THE DISTRIBUTION, ECOLOGY, AND LIFE HISTORY OF BUXRAUMIA APHYLLA HEDW. IN NEWFOUNDLAND

JAMES A. HANCOCK

THE DISTRIBUTION, ECOLOGY, AND LIFE HISTORY

OF *BUXBAUMIA APHYLLA* HEDW. IN NEWFOUNDLAND

by

© James A. Hancock, B.Sc.

A Thesis
submitted in partial fulfilment
of the requirements for the degree of
Master of Science,
Department of Biology,
Memorial University of Newfoundland.

October, 1973

"This is as strange a thing as e'er I looked on,

as disproportionate in manners as in shape."

Britton (1896), from Shakespeare: "The Tempest."
Photo by Mr. R. Ficken.

Abstract

The moss *Buxbaumia aphylla* has been found at 75 localities in southeastern Newfoundland and 2 localities on the west coast of the island, mostly in open *Kalmia* heaths on thin, acid (pH 5) humus. It is very abundant at 13 sites, moderately abundant at 24 sites, and scarce at 40 sites. The species' density, associated plant species, and fire succession have been recorded at some sites where the species was particularly abundant.

The mineral element content of plant tissues and substrate were analyzed and represent the first data for bryophyte sporophytes. Almost all elements found in gametophytes were found in the sporophyte of *Buxbaumia aphylla*. Silver, previously found only in *Polytrichum* and *Atrichum*, was found in *Buxbaumia*.

Permanent plots enabled observations to be made on annual production of sporophytes and on their development and maturation. Sudden frosts appear to have adverse effects on development, often resulting in high mortality of capsules. The first plants of a new sporophyte generation appear in mid-September but do not mature until the following June, overwintering as immature capsules. Spore dispersal begins in mid-June. From September to June twelve morphological stages of sporophyte development are recognized.

Protonemata of *Buxbaumia aphylla* were maintained in culture for ten months without producing sex organs, but possible asexual propagules were observed.

Of three possible theories to explain the life history of *Buxbaumia aphylla*, the most likely is that the protonemata persist from year to year producing new sporophytes each September. This would refute the assumption that *B. aphylla* is an annual moss and possibly indicate that it is actually a biennial or perennial moss.

Acknowledgements

I gratefully acknowledge Dr. Guy R. Brassard for his suggesting the topic and also for his supervision and valuable advice throughout the course of this study. I also thank the members of my supervisory committee.

I would like to thank the following people for providing me with field or laboratory assistance or for providing information relevant to this study: Dr. D.M.J. Mueller (Texas A & M University), Dr. H.T. Shacklette (U.S. Geological Survey), Mr. C. Butler, Mr. W. Meades, Mr. G. Mitchell, and Mr. J. Tapplin (Newfoundland and Labrador Forest Services).

I thank Mr. R. Ficken for assistance, especially with colour photography and for photographing living plants. The cooperation received from the technicians in the Department of Biology also greatly facilitated this project.

Sincere thanks are extended to my family and to Miss Doris Hoskins for continued encouragement during the writing of this thesis.

This research was carried out with the aid of a Provincial Government Graduate Fellowship and a National Research Grant (A-6683) to Dr. G.R. Brassard.

Table of Contents

List of Figures

List of Tables

Chapter I. Introduction

Representatives of the genus *Buxbaumia* have a life history which differs from all other members of the Division Bryophyta. They are unique because the sporophyte, and not the gametophyte, is the dominant generation. The gametophytes (male and female) are very much reduced with the female gametophyte being visible for only short periods during the year and the male gametophyte consisting of only a few cells enclosing an antheridium. *Buxbaumia* and a related genus, *Diphyscium*, occupy the Subclass Buxbaumiidae in the Class Musci.

Eight species of *Buxbaumia* are recognized throughout the world. *Buxbaumia aphylla* Hedw. and *Buxbaumia indusiata* Brid. (*Buxbaumia aphylla* var. *viridis* DC. in Lam. et DC., *Buxbaumia viridis* Moug. et Nestl.) appear to be distributed widely throughout the world. Smith (1963) reports that *B. aphylla* is known in Europe, Asia, and Japan, as well as in North America where it ranges across the continent. According to Burges (1932), *Buxbaumia indusiata* is scattered sparsely throughout Europe and North America and it has also been found in Central China.

Buxbaumia piperi Best. is reported by Grout (1938) from Washington, Idaho, Montana, and British Columbia. Since then it has been found in California by Jamieson and Holmberg (1969).

Buxbaumia minakatae S. Okamura has been described in Japan (Burges, 1932). This species was collected from Siberia and eastern North America by Grout who named it *Buxbaumia subcylindrica* Grout. Iwatsuki and Sharp

(1969) compared this material with *B. minakatae* from Japan and concluded that both the American and Asiatic material belong to the same species, *Buxbaumia minakatae*.

Buxbaumia minakatae has recently been reported from Deoban, Western Himalayas, India, by Udar et al (1970). However, a subsequent detailed investigation revealed that the plants had distinctive features and another species was named, *Buxbaumia himalayensis* Udar, Srivastava et Kumar (Udar et al, 1971).

Buxbaumia Javanica C. Muell. and *Buxbaumia tasmanica* Mitt. have been found in Java and Tasmania respectively (Burges, 1932).

Burges (1932) reported another species, *Buxbaumia Colyerae* Burges, from material collected by Colyer in New South Wales. This was the first record of this genus from the Australian continent and the plants resembled *Buxbaumia tasmanica* very closely.

Two species of *Buxbaumia* have been found in Newfoundland. They are *Buxbaumia aphylla* and *B. minakatae* with the former being more common and the one on which the present study has been carried out. *Buxbaumia aphylla* was apparently first collected in Newfoundland by D.H. Norris in 1966. However, this report was not published. The presence of *B. aphylla* was first brought to my attention in 1971 when it was found on the Avalon Peninsula of Newfoundland, near Bauline, Conception Bay, by G. Freake and W. Meades, Canadian Forestry Service, St. John's.

Buxbaumia aphylla was originally discovered by Buxbaum in 1728. Haller, in 1742, gave it the name *Buxbaumia* dedicating it to the finder (Britton, 1896). The correct name for the species is *Buxbaumia aphylla* Hedw. (Hedwig, 1801).

Since its original description *Buxbaumia aphylla* has been a very intriguing and exciting plant for bryologists who have collected it.

There have been many common names attached to this moss, all describing the peculiar asymmetric shape of the capsule: Hump-backed elves (Britton, 1896), Elves (Durand, 1901), Powder guns (Grout, 1902), Buds on stalks (Kaiser, 1921), Queer little gnome-like mosses (Svihla and Svihla, 1926), Elves on sticks (Pitman, 1930), Torch-bearers (Pitman, 1930), Bedbug on a stalk (Conard, 1956), Brown shoe moss (Lye, 1968), and Bug on a stick (Udar et al, 1970).

Also, several statements have been used to describe the appearance. Kennedy (Britton, 1896) saw them as 'pictures of a Roman legion under its testudo shields.' Britton (1896) described *Buxbaumia* as "small, antique, bronze lamps, perched on top of a slender pedestal, which looks as if it would topple over with the weight of the vessel so unequally poised on its apex."

Britton (1896) gives two differing opinions concerning the evolutionary position of *Buxbaumia aphylla*. Goebel concluded that, based on the simplicity of the gametophytes, *Buxbaumia* is a primitive form allied to some alga-like progenitor of the mosses. Campbell, emphasizing the complex sporogonium and the saprophytic habit, thought it should be given highest rank in the bryophytes. Britton (1896) also states that the dark color of the capsule and the seeming absence of green leaves were considered by some early botanists to indicate a relationship to the fungi. Bryologists now tend to agree with Campbell's theory. Nyholm (1969) and Crum et al (1973) place Buxbaumiaceae near Polytrichaceae, an advanced family in the phylogenetic arrangement of mosses.

Conard (1956) considered all finds of *Buxbaumia aphylla* to be rare. However, the opinion among most bryologists who have collected it is that it is not rare, e.g. Britton (1896) who states that it is "sporadic but not rare." Smith (1963) believes that "the species is probably not so rare as its infrequent collection would indicate." Steere (1942) says "once the characteristic habitat and plant associations have been observed, this moss may be found very easily, as noted in Pittsburgh by Eastwood, and in Virginia by Fernald."

Buxbaumia aphylla has been collected in a variety of habitats: sandy soil (Anderson, 1951; McClymont, 1950; Pettifer, 1956; Steere, 1942), loam (Baker, 1927; Britton, 1896), humus (Carroll, 1935; Oittinen, 1967; Steere, 1942; Svihla and Svihla, 1926; Taylor, 1972), rotten wood or soil containing rotten wood (Taylor, 1972; Williams, cited by Grout, 1901), colliery debris (Corner, 1967; Corner, 1969), trails in woods (Oittinen, 1967; Steere, 1942), on ground in pine woods (Anderson, 1951; Oittinen, 1967) and roadsides (Oittinen, 1967; Pettifer, 1956; Wheeler, 1901).

Because of the relationship with decaying wood fragments and highly organic soils many people considered this moss to be largely or totally saprophytic, e.g. "saprophytic in habit it occupies among the mosses somewhat the position that the Indian Pipe and Pinesap do in the Heath Family" (Kaiser, 1921).

In many cases where *Buxbaumia aphylla* has been reported in the literature it has been recorded as small in quantity. Oittinen (1967) studied the distribution of *Buxbaumia aphylla* and *B. indusiata* *(viridis)* in Finland. He noted that, even though *B. aphylla* was widely distributed, it was not abundant. Only a few fruiting specimens were found at each locality.

In a study on fire succession in Sweden, Uggla (1958) said that *Buxbaumia aphylla* always occurred in severely burned and insolated spots. It follows fires at a 17-year interval and disappears after a brief flourish of a few years.

Some early bryologists expressed the opinion that *Buxbaumia aphylla* seldom reappears in the same locality year after year (Baker, 1927; Britton, 1901). However, it has been noted that this is not true in all areas. Smith (1963) and McClymont (1950) both reported having observed the moss in the same areas during two consecutive years. In Newfoundland I have observed the species in the same locality for three successive years.

Durand (1901) said that the black soil on which *Buxbaumia aphylla* grows had a green tinge due to persistent protonema. Smith (1963) stated that no protonema was present on the soil when he found *B. aphylla* growing in Iowa in April, 1961. I have found, upon close observation of the soil near *Buxbaumia aphylla* colonies, that a green tinge is often given to the soil by a small leafy liverwort, *Cephaloziella sp.*, which is closely associated with the moss.

McClymont (1950) reported having found two generations of *Buxbaumia aphylla* in September, 1949. One generation was completely mature, some having shed their spores. The other generation was very immature, showing a slight swelling in the region of the spore case. Eastwood (1936) studied the development of the sporophyte and recognized four distinct stages. It is my opinion, after observing the development of two generations of *Buxbaumia aphylla*, that the sporophyte passes through more than four recognizable stages in its maturation.

Forman (1965) studied moss phenology and recognized twelve essential developmental stages of a moss life cycle based on morphology and ecology.

Mueller (1972) cultured *Buxbaumia aphylla* protonemata on vermiculite to study ultrastructure. He says that gametophytes, primarily those bearing an antheridium were occasionally produced more than a year after spore germination but found it impossible to grow sporophytes (personal communication). Dening (1928-29) followed protonemal development in agar cultures and outlined the development of male and female gametophytes in some detail.

One of the aims of this project was to determine the distribution of *Buxbaumia aphylla* in Newfoundland, concentrating mainly in the southeastern portions of the island.

Secondly, an attempt was made to study the autecology of *Buxbaumia aphylla* by noting soil texture, pH, associated species, fire succession, abundance and density of the plants, and organic and mineral element content of the soil. The sites where each of these aspects of the autecology and the life history of *B. aphylla* were studied in Newfoundland are shown in Figure 1 and listed in Table 1.

Thirdly, a phenological study was conducted for *Buxbaumia aphylla*, concentrating on the development and maturation of the sporophyte, since this is the only portion of the life cycle which can readily be observed

Figure 1. Four sites on the Avalon Peninsula where *Buxbaumia aphylla* was closely investigated. Inset shows the island of Newfoundland and the region enlarged in the main map (blackened area).

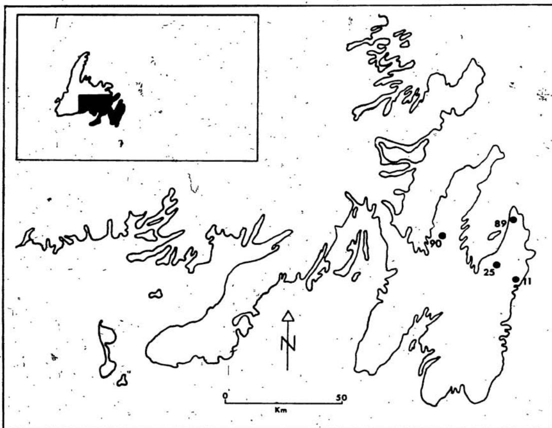

89
90
25
11
N
0
50
Km

Table 1. Four sites where *Buxbaumia aphylla* was closely investigated and the factors studied at each site. (See Figure 1 for actual site locations).

Factors Investigated	Localities and Site Number			
	Bay Bulls (11)	Soldiers Pond (25)	Bauline (89)	New Harbour (90)
Density	+	+		
Fire Succession	+	+	+	+
Mineral Element Content	+	+		
pH	+	+	+	
Soil Organic Content			+	+
Associated Plant Species		+	+	
Annual Production of Sporophytes			+	+
Phenology			+	

in nature. Permanent plots were set out at selected localities to observe individual plants at different times during the year and also to study the annual production of sporophytes.

In order to observe spore germination, development of protonema and possible production of gametophytes (stages not readily visible in the field), attempts were made to culture *Buxbaumia aphylla* on natural and artificial media.

Chapter II. Distribution

1. Method of Study

In May and June, 1972, an intensive search for *Buxbaumia aphylla* was conducted in accessible parts of the Avalon Peninsula and at selected other locations in southeastern Newfoundland. *Kalmia* heaths were selected to search for *B. aphylla* while driving through the region specified above. During the course of the search 89 such sites in southeastern Newfoundland were investigated for the presence and abundance (refer to p. 22) of *Buxbaumia aphylla*. The length of time spent at each site was largely determined by the degree of difficulty in first finding the species (usually not more than 1 hour).

