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Phenology of *Racomitrium lanuginosum* growing at a seasonally snow-covered site on Mt. Fuji, Japan

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ABSTRACT

We investigated the seasonality of the development of the gametangia and sporophytes of *Racomitrium lanuginosum* growing at a seasonally snow-covered site (*ca.* 2200 m altitude) on Mt. Fuji, Central Honshu, Japan. Shoots of *R. lanuginosum* were collected every 2 weeks during the snow-free period (June–November) in 2014. The number of inflorescences and the numbers, sizes, and developmental stages of the male and female gametangia and sporophytes were recorded. Archegonia developed quickly in early spring, but antheridia took longer to develop from the previous summer. Fertilization occurred in June and July and spore dispersal occurred in June of the following year. The archegonia took 1 month to mature, the antheridia took 7–10 months, and the sporophytes took 10 months. The development of the antheridia and sporophytes stopped during the winter when the study site was covered by snow.

1. Introduction

Phenology is the study of the seasonality of events related to reproduction and growth during a life cycle (e.g., Longton, 1979a, 1979b; Stark, 2002). Greene (1960) and Forman (1965) established methods for recognizing the stages in the reproductive cycles of mosses, and since then, many studies have investigated the reproductive phenology of bryophytes (e.g., Clarke and Greene, 1970, 1971; Laaka-Lindberg, 2005; Longton, 1979a, 1979b; Longton and Greene, 1969; Stark, 2002; Zehr, 1979).

Bryophytes show a number of phenological patterns that reflect their adaptation to a wide variety of environments (e.g., Stark, 2002). The relationships between phenology and environmental factors have been investigated in numerous studies (e.g., Chopra and Bahtla, 1983; Laaka-Lindberg, 2005; Longton, 1979a, 1990; Reese, 1984; Stark, 2005; Zehr, 1979).

The length of the growth period is thought to be restricted by several environmental factors, including temperature and water availability. In this study, we focused on the effect of low temperatures on the length of the growth period. Many previous studies have described short growth periods in bryophytes growing in cold habitats, including in polar regions (Clarke and Greene, 1970, 1971; Grimme, 1903; Longton, 1966, 1972, 1979b, 1985; Sagmo Solli et al. 1998) and subalpine zones (Ayukawa et al., 2002). Several studies have reported a phenological pattern in which antheridia and sporophytes have a period of suspended development under snow cover (Ayukawa et al., 2002; Clarke and Greene, 1971; Miles et al., 1989; Laaka-Lindberg, 2005; Longton, 1966, 1972, 1979b; Sagmo Solli et al. 1998). Other studies have described a phenological pattern in which mosses growing in cold habitats develop faster than boreal mosses during the short growth period (Clarke and Greene, 1970, 1971; Grimme, 1903; Longton, 1979b).

Racomitrium lanuginosum (Hedw.) Brid., a moss in the family Grimmiaceae, is generally found in subalpine and alpine zones at mid-latitude locations and on low ground at high latitudes. The phenology of this species at a temperate site in England was investigated by Tallis (1959), but only the timing of capsule development and spore dispersal were recorded. The aim of this study was to clarify the phenological pattern of gametangium and sporophyte maturation in *R. lanuginosum* growing at a site with a short growth period because it experiences seasonal snow cover.

2. Materials and methods

2.1. Study site

Mt. Fuji, a volcano located in central Japan (35°21′ N, 138°43′ E), is the highest mountain in Japan (peak, 3776 m altitude). Its most

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Table 1
Developmental stages of gametangia and sporophytes (according to Ayukawa et al., 2002).

Stages	Explanations
Gametangia	
Juvenile (J)	Small gametangia, up to half the full size
Immature (I)	Gametangia from half to full size, green
Mature (M)	Gametangia still green but with open apex. Spermatozoids are visible, in antheridia
Dehisced (D)	Gametangia brown. Antheridia empty and somewhat shrunken
Sporophytes	
Swollen venter (SV)	The lower part of the archegonium is swollen. This is the first visible sign that the archegonium is fertilized
Early calyptra in perichaetium (ECP)	Calyptra starts to emerge from the bracts
Late calyptra in perichaetium (LCP)	Calyptra from half to almost fully visible above the bracts. Seta not yet visible
Early calyptra intact (ECI)	Calyptra present. Seta ranging from just visible above the bracts to fully elongated. Capsule with the same diameter as the seta
Late calyptra intact (LCI)	Calyptra present. Capsule expanding or has attained full size
Early operculum intact (EOI)	Capsule changes color from green to brown, but more than half the capsule is still green
Late operculum intact (LOI)	More than half the capsule is brown but the operculum is intact
Operculum fallen (OF)	Operculum fallen and spores are dispersed
Empty and fresh (EF)	Capsules of current cycle have released more than 75% of the spores

