



Floristic study of bryophytes in a subtropical forest of Nabeup-ri at Aewol Gotjawal, Jejudo Island

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ABSTRACT: This study presents a survey of bryophytes in a subtropical forest of Nabeup-ri, known as Geumsan Park, located at Aewol Gotjawal in the northwestern part of Jejudo Island, Korea. A total of 63 taxa belonging to Bryophyta (22 families 37 genera 44 species), Marchantiophyta (7 families 11 genera 18 species), and Anthocerotophyta (1 family 1 genus 1 species) were determined, and the liverwort index was 30.2%. The predominant life form was the mat form. The rates of bryophytes dominating in mesic to hygic sites were higher than the bryophytes mainly observed in xeric habitats. These values indicate that such forests are widespread in this study area. Moreover, the rock was the substrate type, which plays a major role in providing micro-habitats for bryophytes. We suggest that more detailed studies of the bryophyte flora should be conducted on a regional scale to provide basic data for selecting indicator species of Gotjawal and evergreen broad-leaved forests on Jejudo Island.

Keywords: bryophyte, Aewol Gotjawal, liverwort index, life-form

Jejudo Island was formed by volcanic activities and has unique topological and geological features. In this unique volcanic terrain, forests established on lava flows are scattered around the island, known as “Gotjawal,” which is a newly coined compound word that comes from dialects spoken on Jejudo Island (Jeju Special Self-Governing Province, 2009; Yoon, 2014). It is difficult to access Gotjawal and use it for agricultural purposes, as the trees and vines are dense, rocks of various sizes are scattered randomly, and the depth of the soil is shallow in Gotjawal. Therefore, thus far it has only been used for grazing cattle, making charcoal or as a firewood source and is commonly recognized as useless land (Jeon et al., 2012; Jeong, 2012, 2015; Yoon, 2014). Recently, however, it has become known that Gotjawal is an area inhabited by various plants and animals where unique and various ecosystems are also sustained; the area serves as a natural waterway of the type necessary to create underground water, and it has high preservation value (Jeon et al., 2012; Kang et al., 2013; Yoon, 2014; Jeong, 2015). In addition, its cultural importance has also emerged. Therefore, scientific studies of Gotjawal have been conducted to examine

geological, ecological, and cultural aspects (Jeong et al., 2013; Jeon et al., 2015). However, a floristic study of bryophytes has not been conducted, except for that at Dongbaek-dongsan of Seonheul Gotjawal by Yim et al. (2013).

The areal ranges and Gotjawal terrains have not yet been established (Jeon et al., 2015). According to Song (2000), Gotjawal can be divided into four major terrains, i.e., Gujwa-Seongsan, Jocheon-Hamdeok, Hangyeong-Andeok, and Aewol. Among them, the Aewol Gotjawal terrain ranges from the Nokome Oreum (833.8 m above sea level) to Nabeup-ri and the far eastern area (90 m above sea level) with a distance of 9.0 km (Song, 2003). This region, which is the highest place within Gotjawal, is the only place where the vertical vegetation ranges from the temperate forest to the subtropical forest, and it is an area of high biodiversity (Kim et al., 2009).

The subtropical forest of Nabeup-ri, which is located at the bottom of Aewol Gotjawal, is also known as Geumsan Park. The forest is the only remaining evergreen forest in Aewol Gotjawal and in the flatlands of the northwestern area of Jejudo Island. In addition, the original vegetation is highly conserved.