2. Results

a. Field Observations

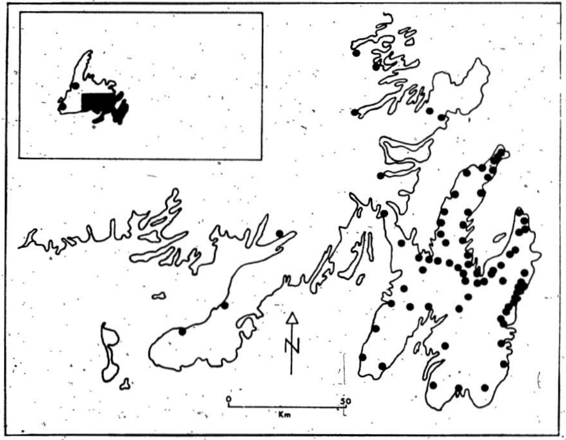
Buxbaumia aphylla was found at 75 of the 89 sites (84%) which were visited in southeastern Newfoundland. *B. aphylla* was also found at two localities (88 and 91) on the west coast of the island, outside the area intensively investigated, bringing the total number of localities where the species was present to 77. These locations are listed below.

At the 14 sites investigated where *Buxbaumia aphylla* was not found the species may have been present but not abundant enough to be detected in the time allotted.

b. Geographic Distribution of *Buxbaumia aphylla* in Newfoundland

The distribution data cited below are mapped in Figure 2. Unless

Figure 2. The known distribution of *Buxbaumia aphylla* in Newfoundland. Inset shows the island of Newfoundland, the two known localities (dots) for *B. aphylla* in western Newfoundland, and the region enlarged in the main map (blackened area).



N
0
50
Km

otherwise specified in the following list, all speciemns were collected and determined by J.A. Hancock. Voucher specimens are deposited in the Bryophyte Herbarium, Memorial University of Newfoundland (NFLD).

Bonavista North District. Sides of trail leading through *Kalmia-Abies* forest near a river. Growing on shallow humus. 50 km SE of Gander along Trans-Canada Highway (Site 36), 17 May 1972, scarce; Trail leading through *Kalmia* heath, bordering mixed forest. Growing on humus. 0.8 km SE of Traytown (Site 35), 16 May 1972, moderately abundant.

Bonavista South District. *Cladonia* covered barren area at top of ridge over vertical shale strata in boulder-strewn forest at mouth of Northwest River near Port Blandford, S of Terra Nova National Park, 9 July 1966, leg. D.H. Norris 3908.

Trinity North District. On rock outcrop along shoreline of a lake. 17 Km W of Trinity, Bonavista Peninsula (Site 37), 18 May 1972, moderately abundant; In forest on top of a large gravel mound. Growing on humus among *Kalmia*. 1.7 km W of Trinity, Bonavista Peninsula (Site 38), 18 May 1972, scarce; Typical *Kalmia*-lichen heathland. Growing on humus. 1.7 km S of North West Brook along Trans-Canada Highway (Site 39), 18 May 1972, moderately abundant.

Fortune Bay District. Heathland, on thin humus among small stones. 1.7 km SE of Garnish, Burin Peninsula (Site 84), 21 June 1972, moderately abundant; Hummock on *Kalmia* heathland. Growing on humus. 2 km N of

Grand Le Pierre (Site 86), 25 June 1972, scarce.

Burin District. Sloping *Kalmia-Cladonia* heathland bordering bog. Growing on humus. Molliers turnoff, Burin Peninsula (Site 85), 21 June 1972, scarce.

Placentia East District. Along river bank. Growing amond *Kalmia* and grass, on humus. Long Harbour turnoff along Argentia access road (Site 77), 7 June 1972, moderately abundant; Meadow covered with *Vaccinium angustifolium* Ait. 0.8 km S of Ship Cove, Placentia Bay (Site 79), 7 June 1972, scarce; Opening in mixed forest. Growing on humus among *Kalmia*. 0.8 km W of Southeast Placentia (Site 81), 8 June 1972, moderately abundant; Open *Kalmia*-lichen heathland. 20 km W of Placentia, along Salmonier Line (Site 82), 8 June 1972, very abundant; Meadow with clumps of *Kalmia*. Growing on humus. Cuslett, Placentia Bay (Site 78), 7 June 1972, scarce.

St. Mary's District. Footpath leading through *Kalmia*-mixed forest. Growing on humus along side of path. Peter's River, Holyrood Bay (Site 62), 31 May 1972, moderately abundant; Sloping heathland bordering bog. Growing on humus. 5 km NE of Riverhead, St. Mary's Bay (Site 64), 31 May 1972, scarce; Roadside, on edge of forest. Growing on clay among *Polytrichum* and *Gaultheria*. 5 km NE of St. Catherine's, Salmonier Line (Site 65), 1 June 1972, scarce; Meadow with clumps of *Vaccinium angustifolium* and *Empetrum nigrum* L. Branch, Placentia Bay (Site 80), 7 June 1972, scarce; Footpath in sloping heathland leading to bog.

Growing on humus. 0.5 km W of North Harbour turnoff along Salmonier Line (Site 83), 8 June 1972, scarce.

Ferryland District. Small humus-covered mound in *Abies* forest. Growing on shallow humus among *Kalmia angustifolia* L. and *Vaccinium vitis-idaea* L. Near Middle Pond, 3 km NE of Bay Bulls (Site 10), 9 May 1972, moderately abundant; *Kalmia-Vaccinium-Alnus* heathland near dump. Growing in thin humus. 1 km N of Bay Bulls, near Long Pond (Site 11), 9 May 1972, very abundant; Growing in humus and sandy soil among *Kalmia* and *Abies*, near roadside. Bay Bulls (Site 12), 9 May 1972, scarce; Recently burned heathland. Growing in shallow humus covering rock, 2 km W of Bay Bulls (Site 43), 20 May 1972, scarce; Growing in humus on open *Kalmia* heathland. 2 km N of Witless Bay (Site 13), 9 May 1972, moderately abundant; Growing in meadow scattered with *Kalmia*. 1.5 km NE of Mobile (Site 14), 9 May 1972, scarce; *Kalmia* heathland clearing in mixed forest. Growing on humus. 3 km N of Tors Cove (Site 16), 9 May 1972, scarce; Growing in clay at top of embankment among grass. Near Power House at head of Tors Cove Pond (Site 18), 9 May 1972, scarce; Abandoned road. Growing on humus among scattered *Vaccinium* and *Kalmia*. Lamanche River (Site 19), 9 May 1972, scarce; Disturbed site. Growing on humus among dense growth of *Kalmia*. 0.5 km N of Lamanche turnoff (Site 20), 9 May 1972, scarce; Footpath leading through blanket bog. Growing on humus in path and along edges. 1.5 km N of Brigus South turnoff (Site 21), 9 May 1972, scarce; Typical *Kalmia*-lichen heath. Growing on humus among *Cladonia* spp. 2 km W of Aquaforte, Southern Shore (Site 57), 31 May 1972, moderately abundant; Typical *Kalmia*-lichen heathland. Growing mostly on hummocks in exposed humus. Cappahayden, Southern Shore (Site 58), 31 May 1972, moderately abundant; Typical *Kalmia* heathland bordering small *Abies* forest. 20 km SW of Cappahayden, Southern Shore (Site 59), 31 May 1972, very abundant; Open *Kalmia* heathland near dump. Growing on exposed humus. 2 km E of Trepassey (Site 60), 31 May 1972, scarce; *Kalmia-Cladonia* heath, sloping into bog. 15 km W of Bay Bulls (Site 87), August 1971, moderately abundant.

<u>St. John's North District</u>. Footpath leading into *Abies* forest. Growing on shallow humus among large exposed rocks. Plants surrounded by grass, *Vaccinium*, and *Kalmia*. 2 km NW of Pouch Cove (Site 3), 8 May 1972, moderately abundant; Growing on shallow humus on typical *Kalmia*-lichen heathland. 6.5 km W of Torbay, along Bauline Line (Site 89), 6 July 1972, very abundant.

<u>St. John's East Extern District</u>. Grass meadow merging into *Kalmia-Abies* forest. Growing on humus along edge of drainage ditch. Shoe Cove (Site 4), 8 May 1972, scarce; Abandoned road leading through *Kalmia-Abies* forest. Growing on sloping humus along roadside. 2 km NW of Flat Rock turnoff, Torbay Road (Site 6), 8 May 1972, scarce.

<u>Harbour Main District</u>. Heathland covered with scattered *Kalmia, Juniperus*, and *Abies*. Growing on humus among exposed boulders. 3 km SW of Donovan's Overpass, St. John's (Site 22), 15 May 1972, very abundant; Growing on humus mixed with sandy type soil among (and covering) shale. 1 km W of Paddy's Pond along Trans-Canada Highway (Site 24), 15 May 1972,

scarce; Typical open *Kalmia-Vaccinium* heathland. Growing on humus and sandy soil. Soldiers Pond, Trans-Canada Highway (Site 25), 15 May 1972, very abundant; Typical *Kalmia* heath. Growing on humus. 3.5 km NE of Witless Bay turnoff along Trans-Canada Highway (Site 26), 15 May 1972, moderately abundant; Growing in thick humus on open *Kalmia* heath. 1.5 km W of Holyrood access road along Trans-Canada Highway (Site 27), moderately abundant; Sloping *Kalmia* heath leading into bog. Growing on humus. Junction of Salmonier Line and Trans-Canada Highway (Site 28), 15 May 1972, very abundant; Growing on humus and clay among dense *Kalmia* on slope. 7.5 km NW of Salmonier Line along Trans-Canada Highway (Site 29), 15 May 1972, scarce; Growing on thick humus on typical heathland. 0.5 km E of intersection of Roche's Line and Trans-Canada Highway (Site 30), 15 May 1972, scarce; Small hill on open *Kalmia* heathland. 1 km E of intersection of Hodgewater Line and Trans-Canada Highway (Site 31), 15 May 1972; scarce; Clearing in mixed forest. Growing among *Kalmia* on shallow humus. Holyrood, Conception Bay (Site 69), 1 June 1972, scarce; Footpath leading through *Kalmia* heath. Growing in humus along sides. 25 km NE of St. Catherine's, Salmonier Line (Site 66), 1 June 1972, moderately abundant.

Port De Grave District. On heathland among dense growth of *Kalmia* and *Cladonia* spp. 5 km W of Hodgewater Line along Trans Canada Highway (Site 32), 15 May 1972, moderately abundant; Meadow with scattered *Kalmia*. Growing on thin humus. Marysvale, Conception Bay (Site 68), 1 June 1972, very abundant; Open *Kalmia* heathland. Growing on humus. South River, Conception Bay (Site 67), 1 June 1972, moderately abundant;

Exposed boulder-strewn heathland. Growing on humus. 15 km E of New Harbour, Trinity Bay (Site 90), 16 June 1972, very abundant.

Harbour Grace District. Meadow type vegetation with scattered *Vaccinium* and *Kalmia*. 2 km N of Spaniards Bay (Site 45), 29 May 1972, moderately abundant.

Carbonear District. Meadow with scattered clumps of heath. Growing on loose humus. Carbonear (Site 46), 29 May 1972, scarce; Burned heathland. Growing on humus. 1 km W of Salmon Cove, Conception Bay (Site 47), 29 May 1972, very abundant.

Bay De Verde District. Meadow with scattered *Kalmia*. Growing on humus. Adam's Cove, Conception Bay (Site 48), 29 May 1972, scarce; Typical *Kalmia* heathland near dump. Growing on very shallow humus. Job's Cove, Conception Bay (Site 50), 29 May 1972, very abundant; Heath covering top of cliff. Growing on very shallow humus. 2 km N of Lower Island Cove, Conception Bay (Site 51), 29 May 1972, scarce; Open *Kalmia* heathland. Growing on shallow humus. Old Perlican, Trinity Bay (Site 52), 29 May 1972, moderately abundant; *Kalmia-Cladonia-Rhacomitrium* heathland bordering bog. Turnoff to Grate's Cove along Bay De Verde road, Conception Bay (Site 53), 29 May 1972, scarce; Heathland. Growing among grass. 4.5 km N of Grate's Cove (Site 56), 29 May 1972, scarce; Footpath leading through heathland. Growing on humus among small stones. Lead Cove, Trinity Bay (Site 70), 6 June 1972, scarce.

Trinity South District. Sloping heathland covered with *Kalmia*, *Alnus*, and *Picea*. New Chelsea, Trinity Bay (Site 71), 6 June 1972, moderately abundant; Open *Kalmia* heathland. Growing on humus among scattered exposed rocks. New Perlican, Trinity Bay (Site 72), 6 June 1972, moderately abundant; Growing among *Dicranum spurium* Hedw. on *Kalmia*-lichen heathland. Hopeall, Trinity Bay (Site 75), 6 June 1972, scarce; On humus in footpath leading through *Kalmia-Abies* forest. 7.5 km E of Whitbourne along Trans-Canada Highway (Site 33), 15 May 1972, scarce; Growing on humus on *Kalmia* heathland bordering spruce bog. Junction of Argentia access road and Trans-Canada Highway (Site 34), 7 June 1972, very abundant; *Kalmia* heathland bordering bog. Growing on humus. 11 km S of Whitbourne along Argentia access road (Site 76), 7 June 1972, scarce; Typical *Kalmia*-lichen heathland. Growing on humus. Chapel Arm turnoff along Trans-Canada Highway (Site 42), 18 May 1972, moderately abundant; Typical *Kalmia* heathland. Growing among *Polytrichum commune* Hedw. Bellevue Beach turnoff along Trans-Canada Highway (Site 41), 18 May 1972, moderately abundant; Typical *Kalmia* heathland. Growing in hollow on humus. 0.5 km NW of Arnold's Cove turnoff along Trans-Canada Highway (Site 40), 18 May 1972, scarce; *Kalmia* heathland, on humus. 1 km W of Heart's Desire, Trinity Bay (Site 73), 6 June 1972, scarce; *Kalmia*-lichen heathland. Growing on humus. Cavendish, Trinity Bay (Site 74), 6 June 1972, scarce.

St. George's District. Heathland, on thin humus among *Vaccinium angustifolium*. 8 km NE of Coal Brook along Trans-Canada Highway (Site 88), 20 July 1972, scarce.

St. Barbe South District. Growing on wet humus in seepage area. Gros Morne, Bonne Bay, altitude 800 m (Site 91), 22 May 1973, scarce, leg. G.R. Brassard 7437.

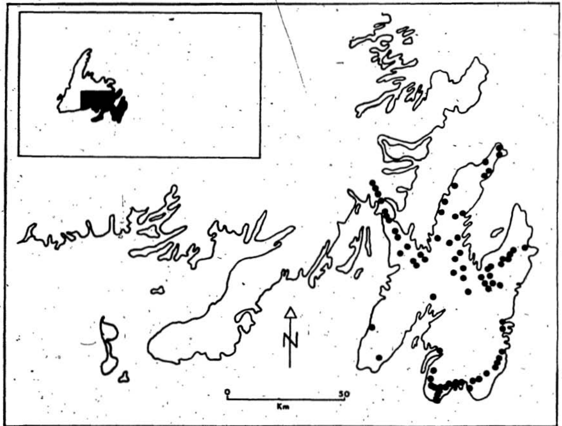
3. Discussion

This unusual moss, which in North America has a wide but very local distribution (Grout, 1938), is very widespread in heathlands of southeastern Newfoundland. Figure 3 shows the distribution of heathlands on the Avalon Peninsula of Newfoundland. A comparison of Figures 2 and 3 shows that *Buxbaumia aphylla* grows in all areas of southeastern Newfoundland where heathlands are found. *B. aphylla* was found growing in a variety of habitats, but the majority of these were heathlands. Once the characteristic habitat was known the sampling was carried out subjectively, since mainly heathlands were searched for the species.

