled for its production on individual plant basis. This was a dry mat area (Table 3-1 - releves 8, 9, 11) near the bog center.

For a true assessment of the species growth the hummock

Fig. 3-24. Growth in length during one growing season for mosses Pleurozium schreberi (dry knoll and forest bog hummock) and Aulacomnium palustre (bog mat). Standard error is plotted for each sample.

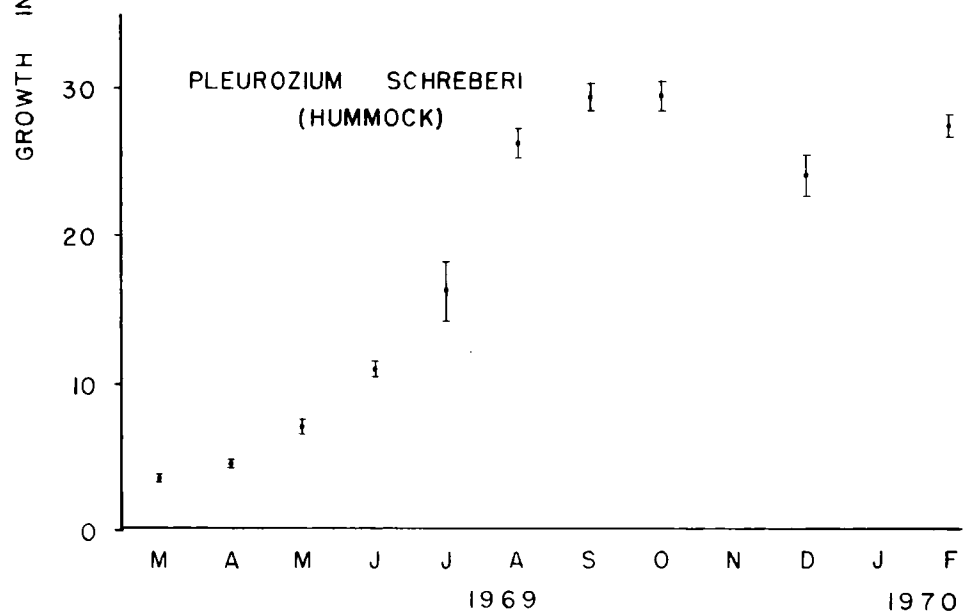
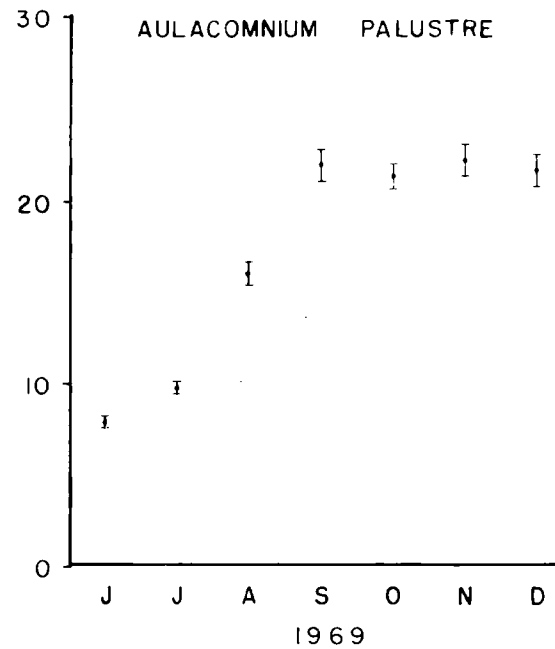
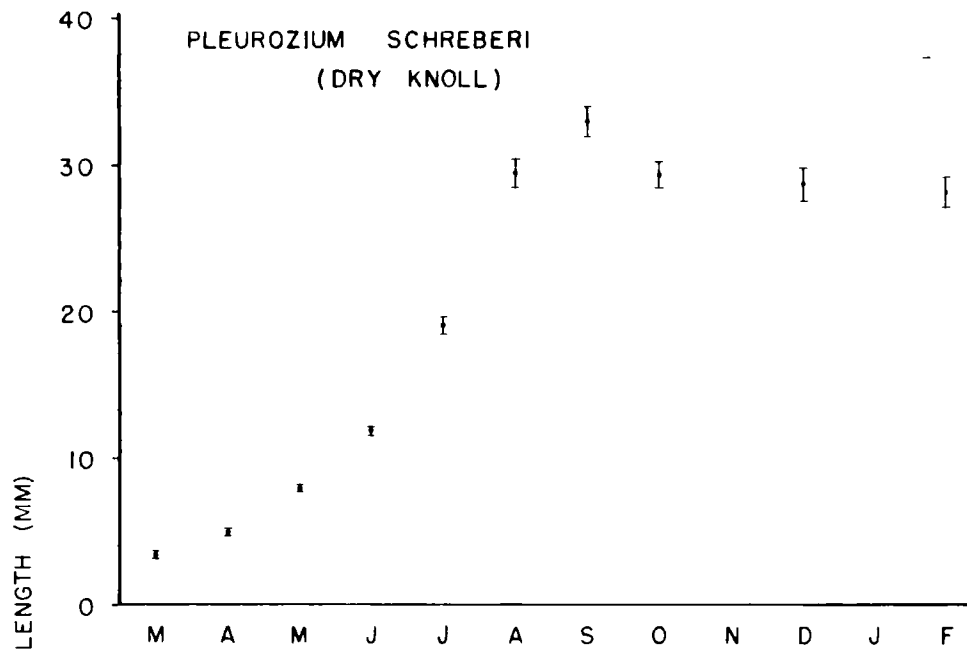
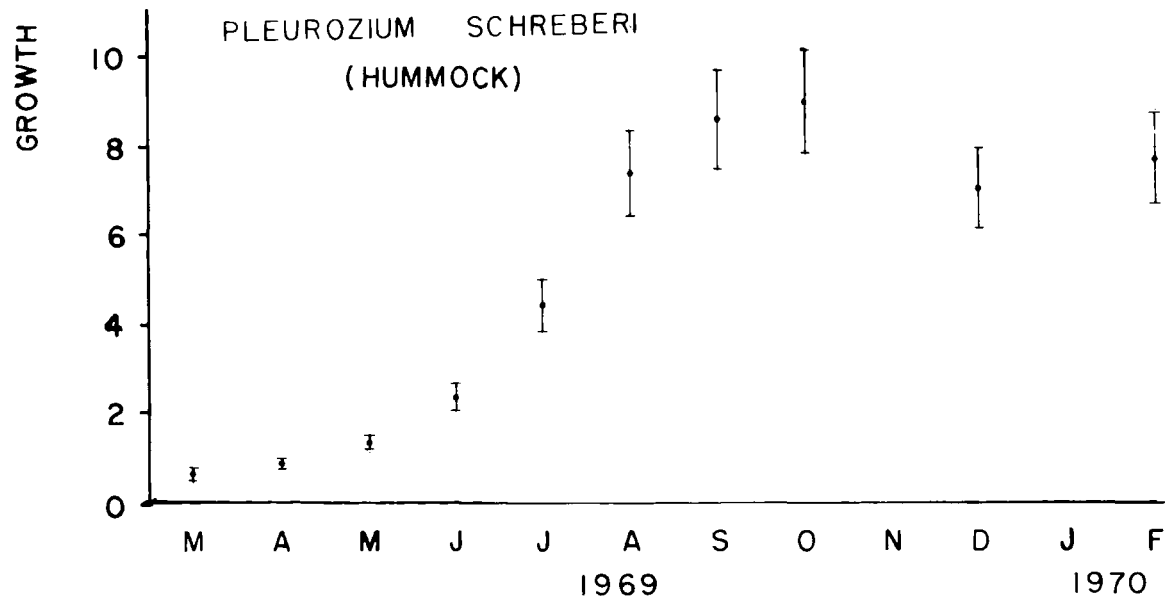
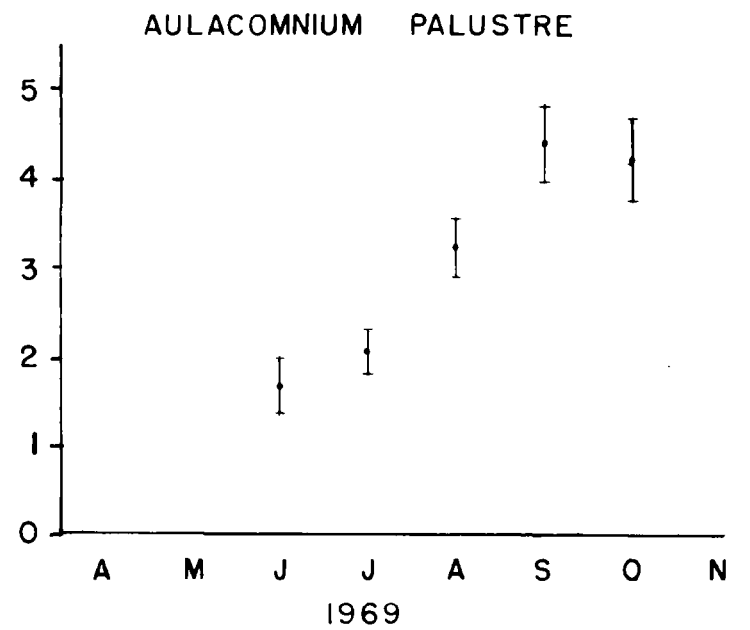
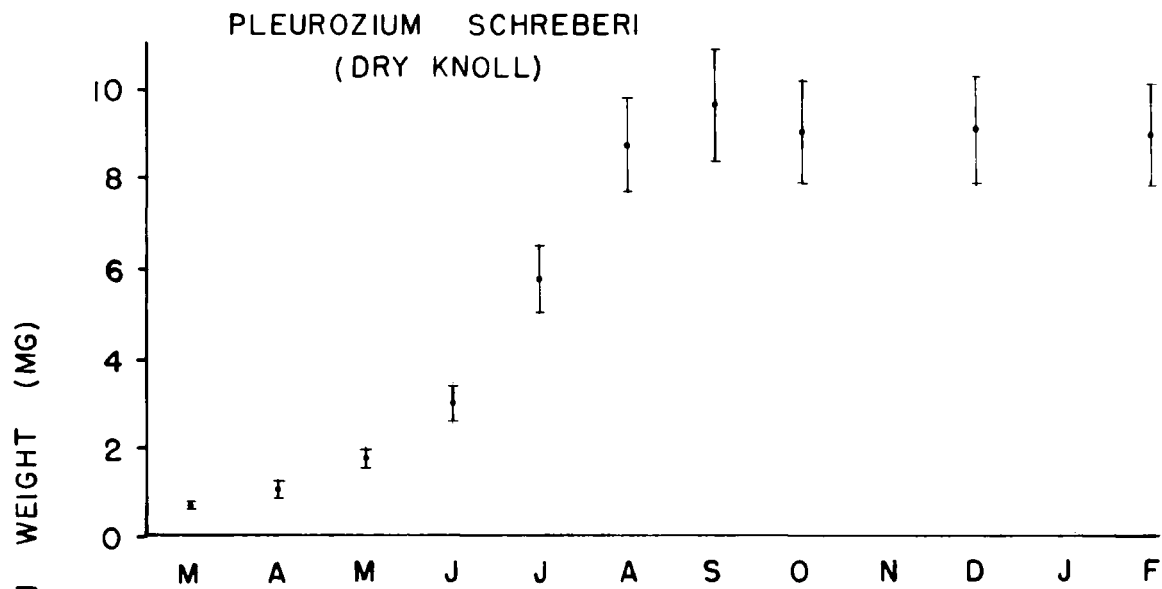


Fig. 3-25. Growth in weight, dry matter, during one growing season for mosses Pleurozium schreberi (dry knoll and bog hummock) and Aulacomnium palustre (bog mat). Standard error is plotted for each sample.



vegetation of the open bog should have also been examined, however, visual comparison indicated little variation in Aulacomnium growth from each site.

Increase in length (Figure 3-24) shows the optimal period of growth to be from June to September congruent with the growth data obtained for the other mosses. There is a direct relation between length and weight increase for corresponding months.

The mean annual plant increase is 2.2 cm in length and 4.4 mg in weight (Figure 3-25).

EXPRESSION OF NET ANNUAL PRODUCTION OF MOSS LAYER:

In all, six mosses have been assessed on an individual plant basis to determine their increase in both length and weight for various habitats on Moorthwaite. To express the amount contributed to the net production of an area by each species, density counts must be made within a unit area. This is a tedious procedure but can provide rather accurate values concerning net production of a moss community. Such counts should be carried out on a monthly basis with each cropping, however, where time does not permit counts should at least be made each season if some idea of growth addition throughout the year is to be attained. Other factors affecting counts are the degree of wetness of the site, especially with regard to the Sphagna, and the amount of disturbance caused by experimental design and sampling procedures. In the present survey counts were made at various intervals for different species pending time available during field operations. It was not within the scope of this investigation

to determine areal production throughout the season for any site but rather to estimate the net annual production with respect to species contribution within habitats. In Table 3-13 this net production is given based on density counts obtained in September and October. Whereas these counts were taken on nearly pure carpets, dominated by one species, in reality many situations have an admixture of mosses. Yet in very few instances do more than two species make up the great percentage of the moss layer in any one habitat in the ombrotrophic portion of the bog.

The values obtained from Moorthwaite Moss are in agreement with estimates from other investigations. In general the net annual production is between 1-10 g/dm² for Sphagnum species. The lowest estimate recorded was 0.77 g/dm² (Chapman, 1965) for a Sphagnum papillosum, Sphagnum magellanicum cover. Malmer (1962) records 3 g/dm² for Sphagnum and Clymo (1970) 2.4 - 4.3 g/dm² for Sphagnum rubellum; 1.9 - 7.9 g/dm² for Sphagnum cuspidatum; 2.1 - 6.1 g/dm² for Sphagnum papillosum; and 2.3 - 6.0 g/dm² for Sphagnum recurvum. In all cases Clymo records values for two sites and three habitats for each species. Furthermore Bellamy and Rieley (1967) report 2.7 g/dm² for Sphagnum fuscum and Pearsall and Gorham (1956) in estimating standing crop of Sphagnum in a number of sites in England give values ranging from 2.3 to 9.6 g/dm².

The present investigation shows that the most productive species per unit area is Sphagnum recurvum in the infilled pool. On the lawn and dry knoll production is similar but significantly less in the fen under heavy forest cover. Sphagnum magellanicum is

Table 3-13. Estimate of growth g/dm² year for each moss species at each habitat investigated on Moorthwaite Moss.

Species	Habitat	# plants dm ² (mean of 10 samples)	Net annual production
Sphagnum recurvum	infilled pool	208	5.93
	lawn	114	4.10
	dry knoll	230	4.37
	marginal fen	134	2.41
Sphagnum magellanicum	lawn	99	3.56
Sphagnum palustre	hummock	90	3.06
Sphagnum rubellum	hummock	390	1.99
	wet mat	308	2.46
Pleurozium schreberi	dry knoll	295	2.66
	hummock	233	2.23
Aulacomnium palustre	open mat (hummock edge)	501	2.20

comparable to Sphagnum recurvum in lawn conditions. Of the hummock varieties Sphagnum rubellum in the open bog is least productive whereas Sphagnum palustre is more productive in slightly less open conditions; however, the Sphagnum rubellum hummocks often have a high density of Pinus sylvestris seedlings. In the wetter mat the Sphagnum rubellum area is more productive than under hummock conditions.

The Pleurozium schreberi vegetation is less productive, however, in both areas this is the moss layer of a dwarf-shrub vegetation. Aulacomnium palustre is also of low productivity status on the mat and this is likely representative of production on the Aulacomnium hummock, as well, although the former is usually under a more dense sedge (Eriophorum angustifolium) cover.

HERBS:

The herbs were the most difficult group with which to conduct productivity measurements within the Moorthwaite Moss vegetation. These difficulties were encountered not only in determining net annual production but also live biomass. Only three herb species are prevalent in the ombrotrophic zones; Eriophorum angustifolium, Eriophorum vaginatum and Narthecium ossifragum. Each species presents its own problems in sampling.

Primary problems are caused by the growth forms with Eriophorum angustifolium and Narthecium ossifragum both rhizomatous and Eriophorum vaginatum a tussock-forming species on the dry knoll.

To compound difficulties Eriophorum retains a portion of live above-ground material throughout the year. Any separation of live and dead material is arbitrary and for these herbs was based on coloration of the leaves and 'fleshiness' of the below-ground basal portion and roots. Die back of perennial herbs must be accounted throughout the season and often employment of simple harvest techniques based on green plant material will yield a poor measure of net primary production. This problem is further discussed by Wiegert and Evans (1964).

Many production analyses have included Eriophorum spp. most of which have employed the paired quadrat technique (Wiegert and Evans, 1964); used by Pearsall and Neubould (1957) and Bliss (1956, 1960, 1966) for Eriophorum communities. All these investigations, however, have been limited to true mineral soil conditions. Malmer (1962) provides data obtained by harvesting for a series of Narthecium ossifragum communities on peatland. A review of production measuring techniques has been prepared by Milner and Hughes (1968) for grassland communities. Unfortunately these methods, like most harvesting procedures, measure only the above ground portion of growth and, in addition, are only reliable where there is a uniform distribution of the species. Such methods are poorly adaptable for dealing with sedge communities normally found on the peatland sites presently investigated. Gore and Olson (1967) also used a destructive harvesting technique to estimate production of Eriophorum vaginatum on an ombrotrophic bog in Finland. This method varied in that modeling was used to assist in production predictions for the species.

Investigations conducted for each of the three dominant herbs are given below.

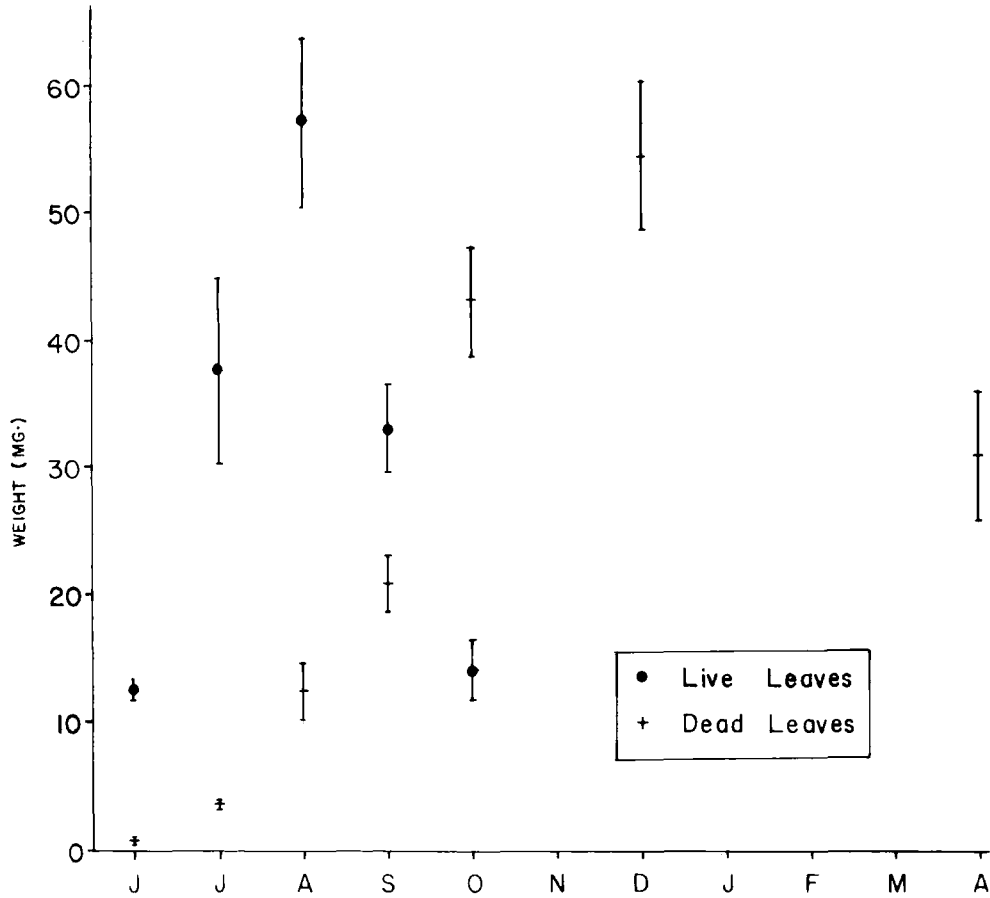
A: Narthecium ossifragum:

This analysis was carried out on one population only, representing the wet Narthecium variant in the open bog (Table 3-1). Summer standing crop of the species consists primarily of leaves with scattered fruiting stems from both current and past years crop. The above-ground growth is first evident by green tips of shoots which are prevalent from early May. By July flowering begins and leaves are tipped with yellow or are faded. October leaves have only few green spots and the majority of the growth is dead. At this stage subsampling of live and dead material is extremely difficult. By December no live material remains in the above-ground portion and only the former inflorescences remain upright. Figure 3-5 shows the early summer aspect of the Narthecium variant. Sampling methods used for obtaining production data are given in Appendix II.

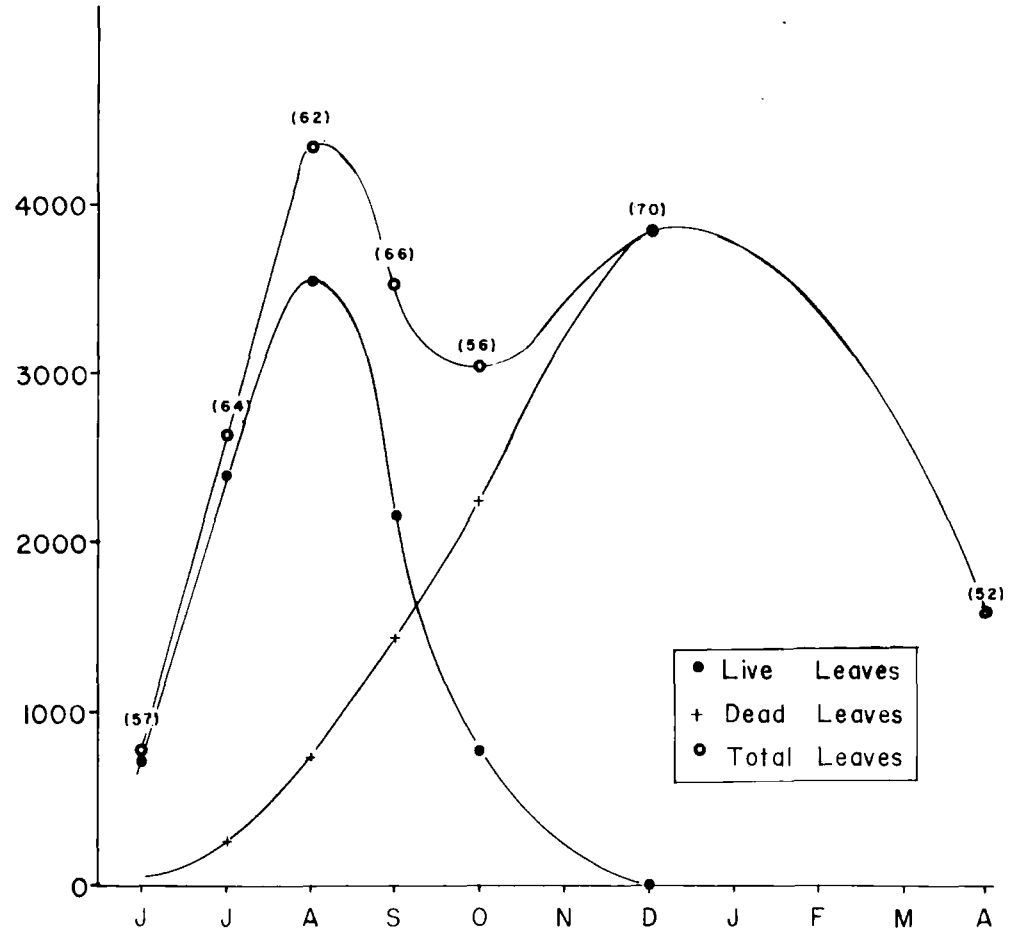
The below-ground sampling proved very tedious with rhizomes and roots of Narthecium forming a dense mass immediately below the surface. Subsampling under field conditions was futile and only a measure of below-ground standing crop was obtained. Results of cropping are given in Table 3-14; additionally the distribution of roots with depth in the peat is given for the Narthecium ossifragum variant in Figure 3-16A.