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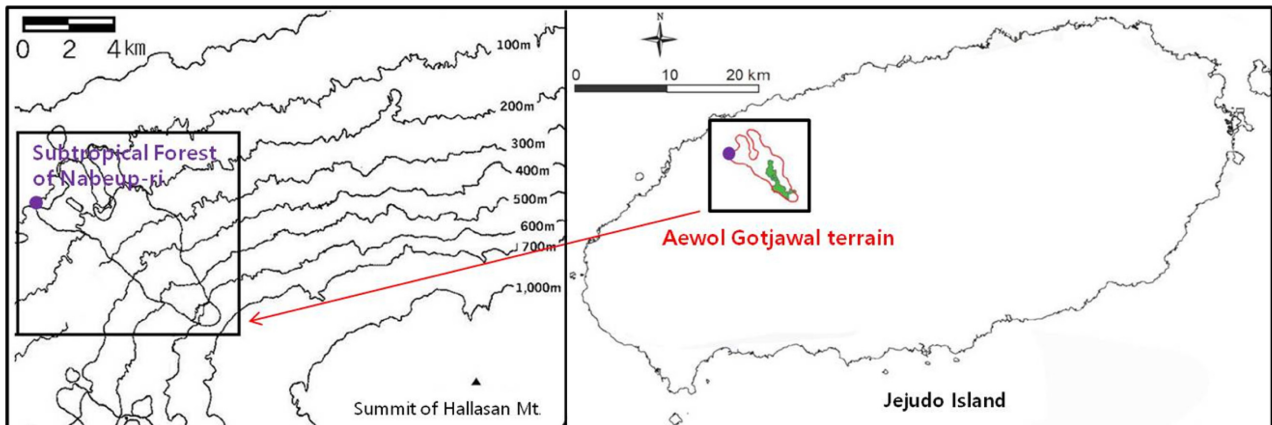


Fig. 1. The locations of the Aewol Gotjawal terrain and a subtropical forest of Nabeup-ri, Jeju Island, Korea.

For these reasons, this area is considered to be a very important region from an academic point of view. Moreover, it is designated and protected as Natural Monument No. 375 by the Cultural Heritage Administration of Korea (The Cultural Property Preservation Bureau, Korea, 1993; Song et al., 2009). The flora and vegetation of vascular plants in this area have been well studied. It has been reported that a total of 123 taxa inhabit in this area, and the plant communities are divided into five groups: the *Quercus glauca* community, *Machilus thunbergii* community, *Celtis sinensis* community, *Pinus thunbergii* community and agricultural land (Boo et al., 2006; Song et al., 2009). However, as stated above, bryophytes have not been studied to date. Therefore, it is necessary to establish a comprehensive flora including bryophytes to provide basic data for the selection of indicator species.

The purpose of this study was to establish a comprehensive flora of the subtropical forest of Nabeup-ri. Furthermore, this study aims to contribute to studies of the bryophyte flora of Gotjawal and the evergreen broad-leaved forests on Jeju Island on a regional scale and to provide basic data for selecting relevant indicator species.

Materials and Methods

Study area

Field surveys were carried out in Subtropical Forest of Nabeup-ri where the dense evergreen broad-leaved forest is distributed with an area of approximately 0.034 km² (Fig. 1).

Identification, nomenclature and arrangement of taxa

The samples collected in the investigated area from July of 2011 to March of 2017 were identified at the species

level by macroscopic morphology and microscopic features using relevant studies (Institute of Botany Chinese Academy of Sciences, 1972; Iwatsuki and Mizutani, 1972; Inoue, 1974, 1976, 1986; Choe, 1980; Noguchi, 1987, 1988, 1989, 1991, 1994; Hwang, 1991; Kim and Hwang, 1991; Gao et al., 1999; Makino, 2000; Iwatsuki, 2001; Li et al., 2001; Wu et al., 2002; Cao et al., 2003; Smith, 2004). The voucher specimens were deposited at the Warm-Temperate and Subtropical Forest Research Center in Korea (WTSFRC). Only one collection number for each taxon was cited to avoid repetition in the floristic list. The nomenclature and arrangement of the taxa follow the system proposed by Goffinet et al. (2009), Crandall-Stotler et al. (2009) and Renzaglia et al. (2008) for mosses, liverworts and hornworts, respectively.

Life forms and substrates

The life forms of bryophytes in the study area were estimated using work by Mägdefrau (1982), and they are also given in the floristic list for each taxon. The records of substrates for each taxon are included in this list.

