Research paper

The Phenology of *Osmunda claytoniana* L. in the Tataka area, Central Taiwan

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【Summary】

The phenology of *Osmunda claytoniana* L. was studied in the Tataka area of Taiwan, a high-elevation (2,600~2,900 m) temperate area, from April to October 2006. There were 38 plants in 2 populations. Frond length, emergence, expansion, and senescence, and spore maturation and release were documented. Fertile fronds emerged during late April to early May, whereas sterile fronds emerged during May to late June. It took 25~45 d for fronds to fully expand. Spores matured in late May and most dispersed from late May to mid-June. Frond number and average length were significantly greater for mature plants than for immature plants. The average length of fertile fronds was not significantly greater than that of sterile fronds. The growing season was from late April to October. Fronds lived 135 d on average. However, pinnae bearing spores (parts of the fertile fronds) senesced within 2 wk after spore release, whereas other pinnae (those without spores) lasted until October.

Key words: fertile frond, *Osmunda claytoniana*, phenology, Pteridophytes, sterile frond.

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研究報告

台灣塔塔加地區絨假紫萁物候學研究

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摘 要

本研究針對塔塔加地區之絨假紫萁進行物候調查研究，自2006年4至10月間調查38個植株之葉發芽、伸展、枯萎、孢子成熟與發散等過程，並記錄葉片長度。結果顯示絨假紫萁孕性葉在4月底5月初發芽，營養葉則由5月初開始發芽，一直延至6月底；葉片自發芽至完全展開需25至45日。孢子成熟時

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間皆在5月底，大部份孢子發散時間為5月底至6月中旬。成熟植株之葉數與平均葉片長度皆大於未成熟植株；孕性葉之平均葉片長度大於營養葉，但未達顯著差異。本研究結果顯示，本種具有強烈的季節性，從4月底至10月為其生長季節，其葉片壽命平均約135天，但生長孢子的羽片在孢子發散2週內即枯萎，其餘未具孢子的羽片則持續存活至9~10月始枯萎。

關鍵詞：孕性葉、絨假紫萁、物候學、蕨類植物、營養葉。

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INTRODUCTION

Phenology is the study of periodic biological phenomena in relation to climate. In plants, phenological studies often examine processes such as leaf emergence, growth, flowering, and fruiting for angiosperms (Van Schaik et al. 1993) and frond emergence, growth, and spore maturation and dispersal for pteridophytes (Sharpe and Jernstedt 1990, Chiou et al. 2001). Phenology is crucial to understanding ecology and is essential for the effective management of rare species (Johnson-Groh and Lee 2002).

Fern phenology has been documented in a variety of taxa and regions, e.g., *Botrychium* in North America (Johnson-Groh and Lee 2002); *Danaea* in Middle and South America (Sharpe and Jernstedt 1990); *Leptopteris wilkesiana* in Oceania (Ash 1986); *Cyathea pubescens* (Tanner 1983), *Alsophila setosa* (Schmitt and Windisch 2006), *Thelypteris angustifolia* (Sharpe 1997), *Dryopteris filix-max*, and *D. dilatata* (Wilmot 1989) in Central and South America; *Thelypteris limbosperma*, *Athyrium disteutifolium*, and *Matteuccia struthiopteris* in north Europe (Odland 1995, 1998); *Polystichum* (Sato 1985a) and the Aspidiaceae in Japan (Sato 1985b); and *Oleandra pistillaris* in Indonesia (Takahashi and Mikami 2006). Studies of fern phenology in Taiwan have focused on lower-elevation species, such as *Sphaeropteris lepifera* (Ying and Huang 1995), *Cibotium taiwanense* (Chiou et al. 2001), *Dicranopteris linearis* var. *linearis*, *Dipteris conjugata* (Ruan 2001), and *Asplenium antiquum* (Tsai 2005).

Osmunda claytoniana L. is distributed from the Himalayas to the Pacific coast of Asia. In Taiwan, this rare species grows in the mountains at mid- to high elevations (2,300 ~ 3,200 m) (Shieh 1994). Its fronds are hemidimorphic, with sterile fronds and fertile fronds whose spores grow only on pinnae of the distal part. It usually grows in open habitats with *Yushania niitakayamensis* and/or *Miscanthus transmorrisonensis*, but little was known about its phenology. This is the first study of the phenology of a high-elevation fern in Taiwan. *Osmunda claytoniana* frond emergence, expansion, and senescence, and spore maturation and dispersal were documented. In addition, the phenology of fertile and sterile fronds was compared.