Figure 3-26. Net production of aboveground portion of Narthecium ossifragum. A: for individual plants within the sampled population; S.E. is given for live and dead components. B: expressed in mg/25 cm² showing portion of live and dead material, density counts are given in brackets for number of stems/25 cm².

NARTHECIUM OSSIFRAGUM



A



B

Above-ground production of Nartheceium, with changes in weight of live and dead fractions for the individual plant throughout the growing season, is shown in Figure 3-26A. At estimated peak crop in late August the mean weight per individual was 70 mg with 57 mg live and 12 mg dead leaf material. After peak crop a rapid decline is evident in the live fraction and by December only dead material is evident above ground. Decomposition of material is accelerated in spring and by April there is a recorded decrease of 24 mg dry matter per plant.

A second measure of production is given in Figure 3-26B. This is based on a unit of 25 cm² and shows the fluctuation in dry matter throughout the growing season. From mean density counts for the species it was determined that the net production by late August was 4170 mg/25 cm². The apparent increase in production from October to December is in part due to an inability to carry out accurate density counts when all leaves are part of the litter layer.

Similar growth and production analysis was carried out by Rawes and Welch (1969) with Carex bigelowii. In their investigation 100 plants constituted a sample and in comparison the standard errors of component weights were more significant than those obtained in the present survey. This may be due to the smaller sample size (30-60 plants) or the uniformity of species distribution and growth in the particular sample site. It may also be a result of differences in sampling technique.

Malmer's (1962b) data for Narthecium communities on the Akhult mire in Sweden give an above-ground standing crop ranging from 60-790 g/m². This portion comprised 85-100% of the total standing crop on the sampled areas. On Moorthwaite Moss, Narthecium is of minor importance as an above-ground producer and seldom contributes more than 20% of the net production within the wet variant. In contrast it is the most important contributor to the underground production in the variant and its rhizomes and roots make up approximately 75% of the underground standing crop. As shown in Table 3-14 this portion of the standing crop is highest in fall and winter with a decrease associated with onset of the growing season.

These results show a close similarity between data obtained from direct harvesting and through density counts. The higher values obtained by harvesting methods in April (42 g/m²) is due to the lack of care in separating previous year litter from older leaves, whereas in the individual cropping (28 g/m²) such care was enforced. Overall the Narthecium plants contribute \approx 70 g/m² to the wet variant above-ground net annual production.

B: Eriophorum angustifolium:

An attempt was made to estimate net annual production of Eriophorum angustifolium by means of individual plant cropping techniques (see Methods - App. II). This analysis included assessment of populations covering much of the open bog surface and the open forested zone. The species is the most common vascular in

Table 3-14. Standing crop of Narthecium ossifragum from the wet variant of the open bog portion of Moorthwaite Moss. All values are in g/m² dry weight. Samples are only replicated for August. Estimates based on density counts are given in brackets.

	A	M	J	J	A	S	O	N	D	J	F	M
Aboveground Live	-	6(-)	14(13)	41(44)	60(55)	37(35)	11(10)	-	-	-	-	-
Dead	42*(28*)	-(-)	1(1)	5(4)	12(9)	22(25)	53(36)	-	62(61)	-	-	37
Below-ground	372	406	-	384	438	505	468	-	515	-	-	415
Standing crop	414	412	-	430	525	579	542	-	577	-	-	452

the open bog understory and is wide ranging, found in all main vegetation zones indicating a tolerance of both wet and dry portions of the moisture gradients; being more frequent in wetter areas. Furthermore, it is found in both bog and fen (scarce in marginal fen) as well as open and shaded habitats. Eriophorum angustifolium is most dense in the Aulacomnium palustre and Sphagnum magellanicum mats. In growth form, the individual plants are small in the wet open bog variants, 5-30 cm of intermediate height on open bog mats up to 60 cm, and in the wooded zones individual plants of 1.5 m were found. Fruiting plants were common on the open bog but infrequent in the wooded zone.

The use of the individual plant cropping techniques was found to be inadequate because of the following reasons:

- (a) inability to establish suitable size classes
- (b) difficulty of determining life span of individual plants in one growing season
- (c) frequency of standing dead plants
- (d) rhizomatous mode of growth
- (e) uneven plant distribution
- (f) difficulty of sorting live and dead fractions

Because of this it was necessary to revert to quadrat harvesting procedures, which would yield a measure of change in dry matter production throughout the year.

Four habitats were sampled with two harvested throughout the season. These were:

- (i) The open bog mat dominated largely by Aulacomnium palustre, Sphagnum magellanicum and Sphagnum recurvum.
- (ii) The open forest dominated by Sphagnum recurvum-Sphagnum palustre.

The two additional sites were sampled at peak standing crop only (late August):

- (iii) Wet variants of open bog.
- (iv) Plants within the Erica tetralix understory of the closed ombrotrophic forest.

Results of these harvests are given in Table 3-15. Plants taken from the open bog showed an increase from May (49.9 g/m²) to August (108.9 g/m²) and dropped again by March (56.3 g/m²) for the above-ground portion. In the open forest the standing crop varied from 71.3 g/m² in May to 93.9 g/m² in July and a subsequent drop to 66.9 g/m² in March. Thus the fluctuations in the dry matter content are much greater in the open bog plants indicating a more rapid turnover of organic matter in the site.

In comparing the above-ground standing crop from the four sites harvested in August the wet variant was found to have the smallest standing crop, 40.9 g/m², with the closed forest (59 g/m²),

Table 3-15. Standing crop of *Eriophorum angustifolium* harvested from four sites on Moorthwaite Moss. Each sample is calculated as the mean of two croppings and expressed in g/m².

Site	Component*	Month						
		M	J	J	A	S	D	M
Open bog (mat)	L	15.7	49.5	67.4	72.9	46.1	23.0	12.6
	D	34.2	54.0	31.7	36.0	47.7	55.6	43.7
	RR	3.2	-	7.9	4.2	6.1	4.2	-
	T	53.1	-	107.0	113.1	99.9	82.8	-
Open bog (wet variant)	L	-	-	-	24.7	-	-	-
	D	-	-	-	16.2	-	-	-
	RR	-	-	-	2.7	-	-	-
	T	-	-	-	43.6	-	-	-
Open forest	L	30.6	42.6	66.5	41.4	37.5	31.8	24.2
	D	39.7	45.7	27.9	35.9	39.4	40.4	42.7
	RR	7.7	-	10.4	4.6	7.4	7.3	-
	T	78.0	-	104.8	81.9	74.3	79.5	-
Closed forest	L	-	-	-	40.7	-	-	-
	D	-	-	-	18.3	-	-	-
	RR	-	-	-	5.9	-	-	-
	T	-	-	-	64.9	-	-	-

*L - live leaves
 D - dead leaves
 RR - rhizome and roots
 T - total

open forest (77.3 g/m²) and open bog (108.9 g/m²) in ascending order. This is more a function of density of individuals/m² rather than plant size.

Although no adequate method of assessing mean individual plant production was devised it was possible to determine the mean live-dead plant ratios for each sample taken throughout the growing season. The live-dead fractions do indicate growth performance of the species within habitat. Figure 3-27 gives the mean live and dead above-ground portions for individuals within the sample obtained from the two main Eriophorum angustifolium sites; the open bog mat and open forest. Both sites have a population with similar live-dead component relationship where the live portion is greater than the dead after June. In conjunction with this new growth the previous years leaves pass to the litter layer. This is indicated by the weight drop of the dead component in July. This drop may in part be attributed to the inclusion of current year plants into the sample. After August there is a diminishing live weight until reaching the level of overwintering crop in December.

Overall the forest plants have a higher mean weight than those of the open bog mat. Also a main difference in performance between the two populations is that the overwintering plants in the shaded habitat (open forest) retain a greater percentage of live (green) plant material.

The August sample from four habitats in August indicate the variation in size of Eriophorum angustifolium plants throughout the ombrotrophic zone. In Table 3-16 it is shown that plants from

Figure 3-27. Mean dry weight (mg) of live and dead factions of Eriophorum angustifolium plants throughout the growing season obtained from A: open bog mat, B: open forest populations.

ERIOPHORUM ANGUSTIFOLIUM

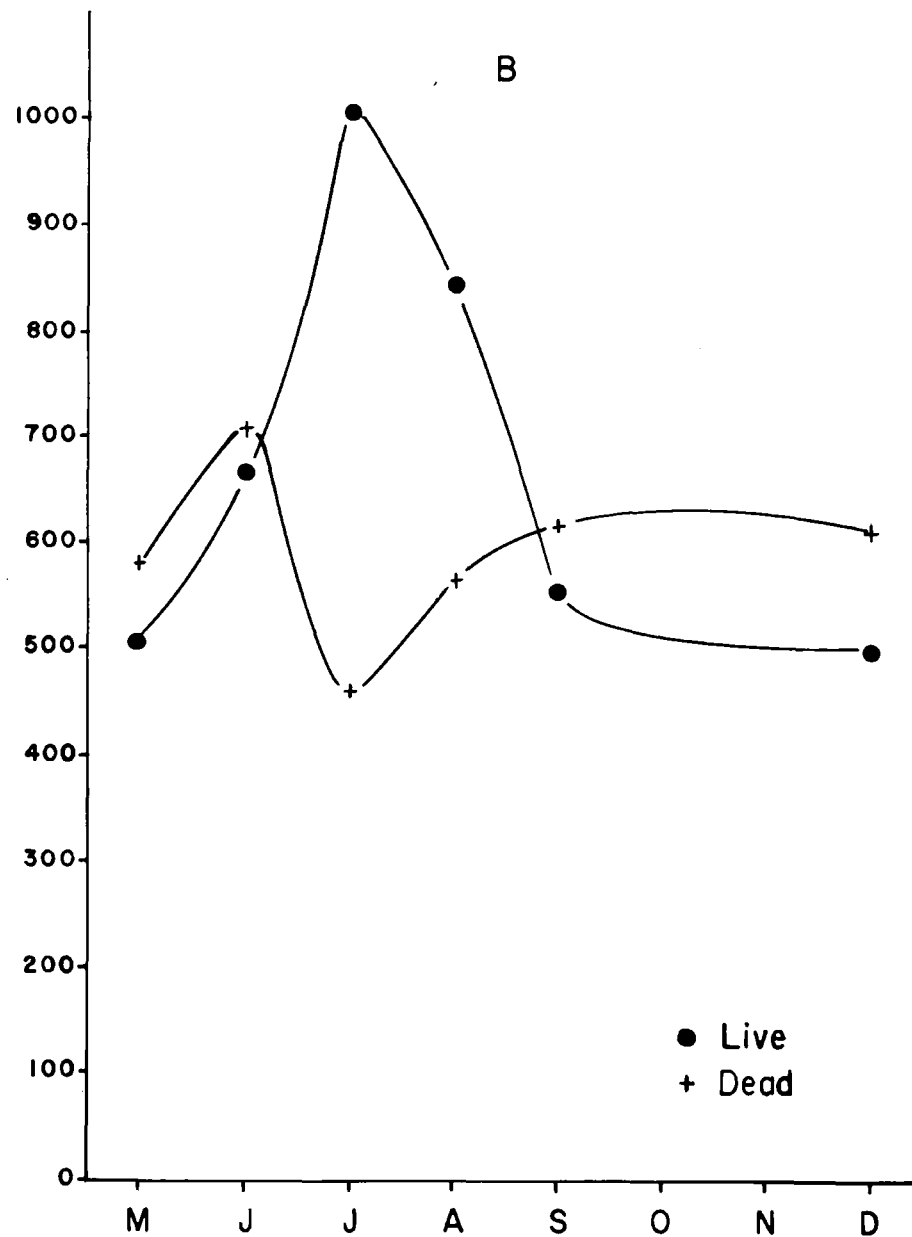
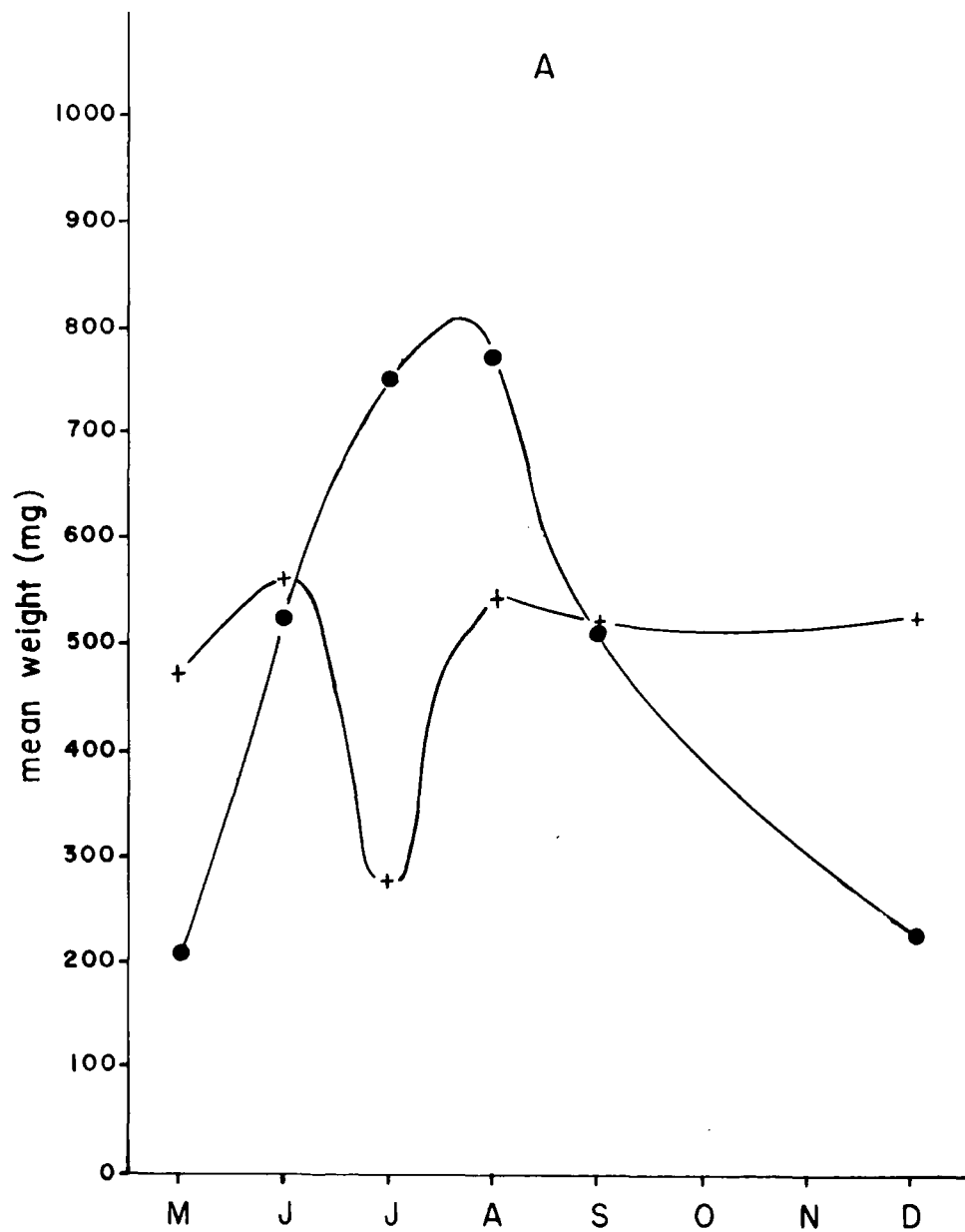


Table 3-16. Mean live and dead dry matter content and live-dead ratios of Eriophorum angustifolium plants from four habitats on Moorthwaite Moss; August samples only.

<u>Site</u>	<u>Live</u>	<u>Dead</u>	<u>Total</u>	<u>L/D</u>
Open bog (wet variant)	315	261	576	1.21
Open bog (mat)	785	552	1337	1.42
Open forest	840	557	1397	1.51
Closed forest	1352	602	1954	2.25

the wetter open bog variants are very small in comparison with those from other sites. Whereas the open bog mat and open forest plants are not significantly different in weight in August, they do come from distinct populations as seen in Figure 3-27. The fourth site, closed forest, has the largest individual plants and the highest live-dead ratio.

C: Eriophorum vaginatum:

Eriophorum vaginatum is a major contributor to community biomass, only in the dry knoll sites dominated by Calluna. Time did not permit adequate sampling procedures to be developed for production analyses. In all, two tussocks were taken intact from the Calluna dry knoll, one in April and the second in August. These samples were located close to one another and were of similar size. An attempt was made to determine the live-dead factions in each sample and compare results. These results are given in Table 3-17.

Table 3-17. Component dry matter content and stand characteristics of Eriophorum vaginatum tussocks taken from Calluna vulgaris dry knoll.

	April	August
Live (aboveground)	10.08	18.60
Dead (total)	34.19	38.49
Roots	4.52	6.24
No live shoots	83	121
Mean live shoot wt. (mg)	122.7	143.6

The live aboveground portion of the tussock, for these two samples, increased from 10.1 - 18.6 gm during the growing season. This is indicative of the influx of new shoots and increase in mean shoot weight of existing viable shoots present at start of the season. The root biomass also increased, however, the accuracy of determination of live root material is questionable. The litter layer and below-ground parts of the plant is comprised largely of dead material from previous years growth. It is possible to separate 1 year old dead from previous year by means of coloration and decomposition of material. At present, methodology for working out production of tussock-forming species is inadequate, however, through dissection and density counts this can possibly be done with a fair degree of accuracy.

SHRUBS:

Six shrub species are found in the ombrotrophic vegetation on Moorthwaite Moss. These are Calluna vulgaris, Erica tetralix, Vaccinium myrtillus, Oxycoccus palustris, Andromeda glaucophylla and Empetrum nigrum. The first four are dominant in particular vegetation types, whereas Andromeda and Empetrum are but minor contributors to the community production. In assessment of the shrubs, however, Pinus sylvestris seedlings up to 2 m in height are included.

Existing methods for measurement of net annual aerial production in dwarf shrub stands are primarily limited to direct harvesting techniques. Descriptions of such methods are given by

Gimingham and Miller (1968), Whittaker (1961, 1963), Ovington et al. (1967) and Jones et al. (1969). These methods are time consuming and laborious and have been used sparingly in the present investigation.

Use is made in the study of the allometric regression techniques for estimating stand biomass and within limits net annual production. Such regression techniques are commonly used in forestry for estimating tree biomass (Ovington and Madgwick, 1959; Baskerville, 1965; Bunch, 1968; Newbould, 1968) and have recently been applied to shrub species as well (Telfer, 1969). For ease of data computing the diameter squared (d^2) is used as the x value in the equation:

$$y = ax + b$$

In addition to providing biomass estimates of whole trees or shrubs the equation has proven successful in use for predicting weights of most components of various species as shown by Monk (1966) and Ovington et al. (1967).

A: Calluna vulgaris:

Figure 3-28A gives the correlation between d^2 and total dry weight for Calluna plants taken from the dry knoll ($r = 0.94$) and from a composite sample of hummock and open forest sites ($r = 0.94$). Furthermore d^2 has been correlated with current branch and leaf dry weight with coefficients of 0.88 and 0.87 respectively for dry knoll and remainder of Calluna populations.

The main difference in the two sample populations is that Calluna plants of the dry knoll have a mean weight of 13.8 gm compared with 2.7 gm for plants from other sites. By using the equations established, biomass estimates were calculated for 10 plots in each population. From the hummock and open forest population, sample plots were selected only from areas where Calluna constituted more than 5% of the plant cover. Current leaf and branch weight estimates were also calculated, however these values, although expressed as net aerial production, are underestimates in that no account is made for increase in stem and older branch wood. Data obtained are summarized in Table 3-18.

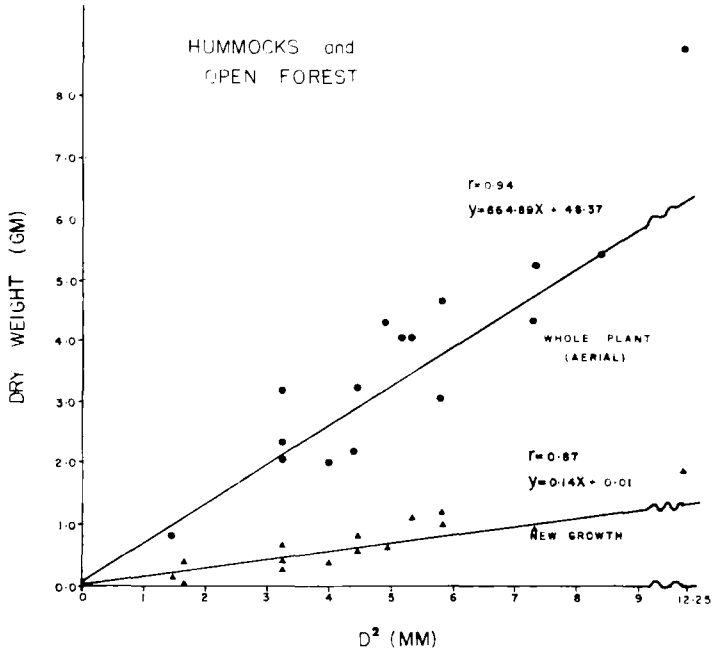
Calluna has been investigated by many researchers in Britain because of its importance as a contributor to heath and blanket bog communities and as a food source for hill sheep and the grouse, Lagopus scoticus. Many values of biomass and standing crop have been recorded, however, in most examples, the Calluna biomass is not given as a percent of the total community biomass. According to Gimingham (1960) a biomass of 1440 gm/m² is reported for Calluna by Mork (1946). Miller and Miles (1970) give a range of values from 15 - 168 g/m² for first year regeneration up to 339 - 625 gm² for a five year old heather following a burn. Bellamy and Holland (1966) provide values of 530 gm/m² at 6 years, 1500 gm/m² at 13 years and 2000 gm/m² at 16 years after burning. The net annual production, calculated by Bellamy and Holland, was 177 ± 23 gm/m², which is comparable to the values obtained in the current investigation (Table 3-18). Rawes and Welch (1969) report a biomass of 501 gm/m² and net annual production of 150 gm/m² for Calluneto-Eriophoretum on blanket bog in Northern England. From a number of mixed sites they report a range of values from 16-768 gm/m² for

Figure 3-28 A: Allometric equations expressing correlation between d^2 and total dry weight in gm of Calluna vulgaris populations from dry knoll and hummock-open forest vegetation types. Equations for new growth are also shown for each population.

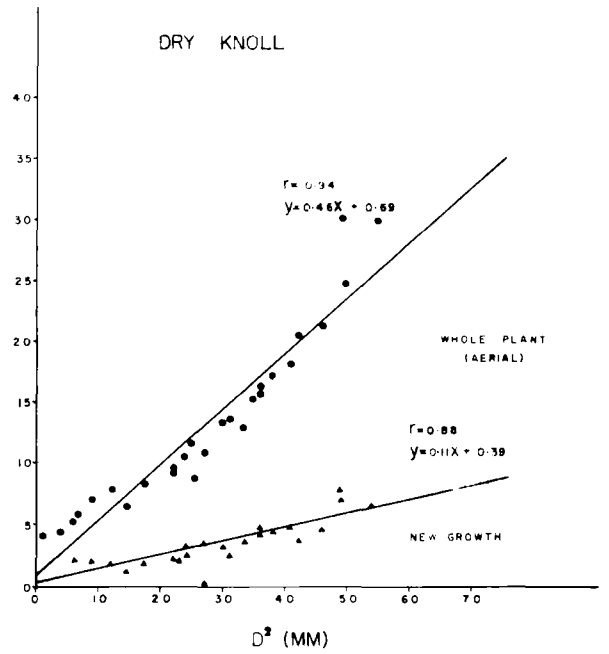
B: Equations for Erica tetralix from both spring and summer populations.