Number of bryophyte taxa and liverwort index

We compared the number of taxa and the liverwort index of the subtropical forest of Nabeup-ri with those of other localities based on related studies [i.e., Deogyusan Mt. (Choi et al., 2010; Yoon et al., 2011), Taebaeksan Mt. (Papp, 2008), Gwanaksan Mt. (Hong, 1960a), Soyosan Mt. (Hong, 1960b), and Dongbaek-dongsan (Yim et al., 2013)]. The liverwort index, based on the finding that liverworts and hornworts tend to prefer more humid conditions than mosses, was calculated as follows (Nakanishi, 2001):

$$\text{Liverwort index(\%)} = \frac{\text{No. of liverworts} + \text{No. of hornworts}}{\text{The total No. of bryophytes}} \times 100$$

Table 1. Comparison of the bryophyte species richness levels and liverwort indexes of the subtropical forest of Nabeup-ri and other localities.

Locality	Area (km ²)	No. of species	Liverwort index
Gotjawal area			
Subtropical Forest of Nabeup-ri (Aewol Gotjawal)	0.034	63	30.2
Dongbaek-dongsan (Seonheul Gotjawal)	1.420	85	27.0
Mountain area			
Deogyusan Mt.	232.000	311	40.8
Taebaeksan Mt.	17.440	144	29.2
Soyosan Mt.	2.472	79	13.9
Gwanaksan Mt.	19.220	78	17.9

Results and Discussion

Number of bryophyte taxa and liverwort index

In this study, a total of 63 species belonging to Bryophyta (22 families 36 genera 44 species), Marchantiophyta (7 families 11 genera 18 species), and Anthocerotophyta (1 family 1 genus 1 species) were determined (Appendix 1). We expect that this study will provide the basic data for selecting indicator species of Gotjawal and the evergreen broad-leaved forests on Jeju Island.

The results of a comparison of the number of taxa indicated that the subtropical forest of Nabeup-ri contained a rich diversity of bryophytes considering the area size (Table 1). Song et al. (2009) considered that the vascular flora of this area does not show high species richness. Nevertheless, this forest was evaluated as a well-conserved area based on a multi-criteria evaluation Matrix (Song et al., 2009), as the area has been well managed by local residents due to cultural influences and has been designated and protected as the natural monument. We agree with the evaluation Song et al. (2009) and consider that the result for the number of taxa is related to the well-conserved forest.

The liverwort index is based on the finding that liverworts and hornworts tend to prefer more humid conditions than mosses. Therefore, it can be used to compare air humidity levels among different sites (Nakanishi, 2001). The liverwort index of the subtropical forest of Nabeup-ri was 30.2%, a value that indicates that the air humidity of the investigated area was relatively low compared to that of Deogyusan Mt. but was higher than that of Taebaeksan Mt., Dongbaek-dongsan, Gwanaksan Mt., and Soyosan Mt. (Table 1). We also suggest that more detailed studies of the bryophyte flora of Korea should be conducted on the regional scale.

Remarkable species

The distributions of *Philonotis turneriana* (Schwägr.) Mitt. (큰물가이끼) and *Homomallium connexum* (Cardot) Broth. (쌍끝양털이끼) were newly recorded from Jeju Island through this study. Species for which the distributions in Korea are not known (except for Jeju-do) thus far, *Eurhynchium savatieri* Schimp. ex Besch. (가는부리이끼), *Taxiphyllum cuspidifolium* (Cardot) Z. Iwats. (뽕족카라잎이끼), and *Plagiochila furcifolia* Mitt. (비자날개이끼), were also found in this study area. However, it is difficult to recognize these bryophytes as endemic species on Jeju Island and assess the rarity or conservation status of bryophytes in this study area because, in the case of Korea, bryophyte flora are unexplored and have been studied by few researchers, aiming mainly at Jeju Island. Therefore, we suggest that comprehensive research on the bryophyte flora of Korea should be conducted continuously.