There seemed to be no relationship between the abundance of *Buxbaumia aphylla* and the location of the individual sites. However, it is more sparsely distributed in the southern parts of the Avalon Peninsula where large quantities of *Rhacomitrium lanuginosum* (Hedw.) Brid. cover the heathlands and humus is scarce. In western Newfoundland *B. aphylla* has a more limited distribution. The bryophyte flora of twenty-one sites was studied in western Newfoundland in the area extending from Port-aux-Basques to Parson's Pond. *Buxbaumia aphylla* was found at only two of these and in both localities it was growing on humus.

The species has been collected mainly in the lowlands (<50 m) but ranges to 800 m altitude (on Gros Morne).

Figure 3. Heathland distribution on the Avalon Peninsula (after Meades, 1973). Inset shows the island of Newfoundland and the region enlarged in the main map (blackened area).


N
0
50
Km

The distribution of *Buxbaumia aphylla* in Newfoundland is similar to the distribution of *B. aphylla* in Finland, as reported by Oittinen (1967). There also it grows on heathlands and was found to be locally ubiquitous in the southern regions. In northern Finland, *Buxbaumia aphylla* is rarer than in the southern parts. This is probably true for Newfoundland also since the abundance of typical heathlands on the Northern Peninsula is much lower than in southeastern Newfoundland.

Chapter III. Ecology

1. Method of Study

While studying distribution, sites where *Buxbaumia aphylla* was found were examined in detail. In addition, other ecological factors were studied at several sites where *B. aphylla* was very abundant (Table 1).

The abundance of *Buxbaumia aphylla* at each of the 77 positive sites was arbitrarily designated as scarce (1-10 sporophytes), moderately abundant (11-100 sporophytes), or very abundant (>100 sporophytes). The abundance was determined by thoroughly searching the area in the immediate vicinity of the first find (approximately 15 m radius) and counting all plants observed.

Two localities (11 and 25) where *Buxbaumia aphylla* was very abundant were chosen to study density of this plant. At Bay Bulls (11) five plots were set out having a fixed width and the length determined by the distance in which approximately 50 plants could be collected (Figure 4). At Soldiers Pond (25) the plants were extremely abundant and the former type of sampling was not necessary. Five 1 m^2 plots (Figure 5) were set out randomly and all the plants within them were harvested. These collections were made on 24 May, 1972 (Bay Bulls) and 25 May, 1972 (Soldiers Pond) when the plants were almost fully developed and easiest to find.

Plant collections made during the density study were used for analysis of mineral element content of the plants. The basal portion (foot and vaginula) of each plant was cut away (Figure 6) as the plants

Figure 4. Plots used to study density of *Buxbaumia aphylla* at Bay Bulls (11). The two stakes in the foreground are 3 m apart. 24 May, 1972

Figure 5. Plots used to study density of *Buxbaumia aphylla* at Soldiers Pond (25). Each of the plots in the photo is 1 m X 1 m. 25 May, 1972

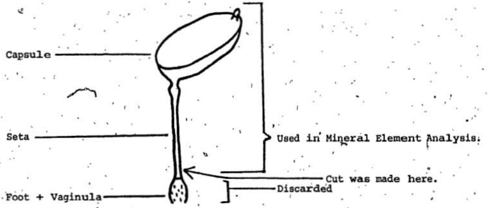


Figure 6. Sketch of *Buxbaumia aphylla* showing the portion of each sporophyte cut away before mineral element analysis.

were collected in the field. Later, in the laboratory, these plants were examined using a dissecting microscope and all adhering grains of soil were removed using a fine brush. These steps were taken to prevent contamination since the mineral elements are each expressed as a percentage or as parts per million (ppm) of the ash content of the plants. After all the plants within a plot were collected a soil sample was taken. Later, the five soil samples and the five plant samples collected at each site were sent for analysis to the Geochemical Census Branch, U.S. Geological Survey (Denver, Colorado).

Analysis for organic content of the substrate was made on soil from sites 89 and 90. Ten samples, each taken to a depth of 5 to 6 cm, were analyzed from each site. The percent carbon and the percent organic matter were determined in the laboratory by chemical analysis using the 'Oxidizable Matter by Chromic Acid with H_2SO_4 Heat of Dilution' method known as the Walkley-Black method (Jackson, 1965). However, minor alterations were necessary since the soil was mostly humus with a high organic content. 15 ml of $K_2Cr_2O_7$ were used in place of 10 ml to assure complete oxidation of the organic matter. These alterations were also made in the reagent blank and thus these changes were accounted for in the calculations.

The pH of the habitat was recorded at Bauline (89), Bay Bulls (11), and Soldiers Pond (25). Twelve readings were taken at each site using a Beckman pH meter. Each analysis was made directly in the field using randomly-chosen portions of soil taken to a depth of 5 to 6 cm. The soil samples were mixed with distilled water in 200-ml beakers resulting in a paste mixture and recorded immediately.

In its habitats, which are mainly heathlands, a number of plant species repeatedly occur in association with *Buxbaumia aphylla*. Two sites were chosen to investigate these species in an attempt to determine the degree of association. The sites chosen were Soldiers Pond (25) and Bauline (89). A grid, 15 cm X 15 cm, initially designed for observations on permanent plots, was used (Figure 7). At each site the grid was thrown randomly 10 times and each time all the different species either partially or wholly encompassed within the grid were recorded. The results of both sites were combined to assign each species with a frequency index.

$$\text{Frequency Index} = \frac{\text{Total Number of Occurrences}}{\text{Total Number of Quadrats Sampled}}$$

No long-term records of fires in southeastern Newfoundland exist. However, information dealing with recent fires at several *Buxbaumia* sites was supplied by Mr. J. Tapplin, Newfoundland and Labrador Forest Services, St. John's, who recalled the fires from memory.

2. Results

a. Field Observations

In Newfoundland *Buxbaumia aphylla* most often grows in dry, open *Kalmia* heathlands, which are very widespread in southeastern Newfoundland. Figure 8 shows a typical heathland where *B. aphylla* grows and Figure 9 shows the plants growing on this heathland. However, it has been collected in a variety of other habitats: roadsides, footpaths, abandoned

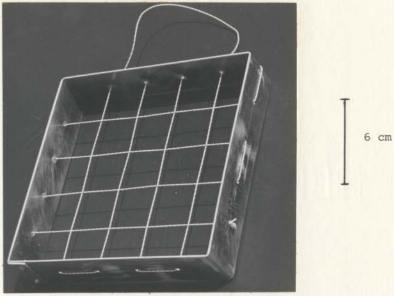


Figure 7. Grid used for observations on *Buxbaumia aphylla* plots.

Description:

The grid shown in Figure 7 was constructed using an aluminium strip (3.4 cm wide) which was bent to form a square with inside measurements 15 cm X 15 cm. The free ends overlapped and were fastened using 2 sheet metal screws. Four holes (1/16 inch diameter) were drilled in each side at intervals of 3 cm. The grid was then strung in tennis racket fashion using nylon twine, resulting in twenty-five 9 cm^2 sections.

Figure 8. Typical habitat for *Buxbaumia aphylla* in southeastern Newfoundland, an open *Kalmia* heathland at Bauline (89). Photo by Dr. G.R. Brassard.

Figure 9. Close-up of ground cover shown in Figure 8. Note two sporophytes of *Buxbaumia aphylla* 2.5 cm below and to the left of lens cap (5 cm in diameter). Photo by Dr. G.R. Brassard.


ASAHI
PENTAX

roads, forests, and at one site, on a rock outcrop along the edge of a lake (Figures 10 and 11).

At approximately 80% of the sites *Buxbaumia aphylla* was growing on shallow humus (<5 cm deep). However, in other habitats it grows directly on clay, on sandy soil, and on gravel.

Oittinen (1967) reported that in Finland *Buxbaumia aphylla* is a weak competitor and grows in trampled places and on soil laid bare by rain, as well as dry heath forests where it is common. He also said that the habitats of this species are always more or less exposed to the sun. In Newfoundland *Buxbaumia aphylla* is as common in the footpaths leading through a heathland as in the heathland itself. Along these paths humus is compacted, insolation is increased and competition is at a minimum, conditions which agree with Oittinen's findings. Its occurrence in footpaths seems to indicate a relationship to human activity. This is supported by the fact that at several sites *Buxbaumia aphylla* was growing very close to disposal dumps. However, the effects of man's influence are not distinct.

Some workers have noted capsule orientation of *Buxbaumia aphylla*. Huntington (1901) and Cresson (1904) stated that the capsules point to the south. Taylor (1972) analyzed 292 plants and reported that the direction of the capsules was primarily south to southwest but plants were also observed to point in all other directions. Durand (1901) was unable to establish any uniformity in the direction of the capsules on level ground. Smith (1963) said that the capsules showed no orientation with respect to slope. During my field observations no obvious capsule orientation was observed. However, when growing on a slope the capsules usually point

Figure 10. Unusual habitat for *Buxbaumia aphylla*. Shoreline of a lake located 17 km W of Trinity, Bonavista Peninsula (37). 18 May, 1972. Photo by Dr. G.R. Brassard.

Figure 11. Close-up of area shown in Figure 10 where *Buxbaumia aphylla* was found (arrow indicates actual spot). The rock outcrop in this photo is approximately 10 m from edge of water. 18 May, 1972. Photo by Dr. G.R. Brassard.

upwards towards the greatest incidence of light, as mentioned by Taylor (1972).

b. Abundance and Density

Of the 77 sites where *Buxbaumia aphylla* was found it was very abundant at 13 sites, moderately abundant at 24 sites, and scarce at 40 sites.

At Bay Bulls (11) and Soldiers Pond (25) *Buxbaumia aphylla* was very abundant but the density of sporophytes was very different at the two sites, as seen in Tables 2 and 3. At Bay Bulls the density was less than 1 plant $/m^2$ while at Soldiers Pond the density was 208 plants $/m^2$. The sporophytes of *B. aphylla* most often grow singly but they may also grow in dense clumps. At Site 28 (Junction of the Salmonier Line and the Trans-Canada Highway) where *Buxbaumia aphylla* was very abundant, 13 plants were found growing within 5 cm^2 (Figure 12).

c. pH

The habitat pH readings taken at Bauline (89), Soldiers Pond (25), and Bay Bulls (11) are recorded in Table 4. One sees that *Buxbaumia aphylla* grows in acid conditions, with pH ranging from 4.3 to 5.3 with a mean of 5.1.

d. Organic Content of Soil

The percent carbon and percent organic matter for the soil samples from Bauline (89) and New Harbour (90) analyzed by the 'Walkely-Black' method are listed in Table 5.

Table 2. Results of density study at Bay Bulls (11) showing dimensions of plots and number of sporophytes collected in each.

Plot Number	Plot Dimensions	Plot Area	Total Number of Sporophytes	Sporophytes per m^2
1	7 m X 10 m	70 m^2	49	0.7
2	3 m X 10 m	30 m^2	55	1.5
3	5 m X 20 m	100 m^2	50	0.5
4	3 m X 14 m	42 m^2	53	1.3
5	4 m X 13 m	52 m^2	52	1.0
Total		294 m^2	259	

Table 3. Results of density study at Soldiers Pond (25) showing dimensions of plots and number of sporophytes collected in each.

Plot Number	Plot Dimensions	Plot Area	Total Number of Sporophytes	Sporophytes per m^2
1	1 m X 1 m	1 m^2	168	168
2	1 m X 1 m	1 m^2	194	194
3	1 m X 1 m	1 m^2	163	163
4	1 m X 1 m	1 m^2	447	447
5	1 m X 1 m	1 m^2	67	67
Total		5 m^2	1039	

Figure 12. Thirteen sporophytes found growing in a clump at Site 28 (junction of Salmonier Line and Trans-Canada Highway). Sporophytes are growing in an area 5 cm^2. 15 May, 1972. Photo by J. Hancock.

Table 4. pH readings from three sites where *Buxbaumia aphylla* was very abundant.

Sample Number	Bauline (12 Sept, 1972)	Soldiers Pond (12 Sept, 1972)	Bay Bulls (19 Sept, 1972)
1	4.9	4.7	4.3
2	4.9	5.2	5.1
3	5.0	5.4	5.0
4	5.2	5.0	4.9
5	5.1	5.3	4.6
6	5.3	5.1	5.1
7	5.0	5.1	4.9
8	5.4	5.2	4.8
9	5.0	5.3	5.0
10	5.2	4.9	5.0
11	5.4	5.1	5.1
12	5.5	5.0	4.9
Mean	5.2	5.1	4.9

Table 5. Percent carbon and percent organic matter of ten soil samples from each of New Harbour (90) and Bauline (89).

Sample Number	New Harbour		Bauline	
	% Carbon	% Organic Matter	% Carbon	% Organic Matter
1	40.95	70.34	37.05	63.73
2	35.88	61.71	23.79	40.92
3	45.63	78.48	18.33	31.53
4	28.86	49.64	41.73	71.78
5	46.02	79.15	35.88	61.71
6	25.74	44.27	24.96	42.93
7	42.90	73.79	17.94	30.86
8	46.41	79.83	17.94	30.86
9	42.12	72.45	33.15	57.02
10	54.21	93.24	34.71	59.70
Mean	40.87	70.29	28.55	49.10

The organic matter content is much higher at New Harbour than at Bauline. This is explained by describing the areas sampled. The New Harbour site was a heathland with a very uniform, thick humus layer. At Bauline the area sampled was along an old abandoned road which bordered a heathland. Here the humus was scattered in patches and also less deep. At Bauline more mineral soil was included with the samples, all of which were taken to a depth of 5 cm, and thus the organic content was lower.

e. Mineral Element Content

The mineral element content of the plant samples and underlying substrate from Soldiers Pond area and Bay Bulls was determined for 51 elements. All samples were analyzed (by Geochemical Census Branch, Denver, Colorado) by emission spectrography for aluminium, antimony, arsenic, barium, beryllium, bismuth, boron, cadmium, calcium, cerium, chromium, cobalt, copper, europium, gallium, germanium, gold, hafnium, indium, iron, lanthanum, lead, lithium, magnesium, manganese, molybdenum, nickel, niobium, palladium, phosphorus, platinum, potassium, rhenium, scandium, silicon, silver, sodium, strontium, tantalum, tellurium, thallium, thorium, tin, titanium, tungsten, uranium, vanadium, ytterbium, yttrium, zinc, and zirconium. Soil samples from Bay Bulls were also analyzed for neodymium, praseodymium, and samarium by the same technique.