CALLUNA VULGARIS

HUMMOCKS and
OPEN FOREST

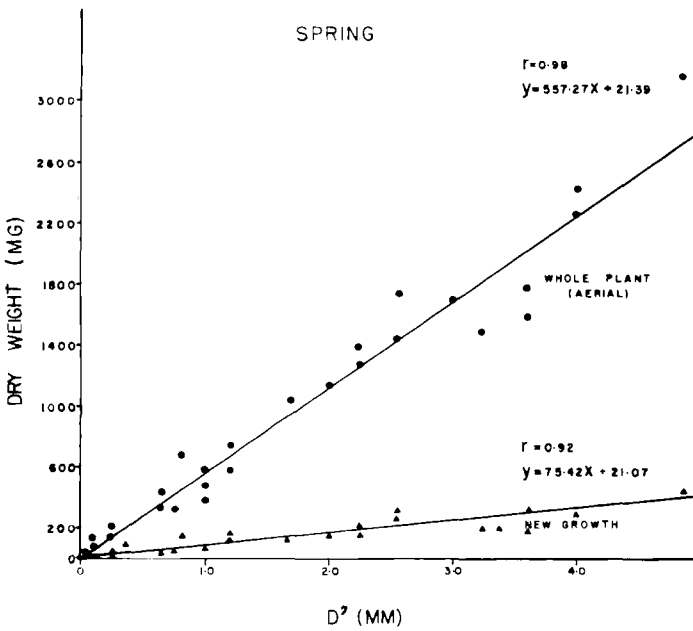


DRY KNOLL



ERICA TETRALIX

SPRING



SUMMER

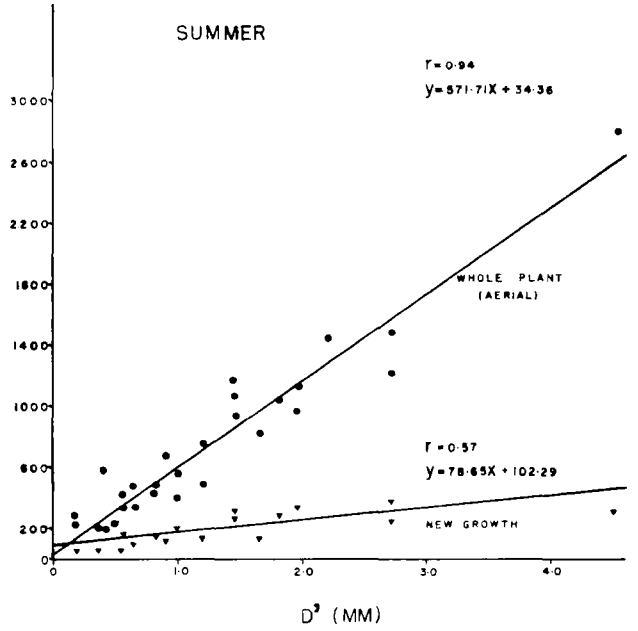


Table 3-18. Biomass, net aerial production and stand characteristics of Calluna vulgaris populations on Moorthwaite Moss. Weights are expressed as gm/m² o.d.w. 95% confidence limits are calculated.

No. of plots	Site	Age	Height cm	Density stems/m ²	Predicted biomass	Harvested biomass	Net production	% of Understory biomass
10	Dry knoll	10.5 ± 2.8	50.8 ± 7.2	77 ± 29	1156 ± 536	11400	240 ± 92	75 - 90
5	Open forest	4.5 ± 2.0	45.2 ± 10.4	185 ± 61	570 ± 209	540	114 ± 39	60 - 80
5	Lawn & hummocks	3.0 ± 2.2	21.3 ± 10.6	42 ± 47	68 ± 68	33	27 ± 20	5 - 20

Calluna, and site production on blanket bog of 69 - 439 gm/m².

Nicholson and Robertson (1958) give biomass values for hill peat ranging from 400 - 1066 gm/m².

The small amount of true heath on Moorthwaite is restricted to the dry knoll vegetation which is characteristically acidic and nitrogen rich. This heath is comparatively more productive than heath vegetation reported from hill or blanket peatland. This may be partially due to a longer vegetation season and absence of grazing pressure. Figure 3-9 shows an area of the dry knoll with the more open aspect of development. The mature phase is evident and although mean age of Calluna plants in the stand is 10.5 the range is 7 - 20+ years.

B. Erica tetralix:

Erica tetralix is the dominant shrub of the forested portion of the bog and as its coverage increases in shaded sections Calluna decreases. On Moorthwaite, Erica is found in all but the wettest emergent vegetation and the more nutrient-rich marginal fen. Figure 3-10 shows the typical understory cover of Erica in the Pinus sylvestris forest.

Growth performance of the species varies with habitat and has a more robust development in the forested zone and more sparse smaller plant development in open bog and Calluna-dominated vegetation. Bannister (1966) notes that Erica tetralix performs most favourably in drier sites with Calluna absent and is poorly developed when competing with Calluna. Also maximum development occurs in wet heaths and oligotrophic flushes whereas growth is straggling in most bogs.

Moore (1962) states that Erica is not particularly common in woodland communities. On ameliorated peatland it increases in importance, but only temporary, ultimately leading to elimination of suitable habitats.

In construction of prediction equations, Erica on all habitats in Moorthwaite was treated as a single population. These equations and graphical representation of the Erica tetralix samples are given in Figure 3-28B, for both the spring (early June) and summer (late August) aspects of development. Even with the combination of poor- and well-developed plants in the population sample high correlations were found to exist between d^2 and total weight (0.98) in spring and (0.94) summer. Plants in the summer aspect have a very slight total weight increase over the spring plants. This may be due to increase in flowering structures at peak standing crop. These differences in samples however are not significant.

The new growth of Erica was found to be highly correlated with d^2 in June ($r = 0.92$) but much less so ($r = 0.57$) for the August plants. This variation in the August sample may be partially caused by the differences in flowering between individuals. The slopes of the lines of best fit indicate that the greater part of growth has occurred early in the season. Table 3-19 summarizes the data calculated for Erica on the site.

From the data it is clear that Erica plays an important role only in the closed forest in terms of production. Unfortunately no comparative data could be found in the literature researched.

Table 3-19. Biomass, net aerial production and stand characteristics of Erica tetralix vegetation on Moorthwaite Moss. All weights in gm/m² o.d.w.; 95% confidence given; (7) estimates only.

Site	No. of plots	Age	Height	Density	Predicted biomass	Harvested biomass	Net production	% of site biomass
Closed forest	10	3.8	28.4 ± 5.1	327 ± 164	374 ± 143	452	70 ± 39	80 - 95
Dry knoll	3	3.4	18.1 ± 3.7	49 ± 23	31 ± 19	22	11 ± 6	0 - 10
Open forest	6	2.7	19.2 ± 6.9	51 ± 71	27 ± 22	7	(7)	0 - 10
Open bog	4	2.9	8.3 ± 3.4	37 ± 42	6 ± 7	16	(2)	0 - 5

C: Vaccinium myrtillus:

Vaccinium myrtillus is a deciduous rhizomatous shrub, with aerial shoots erect and is from 10-60 cm in height (Ritchie, 1956). As a result of its vegetation reproduction it occurs as large clonal patches 5-15 m in diameter and occasionally admixed with other ericaceous shrubs. On Moorthwaite, Vaccinium myrtillus is dominant on dry knolls in more shaded areas. Koie (1938) states that it is a 'facultative shade plant'. It is more tolerant to such areas than is Calluna. The Calluna dry knoll has only a sporadic cover of Vaccinium myrtillus but where found, plants retain leaves year around in comparison to the Vaccinium knoll plants which drop all leaves by October. Vaccinium is relatively common in the forest understory but is seldom dominant. Furthermore the forest plants are mostly smaller than the dry knoll plants.

Prediction equations were established for two Vaccinium populations: the dry knoll and the forest (Figure 3-29). The correlations found were $r = 0.95$ for dry knoll and $r = 0.93$ for forest plant total dry weight plotted with d^2 . Slope for the equations indicate that the forest plants are heavier than plants of similar d^2 on the Vaccinium dry knoll. This may be partially due to loss of a portion of the leaves from the dry knoll population at the time of sampling (August).

New growth per plant was more difficult to delineate in Vaccinium than for the other ericaceous shrubs with less distinction between current and previous years branches. Production data for the species are given in Table 3-20.

Figure 3-29. Allometric equations showing correlation between d^2 and both total dry weight and new growth determined for two populations of Vaccinium myrtillus from Vaccinium dry knoll and ombrotrophic forest.

VACCINIUM

MYRTILLUS

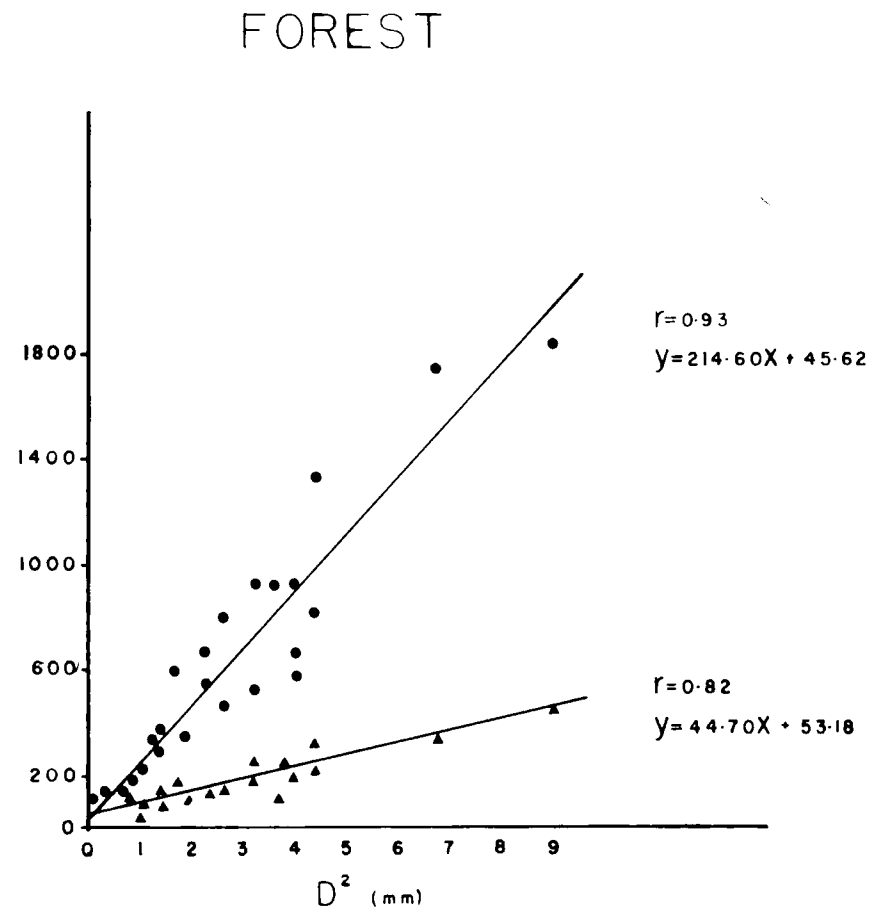
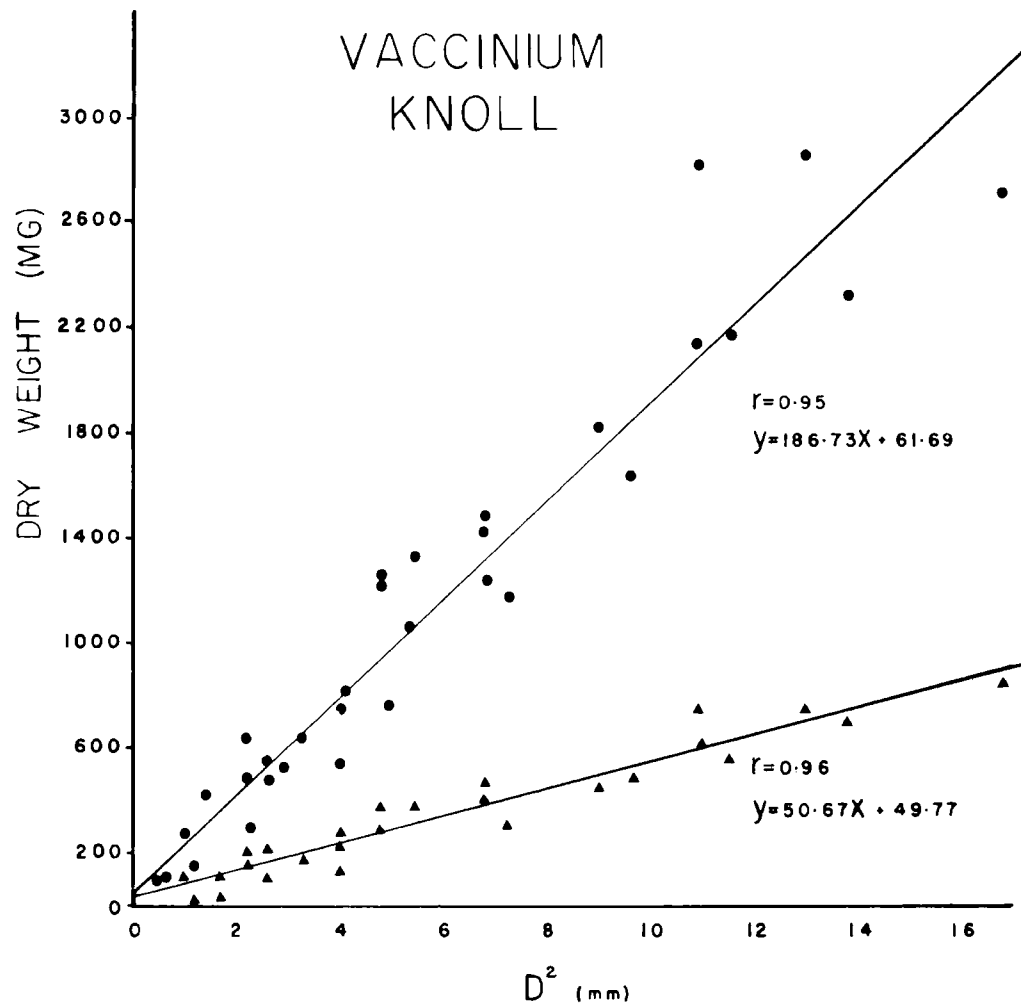


Table 3-20. Biomass, net production and stand characteristics of Vaccinium myrtillus within two vegetation types on Moorthwaite Moss. All weights are in g/m² (o.d.w.); where given limits are calculated for 95%.

Site	Age	Weight	Density	Biomass		Net prod.	% of biomass
				Predicted	Harvested		
Vaccinium knoll	(1-7)	20.8 ± 4.6	388 ± 182	480 ± 246	593	160 ± 61	75-95
Forest	(1-7)	16.9 ± 3.7	84 ± 63	32 ± 50	-	6.7 ± 8.1	5-20

Traczyk (1967) determined the average growth of Vaccinium myrtillus as 121 mg/plant in the herb layer of Tilio-Carpinetum in which the species contributed only 1-2% of total net production. In the Vaccinio-myrtilli-Pinetum, Vaccinium myrtillus production was 30-60% of the total and plant density from 19-88 individuals/m². The individual net production was 181 mg.

D: Oxycoccus palustris:

No production data were obtained for Oxycoccus palustris other than its contribution to the biomass of open bog communities in which it is an important producer. These values are given in Table 3-10 (Vol. II).

E: Pinus sylvestris (seedlings)

Pinus sylvestris seedlings are abundant in the open bog sites on Moorthwaite and almost absent in shaded forest. Natural regeneration is occurring and most favourable seedbeds are the Sphagnum hummocks and Aulacomnium mat. Seedlings are mostly slow growing and some individuals examined indicated severe checking. Majority of the seedlings are 1-12 years and few exceed 1-5 m in height. More successful seedlings show a healthy development, possibly to the detriment of their poorly growing counterparts.

Prediction equations were established for the seedlings including the whole plant, aerial and root portions (Figure 3-30). Correlation was found highly significant with $r = 0.98$ for both whole and aerial plant and 0.94 for the roots.

Density counts for seedlings were made from 10 x 10 m squares within the surface grid. In all, 37 plots were counted with density range from 0 in dense forest to 160 in open bog. In the forested areas, although Pinus seedlings were absent, Betula pubescens seedlings increased and ranged from 4-30/square.

Ovington et al. (1967) found correlations of $r = 0.98$ for d^2 plotted against total tree dry weight and $r = 0.93$ for d^2 plotted against total root dry weight of Pinus radiata taken from upland soils. These relationships are close to those expressed in Figure 3-30. Each equation, however, should only be used for prediction of production and biomass on the site from which they are constructed.

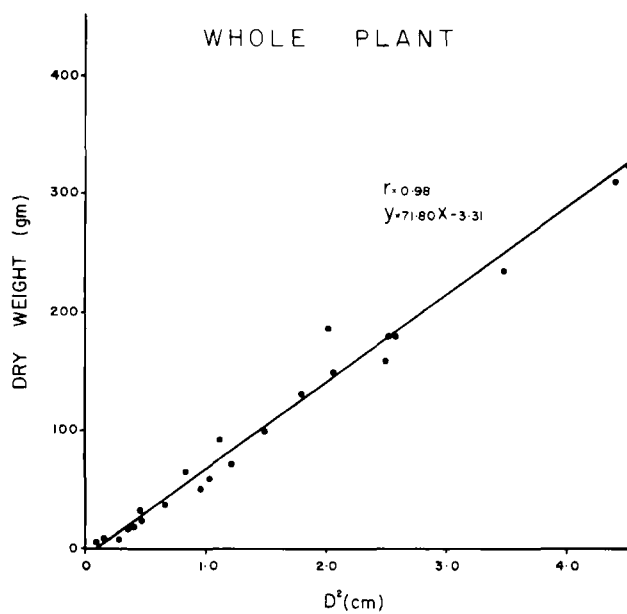
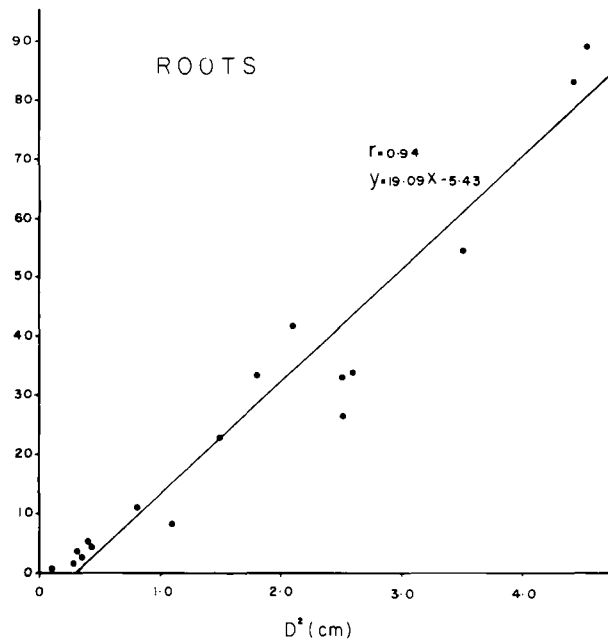
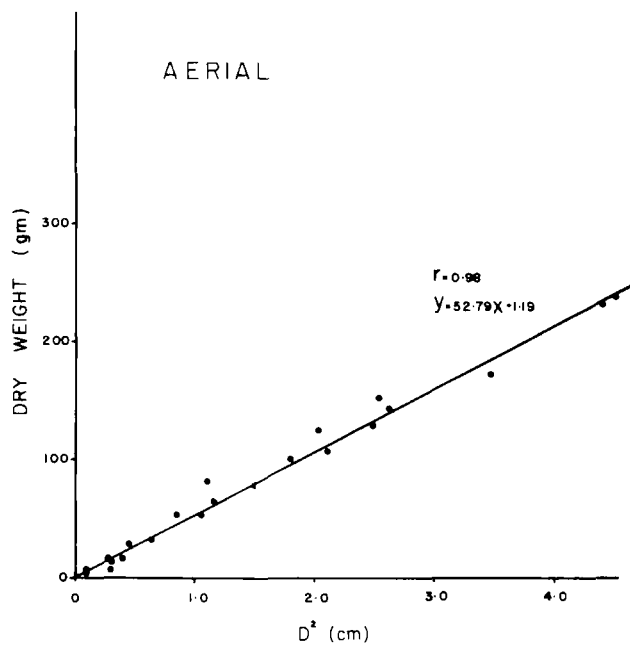
TREES:

Moorthwaite Moss is largely forested by Pinus sylvestris with Betula pubescens occurring sporadically. Pinus is found in all main vegetation units except the soligenous fen in which there is an admixture of Betula and Salix. Pine colonization of topogenous bogs, variously dominated by Eriophorum spp., Trichophorum caespitosum and Sphagnum mosses, is often abundant in the presence of a good supply of seeds (McVean, 1963). This is the case at Moorthwaite where a seed source is provided by the remnants of an old plantation at the southern extremity of the bog.

The stand characteristics support the possibility of natural regeneration and also reflect anthropogenic influences. Trees at the outer edge of the bog are both largest and oldest ranging from 60-120

Figure 3-30. Correlation between d^2 and aerial, roots and whole plant dry weight of Pinus sylvestris seedlings.

PINUS SYLVESTRIS



years with height 14 m. Toward the centre is the ombrotrophic forest, with an uneven age structure of 20-70 years. Stem growth in the closed forest is straight with a high canopy and few low branches. Many standing dead remain, indicating the natural thinning through competition and disease. Canopy cover is greater than 50% and the stand is 10-12 m in height.

Further toward the centre is the open forest. This is not sharply defined, but rather forms a transition between closed forest and open bog conditions. This is also the forest type of the Calluna dry knoll. Trees are more scattered and generally 10 m in height. Branching is often low on the stem and may be large in size resulting in trees with a poorer growth form than those in closed forest. The majority of larger trees are 40-50 years with a break in age structure to 20 year-old trees. Thus there is little gradation of age in the forest stand and a semi-irregular pattern exists. Steven and Carisle (1959) report similar patterns for native pinewoods in Scotland.

The open portions of the bog have few trees and are primarily seedbeds with numerous seedlings present. McVean (1963) reports that initial establishment is excellent among the Sphagnum-Eriophorum lichen hummocks but that early growth is slow. He also states that growth depends largely on the firmness of the underlying peat, height of water table and exposure to strong winds.

On Moorthwaite the anthropogenic influences on the tree layer include cutting, fire and exposure of surrounding mineral soil through drainage and agricultural practices resulting in conditions amenable to windthrow. Furthermore, increased nutrient levels of the site are due to windblown fertilizers from surrounding farms.

In addition to aboveground stand characteristics the root development was also observed. This was carried out on trees toppled by windthrow and excavation of root systems of many smaller trees and seedlings. Rooting systems in bog soils are generally poorly developed due to lack of oxygenation or low nutrient content in the peat. Root penetration seldom exceeds 30 cm below the surface and the great majority of roots are within the top 15 cm. Paavilainen (1967) found the mean root penetration to be 12.5 cm for Pinus sylvestris on bog sites. Distribution of main laterals and length of tap root is also greatly affected by aeration and nutrient deficiency. Yorke and Pollett (1969) report lateral development up to 16 m for Larix laricina from ombrotrophic bog. This was accompanied by poor secondary root development and dead tap root.

Root systems of Pinus on Moorthwaite although in the upper peat strata (0-30 cm) are mostly well developed with many short roots near the surface. In most cases viable tap roots were found. This development is evident despite a high water table in many areas.