Life forms

We estimated the life form of each taxon in the study area, as presented in Fig. 2. The predominant life form was the mat form (25 species, 39.7%) followed by the weft (17 species, 27%), tall turf (9 species, 14.3%), fan and cushion (4 species, 6.3% each), and short turf and tail (2 species, 3.2% each) forms. We analyzed the results based on the relationship between the adaptive strategy and life form of bryophytes according to Kürschner (2004), Uyar et al. (2007), and Glime (2017). As a result, the rate of pleurocarpous bryophytes (the mat, weft, fan, and tail life forms) dominating in mesic to hygic sites amounted to 76.2%, whereas acrocarpous bryophytes (the tall turf, short turf, and cushion life forms), mainly observed in xeric habitats, amounted to 23.8% (Appendix 1, Fig. 2). These values indicate that such forests are widespread in the study area.

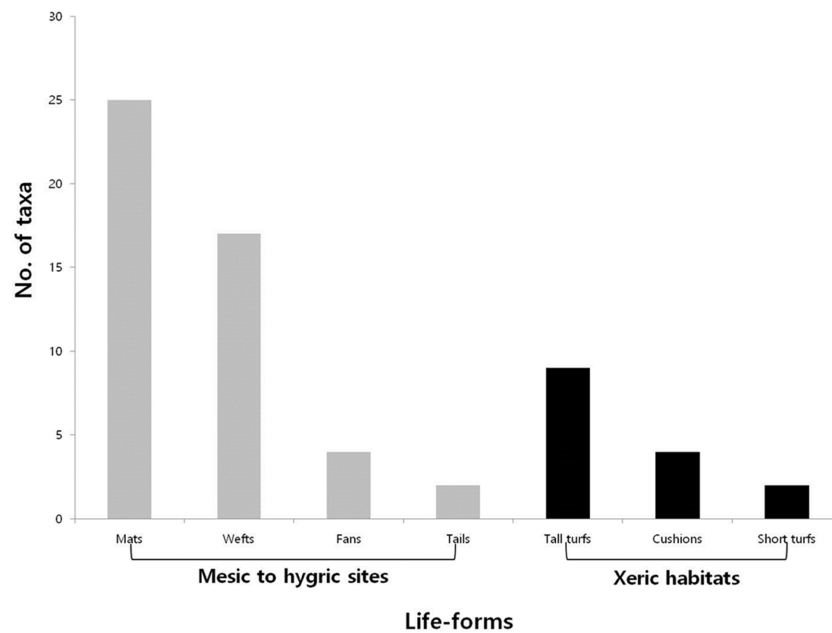


Fig. 2. Life form spectrum of the bryophytes in the study area.

Table 2. The numbers of taxa according to the substrate in the study area.

Substrate	No. of taxa
Specific to only one substrate	
L	25
P	16
X	2
S	2
Common to two or more substrates	
L and P	8
L and S	1
L and X	3
L, P, and X	5
L, P, and S	1
Total	63

L, epilithic; P, epiphytic; X, epixylous; S, on the soil.

It is meaningful that the rates of pleurocarpous bryophytes are higher in this area than in Dongbaek-dongsan (70.6%), identical to the liverwort index (Yim et al., 2013). These values indicate that the subtropical forest of Nabeup-ri at Aewol Gotjawal is relatively more humid than Dongbaek-dongsan at Seonheul Gotjawal.

Distribution pattern

We estimated the substrates for each taxon to investigate the

distribution pattern. The numbers of taxa according to the substrate are presented in Table 2. Upon an investigation of the substrates, the bryophytes on rocks were most diverse, at 40 taxa, followed by those on bark (33 taxa), decayed trees (10 taxa), and soil (4 taxa). The results appear to stem from the fact that volcanic rock masses of various sizes lay scattered over the study area, offering numerous micro-habitats for bryophytes due to one of the characteristics of Gotjawal: it is a place where rocks of various sizes are scattered randomly.