The spectrographic method is not accurate for certain elements given above although values have been assigned. These elements are zinc, phosphorus, and calcium. Soil samples from both areas were analyzed for these elements by atomic absorption methods. However, the plants sampled were insufficient for these analyses.

The results of these analyses may be found in Appendix 1. The plant samples were oven dried and ashed (in Denver) before analysis and the percent ash for each sample is given in Tables 6 and 7. These values range from 2.8 percent to 4.0 percent, indicating an almost complete lack of contamination of the plant material since most bryophytes ash to 3-6 percent of their dry weight (Shacklette, personal communication).

At Soldiers Pond and Bay Bulls *Buxbaumia aphylla* was very abundant but showed a marked difference in the density. However, no significant difference in mineral element content of soils of the two areas is evident.

f. Associated Plant Species

Table 8 shows the plant species which were associated with *Buxbaumia aphylla* at Soldiers Pond (25) and Bauline (89), their occurrences in 10 quadrats taken at each site, and the total frequency index calculated for each species from the 20 quadrats sampled. The cumulative total of the number of associated species has been plotted against the 10 quadrats sampled at each area (Figure 13). *Cephaloziella* sp., a leafy liverwort, is often associated with *B. aphylla* but no figures are available concerning its frequency since its small size made field identification impossible.

g. Fire Succession

Information concerning fires on the Avalon Peninsula indicates that at least four of the 13 sites where *B. aphylla* was very abundant were burned recently. Soldiers Pond, Bauline, New Harbour, and Bay Bulls were burned in 1957, 1958, 1961, and 1962 respectively (Tapplin, personal communication).

Table 6. Percent ash for five *Buxbaumia aphylla* samples from Soldiers Pond (25).

Sample Number	Sample Weight gm	Weight of Ash gm	Percent Ash
1-1	.300	.0120	4.0
1-2	.380	.0130	3.4
1-3	.260	.0084	3.2
1-4	.630	.0212	3.4
1-5	.113	.0032	2.8

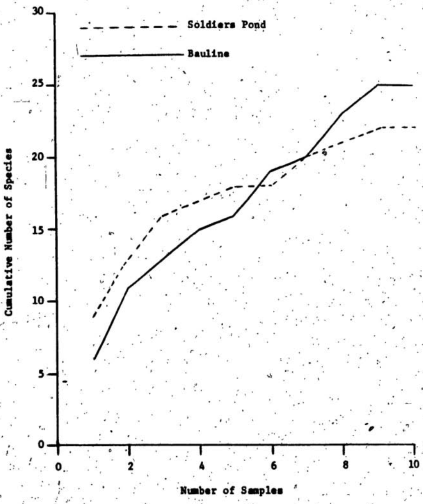
Table 7. Percent ash for five *Buxbaumia aphylla* samples from Bay Bulls (11).

Sample Number	Sample Weight gm	Weight of Ash gm	Percent Ash
2-1	.064	.0022	3.4
2-2	.064	.0022	3.4
2-3	.094	.0032	3.4
2-4	.099	.0036	3.6
2-5	.102	.0032	3.1

Table 8. Plant species associated with *Buxbaumia aphylla* at Soldiers Pond (25) and Bauline (89).

Species	Occurrences in 10 quadrats Soldiers Pond	Bauline	Total frequency index in 20 quadrats
Vascular plants (nomenclature from Gleason and Cronquist, 1963).			
Calamagrostis pickeringii Gray.	2	8	0.50
Cornus canadensis L.	0	4	0.20
Deschampsia flexuosa (L.) Trin.	5	9	0.70
Empetrum nigrum L.	6	1	0.35
Juniperus communis L.	1	1	0.10
Kalmia angustifolia L.	6	4	0.50
Ledum groenlandicum Oeder.	2	3	0.25
Linnaea borealis L.	0	3	0.15
Lycopodium complanatum L.	3	2	0.25
Maianthemum canadense Desf.	7	3	0.50
Potentilla tridentata Soland.	3	4	0.35
Vaccinium angustifolium Ait.	7	8	0.75
V. oxycoccus L.	1	0	0.05
V. vitis-idaea L.	8	2	0.50
Bryophytes (nomenclature from Crum, Steere and Anderson, 1973).			
Bryum sp. (unidentifiable)	0	2	0.10
Dicranum fuscescens Turn.	4	0	0.20
D. spurium Hedw.	1	1	0.10
D. undulatum Brid.	0	2	0.10
Pleurozium schreberi (Brid.) Mitt.	0	1	0.05
Pohlia nutans (Hedw.) Lindb.	2	3	0.25
Polytrichum commune Hedw.	0	1	0.05
P. piliferum Hedw.	0	3	0.15
Rhacomitrium lanuginosum (Hedw.) Brid.	1	0	0.05
Lichens (nomenclature from Pollett and Meades, 1970).			
Cetraria islandica (L.) Ach.	2	0	0.10
Cladonia alpestris (L.) Rabenh.	1	0	0.05
C. coccifera (L.) Willd.	4	2	0.30
C. pyxidata (L.) Hoffm.	1	5	0.30
C. rangiferina Wigg.	4	6	0.50
C. verticellata (Hoffm.) Schaer.	0	3	0.15
Cornicularia aculeatea (Schreb.) Ach.	9	4	0.65

Figure 13. The cumulative number of associated species plotted against the number of quadrats sampled at Soldiers Pond (25) and Bauline (89).


Soldiers Pond
Bauline
Cumulative Number of Species
Number of Samples
30
25
20
15
10
5
0
0
2
4
6
8
10

3. Discussion

The typical habitat for *Buxbaumia aphylla* has been described but the factors controlling its occurrence are still not understood. If *Buxbaumia aphylla* succeeds fires in Newfoundland, it does so in a shorter time than in Sweden where it follows at 17-year intervals (Uggla, 1958). In at least four Newfoundland localities the species is present 11 to 16 years after burning.

Three generations of the moss were studied at Bauline and it was noted that the number of sporophytes decreased for each generation, which supports the theory that *Buxbaumia aphylla* is a weak competitor (Oittinen, 1967). During this time the ground coverage by higher plants showed a steady increase.

In its habitats *Buxbaumia aphylla* shows a close association with the heathland plants *Calamagrostis pickeringii*, *Deschampsia flexuosa*, *Kalmia angustifolia*, *Vaccinium angustifolium*, *V. vitis-idaea*, *Cladonia rangiferina*, and *Cornicularia aculeatea*, as well as *Cephaloziella* sp.

The data presented support the fact that *Buxbaumia aphylla* requires acid soil which is high in organic content.

The mineral element content analysis for *Buxbaumia aphylla* is the first study of this sort dealing with bryophyte sporophytes. Shacklette (1965) analyzed mineral element content for 33 bryophytes but used only gametophytes or mixed gametophytes and sporophytes. Almost all elements found in gametophytes (Shacklette, 1965) were also found in the sporophyte of *B. aphylla* (present study) except for some elements which were not detected, probably due to the small size of the plant samples.

An interesting element found in the *Buxbaumia* sporophytes is silver, which was below the detection limit in the substrate. Shacklette (1965) noticed distinctive patterns of element absorption by different bryophytes, but his sampling was not extensive enough to definitely substantiate or refute these indications. Within these limitations it is interesting to note that Shacklette found silver in only *Polytrichum* and *Atrichum*, both belonging to the Polytrichaceae, an advanced family put close to the Buxbaumiaceae in recent phylogenetic arrangements of mosses (Crum, Steere and Anderson, 1973; Nyholm, 1969). Although vague, one could consider this evidence to support the theory that *Buxbaumia aphylla* is an advanced and not a primitive moss.

Concentration of elements in the plant material also occurs for boron, calcium, copper, lead, magnesium, manganese, nickel, phosphorus, potassium, strontium, and zinc.

The high levels of lead in the plant and soil samples are probably due to the contamination effect of automobile emissions since both sampling sites were within 30 m of highways.

Gallium, vanadium, and zirconium were present in the soil samples but not detected in the plant material, while barium, chromium, and iron were approximately equal in concentration in the soil and the plant samples.

Aluminium and titanium were detected in the plant and soil samples but higher levels were found in the soil than in the plant material.

Chapter IV. Life History

1. Method of Study

After noting the abundance of *Buxbaumia aphylla* at Bauline, ten permanent plots (Figure 14) were set out on 24 June, 1971 to study the life history throughout the year. Two additional plots were set out on 23 September, 1971 after finding immature plants of the next generation, and another two plots were set out on 14 October, 1971. Ten study plots were also set out at New Harbour on 22 July, 1971, but the majority of these were destroyed or torn from the ground by berry-pickers during August and September. However, the few that remained were sufficient to serve as a check against the results obtained at Bauline.

The study plots measured 15 cm X 15 cm and were marked by four wooden stakes, one at each corner. On each stake the plot number and the corner location (A, B, C, or D) were written with Magic Markers* to assure uniformity for future observations (Figure 15).

An observation grid (Figure 7) was designed for use in recording changes within the plots. This grid was subdivided into twenty-five 9 cm^2 sections and was placed directly over the plots during observations to aid in locating individual plants.

The main purposes of these plots were to serve as future reference points to observe *Buxbaumia* development and also to follow the annual production of sporophytes in these areas. The plots were visited and the changes in each were recorded at various times during the year.

When the plots were first set out the 1970-71 generation of *Buxbaumia aphylla* was mature, so only information concerning the number

* Manufactured by Carter's Ink Company of Canada Ltd.

Figure 14. Area at Bauline (89) where permanent observation plots were set up. Photo by Mr. R. Ficken

Figure 15. Close-up of one of the plots shown in Figure 14. Each stake is approximately 0.3 m high. Photo by Mr. R. Ficken

of sporophytes which matured was available. For the 1971-72 generation production, mortality, and maturation of sporophytes were recorded, in addition to observing the phenological changes in the development of the sporophytes. Production, mortality, and maturation of sporophytes were again recorded for the 1972-73 generation and the stage of development was recorded for each of the plants in the plots during each visit since the developmental stages had been defined during the previous generation. From the records of individual plots it was possible to determine at different dates the total number of potential sporophytes in each generation.

To study the rate at which *Buxbaumia aphylla* develops from the immature to the mature state frequent collections were made at Bauline during the 1972-73 generation. The plants collected were located outside the permanent plots. These collections were started on 19 September, 1972 when the young sporophytes of that generation were first located and were continued weekly until development slowed down at which time monthly collections were sufficient.

The numbers of sporophytes in the first three collections were rather small since the plants were difficult to find and only a small percentage of the plants had begun to develop. Subsequent collections were larger, ranging from 73 to 135 sporophytes. Collections were interrupted from 17 November, 1972 until 30 April, 1973, the period in which frost in the ground or frequent snowfalls made collecting impossible. The collections were completed on 19 June, 1973 when all the plants had reached their maximum development. Each sample was analyzed in the laboratory within one day of collection and the number of plants in each of the developmental stages was recorded and expressed as a percentage of the total number of plants collected. For collections made immediately after a sudden frost the number of dead sporophytes was also recorded.

Since male and female gametophytes were not found in nature, attempts were made to grow protonemata in the laboratory using both natural and artificial media. The cultures were started on 25 October, 1972 from spores obtained from mature sporophytes collected on 16 June, 1972 at New Harbour. Spores were dissected from the capsules onto a clean glass slide and then sprinkled on the different media.

Spore germination was attempted on moist filter paper, on vermiculite treated with Knop's Solution (Van Andel, 1952), on humus, and on agar plates containing Marchal's Solution (Van Andel, 1952). Water and nutrient solutions used in treating the cultures were all adjusted to pH 5.0 using 0.1N HCl since in its natural habitat *Buxbaumia aphylla* grows in acid conditions. Cultures were kept in a Climatarium* at 22°C and illuminated for 12 hours in every 24 hours. Light was supplied using two 40-watt incandescent bulbs and two 40-watt fluorescent lamps. One agar culture was also placed on a window ledge and a humus culture was placed in a greenhouse in an attempt to imitate natural conditions. Fungal contamination was observed on some of the agar cultures but this did not appear to affect the growth of the protonemata.

2. Results

a. Phenology

The young sporophytes are first noticeable in the field in very early fall. In 1971 the first new sporophytes were found at Bauline on

* Manufactured by E.H. Sheldon Equipment Company. Muskegon, Michigan.

21 September. In 1972 the first new sporophytes were found at Bay Bulls on 19 September. At this time the plants were immature. They develop rapidly for approximately six weeks, undergoing major morphological changes until the onset of cold weather and snowfalls, at which time some have almost reached their greatest size. During the winter little or no development occurs with the plants protected under a layer of snow, and they resume active development in the spring.

A sporophyte was considered to be fully mature when the operculum is ready to be shed. In 1971 the first sporophyte with the operculum shed was noted on 15 June; and in 1973 on 19 June.

Throughout the sporophyte development 12 distinct morphological stages have been recognized. These are described below and sketched in Figure 6.

Descriptions of Developmental Stages of *Buxbaumia aphylla* Sporophyte

Stage 1. Calyptra and tip of sporophyte above ground. Entire structure bright green in color. Few leaves may be visible.

Stage 2. Seta partly elongated, starting to turn red at base. Leaves have disappeared.

Stage 3. Seta almost completely elongated and completely turned red; calyptra light green in color.

Stage 4. Seta completely elongated and turned red. Sporophyte beginning to swell symmetrically in capsule region just below calyptra. Calyptra beginning to split and be forced off but still present.

Stage 5. Secondary swelling beginning in capsule region located above first. Capsule becoming differentiated into neck, urn, and operculum. Calyptra may be present or absent due to secondary swelling.

5a. Calyptra present

5b. Calyptra shed

Stage 6. Upper and lower swellings in capsule region no longer distinguishable but still symmetrical. Calyptra gone from most sporophytes but may be present in some. When present at this stage the calyptra is usually split vertically due to increased swelling.

6a. Calyptra present

6b. Calyptra shed

Stage 7. Capsule begins to bulge on one side. Calyptra gone by this stage. Capsule is a bright shiny green color and the seta is reddish-brown.

Stage 8. Capsule very much swollen on one side and noticeably asymmetrical. Still bright green in color.

Stage 9. Capsule much more swollen and beginning to lean to one side. Capsule begins to turn reddish-brown underneath. Operculum region also takes on a brownish appearance.

Stage 10. Capsule swollen to its maximum size and leaning more to one side. Entire capsule beginning to take on a reddish-brown color and operculum well differentiated.

Stage 11. Capsule almost horizontal. Seta swelling in region immediately below capsule. Entire plant turned a chestnut brown color and shiny. Mature at this stage.

Stage 12. Spores mature and ready to be shed. First operculum is shed and later capsule may (or may not) rupture to aid in spore dispersal.