Stand density and volume measure were obtained from 37, 10 x 10 m units selected subjectively from the established grid (App. II on methods). From the measures recorded an estimate of

Table 3-21. Stand characteristics and stem dry matter content for the Pinus sylvestris forest on Moorthwaite Moss.

Site	No. of plots	Stems/1/10 ha			Dry matter kg/1/10 ha			Wood density
		4m	1.5m	1.5m	Min.	Max.	Mean	
Open bog	6	1-30	10-80	120-1600		307	135.3	0.472 ± 0.28
Open forest	14	40-150	0-80	0-180	506	4229	1737.6	
Closed forest	14	140-240	0-50*	0-210*	4100	14230	8391.9	0.434 ± 0.015

*Betula seedlings

dry matter content was calculated for the stem portion of the forest only. This provides a relative comparison of dry matter in the tree layer of different vegetation zones. These results are summarized in Table 3-21.

SUMMARY AND DISCUSSION:

The present vegetation on Moorthwaite Moss is easily divided into physiognomic structural groups which were enhanced by the systematic Zurich-Montpellier systematic classification which provided a better understanding of the vegetation.

Analysis of substrata on the site further substantiated the vegetational divisions with clear-cut differences in both physical and chemical characteristics of the top 30 cm of peat. The major divisions evident were open bog, dry knoll, ombrotrophic forest and fen peats. Subdivisions of vegetation on the surface of the peats were related to other environmental factors such as shading and microtopographical characteristics such as hummock-hollow series in open bog vegetation.

Within the delineated units estimates of standing crop were determined. From the samples taken both open bog and open forest areas have similar dry matter contents in ground vegetation with biomass ranging from 860 - 1140 g/m². The high water table may inhibit extensive root development and the underground biomass is less than aboveground except for the Narthecium variant where the high density of Narthecium rhizomes reverse the balance. In all

four units examined Sphagnum was dominant and the dividing line between above- and below-ground portions is tenuous.

In contrast to the open wetter communities, the dry knoll vegetations, because of their dominant shrubs, have a higher biomass of 2045 g/m² for Vaccinium and 3114 g/m² for Calluna heath. In both knolls underground biomass exceeds aboveground, in part, due to the root density and below-ground stem of Calluna plants and extensive rhizome development of Vaccinium. The other shrub vegetation, the Erica tetralix understory has a biomass of 939 g/m² (excluding Pinus roots) which is lower because of the production of the tree layer in these areas.

The Pinus sylvestris forest was not included in the above estimates, except for roots excavated with monoliths. Trees are not important producers in the areas sampled except for the Erica tetralix vegetation unit. Comparison of bole dry matter content of the tree layer showed considerable differences from nil on some open bog plots to 14230 kg/1/10 ha in closed forest plots.

Dry matter production was determined for six mosses, three herbs and three shrubs with varying degrees of accuracy dependent on procedures used in sampling and subsampling. From the data obtained distinct variation of performance is evident between vegetation units. In most units the dominant species contributed 80% of the total net annual production and emphasis was placed on individual rather than community or unit production.

Production in the moss layer varied from 2-6 g/dm² with Sphagnum recurvum in the hollow, lawn, and dry knoll having the greatest net annual production 4-6 g/dm² and the Sphagnum rubellum

hummock having least gain of 2 g/dm². Increases in mean length from 1.6 - 7.5 cm/plant and mean weight of 4.4 - 36.0 mg/plant were recorded. The Sphagnum magellanicum, Sphagnum palustre and Sphagnum recurvum lawn plants have the greatest weight increase per individual whereas Sphagnum rubellum and Aulacomnium palustre have small gains recorded per plant. The latter two species, however, have many more individuals per unit area.

Sphagnum recurvum plants, selected from four separate populations, demonstrate significant differences in rates of growth both in length and weight (Table 3-13). The marginal fen plants have the highest recorded weight/cm (5.14) for all Sphagnum recurvum samples. This was attributed to the higher concentration of nutrients in the plant tissues of the fen plants. The greatest increase in both length and weight production was mid-summer, June-August, for all moss species.

In comparison to the moss production analysis, the herbs were not adequately sampled to formulate accurate estimates of net annual productivity. These are not dominants, however, Eriophorum angustifolium is commonly found throughout the sites. Narthecium ossifragum contributes 70 g/m² to aboveground net annual production of its variant, however underground biomass would suggest it may be an important producer of the below-ground production. Outside the Narthecium variant the species is of minor importance as a producer.

Eriophorum angustifolium has a peak standing crop of 44 g/m² in wet open bog to a high of 113 g/m² in drier open bog vegetation. Growth form of individual plants is expressed through small plants in more open wet sites to very large individuals in forested areas. Estimates of net annual production are 60 g/m² on open bog mat and

30 g/m² in open forest. This is a factor of density/unit area and not plant size. No adequate estimate of Eriophorum vaginatum production was determined.

Shrub vegetations were assessed through use of allometric equations. The production in optimal sites were 240 ± 92 g/m² for Calluna; 160 ± 61 g/m² for Vaccinium; and 70 ± 39 g/m² for Erica. These are underestimates, not accounting for stem growth. Also below-ground production was not measured. The decrease in production from Calluna-Vaccinium-Erica can be associated with tree cover which increases greatly from Calluna knoll to Erica understory vegetation. The allometric prediction equations, however, could provide more meaningful data if stem diameters of individual plants were taken over subsequent seasons. In this way the total dry matter increase of the plant could be determined from the prediction equation required no destructive harvesting after construction of the equations. This procedure should be given careful consideration by future production ecologists interested in increment of shrub dry matter over a number of years. Correlations obtained for each species were significant to 0.01.

Equations were calculated for Pinus sylvestris seedlings which were found useful in determining biomass of individuals.

Measures of production have shown considerable differences in production of vegetation units; for example the yield from hummocks in open bog is less than that of mat or lawn and hollow vegetation. Also much of the peatland assessed have a single species accounting for 75% or more of biomass and net annual production of ground vegetation within each of the units delineated through Z-M

methodology. This, however, is in large part due to the type of vegetation being analyzed and may prove less useful in more heterogenous areas.

NUTRIENT CONTENTS WITHIN VEGETATION ON
MOORTHWAITE MOSS

To augment production analysis each species comprising the ombrotrophic vegetation was analyzed for comparison of nutrient concentrations within plant tissues. It was previously discussed that peatland soils are deficient in many nutrients especially in the available form. Moorthwaite Moss has been classified as an ombrotrophic bog and many such deficiencies may be expected. Differences in nutrient concentrations with habitat have been demonstrated, however soil analysis as a diagnostic criteria for site selection is at best a blunt tool. Foliar diagnostic methods are also far from refined, but yet have proved its worth with checked or poorly growing crops (Binns and Grayson, 1967; Watt and Heinselman, 1965; Swan, 1970).

Most elements are not evenly distributed in the plant and even within the same plant part variation can occur. Under normal conditions, however, plant growth and element absorption will parallel one another during much of the growing season (Jones, 1970). If normal growth rates of a plant are interrupted then element accumulation or dilution may occur. In general, nutrient uptake and dry matter accumulation are comparatively slow in very early spring and become very rapid as the season progresses. In mosses this pattern of dry matter accumulation and nutrient uptake is greatly influenced by environmental factors, such as the moisture of underlying substrate.

Literature reviews of investigations on plant nutrient analysis within ecosystems have been given by Rennie (1956) and Rodin and Bazilevich (1967). Also Loach (1964) discusses methods for assessing nutrient status with a general literature review. For a comprehensive account of plant sampling procedures used in nutrient analyses, Chapman (1966) is recommended.

MOSES AND LICHENS:

Detailed analysis of nutrient contents within Sphagnum-dominated moss layers are lacking in peatland investigations. Pyvachenko (1960) reports on cycling of ash elements and nitrogen in bog forests and Rodin and Bazilevich (1967) contain generalized data on nutrient stores within boreal peatland ecosystems. Additionally the nutrient concentrations of particular Sphagnum species have been reported by Kivinen (1933), Malmer and Sjors (1955) and Malmer (1962b, 1964).

In this investigation differences in nutrient concentration were examined for seven mosses and one lichen. For most samples N, P, K, Ca, Mg, Mn, Fe and Zn were determined with total element concentration used in interpretation. The total element form is considered reliable for most elements, however Fe expressed in acid soluble form in plant tissues is believed to be a better indicator of iron status in the substrate (Jones, 1970).

In all samples, except the August collection, whole plants were used for analysis. The bottom few cm were discarded from all plants. This was considered to be the obviously dead portion of the

Table 3-22. Nutrient content, mg/g, in new and old segments of species comprising the moss layer on Moorthwaite Moss; all samples were obtained in August.

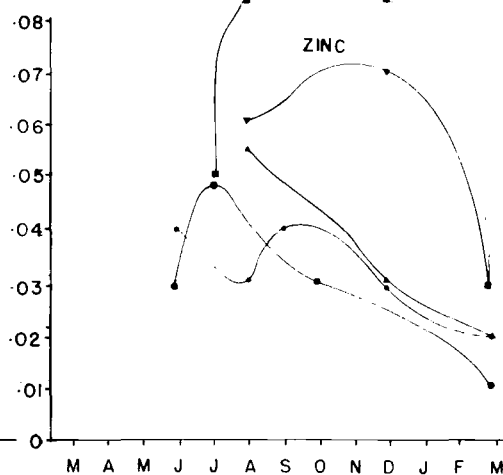
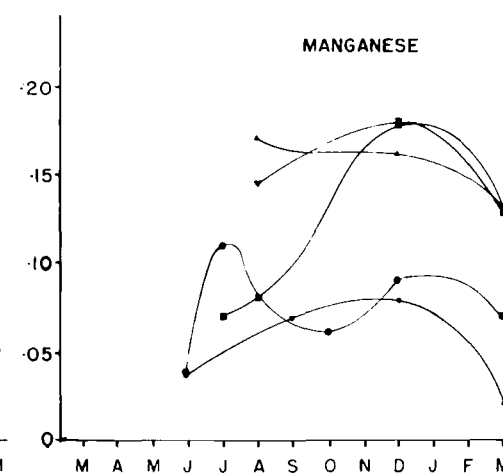
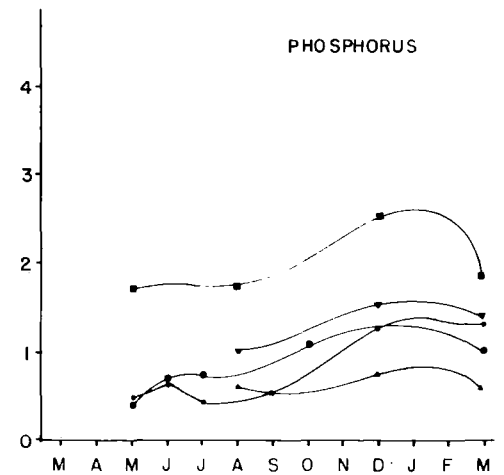
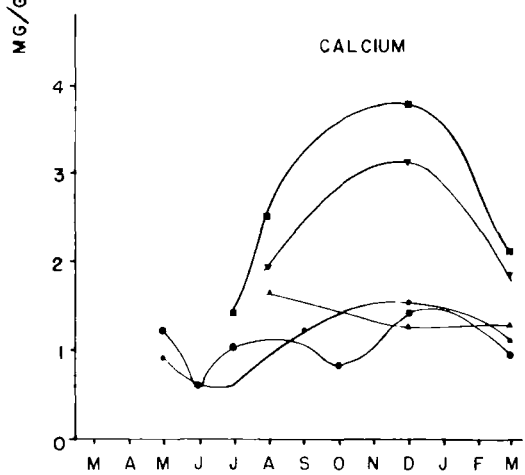
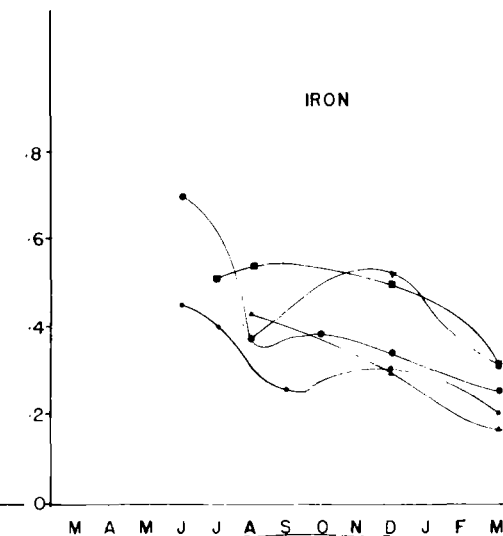
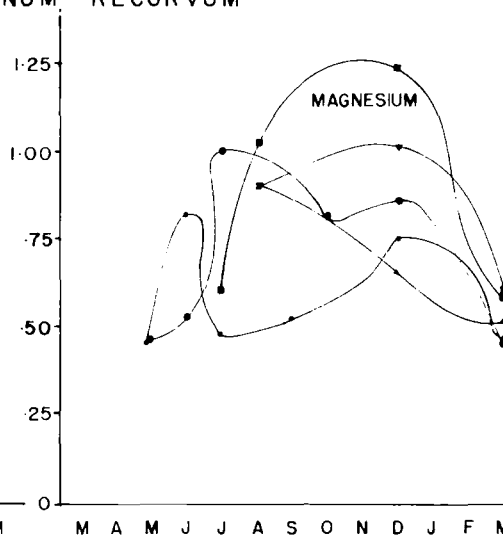
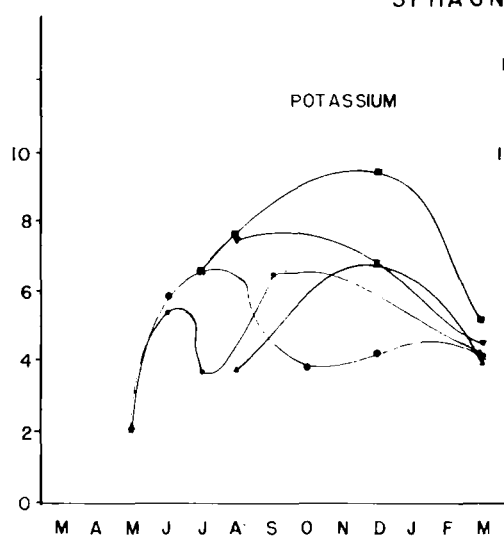
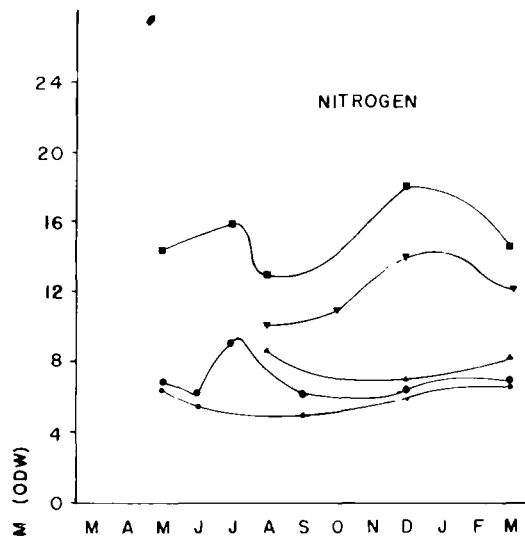
Species	Habitat	N	P	K	Ca	Mg	Mn	Fe	Zn
<i>Sphagnum recurvum</i> (new)	DK	8.30	0.72	5.20	1.60	0.86	0.18	0.32	0.05
(old)		6.40	0.53	2.35	1.60	0.97	0.16	0.52	0.06
<i>Sphagnum recurvum</i> (new)	MF	11.40	1.63	7.40	1.50	0.97	0.12	0.30	0.05
(old)		10.10	0.89	7.60	2.30	0.82	0.17	0.40	0.07
<i>Pleurozium schreberi</i> (new)	MF	13.80	1.60	6.80	1.00	0.92	0.08	0.14	0.06
(old)		8.10	0.90	3.30	1.60	0.64	0.10	0.45	0.06
<i>Aulacomnium palustre</i> (new)	L	7.60	0.92	-	1.40	-	0.37	0.80	0.12
(old)		8.30	0.67	2.00	1.60	0.72	0.24	0.35	0.06
<i>Cladonia impexa</i> (new)	DK	7.90	0.47	0.47	1.30	0.29	0.04	0.15	0.05
(old)		4.20	0.28	1.22	0.60	0.26	0.04	0.40	0.04
<i>Sphagnum palustre</i> (new)	MF	15.60	1.38	9.90	1.20	0.82	0.08	0.50	0.06
(old)		10.60	0.94	2.45	2.00	0.75	0.10	1.00	0.05
<i>Sphagnum magellanicum</i> (new)	L	8.50	0.72	5.10	1.20	0.90	0.05	0.30	0.05
(old)		7.50	0.95	4.90	1.60	0.90	0.05	0.50	0.05
<i>Sphagnum rubellum</i> (new)	DK	9.60	0.70	3.10	1.60	1.00	0.08	0.45	0.05
(old)		6.30	0.57	1.80	1.60	0.97	0.10	0.50	0.06
<i>Polytrichum commune</i> (new)	MF	20.80	2.45	10.30	1.40	0.94	0.06	0.42	0.09
(old)		17.60	2.22	5.30	2.00	0.97	0.08	0.50	0.10

DK - dry knoll
 MF - marginal fen
 L - lawn (open bog)

Figure 3-31. Differentiation of plant nutrient contents throughout the year for Sphagnum recurvum selected from five habitats on Moorthwaite Moss.

- - Marginal fen
- ▼ - Closed forest
- ▲ - Dry knoll
- - Lawn (open bog)
- - Infilled pool (hollow-open bog)

SPHAGNUM RECURVUM



plant. Analyses of the August samples were conducted on both new and old segments and results are given in Table 3-22. New segments were found to have higher N, P, K concentrations and less Ca, Fe than older segments; Mn, Mg, and Zn show little variation except for individual species. The lichen species, Cladonia impexa does have a higher Ca content in the newer portion with 1.20 mg/g compared with 0.60 mg/g in the older parts. Tamm (1953) reports higher N, P, K in new segments from Hylocomium splendens and an increase in Ca, Mn, Fe for old segments. Mosses taken from fen habitats had highest N, P, K on dry weight basis with Polytrichum commune having highest recorded values for all three elements.

Sphagnum recurvum is the dominant moss in the ground flora and exhibits a wide tolerance of moisture and nutrient regimes on Moorthwaite Moss. Through determination of the nutrient differences of this moss along these environmental gradients samples of Sphagnum recurvum were selected from five habitats:

- (a) Marginal fen
- (b) Closed forest
- (c) Dry knoll (*Calluna*)
- (d) Lawn (open bog mat)
- (e) Infilled pool (open bog hollow)

Results obtained are given in Figure 3-31.

From these results it was noted that nutrient concentrations for plants of Sphagnum recurvum from each habitat vary considerably throughout the season. This was also reported by Malmer (1962) for

Sphagnum magellanicum and Streeter (1965) for Acrocladium cuspidatum. In addition to seasonal fluctuations there are differences in nutrient concentration associated with habitat. These differences are related to similar variation of nutrient concentration of peat underlying each of the vegetation units (Table 3-8).

Nitrogen content within Sphagnum recurvum tissues depends largely on habitat. The marginal fen plants have 13-18 mg/g N, the highest recorded content, followed by plants from closed forest, dry knoll, lawn and infilled pool. Underlying peats of the fen, forest and dry knoll have a N content of 7-14 mg/g, whereas open bog peats have a lower content of 5-8.5 mg/g. Conversely, the lawn and pool Sphagnum recurvum plants have a higher growth potential and dry matter accumulation, which may tend to dilute nutrient concentration.

The other nutrients, except Mn, have higher values recorded from fen and forest Sphagnum recurvum plants with little differentiation among remaining three sites. This may be partly due to the washing of available nutrients from the foliage of the tree canopy in the fen and forest sites. Manganese contents were anomalous in that the dry knoll plants have higher concentrations than open bog samples. This is in contrast with Mn content of the knoll peats, which have lowest recorded Mn contents for the whole site. The Mn content in the knoll sample, however, may be due in part to a leaching of AMn from the overlying Calluna plants which have an exceptionally high Mn content (Figure 3-36).

Kivinen (1933) and Malmer and Sjors (1955) report that P contents of several Sphagnum spp. were lower than that of underlying peat. In this study P in Sphagnum recurvum was found to be either equivalent or greater than that recorded for the peat.

Infrequent sampling did not permit adequate interpretation of seasonal fluctuations of nutrient content, however there is a general trend of an increase from spring to winter conditions with subsequent decrease in content during late winter. One exception was Fe which showed an apparent decline in contents throughout the growing season when expressed on dry weight basis. On peatlands these seasonal fluctuations are often brought about by changes in hydrological and pH conditions of the habitat.