MATERIALS AND METHODS

The phenology of *O. claytoniana* was recorded from 15 April to 3 October 2006 at 2 locations in the Tataka area of Yushan National Park. Plot 1 (2,610 m), with 26 plants, is near the Tataka Tourist Center at 23º29’ 10.99”N, 120º53’25.54”E. Plot 2 (2,870 m), with 12 plants, is near Lulin Shan at 23º28’ 25.36”N, 120º53’4.89”E (Fig. 1). Although the latitude is subtropical, the climate at the elevation of the study plots is temperate.

Events recorded included frond emergence and expansion, and spore maturation and release. Sporangia are deep green at

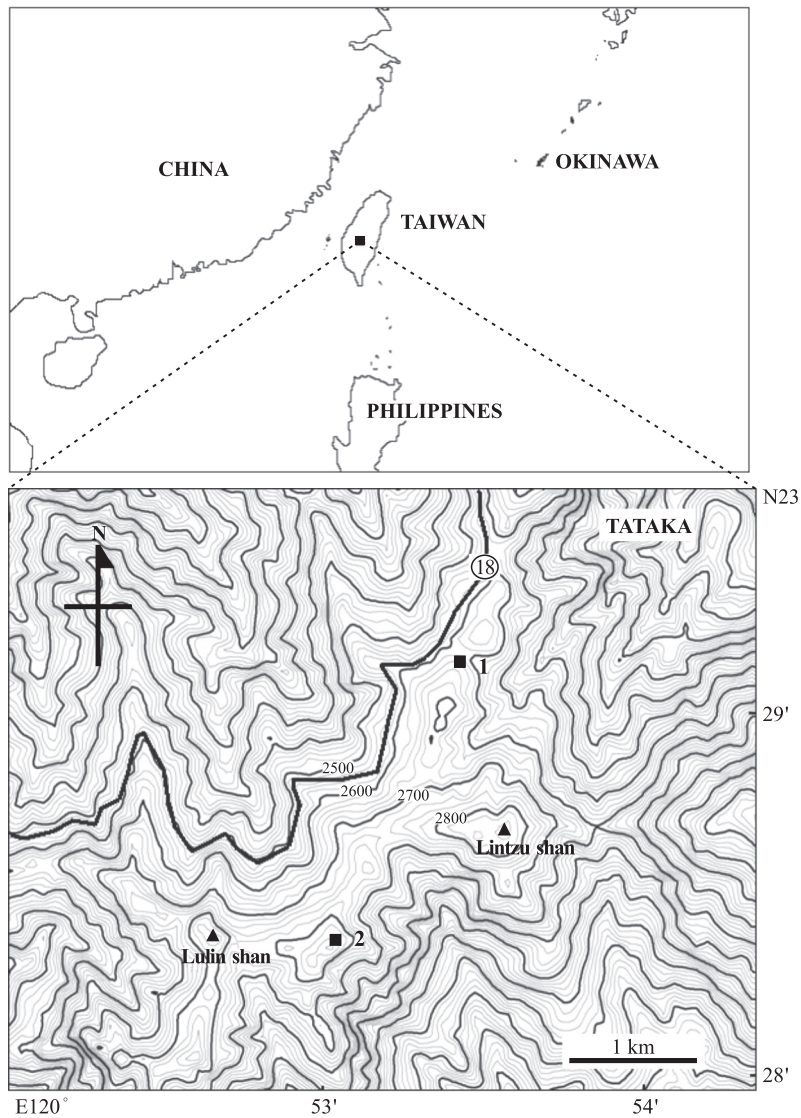

Fig. 1. Locations of the 2 studied plots (solid squares) and the Highway 18. This Taiwan map was modified from http://maps.google.com

maturity and turn brown when spores are released. Mature plants were defined as those having spore-bearing fronds while immature plants lacked them (Aguraiuja 2001). In this study, 15 plants were mature and 23 were immature. Frond length and the number of fronds on each plant were recorded, and the correlation between plant size and maturity was determined.