12a. Operculum shed

12b. Operculum shed and capsule ruptured

These stages are diagramatically represented in Figure 16 and photographs of actual specimens in several of these stages may be found in Figures 17 to 23.

The rate of development based on the collections which were made from 19 September, 1972 to 19 June, 1973 are shown in Appendix 2. These numbers have been transformed into histograms expressed as percentages of the total number of plants in each collection (Figure 24).

Most of the new generation sporophytes are visible by 16 October. After that date no more new plants were seen until 17 November when only 1% of the plants collected were in Stage 1. The histograms also show that the majority of the plants have reached Stage 8 by 17 November and overwinter in this form. Development had progressed considerably by

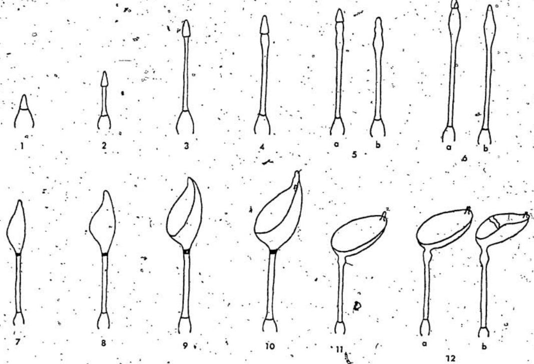


Figure 16. Diagramatic representation of twelve developmental stages of *Buxbaumia aphylla* based on morphological changes during maturation of the sporophyte.

Figure 17. Stage 1 in development of *Buxbaumia aphylla*. X304
7 March, 1973

Figure 18. Stage 2 in development of *Buxbaumia aphylla*. X190
7 March, 1973

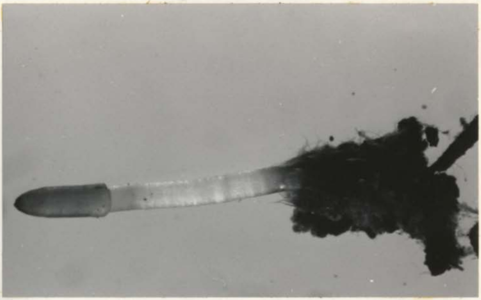


Figure 19. Stage 7 in development of *Buxbaumia aphylla*. Approximately X6
2 October, 1972

Figure 20. Stage 8 in development of *Buxbaumia aphylla*. Approximately X6.5
2 October, 1972

Figure 21. Stage 10 in development of *Buxbaumia aphylla*. X4.3
June 1971.

Figure 22. Stage 11 in development of *Buxbaumia aphylla*. X7.6
7 March, 1973

Figure 23. Stage 12b in development of *Buxbaumia aphylla*. X7.6
7 March, 1973

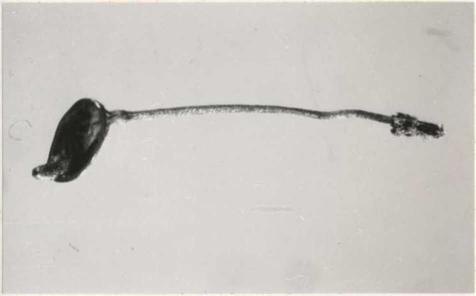
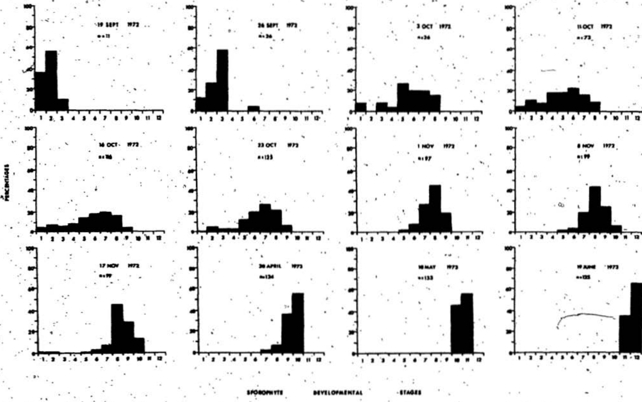


Figure 24. Histograms showing rate of development of *Buxbaumia aphylla* sporophytes based on plant collections made from 19 September, 1972 to 19 June, 1973.


PERCENTAGES
19 SEPT 1972
26 SEPT 1972
3 OCT 1972
11 OCT 1972
16 OCT 1972
23 OCT 1972
1 NOV 1972
8 NOV 1972
17 NOV 1972
20 APRIL 1973
10 MAY 1973
19 JUNE 1973
SPOROPHYTE DEVELOPMENTAL STAGES

30 April, 1973 when the next collection was made. The majority of the plants reach Stages 11 and 12 during the first two weeks in June and at this time are considered mature.

b. Annual Production of Sporophytes

Appendix 3 shows in detail the exact locations, morphological stages, and mortality of each sporophyte noted in the permanent plots at Bauline during the period from June, 1971 to June, 1973. Plot 2 is discussed below as an example to explain the changes observed within the plots.

Plot 2. On 24 June, 1971 the locations of thirteen mature sporophytes of the 1970-71 generation were observed.

On 23 September, 1971 only one new sporophyte of the 1971-72 generation was present while 12 additional sporophytes were present on 14 October, 1971. After the winter it was noticed that 7 more new sporophytes had appeared in the plot by 1 May, 1972, but also that 7 sporophytes had died leaving 13 potential sporophytes on that date. Observations made on 22 May, 1972 and 15 June, 1972 showed that by 15 June, 1972 six of the potential sporophytes on 1 May, 1972 had died, one sporophyte had shed its operculum, and the other six sporophytes were growing but still had not released their spores. The final observation for the 1971-72 generation was made on 1 August at which time five of the six remaining sporophytes had each shed its operculum. Only one sporophyte had not released its spores by 1 August, 1972.

On 3 October, 1972 the first observation on the 1972-73 generation was made. At this time 2 immature sporophytes were present, one at Stage 4 and the other at Stage 2. On 11 October, 1972 it was noticed that the plant at Stage 4 had died while the plant at Stage 2 had progressed to Stage 6. By 17 October, 1972 this sporophyte had reached Stage 7 but on 30 November, 1972 this sporophyte was also dead. No additional sporophytes were observed in Plot 2 during the 1972-73 generation.

From the results in Appendix 3 Tables 9, 10, and 11 were constructed showing the actual number of potential sporophytes at different times of the year for the three generations. In each plot there is a general decrease in the number of sporophytes which matured each year. This can be attributed to the fact that the plots were becoming increasingly covered with other plants, thus eliminating *Buxbaumia aphylla*.

Often the number of potential sporophytes in one generation is far less at maturity than at the beginning. This is due to adverse ecological factors; for example, during the night of 22 October, 1972 the temperature was quite low and a heavy frost covered the ground. As a result the collection of 23 October, 1972 showed a very high mortality. Approximately 25% of the plants collected were dead. During the 1971-72 generation only 41 out of 144 potential plants (29%) observed in the 14 permanent plots at Bauline actually matured. During the 1972-73 generation only 8 out of 61 potential plants (13%) in the same plots matured.

Close analysis of Appendix 3 shows that in some of the plots the sporophytes were found within the same general area within the plots for three generations. For example, in Plot 2 the sporophytes of the three generations observed were all found within 11 of the twenty-five

Table 9. Total number of sporophytes of *Buxbaumia aphylla* which matured in each plot at Bauline during the 1970-71 generation.

Plot Number	Total number of mature sporophytes (24 June, 1971)
1	9
2	13
3	6
4	9
5	8
6	8
7	5
8	24
9	11
10	9
Total	102

Explanation of Tables 10 and 11.

The dates for which the potential number of sporophytes is given represent those dates at which significant changes had been observed in the plots. Observations other than the initial one are given using the formula:

$$a + b - c = d$$

Where,

a = number of sporophytes present in that plot on the previous observation date given in table

b = number of additional sporophytes which had arisen since previous observation date given in table

c = number of sporophytes which had died since previous observation date given in table

and d = number of potential sporophytes present on the date given.

Table 10. Total number of potential sporophytes of *Buxbaumia aphylla* in each plot at Bauline at different dates during the 1971-72 generation.

Plot Number	Total number of potential sporophytes			
	23 Sept. 1971	14 Oct. 1971	1 May 1972	15 June 1972
1	0	0+2-0=2	2+4-2=4	4+0-2=2
2	1	1+12-0=13	13+7-7=13	13+0-6=7
3	0	0+0-0=0	0+4-0=4	4+0-2=2
4	0	0+0-0=0	0+0-0=0	0+0-0=0
5	0	0+2-0=2	2+2-1=3	3+0-2=1
6	0	0+12-0=12	12+5-10=7	7+0-5=2
7	7	7+2-0=9	9+2-3=8	8+0-4=4
8	0	0+7-0=7	7+4-4=7	7+0-2=5
9	0	0+1-0=1	1+0-0=1	1+0-1=0
10	0	0+2-0=2	2+1-0=3	3+0-1=2
26	1	1+5-0=6	6+1-4=3	3+0-2=1
27	1	1+1-0=2	2+0-1=1	1+0-0=1
31	no data	39	39+4-24=19	19+0-10=9
32	no data	13	13+2-10=5	5+0-0=5
Total	10	108	78	41

Table 11. Total number of potential sporophytes of *Buxbaumia aphylla* in each plot at Bauline at different dates during the 1972-73 generation.

Plot Number	Total number of potential sporophytes			
	3 Oct. 1972	17 Oct. 1972	30 April 1973	19 June 1973
1	0	0+1-0=1	1+0-1=0	0+0-0=0
2	2	2+0-1=1	1+0-1=0	0+0-0=0
3	0	0+1-0=1	1+0-1=0	0+0-0=0
4	0	0+0-0=0	0+0-0=0	0+0-0=0
5	0	0+1-0=1	1+0-0=1	1+0-1=0
6	1	1+9-0=10	10+2-7=5	5+0-3=2
7	0	0+3-0=3	3+1-3=1	1+0-0=1
8	0	0+6-0=6	6+1-5=2	2+0-1=1
9	0	0+2-0=2	2+1-2=1	1+0-0=1
10	1	1+0-0=1	1+0-1=0	0+0-0=0
26	0	0+5-2=3	3+0-3=0	0+0-0=0
27	2	2+3-0=5	5+1-5=1	1+0-1=0
31	6	6+7-3=10	10+1-7=4	4+0-2=2
32	3	3+0-0=3	3+1-3=1	1+0-0=1
Total	15	47	16	8

9 cm^2 sections of the grid. In the other 14 sections of the grid, no sporophytes were noticed during the three generations. This indicates that the protonemata may be persistent year after year and produce new sporophytes each year.

c. Culturing

Spores germinated in each of the methods tried but the vigor of growth and the length of time to obtain germination varied with conditions and culture media used.

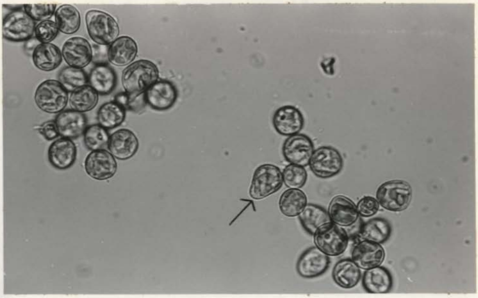
In the Climatarium germination of spores on the moist filter paper and vermiculite was first noticed after 12 days. The humus and agar cultures showed germinating spores after 7 days. However, in the Climatarium growth was slow on all cultures and unsuitable for obtaining a good growth of protonemata. Both the humus culture in the greenhouse and the agar culture on the window ledge showed spore germination within 5 days. Growth was vigorous and both cultures formed a dense mat of interwoven protonemal filaments within one month. Spore germination and growth of filaments were photographed from samples taken periodically from the agar culture on the window ledge (Figures 25, 26, and 27). The protonemata failed to produce sex organs during the eight months they were observed growing.

When the agar cultures were 3-4 months old they began to dry out and the protonemata had to be transferred to new media. Protonemal filaments in these old cultures began to break up and the cells became thick-walled and rounded. These structures (Figures 28 and 29) are probably used in asexual propagation of the protonemata although germination of

Figures 25 and 26. Initial stages of spore germination in *Buxbaumia aphylla* from cultures 7 days old.

Figure 25. Note that spore wall merely bulges (arrow). X760
31 October, 1972.

Figure 26. Note formation of first cross wall (arrow) in filament development. X1188 31 October, 1972.



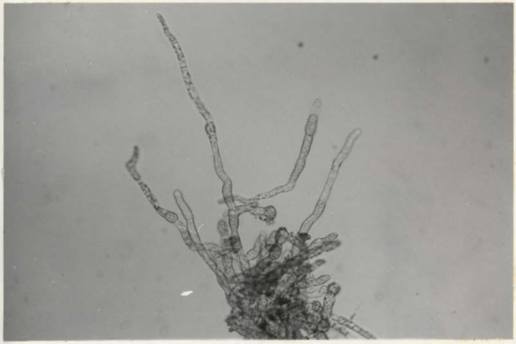


Figure 27. Protonemal filaments of *Buxbaumia aphylla* from culture 45 days old. X190. 8 December, 1972.

Figures 28 and 29. Formation of possible asexual propagation structures in *Buxbaumia aphylla* protonemata. Note chainlike series of rounded cells which break apart. From cultures 156 days old.

Figure 28. X190. 29 March, 1973.

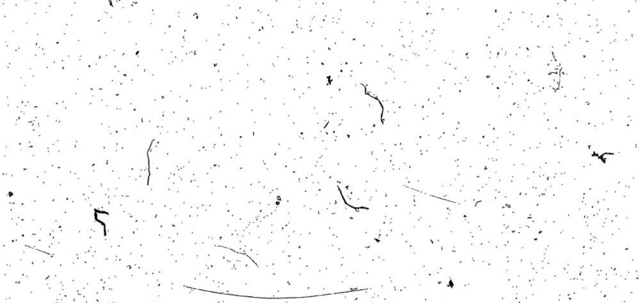


Figure 29. X304. 29 March, 1973.

these structures was not observed. This same phenomenon was noted by Dening (1928-29) who found that the rounded cells did germinate into new protonemata.

3. Discussion

The life history of *Buxbaumia aphylla* has been studied continuously from June, 1971. In Newfoundland each generation produced fewer sporophytes than the preceding generation indicating that the plants may be becoming progressively less abundant after a short flourishing period, as reported in Sweden by Uggla (1958).

Mortality rate is high among the immature sporophytes. Most sporophytes which die do so between 15 October and 15 November when cold temperatures at night are common. During this time the sporophytes affected may be at any stage from 1 to 9. These sudden adverse conditions affect the sporophytes when they are most actively developing and the cells are rapidly dividing.

In spring when most plants are developed to Stage 9 or beyond, mortality is not as high. Most plants do not seem to be affected when Stage 11 is reached (June of the following year). However, it was noticed that several plants had the capsule broken from the seta in Stage 11. This is probably due to physical factors such as wind and rain, since the sporophytes become brittle when they mature.