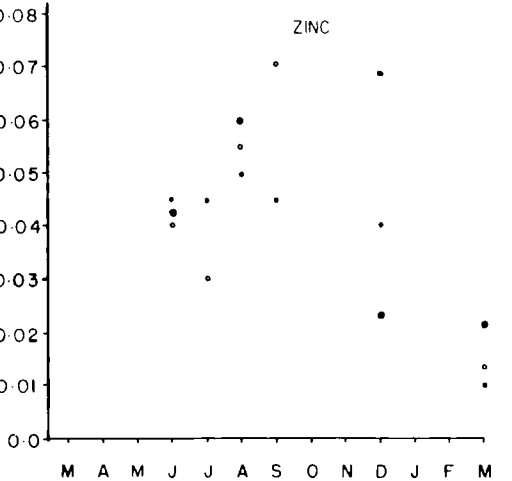
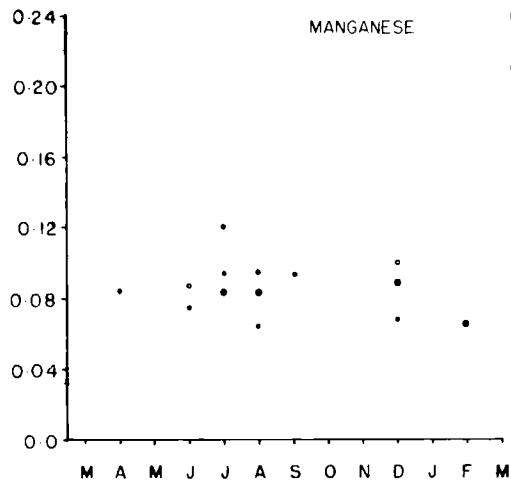
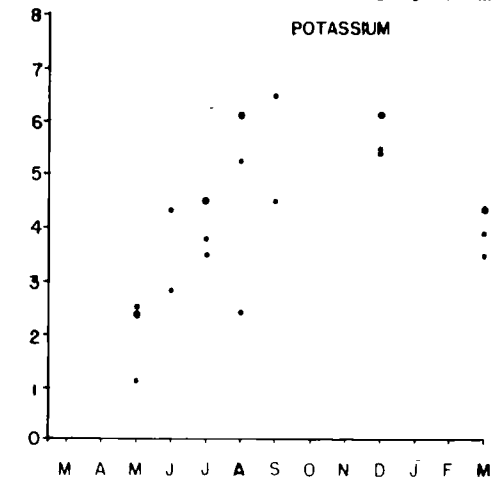
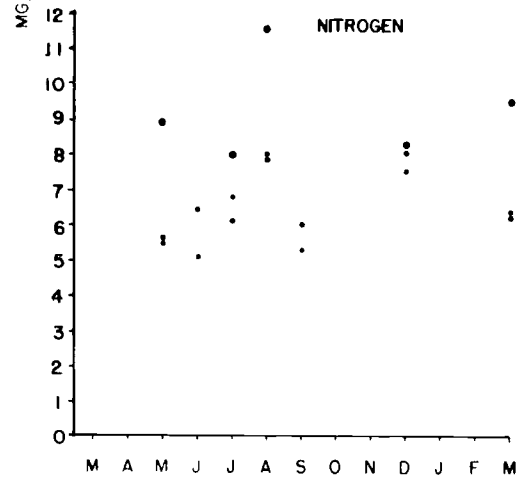
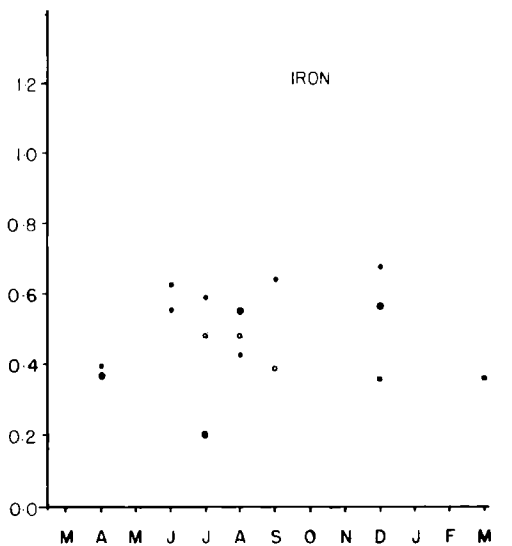
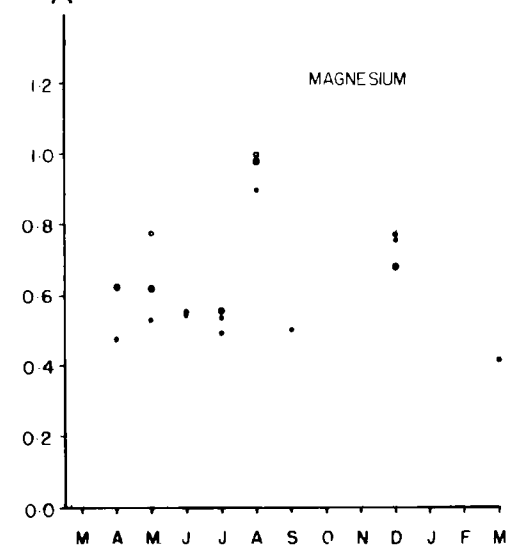
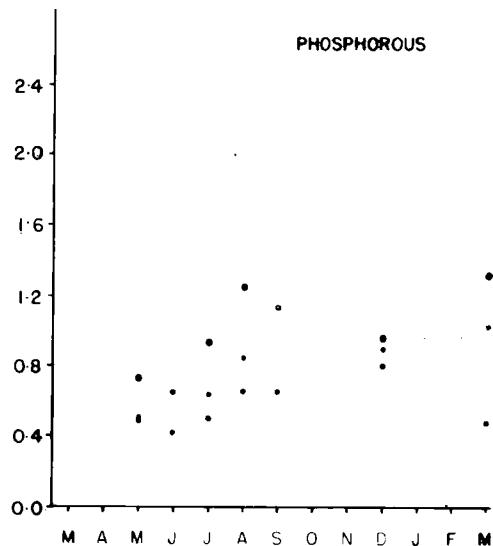
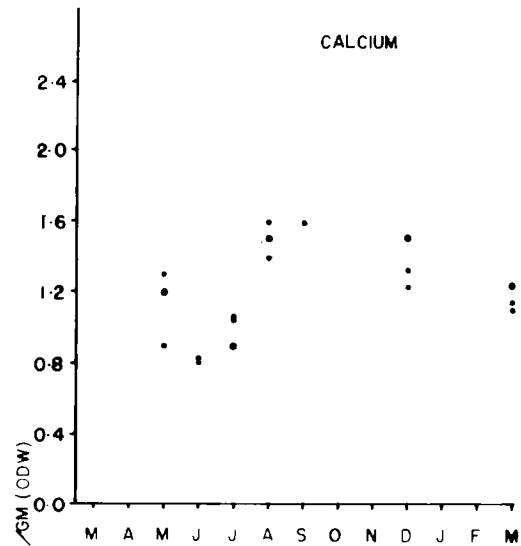
Samples taken in March indicated least differentiation between site and nutrient tissue content in Sphagnum recurvum. This is a result of decline in nutrient content of plants from fen and forest. Samples from the open bog sites showed little change. This may also be due to a lessening of nutrient leaching from the tree canopy in winter which is reflected in element adsorption by the Sphagnum.

The remainder of the mosses and Cladonia impexa was also sampled throughout the season, but only within the ombrotrophic vegetation. Results are given in Figure 3-32. Sphagnum palustre plants from open forest hummocks have N and P content similar to that found in Sphagnum recurvum from the forested zone. Other Sphagna, Sphagnum magellanicum and Sphagnum rubellum from lawn and hummock respectively, have N and P similar to values obtained for open bog samples of Sphagnum recurvum. Pleurozium schreberi taken

Figure 3-32. Nutrient contents in tissues of mosses and lichen from selected habitats on Moorthwaite Moss for each season.

- A: *Sphagnum palustre* (●) - open forest
Sphagnum magellanicum (•) - open bog lawn
Sphagnum rubellum (◦) - hummock
- B: *Aulacomnium palustre* (●) - open bog mat
Pleurozium schreberi (◦) - dry knoll
Cladonia impexa (★) - open bog and dry knoll

A



from dry knoll vegetation had higher N, Mn and Ca contents with K, P, Mg, Fe and Zn similar to open bog *Sphagna*. *Aulacomnium palustre* from open bog had higher P, Mn and Ca with K, N, Mg, Fe and Zn comparable to *Sphagna* concentrations. The lichen *Cladonia impexa* from open bog and dry knoll had lower contents of all nutrients except Zn than found in the mosses.

HERBS:

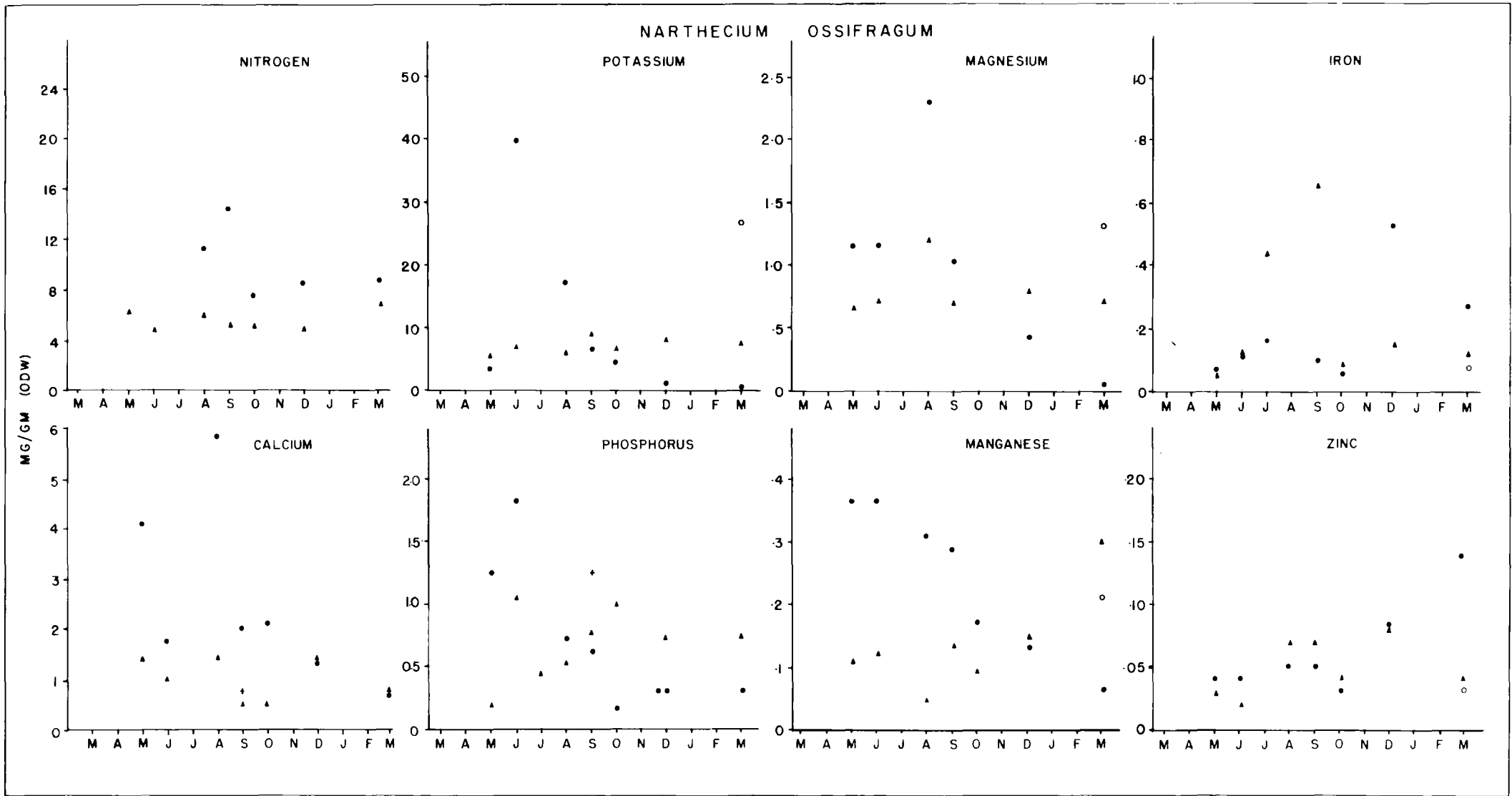
Samples of *Narthecium ossifragum* from the open bog wet variant, *Eriophorum vaginatum* from dry knoll vegetation, and *Eriophorum angustifolium* of open bog mat and open forest were analyzed. Results are presented in Figures 3-33, 3-34 and 3-35 respectively. *Narthecium ossifragum* was subdivided into above-ground leaves and below-ground roots and rhizomes. No attempt was made to subdivide leaves into live and dead components due to difficulties encountered in separation. For both *Eriophorum* species leaves were divided into live and dead, and for *Eriophorum angustifolium* samples of roots and rhizomes were also taken. Plants were not separated into size or age categories.

Nitrogen contents in the herbs were found to be highest in *Eriophorum angustifolium* plants taken early in the growing season. Values ranged from 16-25 mg/g N in both roots and live leaves. This is followed by a mid-summer drop to 12-16 mg/g in open forest and 8-12 mg/g in open bog plants. During winter high values were again recorded from both habitats. Live leaves from *Eriophorum vaginatum* had a more stable N content of 14-18 mg/g throughout. *Narthecium*

Figure 3-33. Mineral nutrient status of Narthecium ossifragum
from open bog wet variant on Moorthwaite Moss.

leaves ●

roots ▲



leaves had an increase in N during mid-summer with a drop accompanying onset of die back in late summer. The lowest N values were recorded from roots and rhizomes of Narthecium with only 5-8 mg/g. The AN on the open bog peats is very low at 0.8 - 0.9 g/m² whereas the open forest peats sampled for Eriophorum angustifolium has 2.0 - 3.0 g/m² and the dry knoll 2.0 - 8.0 g/m².

Phosphorus is high in the herbs with extremely high values in roots of Eriophorum angustifolium from the forested zones with a maximum content of 8.05 mg/g. Plants taken from the open bog mat have a greater seasonal fluctuation and a maximum of 4.73 mg/g. Both maxima were recorded in the December samples. Live leaves of Eriophorum angustifolium have a lesser P content than the roots in all but one sample. The dead leaves, however, show a rapid loss of P and contents are primarily 1.0 mg/g. Eriophorum vaginatum live leaves have a P content ranging from 1.5 to 1.8 mg/g which is considerably less than Eriophorum angustifolium. Leaves from Narthecium have their highest P concentration in early spring 1.2 - 1.8 mg/g dropping by August to 0.7 mg/g and to 0.5 mg/g in winter with loss during die back. The roots of Narthecium with more constant P content have higher values in late summer until the following spring. Generally the P contents in the herbs are similar to N with Eriophorum angustifolium having highest concentrations with Eriophorum vaginatum and Narthecium ossifragum following. The exceptionally high P values in particular herb components is of ecological importance in that P is often the deficient major nutrient on such peatland types.

Figure 3-34. Mineral nutrient contents of Eriophorum vaginatum
from dry knoll vegetation on Moorthwaite Moss.

● - live leaves

▽ - dead leaves

ERIOPHORUM VAGINATUM

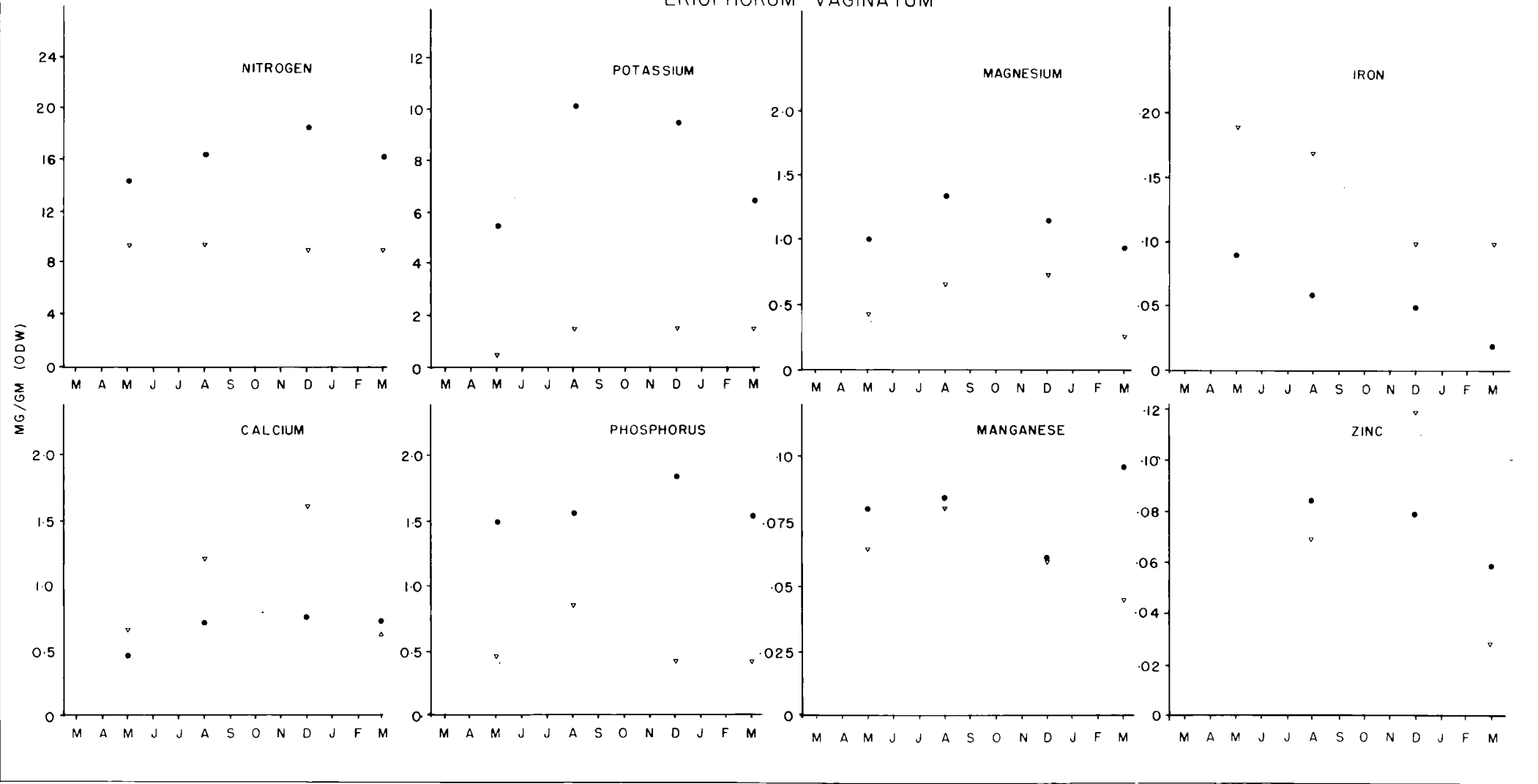
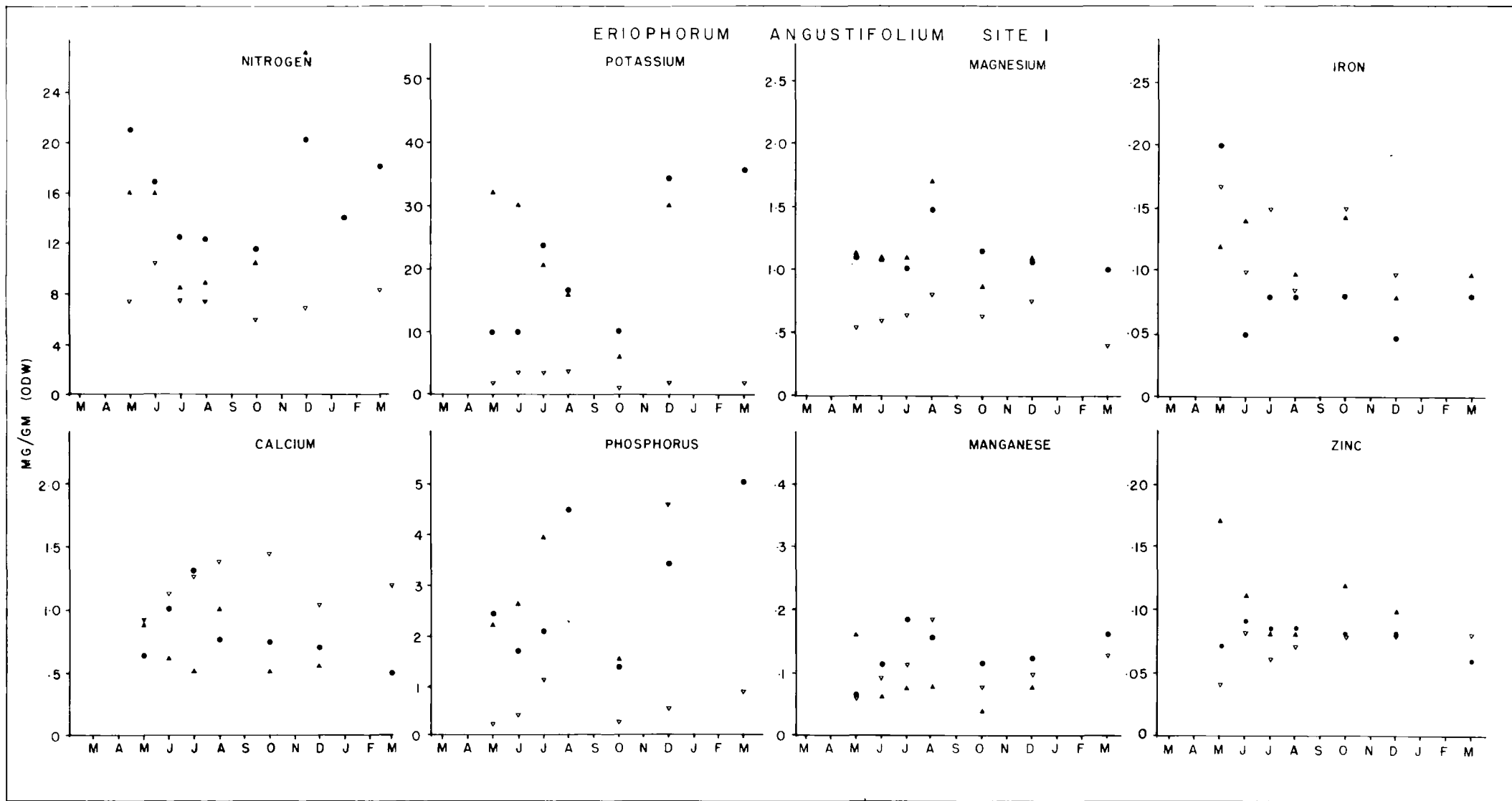


Figure 3-35. Mineral nutrient status of Eriophorum angustifolium
sampled from A: open bog and B: open forest vegetation.

- - live leaves
- ∇ - dead leaves
- ▲ - roots and rhizomes



Exceptionally high concentrations of K are present in live leaves and roots of Eriophorum angustifolium. Root K content is highest in early growing season whereas live leaves have highest values in summer and fall samples. In the dead leaves K, being easily leached from the leaves, is very low in concentrations. Maximum K contents in Eriophorum angustifolium samples were 37.0 mg/g. Eriophorum vaginatum leaves have more moderate K levels throughout the years at 5-10 mg/g. In contrast, Narthecium leaves incorporate high K in early summer, at peak growing period of 40 mg/g with a rapid decline to 1.0 mg/g toward the fall and winter. Roots and rhizomes of Narthecium have much less K on dry weight basis than its counterparts from Eriophorum angustifolium taken from nearby open bog mat with similar K contents in underlying peat substrate.

Magnesium contents are more constant in live leaf samples from all three species ranging from 0.5 - 2.4 mg/g. Little difference was found between root and live leaf samples of Eriophorum angustifolium. Highest Mg contents were recorded from Narthecium leaves in August with 2.37 mg/g. This is reflected in the AMg peat contents where the open bog wet variant has highest weight values of 0.49 mg/g compared with 0.38 mg/g in forest and 0.36 mg/g on the dry knoll. Taken on volumetric basis, however, the order of AMg content is reversed.

Eriophorum species have a Ca range of 0.4 - 1.5 mg/g with roots and rhizomes having lowest values followed by live and dead leaves. Narthecium leaves are anomalous in that the leaves have Ca content in excess of 5 mg/g during summer followed by sharp drop to more comparable levels in fall and winter samples. Manganese has a

similar distribution at 0.06 - 0.20 mg/g in Eriophorum and higher levels of 0.25 - 0.35 in Narthecium leaves during the growing season.

Fewer samples were analyzed for the heavy metals, Fe and Zn, however certain trends are indicated. Roots and rhizomes of Eriophorum angustifolium have higher Zn content than either live or dead leaves with the exception of July samples from open forest and June-July samples from open bog in which live leaves have higher concentrations. The Zn range for most samples was 0.04 - 0.15 mg/g. Narthecium roots and rhizomes as well as leaves had lower Zn contents than Eriophorum species with range 0.02 - 0.12 mg/g. Iron contents are also higher in Eriophorum roots and rhizomes than in live leaves. Narthecium, however, had the highest recorded concentration of Fe with root and rhizome and one dead leaf sample in excess of 0.4 mg/g.

SHRUBS:

Nutrient contents for the dominant shrubs on Moorthwaite are presented in Figures 3-36 (Calluna vulgaris), 3-37 (Erica tetralix), 3-38 (Vaccinium myrtillus), and 3-39 (Oxycoccus palustris). The elements N, Ca, Mn and Mg reach their highest concentrations in the leaves of Vaccinium and Oxycoccus in the summer period. Values recorded for Calluna and Erica were considerably less. Potassium is also high in Vaccinium leaves with a high of 16 mg/g in September. This value is much higher than recorded for the other shrubs. Phosphorus concentration in shrub foliar samples was highest in Erica and Calluna, however no trends were diagnosed from the data obtained.

Figure 3-36. Mineral nutrient contents within tissues of various components of Calluna vulgaris selected from Calluna dry knoll vegetation on Moorthwaite Moss.