Based on information from the nearest weather station at Alishan, most precipitation (93.3% of the annual total; > 200 mm in each month) fell from March to September. The average monthly temperature was > 12℃ from April through October and < 11℃ from November through March (Fig. 2). The patterns of the average monthly temperature and precipitation for 2006 were similar to those of

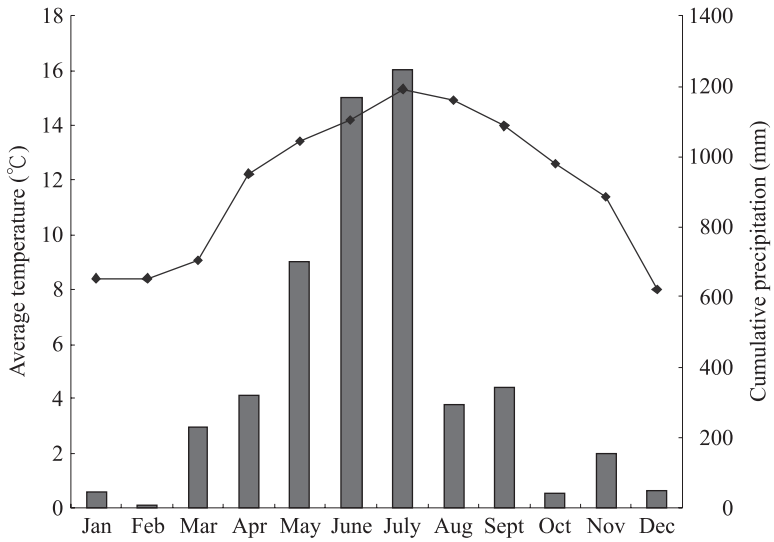

Fig. 2. Meteorogram for the Alishan station, which is near the Tataka area, for 2006. The line indicates temperature; bars indicate precipitation (Data were obtained from the Central Weather Bureau website; http://cwb.gov.tw).

the previous 2 yr (data not shown).

RESULTS

In total, 150 fronds were included in this study. Of these, 30 fronds were fertile, i.e., they had spore-bearing pinnae, and 120 were sterile. All 150 fronds emerged after mid-April 2006, with 79.3% (119/150) appearing by early May and the rest (31 fronds) appearing in the next 2 mo. No frond emerged after early July. It took 33.8±11.0 d from emergence to full expansion. All fertile fronds emerged in April, but only 74.1% (89/120) of sterile fronds emerged in April (Table 1).

All fronds senesced some time during August to October (Table 1). Frond lifespan, from emergence to senescence, averaged 135.6±18.8 d. There was no significant difference between the lifespan of fertile fronds (140.6±15.6 d) and sterile ones (134.4±19.4 d) ($p > 0.05$). However, spore-bearing pinnae senesced within 2 wk after spore release, while sterile pinnae persisted 11~16 wk through the growing season.

All spores matured from 2 to 27 May 2006. Most spores (93%, 28/30 with mature fronds) were released before mid-June, but some were not released until early July (Table 1).

Frond length was measured in August when all fronds were fully expanded. Fertile fronds (80.2±26.5 cm) were longer than sterile fronds (57.5±22.2 cm), but the difference was not significant ($p > 0.05$, Table 2). Fronds of mature plants (73.6±27.8 cm) were longer than those of immature plants (53.7±24.1 cm), but, again, the difference was not significant ($p > 0.05$) (Table 2). Mature plants had significantly more fronds (5.9±2.0) than immature plants (2.7±0.9) ($p < 0.01$). Among mature plants, 80% had more than 4 fronds, whereas only 4% of immature plants had more than 4 fronds. For mature plants, there was a significant linear correlation between the total number of fronds and the number of

Table 1. Numbers of *Osmunda claytoniana* fronds in different life stages in the Tataka area, April to October 2006

All fronds	15 Apr	2 May	27 May	16 June	1 July	2 Aug	2 Sept	3 Oct	Total
Emergence		119	15	13	3				150
Full-expansion			59	68	14	9			150
Senescence							51	99	150
Sterile fronds									
Emergence		89	15	13	3				120
Full-expansion			45	52	14	9			120
Senescence							38	82	120
Fertile fronds									
Emergence		30							30
Full-expansion			14	16					30
Senescence							13	17	30
Spore maturation			30						30
Spore release				28	2				30

Table 2. Frond lengths and numbers for mature and immature plants, and lengths of fertile and sterile fronds, 2 August 2006

	Avg.	Std. dev.	n	Min.	Max.
Frond length (cm)					
Mature plant	73.6	27.8	15	36.6	130.0
Immature plant	53.7	24.1	23	25.0	102.5
Fertile frond	80.2	26.5	29	41.0	135.0
Sterile frond	57.5	22.2	113	24.0	120.0
Frond number					
Mature plant	5.9	2.0	15	3.0	11.0
Immature plant	2.7	0.9	23	1.0	5.0

fertile fronds: y = 0.4749x - 1.085, $r^2 = 0.722$, $p < 0.001$ (Fig. 3).