Svihla and Svihla (1926) followed the maturation of one generation of *Buxbaumia aphylla* and observed a notable decrease in the number of sporophytes present as the plants matured. They attributed this decrease in numbers to a 'black-spored fungus' which they observed growing on the capsules of some sporophytes. Gyorffy (1911) also reported dark spots on the capsules of *Buxbaumia viridis* and said they were caused by a fungus, *Cladosporium herbarum* (Pers.) Link., which is parasitic upon many plants. In my collections of *Buxbaumia aphylla* a black-spored fungus was seen on the upper surface of the capsule of only one sporophyte. This sporophyte had matured, shed its operculum and had the capsule split to release the spores, and was apparently unaffected by the fungal growth.

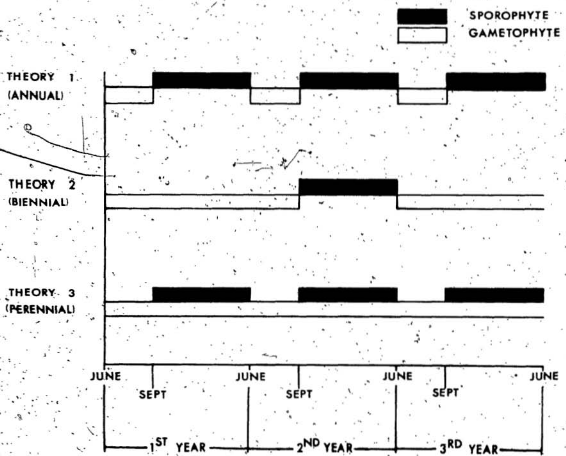
I speculate that the protonemata may persist from one year to the next, possibly being propagated asexually by gemmae or structures similar to those observed in culture (Figures 28 and 29).

There are three main theories which could explain the entire life cycle (Figure 30). The three theories assume that the spores germinate immediately after shedding since in culture it was noticed that the spores germinated in a short time. The first theory is that sporophytes found in September may arise from spores shed in the preceding June. If this is the case one must assume that within this four-month period, the spore germinates to produce a protonema, the protonema produces sex organs which mature, and also that the egg of the archegonium is fertilized. If the rate of development of the protonema in nature is similar to the rate of development in culture (Mueller, 1972) one sees that four months would be too short a time for the development, even if climatic conditions were suitable.

The next two theories are based on the hypothesis that *Buxbaumia aphylla* protonemata are persistent for several years.

The second theory is that the spores shed in June germinate but do not produce sex organs until approximately 10 to 12 months later, and give rise to sporophytes in September of the year following spore-shedding.

Figure 30. Diagramatic representation of three theories to explain the life history of *Buxbaumia aphylla*.

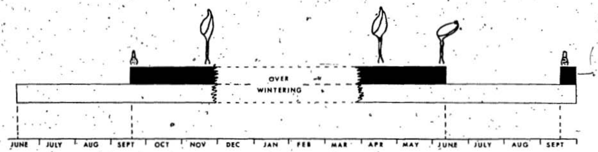

SPOROPHYTE
GAMETOPHYTE
THEORY 1
(ANNUAL)
THEORY 2
(BIENNIAL)
THEORY 3
(PERENNIAL)
JUNE
SEPT
JUNE
SEPT
JUNE
SEPT
JUNE
1ST YEAR
2ND YEAR
3RD YEAR

The third theory is an extension of the second and considers the idea that the protonemata may persist more than one year and produce sporophytes each year. Thus, sporophytes found in September may be from protonemata one, two, or possibly three years old.

If either the second or third theory is acceptable this would refute the assumption that *Buxbaumia aphylla* is an annual moss (Grout, 1938; Taylor, 1972) and would indicate that it is actually a biennial, triennial, or perennial plant.

From my evidence the third theory would seem to be the most likely: that the protonemata persist for several years, possibly reproducing the species asexually by protonemal gemmae, and that each September a new sporophytic generation is initiated from the perennial protonemata, resulting in a new crop of spores the following June. Figure 31 further illustrates this theory, with a persistent protonemal stage, and also shows the phenology of the sporophyte.

Figure 31. Possible life history of *Buxbaumia aphylla* (Theory 3) in relation to phenology of sporophyte.


OVER
WINTERING
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT

Literature Cited

Anderson, L.E. (1951). Mosses of North Carolina VI. Encalyptaceae to Pottiaceae. Bryologist 54(3): 145-161.

Baker, H.R. (1927). *Buxbaumia aphylla* near Newark, Delaware. Bryologist 30(3): 45.

Britton, E.G. (1896). The humpbacked elves. The Observer 7(March): 105-113.

__________. (1901). Some further observations on *Buxbaumia*. Bryologist 4(2): 33-34.

Burges, A. (1932). Notes on the mosses of New South Wales. I. Additional records and description of a new species of *Buxbaumia*. Proc. Linn. Soc. N. S. Wales 57(3/4): 239-244.

Carroll, R.P. (1935). *Buxbaumia aphylla* L. Bryologist 38(6): 116.

Conard, H.S. (1956). The Mosses and Liverworts. Wm. C. Brown Company Publishers. Dubuque, Iowa. 226 p.

Corner, R.W.M. (1967). *Buxbaumia aphylla* (Hedw.): Its occurrence on old colliery debris in Scotland. Trans. of Brit. Bry. Soc. 5(2): 350

__________. (1969). Further observations on the distribution of *Buxbaumia aphylla* Hedw. on colliery debris. Trans. of Brit. Bry. Soc. 5(4): 828-829.

Cresson, E.T. (1904). Notes on rare or little known mosses. Bryologist 7(3): 51-52.

Crum, H.A., W.C. Steere, and L.E. Anderson (1973). A new list of mosses of North America north of Mexico. Bryologist 76(1): 85-130.

Dening, K. (1928-29). Entwicklungsgeschichtliche Untersuchungen am Gametophyten von *Buxbaumia aphylla* (L.). Verhandl. Naturhist. Ver. Preuss. Rheinlande U. Westfalens 85: 306-444.

Durand, E.J. (1901). Some further observations on *Buxbaumia*. Bryologist 4(2): 32-33.

Eastwood, S.K. (1936). Notes on *Buxbaumia aphylla* Linnaeus, Hedwig. Bryologist 39(6): 127-129.

Forman, R.T.T. (1965). A system of studying moss phenology. Bryologist 68(3): 289-300.

Gleason, H.A., and A. Cronquist (1963). Manual of vascular plants of Northeastern United States and adjacent Canada. D. Van Nostrand Company, Inc., Princeton, New Jersey. 810 p.

Grout, A.J. (1901). Notes on *Buxbaumia*. Bryologist 4(1): 8-9.

__________. (1902). The Peristome IV. Bryologist 5(6): 94-95.

__________. (1938). Moss flora of North America north of Mexico. Vol. 1(3). Newfane, Vermont.

Gyorffy, I. (1911). *Cladosporium herbarum* in *Buxbaumia viridi* parasitum. Bryologist 14(3): 41-43.

Hedwig, J. (1801). Species Muscorum Frondosorum. Leipzig. 353 p.

Huntington, J.W. (1901). Notes on *Baxbaumia*. Bryologist 4(1): 8-9.

Iwatsuki, Z. and A.J. Sharp (1969). The bryogeographical relationships between eastern Asia and North America, I. J. Hattori Bot. Lab. 30: 152-170.

Jackson, M.L. (1965). Soil Chemical Analysis. Prentice-Hall, Inc. Englewood Cliffs, N.J. 498 p.

Jamieson, D.W., and L.G. Holmberg (1969). *Buxbaumia piperi* new to California. Bryologist 72(1): 72-73.

Kaiser, G.B. (1921). Little journeys into Mossland III. Bryologizing in early spring. Bryologist 24(2): 19-20.

Lye, K.A. (1968). Moseflora. Universitetsforlaget, Oslo. 140 p.

McClymont, J.W. (1950). Notes on *Buxbaumia*. Bryologist 53(4): 276-277.

Meades, W. (1973). A phytosociological classification of Avalon Peninsula Heathlands. M.Sc. thesis, Memorial University of Newfoundland.

Mueller, D.M.J. (1972). Observations on the ultrastructure of *Buxbaumia* protonema. Plasmadesmata in the cross walls. Bryologist 75(1): 63-68.

Nyholm, E. (1969). Illustrated moss flora of Fennoscandia. II. Musci, fasc. 6. Stockholm, Sweden.

Oittinen, V. (1967). The distribution and ecology of *Buxbaumia aphylla* and *B. viridis* in Finland. Annales Botanici Fennici 4(1): 81-86.

Pettifer, A.J. (1956). *Buxbaumia aphylla* Hedw. in Surrey. Trans. of Brit. Bry. Soc. 3(1): 125.

Pitman, E.M. (1930). Treasures of a South Portland (Maine) woodsy area. Bryologist 33(2): 7-8.

Pollett, F.C., and W.J. Meades (1970). A preliminary checklist of the peatland flora in Newfoundland. Forest Research Laboratory, St. John's, Newfoundland. Information Report N-X-54.

Shacklette, H.T. (1965). Element content of bryophytes. Geological Survey Bulletin 1198-D. U.S. Gov. Printing Office, Washington.

Smith, G.L. (1963). Additions to the moss flora of Iowa. Proc. Iowa Acad. Sci. 70: 64-67.

Steere, W. (1942). Notes on Michigan bryophytes IV. Bryologist 45(6): 153-172

Svihla, R.D., and A. Svihla (1926). Notes on *Buxbaumia aphylla* Haller. Bryologist 29.(3&4): 36-37.

Taylor, J. (1972). The habitat and orientation of capsules of *Buxbaumia aphylla* in the Douglas Lake Region of Michigan. The Michigan Botanist 2: 70-73.

Udar, R., S.C. Srivastava, and D. Kumar (1970). Genus *Buxbaumia* in India. Current Science 39(1): 14-15.

____________________ (1971). A new species of *Buxbaumia* Hedwig, *B. himalayensis* Udar, Srivastava et Kumar, from Deoban, Western Himalayas, India. Trans. of Brit. Bry. Soc. 6: 266-269.

Uggla, E. (1958). Skogsbrandfalt I Muddus National Park. Acta Phytogeographica Suecica 41: 34-116.

Van Andel, O.M. (1952). Germination of the spores and development of primary and secondary protonema of *Funaria hygrometrica*. Trans. of Brit. Bry. Soc. 2: 74-81.

Wheeler, H. (1901). Notes on *Buxbaumia*. Bryologist 4(1): 9.

Appendix 1. Mineral element content for plant and soil samples from Soldiers Pond (25) and Bay Bulls (11).

The "normal" lower limit of detection for the various elements is listed next to the element. There was a problem of small sample size for the sporophyte samples and the analyst had to dilute more than normal with the sodium-silica matrix in order to have enough material. This dilution has the effect of raising the lower limit of detection and gives rise to variable "less than" values. This lower limit is given for the samples with greater-than-normal matrix dilution.

Legend:

G = Greater than 10% or greater than value shown,

- = Not looked for,

N = Not detected, at limit of detection or at value shown,

and L = Detected, but below limit of determination or below value shown.

Mineral element analysis of five soil samples and five plant samples from Soldiers Pond (25).

Elements	Sample 1-1 Plant	Sample 1-1 Soil	Sample 1-2 Plant	Sample 1-2 Soil	Sample 1-3 Plant	Sample 1-3 Soil	Sample 1-4 Plant	Sample 1-4 Soil	Sample 1-5 Plant	Sample 1-5 Soil
Emission Spectrography Method										
%										
Aluminum .001	.1	2.	.2	2.	.2	1.75	.3	1.5	.3	1.75
Calcium .002	7.	.1	10	.07	10	.1	10	.1	10	.07
Iron .001	.2	.18	.2	.18	.2	.2	.2	.2	.3	.15
Magnesium .002	5.	.03	5.	.018	5.	.025	5.	.02	5.	.02
Phosphorus .2	3.	N	3.	N	5.	N	5.	N	5.	N
Potassium 10 *	G	3.	G	3.	G	2.	G	2.5	G	3.
Silicon	-	G	-	G	-	G	-	G	-	G
Sodium .05	-	1.75	-	1.5	-	1.5	-	1.5	-	1.5
Titanium .0002	.015	.03	.015	.03	.015	.03	.015	.03	.03	.03
ppm										
Antimony 150	N	N	N	N	N	N	N	N	N	N
Arsenic 1000	N	N	N	N	N	N	N	N	N5000	N
Barium 1.5	500	600	500	500	500	500	1000	500	1000	500
Beryllium 1	N	N	N	N	N	N	N	N	N10	N
Bismuth 10	N	N	N	N	N	N	N	N	N50	N
Boron 20	200	L	70	L	200	L	50	L	500	L
Cadmium 20	N	N	N	N	N	N	N	N	N300	N
Cerium 150	N	N	N	N	N	N	N	N	N	N
Chromium 1	N	L	2.	L	2.	1.25	2.	1.25	N5*	L
Cobalt 3	N	L	N	L	N	L	N	L	N30	L
Copper 1	100	1.5	100	1.5	100	1.75	150	2.5	100	1.5
Europium 100	N	N	N	N	N	N	N	N	N	N
Gallium 5	N	10	N	7	N	7	N	7	N	7
Germanium 10	N	N	N	N	N	N	N	N	N	N
Gold 20	N	N	N	N	N	N	N	N	N150	N
Hafnium 100	N	N	N	N	N	N	N	N	N	N
Indium 10	N	N	N	N	N	N	N	N	N	N
Lanthanum 30	N	N	N	N	N	N	N	N	N300	N
Lead 10	70	15	100	15	100	17.5	100	15	100	15
Lithium 50	N	N	N	N	N	N	N	N	N	N
Manganese	7000	50	7000	40	10,000	70	10,000	70	10,000	30
Molybdenum 3	N	N	N	N	N	N	N	N	N20	N
Nickel 5	5	L	10	L	7	L	10	L	N30	L
Niobium 10	N	L	N	L	N	L	N	L	N50	L
Palladium 1	N	N	N	N	N	N	N	N	N10	N
Platinum 30	N	N	N	N	N	N	N	N	N300	N
Rhenium 30	N	N	N	N	N	N	N	N	N	N
Scandium 5	N	N	N	N	N	N	N	N	N30	N
Silver .05	7	N	5	N	2	N	7	N	50	N
Strontium 5	1000	70	1000	60	1000	40	1000	40	1000	50
Tantalum 200	N	N	N	N	N	N	N	N	N	N
Tellurium 2000	N	N	N	N	N	N	N	N	N10,000	N
Thallium 50	N	N	N	N	N	N	N	N	N	N
Thorium 200	N	N	N	N	N	N	N	N	N	N
Tin 10	N	N	N	N	N	N	N	N	N50	N
Tungsten 100	N	N	N	N	N	N	N	N	N5000	N
Uranium 500	N	N	N	N	N	N	N	N	N3000	N
Vanadium 7	N	8.5	N	7	N	7	N	7	N50	L
Ytterbium 1	N	L	N	L	N	L	N	L	N	L
Yttrium 10	N	L	N	L	N	L	N	N	N50	L
Zinc 200	700	N	700	N	1000	N	1000	N	N2000	N
Zirconium 10	N	70	N	70	N	60	N	70	N50	30
Atomic Absorption Method										
Calcium (CaO) %	-	0.21	-	0.16	-	0.21	-	0.19	-	0.17
Phosphorus (P_2O_5) %	-	0.10	-	0.19	-	0.10	-	0.09	-	0.10
Zinc ppm	-	12.5	-	10	-	12.5	-	15	-	15

* For Potassium, 10 represents the upper detection limit.