recent eruption was in 1707 (Adachi et al., 1996; Tsuya, 1971). The ground between the summit and the hillside of this mountain is covered with a thick layer of basaltic scoria formed by past eruptions. The tree line is located at around 2500 m altitude. Populations of *R. lanuginosum* are present on the bare ground, which is composed of erupted product, at altitudes of 1000–3776 m (Takaki, 1971). *Racomitrium lanuginosum* is a dioecious moss that forms vast mats on sand or rock at open sites.

We selected a site on a northeast-facing ridge at 2200 m altitude (35°23′ N, 138°42′ E). The forest at this site consists of *Larix kaempferi* (Lamb.) Carrière, *Abies veitchii* Lindl., *Tsuga diversifolia* (Maxim.) Mast., *Vaccinium vitis-idaea* L., and *Rhododendron brachycarpum* D. Don ex G. Don. The forest floor is covered by a homogeneous population of *R. lanuginosum*.

2.2. Methods

The air temperature and relative humidity at ground level were measured with data loggers (HOBO® Pro v2 Part No. U23-001, Onset Computer Corp., Bourne, MA, USA) housed in a plastic box, at 1 h intervals between 15 June 2014 and 20 July 2015.

Every 2 weeks between 2 June and 15 November 2014, samples

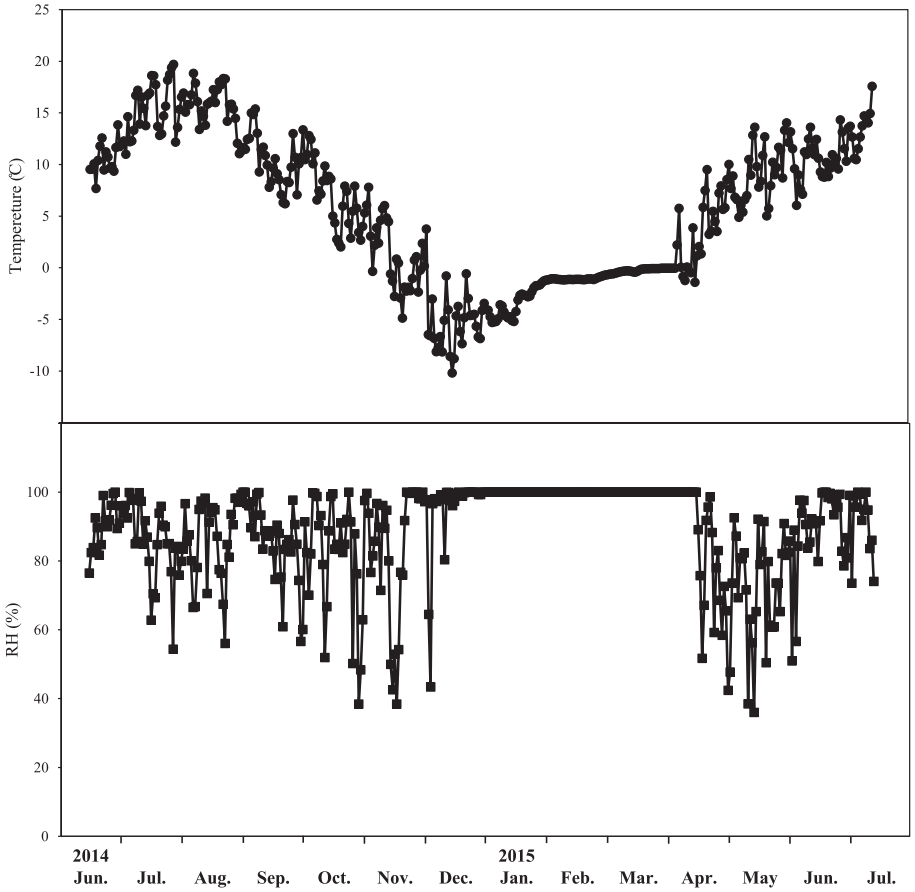

Fig. 1. Mean daily temperature (●) and relative humidity (■) at ground level at the study site between 15 June 2014 and 13 July 2015.