- - leaves
- - aboveground woody parts
- ▲ - below-ground stem
- - fine roots

CALLUNA VULGARIS

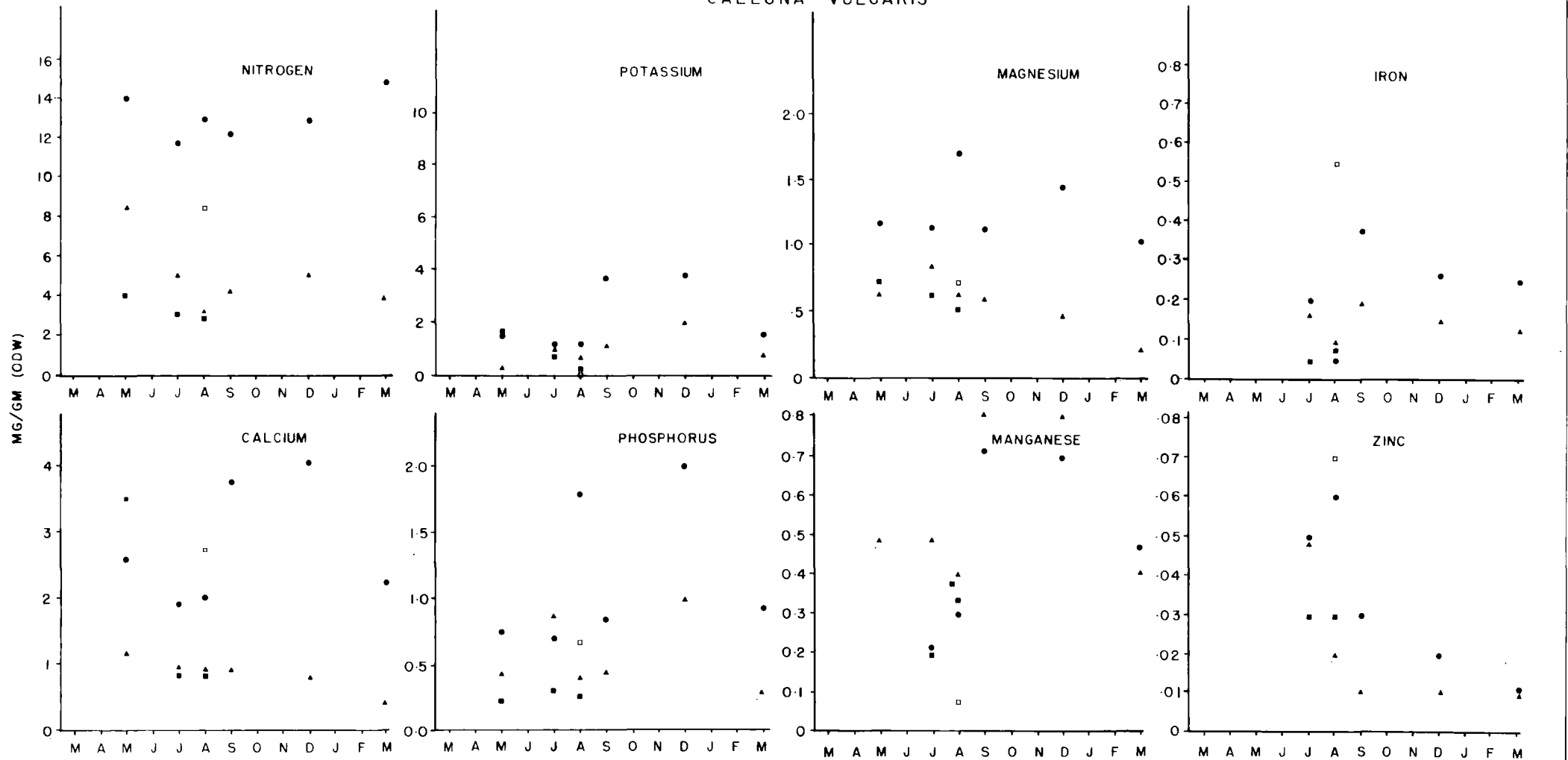


Figure 3-37. Nutrient concentrations within various components of Erica tetralix selected from closed forest understory on Moorthwaite Moss.

- - all leaves
- - new leaves only
- ▲ - woody aboveground
- △ - new branches only
- ▣ - roots

ERICA TETRALIX

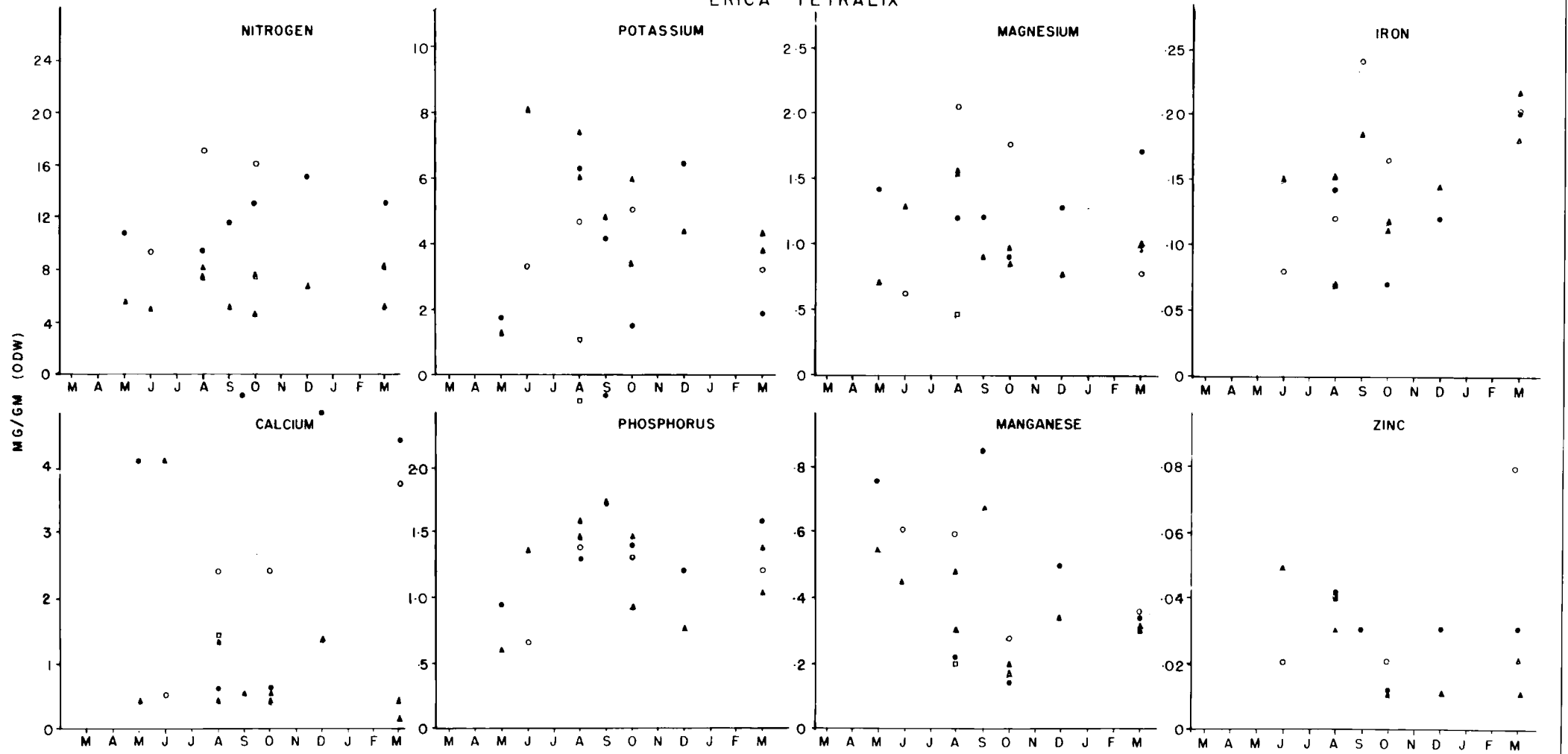


Figure 3-38. Nutrient contents within components of Vaccinium myrtillus sampled from the Vaccinium knoll vegetation on Moorthwaite Moss.

● - leaves

△ - stem and branches

▲ - roots

VACCINIUM MYRTILLUS

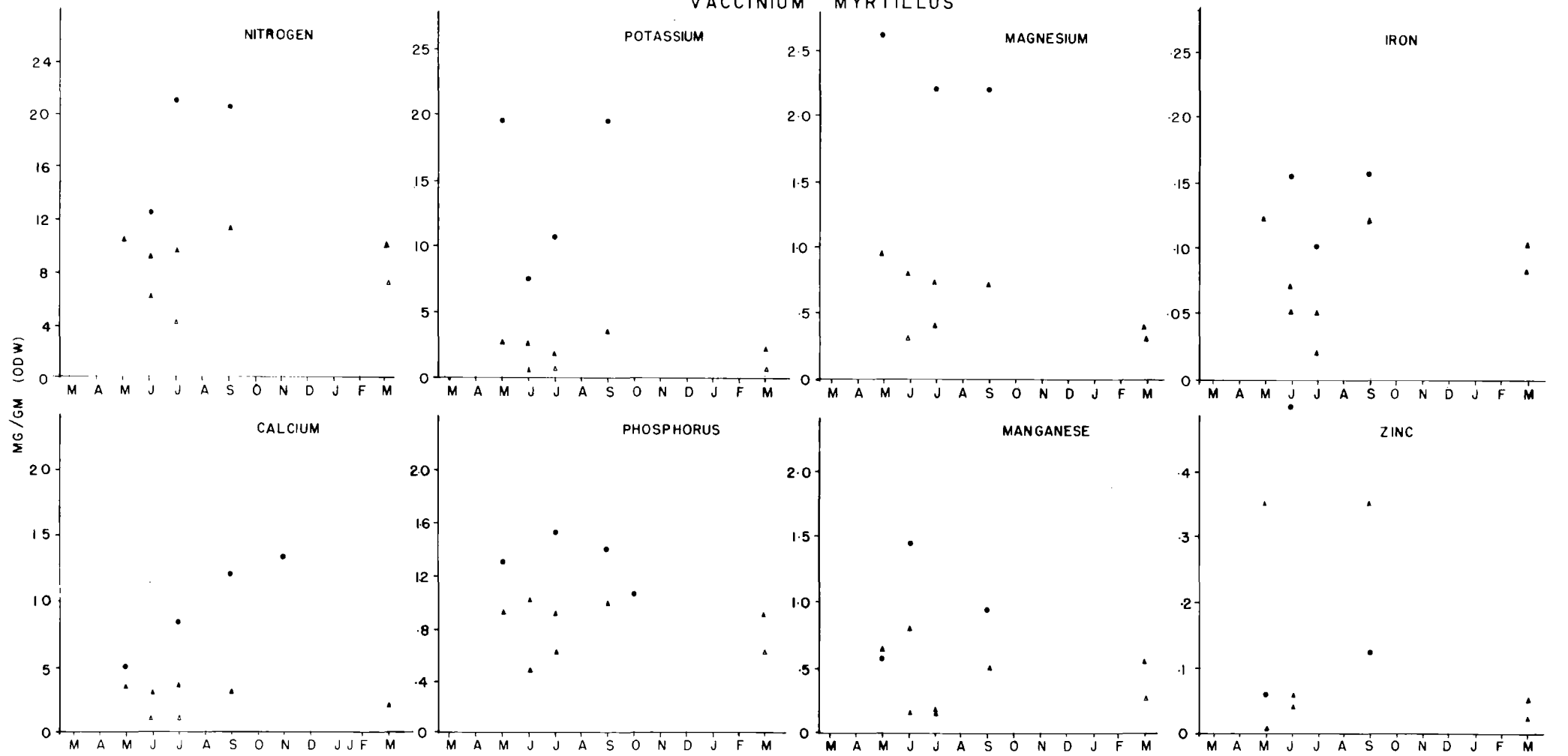


Figure 3-39. Nutrient contents in components of Oxycoccus
palustris from open bog habitats on Moorthwaite Moss.

● - leaves

▲ - woody stem and roots

The heavy metals Fe and Zn were also variable throughout the season, however Calluna vulgaris does have higher Fe concentrations than the other shrubs with concentrations of 0.52 mg/g in the August root sample and 0.33 mg/g in September leaves. In all shrubs Zn ranges from .01 to .08 mg/g.

When assessed as a group the shrubs have a higher Mn content than either the mosses or herbs. These high values have been recorded from both the wood and leaves of the plants with the leaves having the higher overall values.

Calluna vulgaris has been investigated by Aaron (1964) for mineral nutrient status because of its importance in areas of possible afforestation. The foliar contents obtained from a number of heathland sites would indicate that the Moorthwaite Calluna from the dry knoll is low in comparison of N and K but higher in P during winter with similar summer values. The graphs provided by Aaron (1964) show much less fluctuation throughout the year which is possibly indicative of more stable soil conditions in the area investigated.

PINUS SYLVESTRIS:

In Table 3-23 the mineral status of foliar samples are given for both the trees and seedlings of Pinus sylvestris selected from different vegetation units on Moorthwaite Moss. Although samples were taken in August it is recommended that foliage samples obtained during period of dormancy would be more amenable for interpretation purposes (Tamm, 1955). The tree samples were taken

Table 3-23. Nutrient content in foliage of Pinus sylvestris from selected sites on Moorthwaite Moss taken in August; all values are in mg/g.

Site	Age of tree	Age of leaves	N	P	K	Ca	Mg	Mn	Fe	Zn
Center	50	1	12.20	2.00	6.60	1.20	0.86	0.13	0.10	0.06
		2	13.10	1.40	5.20	1.40	0.97	0.32	0.37	0.06
		3	5.70	0.53	2.20	1.95	0.98	0.36	0.35	0.06
Dry knoll	50	1	13.80	1.45	6.45	1.40	1.04	0.18	0.05	0.06
		2	15.20	1.17	4.90	2.00	1.09	0.28	0.10	0.07
		3	6.10	0.67	3.30	2.20	1.05	0.30	0.15	0.07
Forest	50	1	12.20	1.52	7.80	1.70	1.10	0.22	0.05	0.06
		2	12.20	1.83	4.90	4.20	1.41	0.48	0.25	0.07
		3	10.70	0.85	3.30	4.60	1.41	0.30	0.15	0.06
Fen	40-45	1	16.30	1.94	5.50	1.60	1.09	0.14	0.10	0.05
		2	14.60	1.42	3.50	3.20	0.90	0.28	0.22	0.06
		3	10.70	1.07	3.30	3.70	0.97	0.32	0.24	0.07
Center	10	1	16.20	2.15	4.25	0.80	0.90	0.11	0.20	0.06
		2	13.80	1.34	5.50	2.20	0.82	0.22	0.12	0.11
Dry knoll	8-10	1	13.30	2.12	7.15	1.70	1.72	0.86	0.10	0.03
		2	13.20	1.03	4.25	2.30	0.92	0.15	0.05	0.04
Center (poor growth)	6-7	1	10.90	1.62	8.20	1.30	0.84	0.20	0.05	0.04
		2	8.50	0.92	6.45	3.00	0.97	0.37	0.17	0.06
Edge	5-6	1	16.30	1.94	5.50	1.60	1.09	0.14	0.10	0.05
		2	14.60	1.42	3.50	3.20	0.90	0.28	0.22	0.06
Fen	10	1	12.80	2.97	7.60	1.00	0.90	0.20	0.05	0.05
		2	10.30	1.27	4.45	2.90	0.79	0.32	0.15	0.06

from the lateral end of healthy branches near the base of the crown. Samples of seedling foliage were prepared as follows: all first and second year needles were stripped from the seedlings and separated into two samples which were ground in preparation of analysis. Tree samples were also subdivided on age.

Results show that N, P, K all decrease considerably with age of the leaves whereas Mg, Zn remain unchanged and Ca, Fe, Mn increase. Not enough samples were analyzed from each site for comparison of contents within vegetation units, however the range of values for each nutrient was of little difference. Tree growth on the site is moderate to good near the borders with mostly poor to moderate tree growth in the open forest areas. Nitrogen values of one year old leaves range from 10-17 mg/g which is comparable to results published for Pinus sylvestris from rather poor, but fertilized sites (Binns, 1959; Brown et al. 1964). The P contents range from 1.42 - 2.00 mg/g in older trees and 1.62 - 2.97 mg/g in seedlings which is indicative of a good P supply in the substrate; the nutrient deficiency symptoms for P become evident between 0.6 - 1.0 mg/g P (Carlisle and Brown, 1968). Similarly K ranges from 4.25 - 8.20 mg/g which is also above deficiency levels given at 3-4 mg/g K. These values exceed values of 2.5 - 5.7 mg/g K recorded by Brown et al. (1964) for Pinus sylvestris on afforested blanket peat. Holmen (1964) gives values ranging from 3.0 - 6.9 mg/g K for leaves of Pinus sylvestris from a number of afforested peatland sites in Sweden. Porgasaar (1965) reported the following values for N, P, K for a number of site types (given in mg/g).

	N	P	K
Calluna type	15	1.5	5.6
Vaccinium type	18	1.6	6.8
Old arable land	19	2.2	8.0
Raised bog	13	1.3	6.4

The other nutrients Ca, Mg are similar in concentration to that recorded by Holmen (1964), however Mn, Fe and Zn are all in higher concentration on Moorthwaite than Pinus sylvestris on blanket peats (Brown et al. 1964). Little difference was found between older trees and young seedlings in terms of mineral nutrient contents.

DISCUSSION:

A survey of the mineral nutrient status of the plant species comprising the ombrotrophic vegetation on Moorthwaite Moss indicates that the major plant groups, mosses, herbs and shrubs differ greatly in their demands on certain nutrients and affect the distribution of such nutrients within the ecosystem. In Tables 3-8 and 3-9 the nutrient contents of the peats are given as well as other physical and chemical characteristics. It was found that the total contents of many elements are similar to those recorded from similar ombrotrophic peats, however the available fractions were higher.

Nutrient distributions show that N content in the ombrotrophic zone is least in the Sphagna and other mosses, high in the Eriophorum species, low in Narthecium in the herb layer, low in Calluna, moderate in Erica, high in Vaccinium and Oxycoccus and moderate in Pinus. Overall the N content is not high because of the

lack of mineralization in the peat soils and the tie-up of N in the mor peats of the dry knoll. Phosphorus is relatively low in mosses and shrubs but is exceptionally high in Eriophorum angustifolium with values up to 8.05 mg/g. Both the above- and below-ground parts have high P contents in this species and although it is not a dominant in terms of dry matter production, it can have an important influence on the site production because of the tie-up of the nutrient which is most commonly deficient in peat soils.

Eriophorum angustifolium plants in the closed forest and forest vegetation can reach very large size on Moorthwaite which may in part be attributed to the P supply. In addition to Eriophorum, the Pinus sylvestris seedlings have high P foliar contents which also indicates the relative abundance of the element in available form. This is an anomalous condition on ombrotrophic peat soils which may be attributed to the addition of P and PK fertilizers from surrounding farmland either through wind or drainage activity.

Potassium deficiencies have also been reported from foliage analysis of plants from peat soils. The herbs can also tie-up large amounts of K during the growing season with values recorded in excess of 35 mg/g K for Eriophorum angustifolium and Narthecium leaves. Similar occurrences of large amounts of K have been reported by Siccama et al. (1970). Throughout the vegetation K is fairly abundant indicating no present deficiency of the element. This may also be due to slight eutrophication from surrounding farmland.

Calcium is least in the mosses and herbs with exception of Narthecium ossifragum leaves from which high Ca contents are evident, up to 5.9 mg/g during summer months. As expected Ca is high in

shrubs with highest recorded values for whole area found in Vaccinium (12.25 mg/g) and Oxycoccus (10.25 mg/g) leaves.

Magnesium follows the Ca pattern with highest values in Narthecium and Vaccinium leaves.

Manganese is low in mosses and herbs, high in woody plants. The Mn contents are also highest in the Vaccinium and Oxycoccus leaves. The heavy metals assessed were Fe and Zn of which Fe is most concentrated in the tissues of the mosses and again in Narthecium leaves. Zinc is fairly evenly distributed throughout with slightly higher contents in the Narthecium leaves, 0.13 mg/g, and Eriophorum angustifolium roots (0.17 mg/g).

In both moss segments and leaves of Pinus sylvestris the new growth had higher concentrations of most nutrients. Leaves older than three years were rarely occurring on trees in the open centre and dry knoll and when analyzed were found to retain only small quantities of N, P, K. Trees nearer the edge of the site and in the forest did have few four-year-old leaves and the three-year-old leaves analyzed retained more NPK on dry weight basis than did trees in more ombrotrophic sites.

Nutrient contents in the substrate are reflected in the results obtained from moss analysis. Sphagnum recurvum especially can be used as a site indicator of nutrient status exhibiting a sensitivity for adsorption with respect to available fraction of each nutrient. One important trend however is seasonal fluctuation of nutrients within plant tissues, not only of mosses but also in herbs and shrubs. For comparative studies of nutrient contents among species or of species in habitat the samples must be taken at the

same period in the growing season. The hydrological conditions and pH factor probably accentuate this factor in peatland vegetation.

Moorthwaite Moss is possibly influenced by eutrophication from surrounding farms from which both P and K are added to the site. Despite this added nutrient no species was found in the ombrotrophic zone which would indicate more nutrient-rich conditions and on basis of present species composition this portion of the site could still be classified as ombrotrophic bog.

SECTION 4

SUMMARY AND CONCLUSIONS

INTRODUCTION

This work involves a series of investigations on communities and individual species performance in boreal peatlands. Emphasis has been placed on particular aspects of site classification using qualitative phytosociological methods backed by quantitative measure of chemical and physical site parameters. In addition, an effort has been made to assess individual species production on bog and to provide insight into nutrient distribution throughout the moss, shrub and herb layers comprised of these species.

PEATLAND CLASSIFICATION:

(1) The needs for peatland classification in North America are many: required in biophysical land classifications of northern regions; little known of their ecology; recent development of northern regions; sheer amount of peatland, 500,000 sq. miles in Canada, 2,000,000 ha in Newfoundland.

(2) Two of the major problems confronting peatland ecologists are terminology and selection of classificatory technique. The existing classifications may be grouped into three basic approaches: morphological, phytosociological and ecological. These approaches are not specifically related to schools of thought, but rather refer to the particular level of investigation. For example, in a morphological context, peatlands are classified into formations based on combination of landform and vegetation, Cajander's 'moorkomplextypen', Du Rietz' 'bog-fen',

Tansley's 'raised-blanket bog'. Phytosociological subunits make up the larger morphological units. This phytosociological approach provides understanding of vegetational composition and distribution, as well as vegetation-site relationships. The ecological approach aligns peatland types along environmental gradients, primarily gradients dependent on nutritional or hydrological substrata characteristics. Such investigations provide information lending to aut- and synecological understanding of species and species groups. Also, ecological studies can increase understanding of the mechanics of geomorphological influences on peatland sites.

(3) The Z-M techniques have been used to classify peatlands in central Newfoundland with derived units placed within an ecological framework as suggested by Du Rietz (1954), and are categorized as ombrotrophic, weakly minerotrophic or euminerotrophic. Furthermore, the units have been typed as bog, fen or marsh. Thus the study has encompassed elements of the three basic approaches.

(4) Twelve peatland associations were detected in the study region comprising a variety of bog and fen types. By comparison with results of other surveys, it was concluded that the central Newfoundland peatlands do reflect more continental conditions than do other peatlands in Newfoundland with a climatic restriction of *Kersni* highmoor (*Kalmiето-Sphagnetum fusci*) and fen hummock (*Calamagrostiето-Sphagnetum fusci*) associations to this region. Unlike the more oceanic vegetation, central Newfoundland peatlands can be classified as fen or bog with suitable indicator species in either category. Oceanic

peatlands, influenced by higher precipitation and drainage from poor upland soils offer no easy division of bog and fen.

(5) A comparison of data with that reported from Fennoscandia surveys indicate a similarity between peatland formations described from Southwest Sweden and those of central Newfoundland. The use of the Uppsala methodology in Swedish surveys did not detract from such comparison between associations and Du Rietz' alliances.

(6) There are four major associations, in terms of areal extent, in central Newfoundland: the Kalmiето-Sphagnetum fusci (raised bog); Vacciniето-Cladoniетum boryi (exposed blanket bog); Scirpiето-Sphagnetum papilloси (poor fens); and the Potentilleето-Campyliетum stellatae (rich fens). These peatland types occur throughout the Island, although rare in coastal and high altitude regions. For forestry utilization only these four associations need be considered.

(7) To assist researchers in field identification of associations, a key has been devised based on presence or absence of only 22 species. This key should prove useful for foresters and other applied researchers.

(8) It is suggested that peatland classification in Canada should, at present, be kept at the association level with synthesis subject to attainment of adequate field records. This will avoid the necessity of changing poorly contrived hierarchical units at alliance, or above levels in the future.