Mineral element analysis of five soil samples and five plant samples from Bay Bulls (11).

Elements	Sample 2-1 Plant	Sample 2-1 Soil	Sample 2-2 Plant	Sample 2-2 Soil	Sample 2-3 Plant	Sample 2-3 Soil	Sample 2-4 Plant	Sample 2-4 Soil	Sample 2-5 Plant	Sample 2-5 Soil
Emission Spectrography Method										
%										
Aluminum .001	.5	2.5	.3	5.	.5	5.	.3	5.	.2	5.
Calcium .002	7.	.13	5.	.15	5.	.15	5.	.15	7.	.13
Iron .001	.3	.85	.2	1.5	.3	1.5	.3	1.75	.5	2.
Magnesium .002	5.	.13	5.	.15	5.	.15	5.	.15	5.	.18
Phosphorus .2	7.	N	5.	N	5.	N	5.	N	5.	N
Potassium 10*	G	1.5	G	1.5	G	1.[illegible]	G	1.5	G	1.5
Silicon	-	G	-	G	-	G	-	G	-	G
Sodium .05	-	.53	-	1.5	-	1.25	-	1.75	-	1.75
Titanium .0002	.03	.25	.02	.25	.03	.25	.03	.1	.05	.2
ppm										
Antimony 150	N2000	N	N2000	N	N1000	N	N1000	N	N1500	N
Arsenic 1000	N10,000	N	N10,000	N	N5000	N	N5000	N	N7000	N
Barium 1.5	300	150	200	200	500	200	500	250	500	200
Beryllium 1	N15	N	N20	N	N10	N	N10	N	N10	N
Bismuth 10	N100	N	N100	N	N50	N	N50	N	N70	N
Boron 20	1000	L	700	L	500	L	500	L	700	L
Cadmium 20	N500	N	N500	N	N300	N	N300	N	N300	N
Cerium 150	N	L	N	L	N	L	N	L	N	L
Chromium 1	N10	17.5	N10	30	N5	30	N5	30	N7	30
Cobalt 3	N50	L	N50	L	N30	L	N30	L	N30	L
Copper 1	150	10	100	8.5	100	8.5	100	8	150	7
Europium 100	N	N	N	N	N	N	N	N	N	N
Gallium 5	N	20	N	20	N	20	N	20	N	15
Germanium 10	N	N	N	N	N	N	N	N	N	N
Gold 20	N200	N	N200	N	N150	N	N150	N	N150	N
Hafnium 100	N	N	N	N	N	N	N	N	N	N
Indium 10	N	N	N	N	N	N	N	N	N	N
Lanthanum 30	N500	L	N500	L	N300	L	N300	L	N300	L
Lead 10	N100	15	N100	30	N50	15	N50	15	N70	13
Lithium 50	N	N	N	N	N	N	N	N	N	N
Manganese	15,000	150	10,000	100	10,000	150	10,000	150	10,000	150
Molybdenum 3	N20	N	N30	N	N20	N	N20	N	N20	N
Neodymium	-	L	-	L	-	L	-	L	-	L
Nickel 5	N50	L	N50	L	N30	L	N30	L	N30	L
Niobium 10	N100	L	N100	L	N50	L	N50	L	N70	L
Palladium 1	N20	N	N20	N	N10	N	N10	N	N15	N
Platinum 30	N500	N	N500	N	N300	N	N300	N	N300	N
Praseodymium	-	N	-	N	-	N	-	N	-	N
Rhenium 30	N	N	N	N	N	N	N	N	N	N
Samarium	-	N	-	N	-	N	-	N	-	N
Scandium 5	N50	8	N50	13	N30	13	N30	12	N30	8
Silver .05	N5	N	N5	N	10	N	5	N	7	N
Strontium 5	700	70	300	70	1000	85	500	70	700	70
Tantalum 200	N	N	N	N	N	N	N	N	N	N
Tellurium 2000	N20,000	N	N20,000	N	N10,000	N	N10,000	N	N15,000	N
Thallium 50	N	N	N	N	N	N	N	N	N	N
Thorium 200	N	N	N	N	N	N	N	N	N	N
Tin 10	N100	N	N100	N	N50	N	N50	N	N70	N
Tungsten 100	N1000	N	N1000	N	N500	N	N500	N	N700	N
Uranium 500	N3000	N	N3000	N	N3000	N	N3000	N	N3000	N
Vanadium 7	N70	50	N70	60	N50	70	N50	70	N50	70
Ytterbium 1	N	1.75	N	2	N	2	N	2	N	2
Yttrium 10	N100	15	N100	15	N50	15	N50	15	N70	15
Zinc 200	N3000	N	N3000	N	N2000	N	N2000	N	N2000	N
Zirconium 10	N100	100	N100	85	N50	85	N50	100	N70	85
Atomic Absorption Method										
Calcium (CaO), %	-	.22	-	.19	-	.26	-	.21	-	.18
Phosphorus (P_2O_5) %	-	.22	-	.20	-	.19	-	.25	-	.23
Zinc ppm	-	33	-	30	-	33	-	35	-	35

* For Potassium, 10 represents the upper detection limit.

Date	Number of sporophytes reaching stage												Total
	1	2	3	4	5	6	7	8	9	10	11	12	
19 Sept, 1972	4	6	1										11
26 Sept, 1972	3	7	15			1							26
3 Oct, 1972	2		2	1	7	5	5	4					26
11 Oct, 1972	3	7	5	13	13	16	11	5					73
16 Oct, 1972	5	9	7	10	17	21	23	19	5				116
23 Oct, 1972	1	7	4	4	16	25	33	27	8				125
1 Nov, 1972					2	8	26	43	18				97
8 Nov, 1972					2	4	19	43	24	7			99
17 Nov, 1972	1	1			1	3	7	45	28	13			99
30 Apr, 1973							3	8	45	68			124
18 May, 1973										60	73		133
19 June, 1973											47	88	135

Appendix 2. Number of sporophytes reaching each developmental stage for collections of *Buxbaumia aphylla* made during the 1972-73 generation.

Appendix 3. Observations on *Buxbaumia aphylla* in permanent plots at Bauline at various dates from 24 June, 1971 to 19 June, 1973.

Legend:

▼ = Location of sporophytes in 1970-71 generation

● = Location of sporophytes in 1971-72 generation and 1972-73 generation

■ = Dead sporophytes

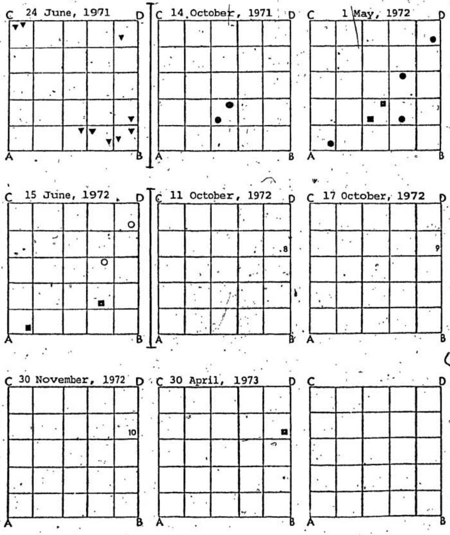
O = Sporophytes with operculum shed

1-12 = Actual stages of sporophytes at different times during 1972-73 generation.

Each generation is separated by a solid line.

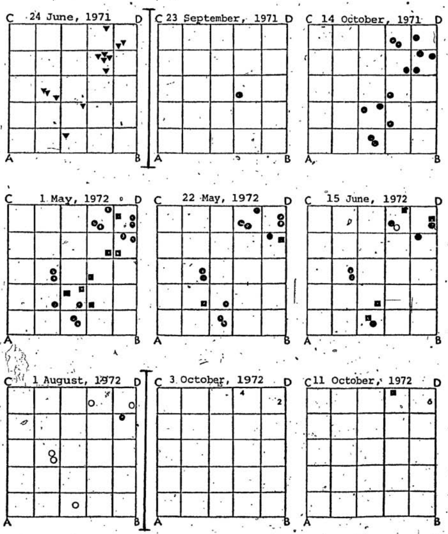
Permanent Plots for Studies on *Buxbaumia aphylla*.

Location: Bauline ; Plot Number 1.



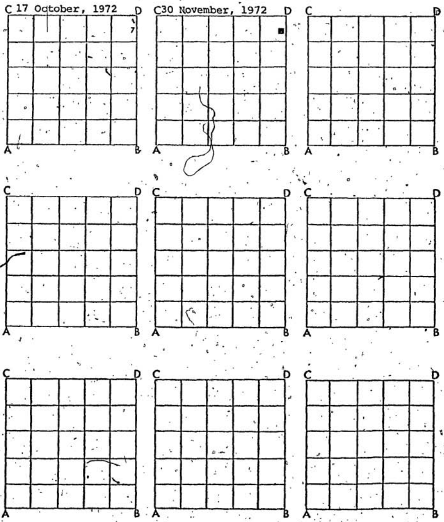
Permanent Plots for Studies on *Buxbaumia aphylla*.

Location: Bauline ; Plot Number 2 .



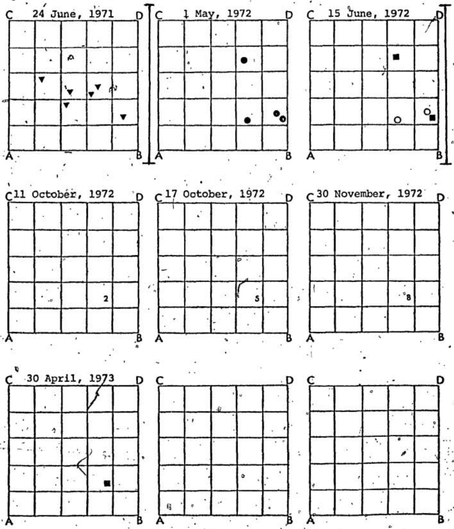
Permanent Plots for Studies on *Buxbaumia aphylla*.

Location: Bauline , Plot Number 2 .



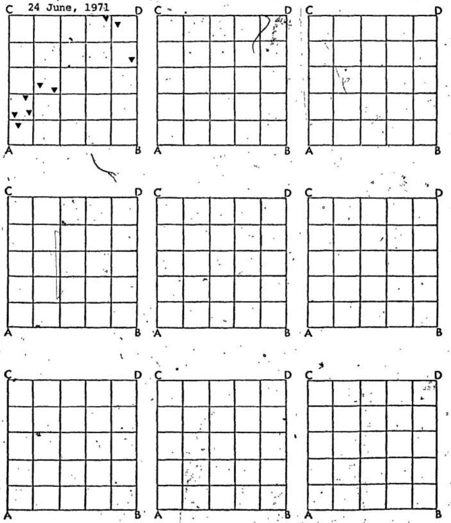
Permanent Plots for Studies on Buxbaumia aphylla.

Location: Bauline , Plot Number 3 .



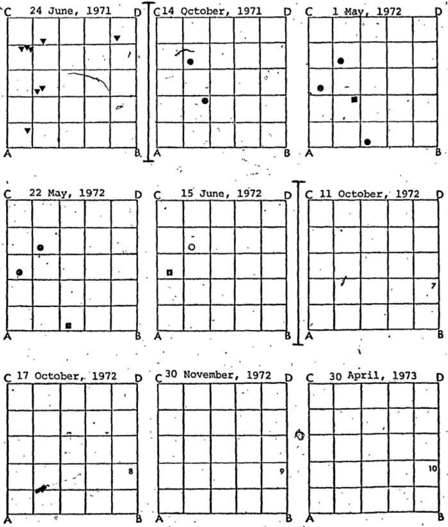
Permanent Plots for Studies on *Buxbaumia aphylla*.

Location: Bauline, Plot Number 4.



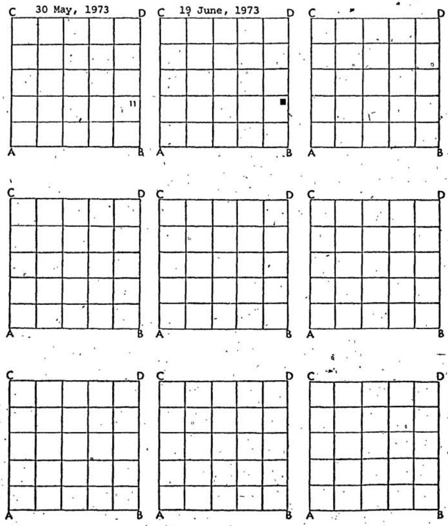
Permanent Plots for Studies on *Buxbaumia aphylla*.

Location: Bauline ; Plot Number 5 .



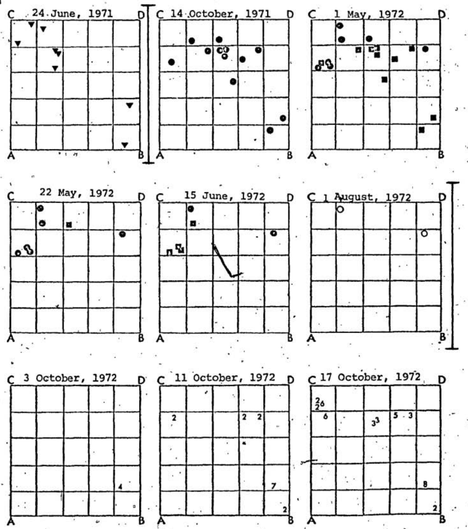
Permanent Plots for Studies on *Buxbaumia aphylla*.

Location: Bauline ; Plot Number 5 .



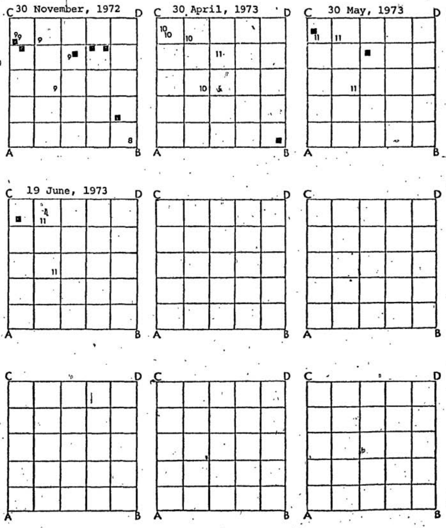
Permanent Plots for Studies on <u>Buxbaumia aphylla</u>.