DISCUSSION

Seasonality of frond emergence and expansion

In some tropical regions with distinct wet and dry seasons, fern fronds emerge and grow quickly before or during the first part of the rainy season. Examples include *Alsophila salvinii* in South America (Seiler 1981);

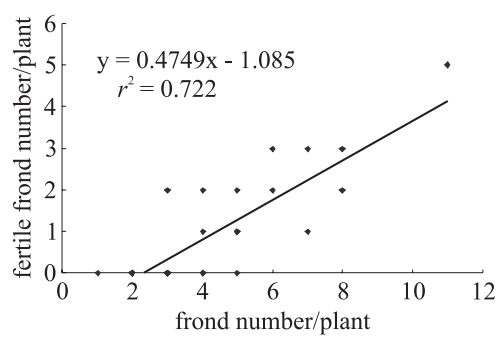

Fig. 3. Correlation between total frond number and fertile frond number of mature plants.

Cyathea pubescens (Tanner 1983), *Alsophila setosa* (Schmitt and Windisch 2006), *Danaea wendlandii* (Sharpe and Jernstedt 1990), and *Thelypteris angustifolia* (Sharpe 1997) in Central America; *Acrostichum danaeifolium* (Mehltreter and Palacios-Rios 2003) and the secondary axes of *Lygodium venustum* in Mexico (Mehltreter 2006); and *Oleandra pictillaris* in Indonesia (Takahashi and Mikami 2006).

In temperate regions, however, frond growth is controlled primarily by temperature (Odland 1995, 1998). Fronds of *Botrychium gallicomontanum* emerge in spring (April~ May), expand fully in May to July, and no new fronds emerge after July (Johnson-Groh and Lee 2002). Fronds of *Osmunda japonica* and *O. cinnamomeum* var. *fokiensis* grow during May and June (Sato and Sakai 1980).

In northern and northeastern Taiwan, where precipitation is abundant in all seasons, temperature and/or the light regime are the main factor(s) affecting frond emergence (Chiou et al. 2001). For example, fronds of *Cibotium taiwanense* emerge in all seasons except winter (Chiou et al. 2001); fronds of *Asplenium antiquum* emerge between spring and summer (Tsai 2005). However, fronds of *Dicranopteris linearis* var. *linearis* and *Dipteris conjugata* (Ruan 2001), which also grow in northeastern Taiwan, emerge between winter and spring. In the study area, it is probably too cold for fronds of *O. claytoniana* to emerge in seasons other than spring and summer.

Fertile and sterile fronds frequently emerge at different times. For example, the fertile and sterile fronds of *Cibotium taiwanense* emerge in early spring and in summer, respectively (Chiou et al. 2001). *Danaea wendlandii* produced fertile fronds from April to May and sterile fronds from May to June (Sharpe and Jernstedt 1990). Fertile fronds of *Dryopteris filix-max* (Bauer et al. 1991) emerge in spring (April ~ May), and the sterile fronds of both species emerge after May. All fertile and most sterile fronds (74.1%) of *O. claytoniana* in this study emerged in April, and the other sterile ones emerged from May to July.

Frond senescence

The timing of frond senescence varies among species. In South America, fronds of *Cyathea pubescens* senesce throughout the year (Tanner 1983). In Taiwan, most fronds of *Cibotium taiwanense* senesce in summer (Chiou et al. 2001). Fronds of *Alsophila setosa* senesce when temperatures and precipitation are low, or frost occurs (Schmitt and Windisch 2006). In Hokkaido, all fertile fronds of *Dryopteris filix-max* that emerged in April senesced in October and December, but sterile fronds that emerged in June through August did not die until April through June of the following year (Bauer et al. 1991). In Hokkaido, the fronds of 2 summer-green species, *Osmunda japonica* and *O. cinnamomeum* var. *fokiensis*, senesce in October and November (Sato and Sakai 1980), much like *O. claytoniana* in this study, whose fronds senesced in September and October although the spore-bearing pinnae faded soon after spore release.