(9) To both enhance and substantiate the proposed vegetation units for central Newfoundland, their peat substrata were sampled and analysed to determine physical and chemical properties. Peat soils

were identified relevant to botanic constituents, e.g. Sphagnum, sedge or woody. Measurement of physical factors showed that bulk density, water content and decomposition could be used, with success, as diagnostic criteria for separation of nutrient poor and nutrient rich peats (Table 2-17). Similarly, pH varied with range of 3.2-4.0 in bog peat and 3.8-6.5 in fen peat. However, a more definitive division of peat soils, relative to corresponding vegetation, was based on nutrient concentrations, both for total and available fractions. The nutrients N, P, K, Ca, Mg, Mn, Na, Fe, Zn were assessed and a high correlation was established for N, Ca, Fe, Mn as well as for available Ca.

(10) Available P is higher in poor peat soils than in fens which may in part be attributed to the fixing of P as iron and aluminum phosphates. The Fe contents in the Newfoundland fens are extremely high due to the abundance of iron leached from upland podzols and deposited into the peats by soligenous waters.

(11) The fen hummocks, Calamagrostiето-Sphagnetum_fusci, were found to be sharply subdivided, based on nutrient contents, into higher hummocks, comprising the subassociation Kalmietosum and into the lower hummocks of the Typicum. The former was considered to be weakly minerotrophic whereas the Typicum was euminerotrophic. The association Eriocauletum_septangulare, although found only in fen pools of eutrophic sites, were categorized as weakly minerotrophic on basis of nutrient content of underlying peats.

(12) An assessment of peatlands in central Newfoundland for afforestation purposes revealed that only two associations, the Scirpieto-Sphagnetum papillosoi and the Potentilieto-Campylietum stellatae were of sufficient area and richness to economically support afforestation programs. It is recommended that criteria be established for mapping these fen varieties using aerial photography. Furthermore, in Newfoundland, where agricultural land is limited, such areas could be utilized for forage and vegetable crops.

(13) This classification of interior peatlands and analysis of their related peat characteristics is the first step in an extensive land-use program designed to evaluate Newfoundland's peatland resource. Newfoundland is ideally suited for peatland ecological sites with large areas of virgin bog and fen comprised of many varieties. However, efforts must be made to set aside examples of each peatland type for future undestructive research. Without doubt, in the near future, this resource will be subject to heavy industrial pressures and once set to plough it will be forever gone.

PRODUCTION AND MINERAL NUTRIENT STUDIES IN PEATLAND COMMUNITIES:

(1) The Z-M methods were successfully used in classifying peatlands in central Newfoundland. In a modified way these methods were used to delineate vegetation units on one particular bog, Moorthwaite Moss, in northwest England. This site had undergone an hydroseral development and at present is heavily forested near the edges with decreasing density of trees (Pinus sylvestris) toward the centre, where a small open bog persists.

(2) The vegetation units were established for purpose of providing basic units in productivity and mineral nutrient studies. Using a combination of phytosociologic and physiognomic criteria, six vegetation units were determined: open bog, dry knoll, open forest, closed forest which make up the 'ombrotrophic' zone, and the soligenous and marginal fens of the 'minerotrophic' zone. Emphasis of investigation was placed on the ombrotrophic zone, which was subsequently classified as the association Erico-Sphagnetum magellanicum.

(3) Both physical and chemical peat properties were examined. It was found that bulk density, decomposition, water content and pH could be adequately utilized for separation of peat types. For example, mor peat soil of dry knoll was most acidic, 2.9, whereas the mor soil underlying Erica tetralix communities had a pH of 3.15-3.31. By comparison Vaccinium knoll peat (3.30), open bog Sphagnum peat (3.45-3.78), marginal fen (4.10-4.30) and soligenous fen (4.72-5.10) followed suit.

(4) Nutrient contents of peat are given in weight and volumetric measure, however, recorded values did not provide clear-cut criteria for peat classification, with possible exception of calcium. The distributions of N, P, K, Ca, Mg, Mn, Na, Fe, Zn are discussed and where possible, patterns of distribution are explained. In general, the total nutrient contents of the Moorthwaite peats are low, in comparison with similar peats in Newfoundland, however, the available nutrient contents are mostly higher.

(5) The initial aim of production analysis was to estimate and compare community net annual increments of the major vegetation units. This, however, was not completed because of large error factors introduced by the use of available methods. Thus the studies in site productivity were limited to determination of plant biomass in each unit, and where possible, the determination of net annual production for particular species. The standing crops and biomass were obtained from 7 vegetation types and the percentage biomass input per individual species was calculated. Estimates of biomass ranged from a low of 862 g/m² in Sphagnum communities to 3114 g/m² in the Calluna heath. The tree layer was excluded from the estimates, however, dry matter estimates for the trees were also calculated with a range in value from nil in open bog plots to 307 g/m² (mean 135.3 g/m²). By comparison, tree layer in open forest had a mean of 1738 g/m² and in closed forest plots, 8391 g/m². It was found that most vegetation units had a single species contributing more than 50% of total biomass. In communities dominated by ericads, Calluna contributes 75% of biomass, Erica, 85%, and Vaccinium, 80%, respectively.

(6) Dry matter production was determined, during one growing season, for the six mosses dominant in various vegetation types; these were: Sphagnum recurvum, Sphagnum magellanicum, Sphagnum palustre, Sphagnum rubellum, Pleurozium schreberi, and Aulacomnium palustre. In addition, rough estimates of net annual production were calculated for Eriophorum angustifolium and Narthecium ossifragum. Shrubs included in the analysis are Calluna vulgaris, Erica tetralix and Vaccinium angustifolium.

(7) Sphagnum recurvum plants were sampled throughout the season from four populations, each representative of a particular vegetation. Results showed that the species differed in growth performance in each habitat. Plants from infilled pools and Sphagnum lawn had greatest length and weight increase followed by dry knoll and marginal fen plants. Mean length increase ranged from 3.5-7.5 cm and mean weight from 18.0-36.0 mg per individual plant. On an area basis dry matter input was 2-6 g/dm² for Sphagnum recurvum populations. Other Sphagna increments ranged from 1.6-4.6 cm in length and 5.1-36.0 mg in weight per plant. Comparatively, Pleurozium populations had mean annual increments of 2.9-3.3 cm and 9.0-9.6 mg per plant and for Aulacomnium plants from a single sample site, 2.2 cm and 4.4 mg. On an area basis the mosses, other than Sphagnum recurvum, had a net annual production between 2.0 g/dm² and 3.6 g/dm². It was concluded that the method used, Clymo (1970), although both tedious and time consuming, can yield rather accurate estimates of net annual production for Sphagnum populations. These estimates, however, should not be used to provide 'guesstimates' for larger areas such as m² or larger units because of variation in moss populations, in composition and density of individuals, over relatively small distances.

(8) Herb and shrub species on Moorthwaite offered difficulties in assessing their net annual production because of their modes of reproduction, growth form and distributions. Nevertheless, an estimate of net annual production was determined for Narthecium ossifragum, 70g/m² within the Narthecium variant. Eriophorum angustifolium, occupying most habitats on the site, had a net annual production of 60 g/m² in open bog and of 30 g/m² in forest populations.

(9) Allometric equations were calculated and utilized to determine dry matter production for Calluna, Erica tetralix and Vaccinium myrtillus. The Calluna heath, occupying the dry knoll, had a predicted biomass of 1156 ± 536 g/m² and an actual biomass of 1400 g/m². Net production was 240 ± 92 g/m². Calluna performance is influenced by increased shade with a drop in net annual production to 114 ± 39 g/m² in the open forest understory. Similarly in areas of wet soil on open bog, Calluna produced only 27 ± 20 g/m². In the shaded forest Erica reaches its optimum with production of 70 ± 39 g/m², however, it declines rapidly in open competition on dry knoll to 11 ± 6 g/m² and in open wet bog to 2-7 g/m². Vaccinium myrtillus is also dominant in only one vegetation type in which it produces 160 ± 61 g/m². Elsewhere, Vaccinium is of minor importance producing only 6.7 ± 8.1 g/m² in the forest understory. On the open bog sites, Oxycoccus palustris is the most important shrub, however, no adequate sampling method could be devised to estimate its production. Biomass estimates, however, showed that Oxycoccus contributed 7-15% of the total in Sphagnum communities.

(10) The tree layer, dominated by Pinus sylvestris, has a stand density ranging from 1-30 on open bog, 40-150 in open forest, and 140-240 stems/1/10 ha in closed forest plots. In contrast, the pine seedlings had a density of 120-1600 stems/1/10 ha on open bog diminishing to no viable seedlings in closed forest. However, Betula pubescens seedlings were often present in the closed forest understory. The growth performance of the tree layer and evident seedling regeneration in open sites indicate that Moorthwaite is still in a

dynamic growth phase which in the next 20 years will possibly result in complete forest cover development. The pine seedlings, occupying the centre range in age from 1-12 years indicating that seedbed conditions have been favorable in recent years.

(11) In association with productivity analysis, the nutrient contents of plant tissues, in particular from species previously assessed, were determined. These nutrients include N, P, K, Ca, Mg, Mn, Na, Fe, Zn.

(12) The first nutrient analysis was conducted on the moss species with a comparison made between new and old segments. The new segments had higher N, P, K and Mg and lower Ca, Mn, Fe than did older segments. In addition, it was noted that segments from fen plants had consistently higher concentrations of N, P and K.

(13) It was found that nutrient contents varied considerably throughout the season, even in the same plant part. This was partially attributed to change in hydrological conditions of the substrata throughout the growing season. Sphagnum recurvum was analysed from five locations, adding closed forest to the existing four locations used in production studies. Both fen and closed forest plants had higher nutrient concentration in comparison to Sphagnum recurvum plants from open bog and dry knoll. Seasonal differences were also greater in the fen and forest plants. This fluctuation possibly was a result of an influx of nutrients from overhead canopy, through litter fall and leaching. In support of this, the March nutrient contents indicated little variation associated with habitat. This observation was also true for other mosses in the ground layer. Another noticeable trend in nutrient analysis of mosses was that Aulacomnium palustre

contained higher P, Mn and Ca than *Sphagna* from similar sites, whereas *Cladonia impexa* had lower contents of all nutrients except Zn.

(14) Analysis of nutrient content in herbaceous plants indicated their particular importance in P distribution and cycling. Extremely high P values were recorded from winter samples of *Eriophorum angustifolium*. This is followed by a rapid loss in P throughout late winter and spring. Potassium is also high in *Eriophorum* and in *Narthecium* during growing season, however, K is easily leached out of the plant tissues with die-back. *Narthecium* is also an important species, with respect to Ca and Mn, which occurs in high concentrations.

(15) In the shrub species N, Ca, Mn and Mg are greatest in *Vaccinium myrtillus* and *Oxycoccus palustris*. Potassium is highest in *Vaccinium* leaves whereas P is more heavily concentrated in new growth of *Calluna* and *Erica tetralix*. Iron is high in *Calluna* woody parts.

(16) An analysis was also made for nutrient content in *Pinus sylvestris* leaves, which showed N, P, K to be greatest in new leaves. The older leaves had higher Ca, Fe and Mn content. Analyses obtained from other surveys showed that the nutrient contents of the pine leaves on Moorthwaite were rather high in comparison to those from other peat sites.

(17) Over all, there are definite nutrient preferences demonstrated by the moss, herb and shrub plants. For the mosses there is a relationship between plant tissue and underlying peat nutrient concentration, however, this is not always reflected in growth

performance. For example, Sphagnum recurvum has greatest increment of length and weight in the infilled pool, but is underlain by nutrient poor peat. Conversely, although on a richer substrate, the fen Sphagnum plants have small recorded growth increment. The difference in nutrient uptake is reflected in the weight/unit length for the plants with 3.80 mg/cm recorded for the pool plants and 5.10 mg/cm in fen plants.

(18) Although a measure of individual species performance was obtained, for selected dominants on Moorthwaite Moss, it was not feasible to determine community production or nutrient stores because of limitations imposed by the techniques used. This and other limitations of technique are discussed in the text, indicating a need for the development of field production methods suitable for meeting such work requirements in peatland ecosystems.

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APPENDIX I

KEY TO PEATLAND ASSOCIATIONS
IN CENTRAL NEWFOUNDLAND

For use of this key in the field an area not less than 5 sq m or greater than 15 sq m should be chosen in vegetation which appears uniform.

1. Are 2 or more of the following species present?

Ledum groenlandicum, Sphagnum fuscum, Rubus chamaemorus

Yes - go to 3

No - go to 2

2. Are 3 or more of the following 5 species present?

Sphagnum pulchrum, S. papillosum, S. magellanicum,
Mylia anomala, Polytrichum strictum

Yes - Scirpieto-Sphagnetum papillosum

(Mesotrophic bog)

No - go to 6

3. Are 2 or more of the following 3 species present?

Vaccinium vitis-idaea var minus, Vaccinium uliginosum
var alpinum, Cladonia boryi

Yes - Vaccinieto-Cladonietum boryi

(Coastal blanket bog)

No - go to 4

4. Is Kalmia angustifolia present?

Yes - go to 5

No - CalamagrostietSphagnetumfusci
(Ombrotrophic hummocks usually in
rich eutrophic fen)

5. Are Calamagrostis inexpansa or Lonicera villosa present?

Yes - CalamagrostietoSphagnetumfusci
(Ombrotrophic hummocks in mesotrophic fen)

No - KalmietSphagnetumfusci (dwarf shrub or
oligotrophic bog)

6. Is Eriocaulon septangulare present?

Yes - Eriocauletumseptangulare (fen pools)

No - go to 7

7. Are 2 or more of the following 3 species present?

Droseraintermedia, Lycopodiuminundatum, Sphagnum
pylaesii

Yes - LycopodietSphagnetumpylaesii
(submerged areas of fen)

No - go to 8

8. Is Campylium stellatum present?

Yes - go to 9

No - go to 10

9. Are either Potentilla fruticosa or Scirpus cespitosus present

Yes - Potentillieto-Campylietum stellatae
(rich fen)

No - Betuleto-Campylietum stellatae (poor fen)

10. Is Carex rostrata present?

Yes - Myricieto-Caricetum rostratae (marsh)

No - go to 11

11. Are Carex exilis and C. livida both present?

Yes - Caricieto-Droseretum intermediae (wet fen)

No - go to 12

12. Carex exilis present - Caricetum exilis (open poor fen)

Carex livida present - Caricetum lividae (open rich fen)

This key is only for the central Newfoundland area and will be extended for other parts of the Island as data become available.

APPENDIX II

METHODS

Throughout the text the methods used are only discussed in full where it is thought necessary to aid the understanding of the reader and enhance the flow of the thesis. Technical accounts of methods referred to, but not given, are elaborated in this section. The methods are arranged according to their incorporation in the text.

SITE SELECTION:

Selection of sample sites in central Newfoundland was made following investigation of Department of Mines and Technical Survey topographic maps of the area at scales 1:50,000 and 1:250,000. Aerial photographs from government and industrial sources were obtained with complete aerial coverage at 1:50,000 and 1:15,840, in addition 1:12,000 photos were available for a limited area. Aerial photography was also flown to provide further information of community distributions in one representative area using Infrared Aero Film, Type 8443; Ektachrome high speed daylight, Type 5257 for color and Pan X for black and white. This was conducted on a 1:10,000 scale. The aerial photographs were also used in the field as maps to determine means of accessibility in more difficult terrain.

PHYTOSOCIOLOGICAL METHODS:

Z-M METHODOLOGY:

Detailed accounts of the Z-M school are provided by Poore (1955), Becking (1957), Ellenberg (1956), Damman (1964), O'Sullivan (1966), and Bridgewater (1970). For the benefit of the

North American reader not familiar with the method the following summary is provided, closely following the format of O'Sullivan (1966).

Stands of vegetation are sought for description which are considered to be homogenous with regard to their physiognomy and ecology or as stated by Braun Blanquet (1951) "uniform especially in relation to floristic make-up which in turn will decide the physiognomy of the community". The stand should also be uniform with regard to relief and soil conditions insofar as possible to judge in the field. Because of the peculiar nature of hydrological and mineral regimes as well as other natural phenomena in peatlands sharp changes occur in the vegetation, which allow successful application of the classificatory approach. Two qualitative characteristics of each stand assessed by ocular estimate are cover abundance and sociability (Table 5-1). The inclusion of a sociability number for each species is important as it gives a more complete picture of the community structure and of the communal organization of the vegetation.

Table 5-1. The Braun-Blanquet scale for phytosociological description of plant community.

Cover Abundance	Sociability
r(or) 1st - 1 plant	1 - single stem or shoot
x(or) + - sparse, very low cover	2 - small tuft (or) loose tussocks
1 - common small cover	3 - small patches or carpets
2 - 5-25% cover (or) low cover but high numbers	4 - extensive patches or carpets
3 - 25-50%, any no. of individuals	5 - plants in great crowds giving complete dominance
4 - 50-75%, any no. of individuals	
5 - 75-100%, any no. of individuals	
(+) - occur just outside record area	

The size of the area chosen is determined by a 'minimal area' measurement which is made for distinct vegetation types (Ellenberg, 1956). This 'minimal area' is found by recording the number of species in a small (usually $\frac{1}{4} \times \frac{1}{4}$ m sq.) quadrat and then doubling this in size, until the number of new species recorded is negligible. For this investigation 'minimal areas' were determined on four physiognomical vegetation types, ombrotrophic bog, mesotrophic bog, mesotrophic fen and ombrotrophic hummock within mesotrophic fen (Figure 5-1). In the latter there is a levelling off at 1 m sq. followed by a sharp rise after 2 m sq. indicating that a new community has been encountered. In addition to cover abundance and sociability the following factors were recorded: percentage of vascular plants, percentage cover of moss layer, slope, altitude and any other pertinent ecological information (e.g. position of water table, etc.).

All site descriptions (termed lists, releves or aufname) obtained during analysis are then synthesized. First step is to enter lists into a 'raw' table from which lists are manipulated to delineate the potential differential species. Such species are either "mutually inclusive" or "mutually exclusive". Following sorting a clean clear-cut table is presented showing the communities obtained. For further elaboration on sorting see Bridgewater (1970) and Moore et al. (1970).

The vegetational units derived from the synthesis are then placed into a hierarchy. The terms referring to class, order, alliance, etc. are an integral part of this hierarchical system of plant community classification proposed by Braun-Blanquet (1921) and

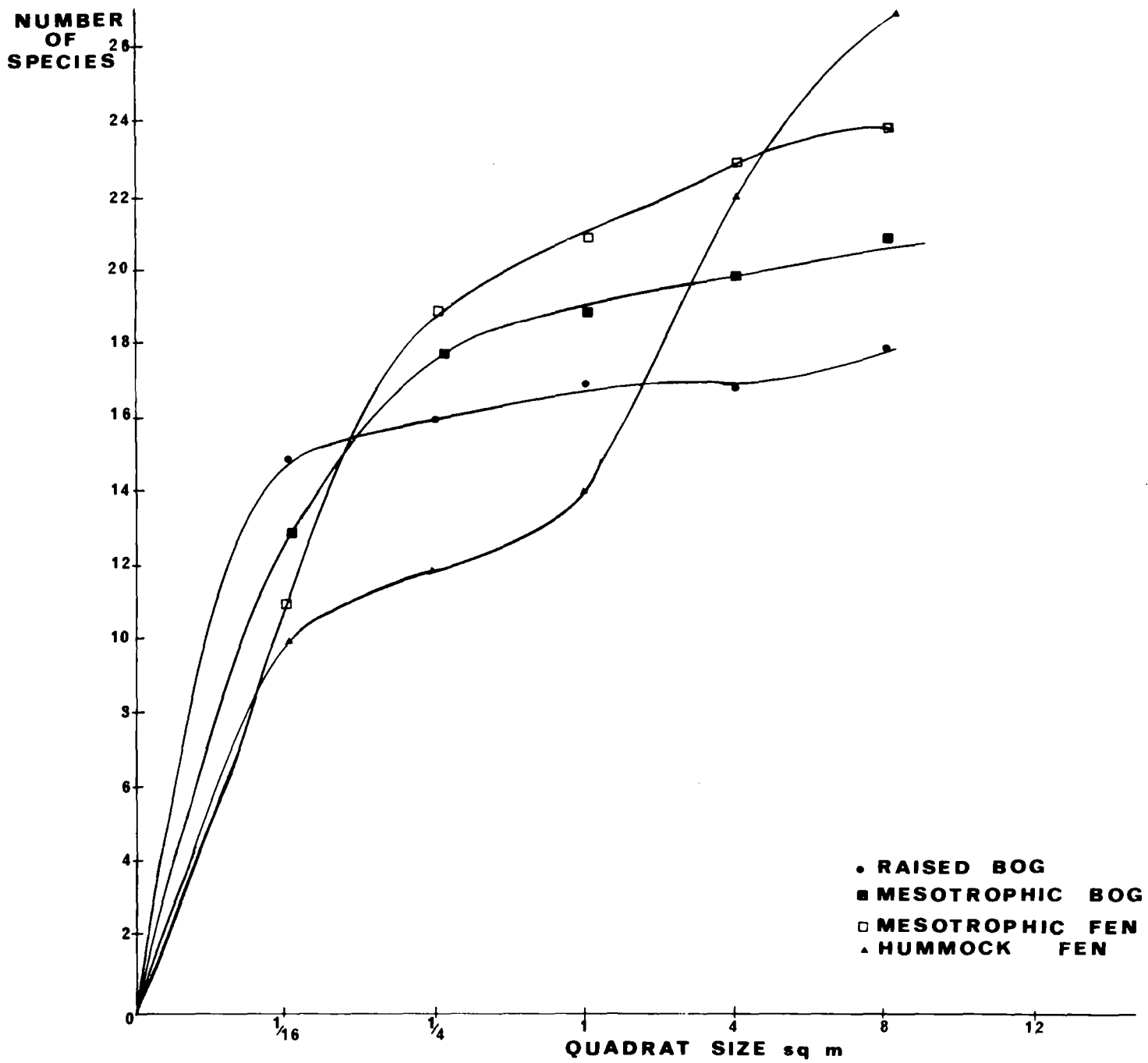


Figure 5-1 Minimal area graphs for basic sociological units.

now widely used throughout the world, especially in Europe. In the example used the units referred to are not necessarily true because there is not, as yet, any established system for North America.

Rank of the community within the hierarchy is denoted by the endings given to community names. For example:

<u>Rank</u>	<u>Ending</u>	
Class	-etea	Oxycocco-Sphagnetea
Order	-etalia	Sphagnetalia magellanici
Alliance	-ion	Kalmieto-Sphagnion
Association	-etum	Vaccinieto-Cladonietum boryi
Subassociation	-etosum	Scirpetosum
Variant	no ending	Empetrum nigrum

The rank ending is added on to the genitive stem of the second genus in the name or to the first where only one genus occurs.

e.g.

Kalmieto-Sphagnion	2 genera
Kalmietion	1 genus

If the generic name of the plant designating the community is not precise for the naming of the community then the species denotation is included in the genitive ----

e.g.

Calamagrostieto-Sphagnetum fusci

Rules for the naming of plant communities of all ranks have been published (Bach, Knoch and Moor, 1962). One important guideline is that "for the naming of an association or a higher unit no more than two plants should be employed".

GROUP ANALYSIS:

Group analysis was used in the Moorthwaite Moss investigation using methods of Crawford and Wishart (1967).

PEAT ANALYSES (PHYSICAL):

(i) Bulk density

A peat sample was taken from the designated peat layer by a sharpened peat shovel. This sample was then sectioned with a knife to obtain a block 100 mm³. The sample was wrapped with airtight plastic and taken to the laboratory where the fresh weight was determined. The sample was dried at 105 C for 24 hours and dry weights were determined. Bulk density was then computed by dividing the dry weight by the constant volume and expressed in g/cc.

(ii) Water content

Water contents of the peat types were determined from the peat samples used for bulk density and was computed as percent of the fresh weight. Water content was also determined for smaller fresh samples by means of an Ohaus Moisture Determination Meter.