Location: Bauline , Plot Number 6 .



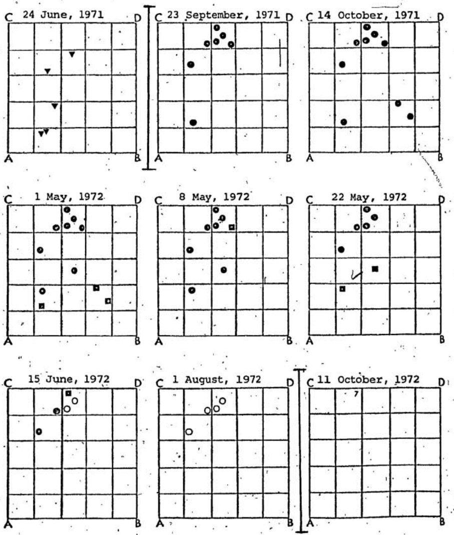
Permanent Plots for Studies on *Buxbaumia aphylla*.

Location: Bauline ; Plot Number 6 .



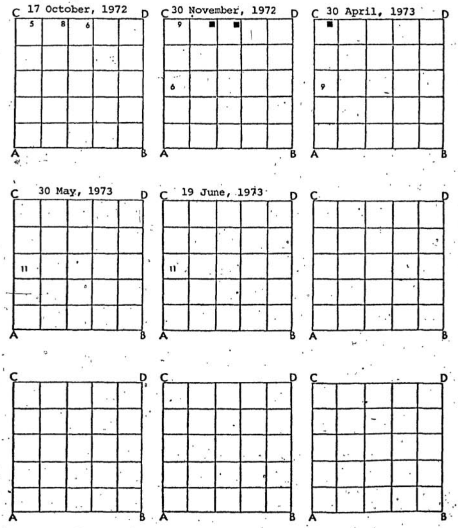
Permanent Plots for Studies on *Buxbaumia aphylla*.

Location: Bauline ; Plot Number 7 .



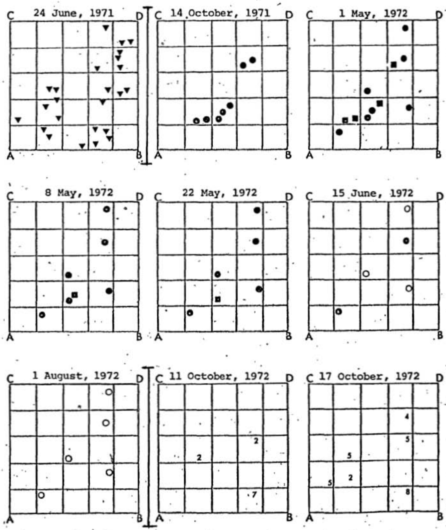
Permanent Plots for Studies on *Buxbaumia aphylla*.

Location: Bauline ; Plot Number 7 .



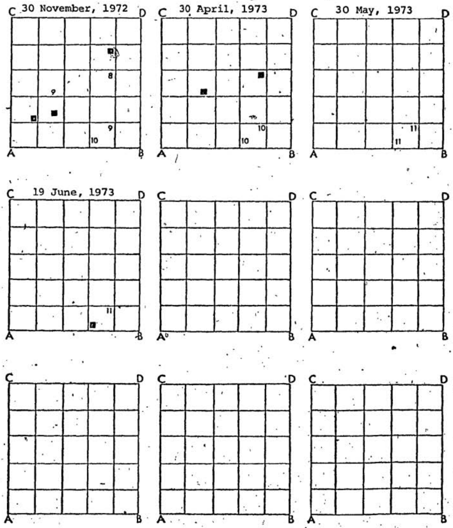
Permanent Plots for Studies on Buxbaumia aphylla.

Location: Bauline ; Plot Number 8 .



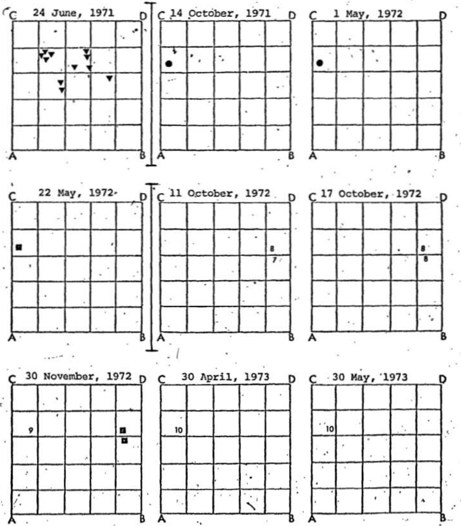
Permanent Plots for Studies on *Buxbaumia aphylla*.

Location: Bauline , Plot Number 8 .



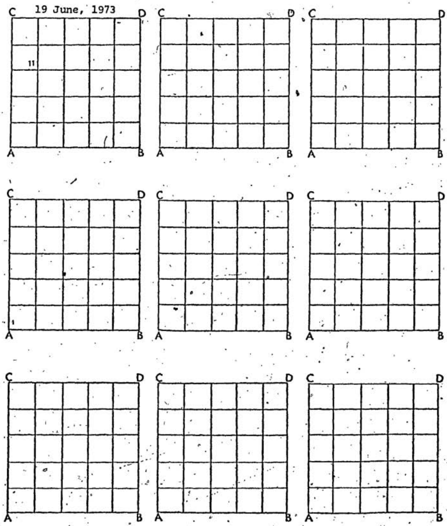
Permanent Plots for Studies on Buxbaumia aphylla.

Location: Bauline ; Plot Number 9 .



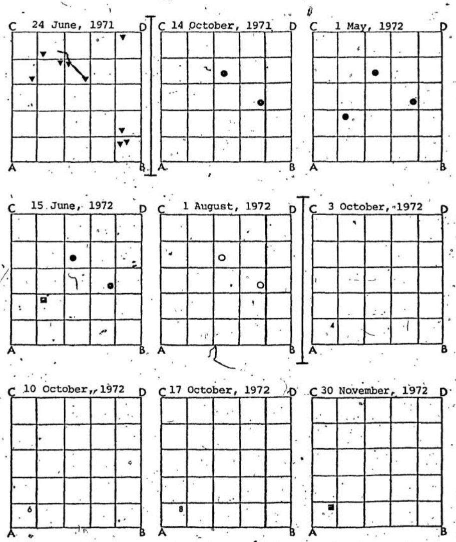
Permanent Plots for Studies on *Buxbaumia aphylla*.

Location: Bauline ; Plot Number 9 .



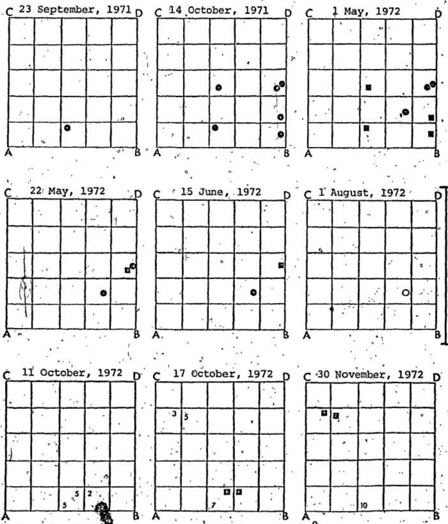
Permanent Plots for Studies on *Buxbaumia aphylla*.

Location: Bauline ; Plot Number 10 .



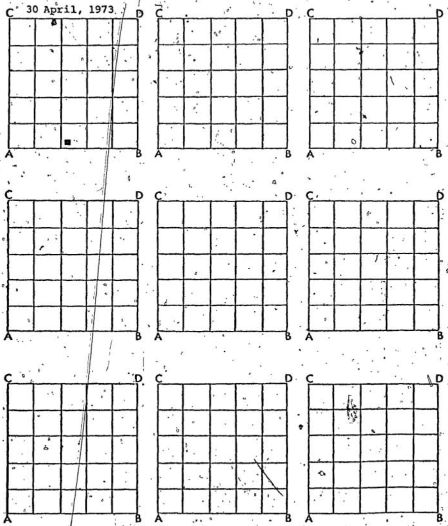
Permanent Plots for Studies on Buxbaumia aphylla.

Location: Bauline, Plot Number 26.



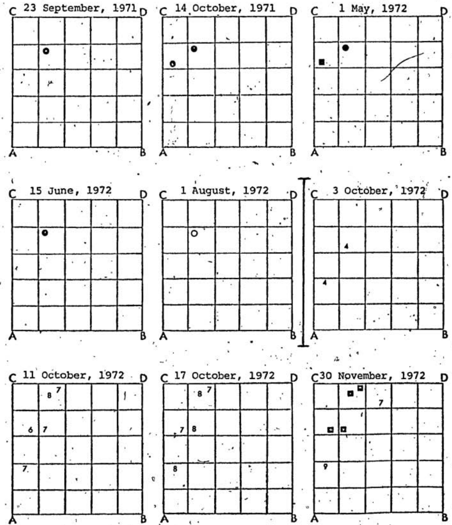
Permanent Plots for Studies on <u>Buxbaumia aphylla</u>.

Location: Bauline ; Plot Number 26



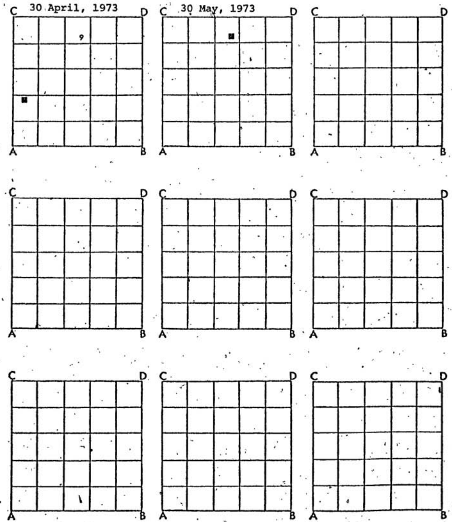
Permanent Plots for Studies on Buxbaumia aphylla.

Location: Bauline, Plot Number 27.



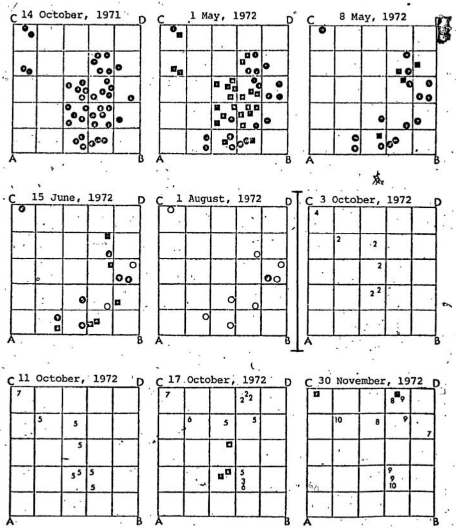
Permanent Plots for Studies on Buxbaumia aphylla.

Location: Bauline, Plot Number 27.



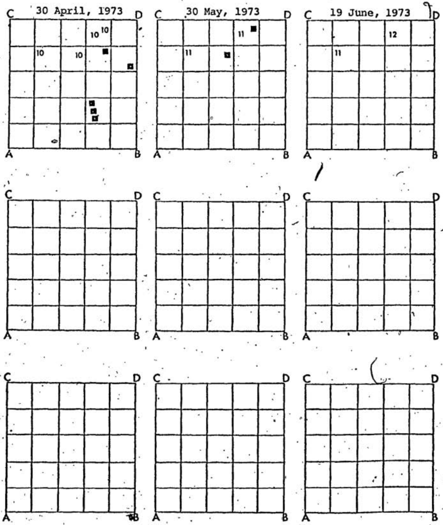
Permanent Plots for Studies on Buxbaumia aphylla.

Location: Bauline ; Plot Number 31 .



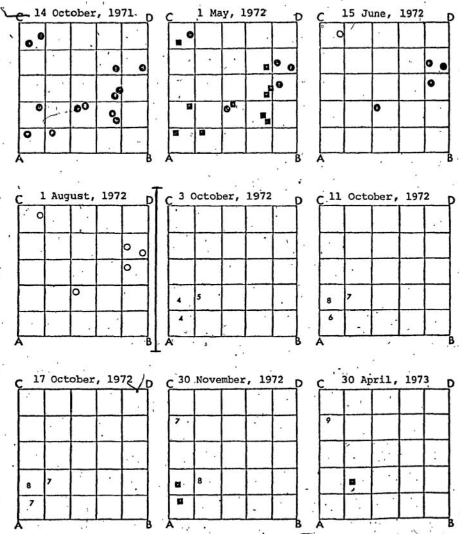
Permanent Plots for Studies on Buxbaumia aphylla.

Location: Bauline, Plot Number 31.



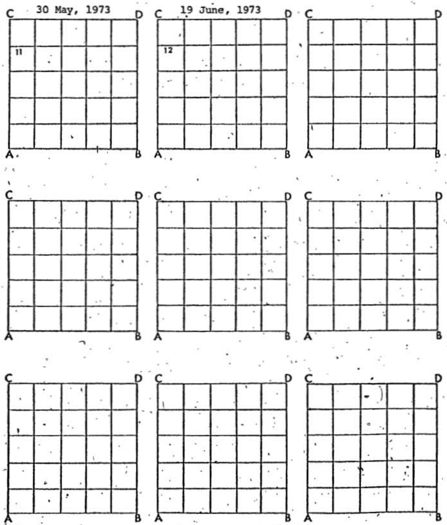
Permanent Plots for Studies on *Buxbaumia aphylla*.

Location: Bauline ; Plot Number 32 .



Permanent Plots for Studies on _Buxbaumia aphylla_.

Location: Bauline ; Plot Number 32 .



MEMORIAL UNIVERSITY OF NEWFOUNDLAND

Department of Sociology & Anthropology

April 2, 1971

Dear Student:

I am a graduate student in Sociology at Memorial University of Newfoundland and am presently engaged in research on the Leisure Patterns of University Students.

Your name, which will now receive a code number, has been picked on a stratified random basis in accordance with information issued by the Registrar's Office. You are a member of the sample which will be used for my study.

A questionnaire will be forwarded to you in a few days. I would appreciate your time and effort in filling out this questionnaire. It will take approximately 30 minutes to complete.

Your co-operation is extremely important in making this research a success.

The questionnaire should be filled out and returned before the end of April or at your earliest convenience.

Would you kindly assist me in this research. Thank you.

Sincerely yours,

Barbara Wakeham.

If you wish to contact me about my work

Home Phone----------- 726-2858

University----------- 579-5081 Ext. 2158