Acknowledgments

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Conflict of Interest

Authors declare that there is no conflict of interest.

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Appendix 1. Floristic list of Subtropical Forest of Nabeup-ri in Korea.

Taxa	Korean name	Life-form	Substrate	Voucher No. (Eun-Young Yim-)
Bryophyta Schimp. 선류식물문				
Polytrichaceae Schwägr. 솔이끼과				
<i>Atrichum rhystophyllum</i> (Müll. Hal.) Paris	아기주름솔이끼	Tall turfs	S	GSP073
Grimmiaceae Arn. 고깔바위이끼과				
<i>Grimmia pilifera</i> P. Beauv.	흰털고깔바위이끼	Cushions	L	GSP084
<i>Schistidium apocarpum</i> (Hedw.) Bruch & Schimp.	고깔바위이끼	Cushions	L	GSP099
Ptychomitriaceae Schimp. 곱슬이끼과				
<i>Ptychomitrium sinense</i> (Mitt.) A. Jaeger	곱슬이끼	Cushions	L	GSP012
Fissidentaceae Schimp. 봉황이끼과				
<i>Fissidens bryoides</i> Hedw.	꼬마봉황이끼	Tall turfs	L	GSP008
Rhabdoweisiaceae Limpr. 주름꼬마이끼과				
<i>Glyphomitrium humillimum</i> (Mitt.) Cardot	깍지이끼	Cushions	L	GSP460
Erpodiaceae Broth. 나무연지이끼과				
<i>Aulacopilum japonicum</i> Broth. ex Cardot	겉주름이끼	Mats	PX	GSP138
<i>Venturiella sinensis</i> (Venturi) Müll. Hal.	나무연지이끼	Mats	P	GSP149
Dicranaceae Schimp. 꼬리이끼과				
<i>Dicranella heteromalla</i> (Hedw.) Schimp.	역새이끼	Tall turfs	L	GSP453
Pottiaceae Hampe 침꼬마이끼과				
<i>Weissia controversa</i> Hedw.	꼬마이끼	Short turfs	S	GSP104
Bryaceae Schwägr. 참이끼과				
<i>Brachymenium nepalense</i> Hook.	노란참외이끼	Short turfs	P	GSP077
Mniaceae Schwägr. 초롱이끼과				
<i>Trachycystis microphylla</i> (Dozy & Molk.) Lindb.	아기초롱이끼	Tall turfs	P	GSP013
Bartramiaceae Schwägr. 구슬이끼과				
<i>Philonotis turneriana</i> (Schwägr.) Mitt.	큰물가이끼	Tall turfs	L	GSP095
Hedwigiaceae Schimp. 툫이끼과				
<i>Hedwigia ciliata</i> (Hedw.) P. Beauv.	툫이끼	Tall turfs	L	GSP088
Leskeaceae Schimp. 고깔검정이끼과				
<i>Haplocladium angustifolium</i> (Hampe & Müll. Hal.) Broth.	침작은명주실이끼	Wefts	LPX	GSP001
<i>Haplocladium microphyllum</i> (Hedw.) Broth.	작은명주실이끼	Wefts	P	GSP450
<i>Leskea polycarpa</i> Hedw.	고깔검정이끼	Wefts	L	GSP079
Thuidiaceae Schimp. 깃털이끼과				
<i>Pelekium versicolor</i> (Hornsch. ex Müll. Hal.) Touw	아기깃털이끼	Wefts	P	GSP215
Brachytheciaceae Schimp. 양털이끼과				
<i>Brachythecium plumosum</i> (Hedw.) Schimp.	날개양털이끼	Wefts	LP	GSP123
<i>Brachythecium populeum</i> (Hedw.) Schimp.	양털이끼	Wefts	LS	GSP043
<i>Bryhnia novae-angliae</i> (Sull. & Lesq.) Grout	세모양털이끼	Wefts	L	GSP035
<i>Eurhynchium hians</i> (Hedw.) Sande Lac.	물가침부리이끼	Wefts	L	GSP355
<i>Eurhynchium savatieri</i> Schimp. ex Besch.	가는부리이끼	Wefts	LPX	GSP134

Table 1. Continued.