(iii) Humification

The degree of humification (decomposition) is determined by use of the von Post (1924) method using the H1-10 scale (Table 5-2). A small peat sample from a known layer is taken into the hand and squeezed. The humification rating is then assigned through use of the table below:

(iv) Peat types

Peat types are named according to the macroscopic fossil remains occurring in each layer. The following symbols of standard use are given:

- Sph - Sphagnum peat (a relatively undecomposed peat comprised mainly of Sphagnum remains);
- Se - Sedge peat (made up primarily of Scirpus, Eriophorum or Carex remains; usually more decomposed than Sphagnum peat);
- W - Woody peat (remains of ericaceous woody shrubs such as Vaccinium, Kalmia, Ledum, Chamaedaphne and Andromeda).

Samples used in stratigraphical investigations were obtained from deeper layers by means of a Hillier peat borer.

PEAT AND PLANT ANALYSES (CHEMICAL)

All peat samples taken for chemical analyses were restricted to the upper 30 cm. A sharpened peat shovel was used to obtain a peat block which was sectioned with a knife into three samples representing the 0-10 cm, 10-20 cm and 20-30 cm layers. All samples were numbered serially with relevés, placed in plastic bags and transported to the refrigeration rooms at the laboratory. Each sample was subsequently separated on a paper tray to facilitate air drying and placed in air-flow cabinets (Nfld.) or oven (Britain) and dried at 85°C for 48 hours. The peats were then grounded through a 1 mm sieve in a Wiley Mill (No. 3) grinder, assigned laboratory numbers and stored in pint containers. These samples were then ready for analyses.

Plant sampling varied according to species and is elaborated further in this section. Once the samples were obtained, however, they were treated similarly in preparation for chemical analyses. The plants were drier at 85°C, ground in a small grinding mill, which was

Table 5-2. Method of determination of humification of raw peat samples (from von Post, 1924).

Humifi- cation scale	Evidence of degree of composition	Plant structure	Mud present	Upon squeezing through fingers		
				Water passing	Amt. of peat substance passing	Residue
1	nil	-	nil	Yes, clear & colorless	-	-
2	almost nil	-	nil	Yes, clear but yellow brown	-	-
3	very little	-	little	Yes, distinctly turbid very turbid	-	not pulpy
4	little	-	some	very turbid	-	somewhat pulpy
5	fairly evident	barely recognizable	moderate amount	moderate amount	some	very pulpy
6	do	indistinct less in residue		-	one-third	very pulpy, shows plant structure
7	strong	fairly recognizable	much	Yes, gruelly & dark in color	one-half	-
8	strong	very indistinct	much	Yes or no. If it does, gruelly	two-thirds	consists of more resistant roots, fibres etc. in main
9	almost fully decomposed	almost unrecognizable	very much	-	almost all, as a uniform paste	-
10	completely decomposed	entirely without plant structure	entirely muddy	no free water	all	-

air-cleaned and brushed before every sample to prevent contamination. The sample was then stored in vials and assigned laboratory numbers.

Analyses were conducted on peat and plant samples to determine total N, P, K, Ca, Mg, Mn, Fe, Zn and Na and for peat samples only, available N, P, K, Ca, Mg, Mn, Fe, Zn, Na. In addition, pH was determined for all peat samples.

PH

The pH of peat samples was carried out on a Beckman Zeromatic pH Meter using the 'sticky point' method. The meter was used manually at all times. The peat was saturated with distilled water and sets of 12 samples were measured at one time with careful washing after each sample was tested.

TOTAL NITROGEN

Use was made of the Kjeldahl method (Figure 5-2) using 0.5000 g of sample (Jackson, 1958, pp. 183-192) % N was determined using the formula:

$$\% N = (\text{ml a in sample} - \text{ml a in blank}) \times N \times \frac{1.4}{\text{wt. sample}}$$

AVAILABLE NITROGEN

Available nitrogen was determined by the exchangeable ammonium and nitrate by steam distillation method (Black, 1965, p. 1191). This method was slightly modified with 1N KCL used in extraction rather than 2N KCL.

TOTAL AND AVAILABLE PHOSPHORUS

Determined by the chlorostannous reduced molybdophosphoric blue color method, in sulfuric acid system (modification of the Osmond



Figure 5-2. Canadian Forestry Service soils laboratory showing Kjeldahl unit in operation.

method - see Jackson, 1958, pp. 7-14; 141). Determination was made with a Beckman DU-2 spectrophotometer.

TOTAL NUTRIENTS (K, Ca, Mg, Mn, Fe, Na and Zn)

Extractions were made by dry ashing samples at 490°C and ash dissolved in 6N HCL with dilution to 100 ml. Determination was made using an Atomic Absorption Flame Emission (Jarrel-Ash) (Figure 5-2B).

AVAILABLE NUTRIENTS (K, Ca, Mg, Mn, Fe, Na, and Zn)

Extractions were made with 1N NH_4OAc and determination made using Atomic Absorption Flame Emission.

READOUT

All nutrient contents were determined from standard prepared curves and expressed in mg/g or ppm.

K-PROBLEM

The TK values obtained from peat samples were much too low, falling below that measured for the AK fraction. This was firstly attributed to problems in ashing procedures with the sample exposed to high temperature for a long period of time resulting in element loss through volatilization. The temperature was cut from 490°C to 425°C, however results were the same.

A second method used was that of sodium fusion (Black, 1965, Part II, p. 955) involving use of platinum crucibles; this yielded results which were seemingly correct. Unfortunately equipment limitations did not permit the method to be used extensively.





B

Figure 5-3. Canadian Forestry Laboratory showing A. Jarrel-Ash Atomic Absorption Flame Emission unit and B. AA unit, dry ashing oven and hood used for extractions.

PRODUCTION ANALYSES

All plant material obtained in production analysis was dried at 85°C for 48 hours or more, depending on the material. In all cases samples were weighed as soon as possible following extraction from the oven to determine dry weight. The samples were then put in paper bags and sealed for further use in chemical analysis.

(i) ESTIMATE OF STANDING CROP:

Areas of uniform vegetation were selected from each of the major vegetation units. From each of seven sites 2 monoliths were taken using a sharp knife and peat shovel. Each monolith was excavated by placing a flat bottomed shovel beneath the sample and lifting with care. Plastic bags were placed over the samples and they were carefully placed in wooden crates lined with brin bags. Each monolith was placed in a cold room until dissected.

The dissection began with removal of all aboveground live material which was subdivided according to species. Each species was divided into various components (see Table 3-10). The arbitrary above-ground division was taken at the surface of the litter layer. The litter was removed in total.

The remainder of the monolith, the peat layer, was then sectioned into 5 cm thick divisions, with care taken not to compress peat or to drag roots. Loose Sphagnum peat makes this operation quite difficult and the degree of accuracy is rather low. Following subdivision of the peat layer each section was put through a series of sieves from coarse (5 mm) to fine (0.5 mm) mesh by means of constant water pressure. This tends to remove the greatest part of the

decomposed peat leaving the roots to be extracted by hand. In some samples sedge remains could only be divided from fine roots with aid of a dissecting scope. In other samples dense root masses were difficult to separate or clean without loss. Examples of this problem are the root masses underlying (a) Narthecium and (b) Calluna communities. Dead wood fragments are also common, but by gently rolling a finger over such fragments they readily crumble and pass through the sieve. The remaining root mass is then subdivided according to species and the dry weights obtained for each section.

(ii) PRODUCTION OF MOSSES

The mosses were divided into two groups:

A: Sphagnum and B: remainder. The methods used in determination of net production for each are different and are treated separately.

A: Sphagnum

Three methods were attempted in estimating Sphagnum production. Firstly, a series of hair nets (Figure 5-4D) were carefully placed over selected areas of Sphagnum where growth appeared uniform and dominated primarily by a single species. These nets were secured by metal rods pushed into the peat around which the net ends were pulled tight. Difficulties were encountered from the outset with the metal rods moving downward in the open bog resulting in movement of the net. Also the Sphagnum plants and bog surface in general were affected by wet and dry periods such that slight fluctuations were recorded sometimes giving a negative result or positive but false increase in height. The object of the net was to

crop the growth above the net surface at intervals to obtain a measure of production. The experiment was poorly designed and nets obstructed upward growth of the Sphagnum plants. The experiment was abandoned.

A second trial involved use of hair rollers (Fig. 5-4 A, B). Sphagnum plants were removed from the bog surface, cut to a known length (5 cm and 10 cm), placed into the rollers and replaced into the bog surface. The object was to harvest a number of these plants throughout the year to measure growth increases in length and weight. After only two removals and edge trampling it was noted that many plants were dead or not actively growing. As a result this experiment was abandoned.

A third trial, which subsequently proved successful, was used throughout the growing season. This is based on the 'capitulum correction' method used by Clymo (1970). This method outlined below is extracted mainly from Clymo (pp. 21-22); however some modifications were used to facilitate the current investigation. The purpose of this method is to allow the researcher to calculate for an error introduced when one cuts off new growth of a Sphagnum plant and uses it as a direct measure of net annual production. The error introduced is through internode extension and is not formed during the growing season. In a species such as Sphagnum fuscum where capitulum weight is high with relation the net annual production this error can be high. This problem of accounting for change in the capitulum (taken as top 1 cm of plant) may be solved by using a calculated line of best fit between capitulum and a unit length of stem with branches stripped off, as demonstrated by Clymo (1970). From the weight of the stem at harvest

an estimate may then be made of capitulum weight at start of experiment.

From near pure Sphagnum carpets plants were randomly selected for each of the main species and for Sphagnum recurvum from 4 habitats and Sphagnum rubellum 2 habitats. From each site a minimum of 30 plants constituted a sample. Each plant was subdivided into capitulum, stem (3 cm near capitulum) and remainder. The remainder was discarded and the stem stripped of branches. Dry weights of each stem and capitulum were obtained and a line of best fit calculated for each population sampled.

Previous to the growing season Sphagnum plants in each of the sampled populations were marked by means of cotton thread loops. Small loops were made and carried into the field. These loops were placed, as close as possible, to the 4 cm mark from the top of the apex of each plant and pulled tight to the stem carefully. In all, hundreds of plants were marked in 8 populations. Some bias was introduced because of the number of persons involved in marking and their own dexterity in fitting loops.

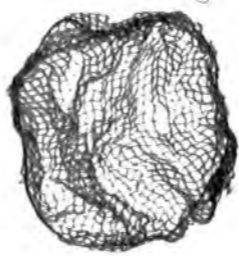
At each harvest a minimum of 60 plants were taken as a sample of the population; these were placed in paper bags and returned to the laboratory. Each plant was cut at the marker and the bottom 1 cm above the marker discarded. The next 3 cm of the stem was cut, stripped of leaves, dried and weighed to estimate the previous capitulum weight. The remainder of the plant above the marker is taken as new growth minus the error estimate made for internodal extension. From this



A



B



D



C



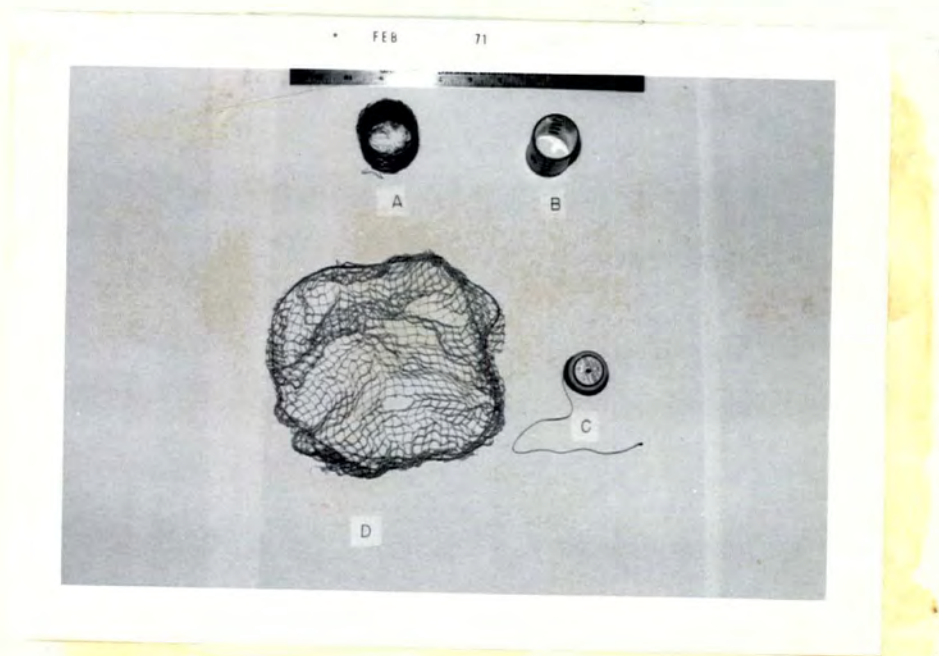


Figure 5-4. Materials used in Sphagnum production analysis
A. Wire 'hair roller', B. Perforated plastic
'hair roller', C. Cotton thread, D. Hair net.

measure the mean net annual production per plant was calculated. Furthermore, with density counts the production was expressed per unit area. Density counts were made per dm^2 within each population.

B: Other Mosses

Two other mosses, Aulacomnium palustre and Pleurozium schreberi, were also sampled from areas with heavy cover of each of these species. For both species estimates of new growth were made from cyclic growth patterns. A sample was made up of 60 plants taken at monthly intervals and selected randomly within the areas designated. The mean net annual production was estimated for each population and with density counts production/unit area were possible. Density counts were per dm^2 for each population.

The main problem in estimating new growth in Aulacomnium palustre is the separation of previous years growth in the late summer and fall portion of the growing season. In spring the distribution is fairly evident but in late season this division between new and old growth becomes more arbitrary. Similarly this problem is also found with Pleurozium schreberi. With Pleurozium also there is an added problem because of lateral growth by branches which may often be discarded by such sampling procedures. It is suggested that a thread loop could be used with these mosses as well as Sphagnum, however, one must be prepared for a thankless, tedious job with much effort for small gains.

(iii) HERB PRODUCTION ANALYSES

A: Nartheceium ossifragum

Monoliths were taken throughout the growing season from the portions of the Nartheceium ossifragum variant with the most uniform distribution of the species. Each monolith was 25 cm² and 30 cm in depth and cut from the peat substrate with a sharp knife and peat shovel. Each block was transported to the laboratory in plastic bags and then dissected with the live Nartheceium plants removed intact. In addition, the roots and rhizomes were removed by washing and the dead material (grey and withered) removed. There was no further sorting of underground material.

The aboveground plants were subdivided into live and dead factions with coloration used as the primary criteria for separation. In September, with many parts of the leaves dying, the live-dead division became more arbitrary. All subsamples were dried, weighed, placed in paper bags, numbered and stored for use in chemical analyses.

From the plants harvested with monolith, a minimum of 30 plants were obtained and the mean weight of whole, live and dead leaves was determined. The standard error was computed and plotted for live and dead material. Density counts of Nartheceium plants/25 cm² were taken and aboveground standing crop and net annual production per unit area calculated.

B: Eriophorum angustifolium

Throughout the bog, areas with uniform distribution of Eriophorum angustifolium were marked out within the 10 m grid. Destructive sampling was carried out in these areas. A square meter was selected in the sample areas and the centre 25 cm² of this meter was sampled with all Eriophorum angustifolium plants removed by hand digging such that the roots could be extracted without excessive loss. Dead standing plants were also taken, minus roots, which were difficult to harvest intact. This was repeated in a second meter plot with similar species growth form and distribution. Additional plants were taken from the surrounding portion of the meter square to estimate individual plant production.

In the laboratory, the plants taken from 25 cm² units were counted and weighed and the mean calculated for the two samples. This was carried out in two vegetation types, open bog and open forest, from May - March with open bog wet variant and closed ombrotrophic forest sampled in August.

To determine individual plant production, 30 plants were randomly taken from the harvested material and subdivided into above-ground and below-ground portions. The former was then divided into live and dead fractions based on leaf and stem color and moistness. Mean weights were obtained for each component within the sample. Because size classes were not accounted for in sampling the standard error was not usable such that only a crude estimate would be made for net annual production (discussed in text). Emphasis was placed on the live-dead proportion as a measure of species performance in habitat.

C: Eriophorum vaginatum

Eriophorum vaginatum was sampled only in April and late August from the dry knoll vegetation. Elsewhere the species is a minor contributor to the net production and was only harvested with standing crop.

Two tussocks of similar size and composition were selected for harvesting with one tussock excavated in April and the second in August. Each tussock was covered with plastic and transported to the laboratory.

The tussocks were divided into dead and live components from both above- and below-ground fractions and the live shoots were counted and weighed separately; the mean weights and standard errors were calculated for each.

(iv) SHRUB PRODUCTION ANALYSES

A: Calluna vulgaris

Areas with uniformly distributed Calluna were selected from each of its main habitats on Moorthwaite. Within each marked area a number of 1 m² quadrats were chosen and destructive sampling was carried out in early September at a time of estimated peak standing crop. Monoliths were extracted in each plot to a depth of 30 cm for use in standing crop measurements discussed previously. In this phase of sampling (in early September) however, only the above-ground portion of the plant was sampled.

All plants within the m² were cut at ground level and each stem at this level was counted as an individual plant. Each individual

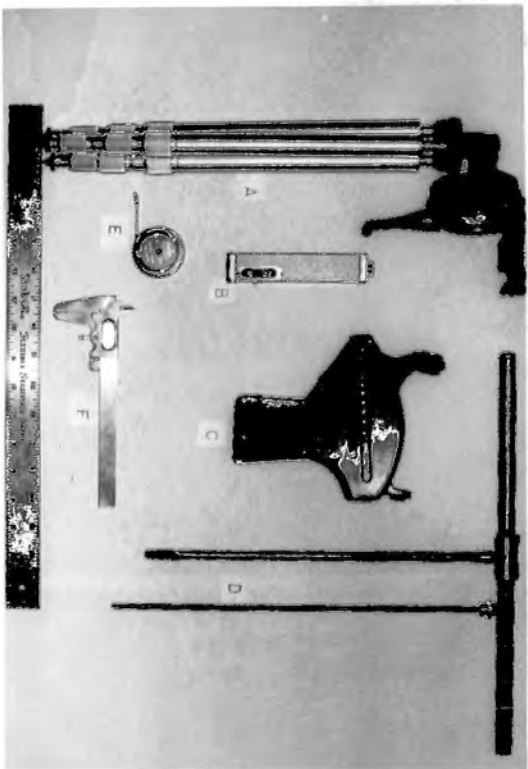


Figure 5-5. Apparatus used in establishing grid and obtaining production data on shrubs and trees.

- A. Brunton transit, B. hand level, C. Hagar,
- D. increment borer, E. diameter tape, and
- F. calipers.

was subsampled into stem, leaves and branches, attached dead, and reproductive structures. The current growth (new twigs and leaves) was separated by clipping. Each shoot was aged at ground level by annual ring count and no difficulties were encountered as reported by Cormack and Gimingham, 1964; the diameter at base was measured using graduated diameter calipers, this was taken from outside bark. In addition the height from ground level was measured for each plant. All measures, except weight, were also obtained from additional plots in the dry knoll (10), open forest (5), and hummock (5) habitats.

From the data obtained through destructive sampling prediction graphs were constructed as described in the text, based on diameter (d^2). From the measured data in undestructive sampling, limits were established for age, height, density, of the populations sampled and expressed on a m^2 basis (Table 3-19).

Predicted biomass and net production were calculated for each population through use of the established prediction equations derived.

Samples were combined for open forest and hummock populations because of the similarity in growth form and size range of the plants involved.

B: Erica tetralix

The sampling procedures followed for Erica were similar to that for Calluna, however prediction equations were calculated for two periods of the growing season, June and August. Furthermore, all Erica plants were treated equally from open bog and forested zones with only one prediction graph used.

C: Vaccinium myrtillus

Sampling procedures were similar to that for Calluna with two populations being considered, the 'Vaccinium knoll' plants and the 'forest' plants. Difficulties were encountered in aging with annual rings poorly defined, however by using thin sections taken from the base under microscopic investigation it was estimated that the whole population fell into the age range 1-7 years.

D: Other shrubs

All other shrubs were sampled in the community standing crop estimates. Oxycoccus palustris, however, was also harvested separately in areas of uniform cover to provide an estimate of the change in biomass throughout the season. This was done by use of the paired quadrat techniques (Weigert and Evans, 1964) using 25 cm² size quadrat.

E: Pinus sylvestris (seedlings)

In sampling Pinus sylvestris seedlings a seedling was arbitrarily defined as a relatively healthy or healthy tree not exceeding 1.50 m in height and showing some uniformity of growth. In contrast, dying or dead Pinus common in shaded areas were excluded from the sampling.

Seedlings were sampled only from sites showing active regeneration and were selected subjectively from the population. When an individual was selected the following procedures were carried out.

(1) In the field:

The height from ground level and the diameter at base were measured, the latter with graduated diameter calipers. Notes were made on the seedbed, the growth status and the types and extent of epiphytes on the bark. The tree was then excavated by hand and trowel.

Subsampling in the field consisted of severing the roots at base and cutting and separation of (i) current branches and leaves, and (ii) 2-year-old branches and leaves. The remainder of the tree was kept intact. Each subsample was placed in paper or plastic bags labeled and transported back to the laboratory.

(2) In the laboratory:

The seedling was first aged by obtaining a section at the base and examining under dissecting scope. The age was determined by annual ring count.

Subsampling was then completed with the divisions of (i) stem, wood and bark, (ii) branch, wood and bark, (iii) current branches, (iv) current leaves, (v) 2nd year leaves, (vi) 3rd year leaves, (vii) roots, (viii) attached dead, and (ix) epiphytes. Each sample was then dried, weighed and stored for chemical analyses.

Overall, all 53 seedlings were sampled, of which 23 were subsampled and used in establishing prediction equations. These samples were taken in all seasons, however sample seedlings used in equation calculations were restricted to the growing season from June - September.

(v) TREES

A: Pinus sylvestris

Time factors did not permit sampling of the tree layer suitable for calculation of allometric equations. To effect this an estimate of the dry matter content was made using indirect methods.

(1) Density counts

Throughout Moorthwaite Moss, 37, 10 M x 10 M units were chosen within a cross section of habitats with 6 from open bog, 14 from open forest, 14 from closed forest, and 3 from mixed forest (disturbed) sites. All stems were counted in each unit with grouping into trees 4 m; 4 m 1.5 M; 1.5 M. Standing dead were also counted separately.

(2) Mensurational data and habitat notes

The four dominant trees in each unit were measured and from this sample an estimate of 'stem' volume for the unit was calculated. For each tree the d.b.h. was taken with diameter tape and height measured by hagas. In addition, age of tree and general growth patterns were determined through cores obtained by means of increment borers. After a core was taken the hole was refilled with a twig to help prevent loss of sap or insect and disease damage. Notes were taken on the growth form of the trees, age variability, site damage, habitat differences, and presence or absence of other tree species.

(3) Volume and dry matter measurement of stem wood

Volume of stem wood was calculated by means of decimal hoppus tables based on d.b.h. and h measure. From this the mean volume/stem was calculated and using density counts estimates of volume for each unit was obtained. Reversion to dry matter of stem wood was based on wood density in each major habitat. From open bog, forest, dry knoll, edge and marginal fen, cores were taken from sample trees (minimum of 3 in each site) and wood density was measured using methods described by Wilson and Ifju (1965) for minute wood specimens. Volume and wood density were then used to estimate stem wood in each unit in kg/ha.

PLANT SAMPLING FOR CHEMICAL ANALYSES

Samples of plants for chemical analyses were collected according to the requirements of the investigation. The plants were harvested when production data and samples were being obtained. All samples were stored in paper bags and not plastic to prevent deterioration of plant tissues. On return to laboratory plants were kept in cold rooms or air dried immediately.

Because of differences in plant nutrient content with habitat, age of individual, season and part of plant examined, all samples were subdivided where required to obtain proper results. These divisions and selective sampling procedures used are discussed in the text.