Spore maturation and release

The timing of spore maturation and release varies with climatic zone and species. In subtropical Taiwan, spores of *Asplenium antiquum* (Tsai 2005), *Dicranopteris linearis* var. *linearis*, and *Dipteris conjugata* (Ruan 2001) are released during summer (July and August). In contrast, most spores of *Cibotium taiwanense* mature in summer and are released the following spring and summer, with a few maturing in winter and being released

the following summer (Chiou et al. 2001). In temperate regions, the period between spore maturation and release is shorter than in subtropical and tropical regions. For example, maturation and release of *Botrychium gallicomontanum* spores take only 1.4 wk, and for *Botrychium mormo*, these processes take 3.2 wk (Johnson-Groh and Lee 2002). In this study, spores of *O. claytoniana*, took about 1 mo, from May to June, to mature and release.

Frond lifespan

The lifespan of pteridophyte fronds varies by species. In species with dimorphic fronds, the lifespan of fertile fronds is much less that of sterile fronds. Fertile fronds dry up and die soon after spore release, e.g., *Acrostichum danaeifolium* (Mehltreter and Palacios-Rios 2003), *Danaea wendlandii* (Sharpe and Jernstedt 1990), and *Thelypteris angustifolia* (Sharpe 1997). There is more variability among monomorphic species. In *Dryopteris filix-mas* (Bauer et al. 1991) and *Cibotium taiwanense*, fertile fronds live longer than sterile fronds (Chiou et al. 2001). Fertile fronds remain green for quite some time (from a few wk through 10 mo) after releasing their spores. In other studies, there is no difference in the lifespan of fertile and sterile fronds, e.g., *Cyathea pubescens* (525 d; Tanner 1983), *Leptopteris wilesiana* (2~2.5 yr; Ash 1986), *Botrychium gallicomontanum*, and *Botrychium mormo* (7.7 ± 2.4 and 11.9 ± 3.5 wk; Johnson-Groh and Lee 2002). *Osmunda claytoniana* is classified as hemi-dimorphic which is between dimorphic and monomorphic (Wagner and Wagner 1977). The lifespan of its fertile fronds is similar to that of its sterile fronds. However, its spore-bearing pinnae dried out soon after spore release, whereas the other pinnae, like sterile fronds, lived 2~3 mo longer.

Plant maturation and the length and number of fertile and sterile fronds

Mature ferns have more fronds and larger stems than immature plants. Both parameters are positively correlated with the plant age. Mature *Acrostichum danaeifolium* has more than 10 fronds (Mehltreter and Palacios-Rios 2003). Fronds of *Asplenium antiquum* produce spores only when stem diameter exceeds 22 cm (Tsai 2005). *Cyathea hornei* produces spores when its stem is taller than 1 m and its fronds are longer than 90 cm (Ash 1987). Mature plants of *Leptopteris wilkesiana* (Ash 1986), *Matteuccia struthiopteris*, and *Thelypteris limbosperma* (Odland 1995) are taller than 30, 60, and 40 cm, respectively. Ash (1986, 1987) and Tanner (1983) showed that the number of fronds was positively correlated with plant height and age. In addition, older plants had greater numbers of fertile fronds and spores than younger plants. In this study, the total number of fronds and the number of fertile fronds of *O. claytoniana* were positively correlated, indicating that mature plants have more fronds than immature plants.

In both monomorphic and dimorphic ferns, fertile fronds are longer than sterile fronds. For example, in *Cibotium taiwanense*, the length of fertile fronds averaged 284 cm, while that of sterile fronds averaged 159 cm (Chiou et al. 2001). Fertile and sterile fronds of *Botrychium gallicomontanum* were 4.7 and 3.9 cm in length, respectively, whereas those of *Botrychium mormo* averaged 3.0 and 2.7 cm (Johnson- Groh and Lee 2002). *Osmunda claytoniana* is hemi-dimorphyllic. Its fertile fronds were slightly longer than the sterile fronds. Longer fertile fronds are thought to favor wind dispersal of spores (Wagner and Wagner 1977).

Frond emergence and senescence, and spore maturation and release of *O. claytoni-*

ana in Tataka, central Taiwan, occurred with obvious seasonality. Like many temperate ferns, *O. claytoniana* is a summer-green fern. The growing season is only about 6 mo long. Spores are released right after maturation. On fertile fronds, spore-bearing pinnae dry up soon after spore release, whereas pinnae without spores live as long as sterile fronds, until early October when all fronds senesce.

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