Taxa	Korean name	Life-form	Substrate	Voucher No. (<i>Eum-Young Yim</i> -)
<i>Rhynchostegium pallidifolium</i> (Mitt.) A. Jaeger	아기양털부리이끼	Wefts	LPX	GSP016
Hypnaceae Schimp. 털깃털이끼과				
<i>Callicladium haldanianum</i> (Grev.) H. A. Crum	풀이끼	Wefts	PX	GSP148
<i>Homomallium connexum</i> (Cardot) Broth.	쌍끝양털이끼	Wefts	PX	GSP092
<i>Homomallium japonicoadnatum</i> (Broth.) Broth.	들쌍끝양털이끼	Wefts	P	GSP078
<i>Pseudotaxiphyllum pohliaecarpum</i> (Sull. & Lesq.) Z. Iwats.	빨간걸주목이끼	Mats	L	GSP117
<i>Taxiphyllum aomoriense</i> (Besch.) Z. Iwats.	검친주목이끼	Mats	L	GSP002
<i>Taxiphyllum cuspidifolium</i> (Cardot) Z. Iwats.	뽕족카라잎이끼	Mats	LP	GSP122
<i>Taxiphyllum taxirameum</i> (Mitt.) M. Fleisch.	주목이끼	Mats	L	GSP005
Plagiotheciaceae M. Fleisch. 산주목이끼과				
<i>Plagiothecium nemorale</i> (Mitt.) A. Jaeger	산주목이끼	Mats	P	GSP029
Entodontaceae Kindb. 윤이끼과				
<i>Entodon sullivantii</i> (Müll. Hal.) Lindb.	가는윤이끼	Wefts	L	GSP017
Pylaisiadelphaceae Goffinet & W. R. Buck. 무성아실이끼과				
<i>Pylaisiadelpha tenuirostris</i> (Bruch & Schimp. ex Sull.) W. R. Buck	무성아실이끼	Mats	P	GSP025
Sematophyllaceae Broth. 나무실이끼과				
<i>Sematophyllum subhumile</i> (Müll. Hal.) M. Fleisch.	나무실이끼	Mats	LP	GSP052
Neckeraceae Schimp. 납작이끼과				
<i>Homalia trichomanoides</i> (Hedw.) Schimp.	윤납작이끼	Fans	LP	GSP032
<i>Neckera pusilla</i> Mitt.	윤아기납작이끼	Fans	P	GSP028
<i>Neckeropsis nitidula</i> (Mitt.) M. Fleisch.	리본납작이끼	Fans	L	GSP094
<i>Thamnobryum plicatulum</i> (Sande Lac.) Z. Iwats.	대호꼬리이끼	Fans	L	GSP031
Anomodontaceae Kindb. 명주실이끼과				
<i>Anomodon minor</i> (Hedw.) Lindb.	푸른명주실이끼	Tails	P	GSP209
<i>Haplohymenium longinerve</i> (Broth.) Broth.	긴줄바위실이끼	Wefts	X	GSP391
<i>Haplohymenium pseudotriste</i> (Müll. Hal.) Broth.	꼬마바위실이끼	Wefts	LPX	GSP004
<i>Haplohymenium triste</i> (Ces.) Kindb.	바위실이끼	Wefts	P	GSP087
<i>Herpetineuron toccocae</i> (Sull. & Lesq.) Cardot	나선이끼	Tails	LP	GSP011
Marchantiophyta Stotler & Crand. -Stotl. 대류식물문				
Conocephalaceae Müll. Frib. ex Grolle 패랭이우산이끼과				
<i>Conocephalum conicum</i> (L.) Dumort.	패랭이우산이끼	Mats	L	GSP080
Metzgeriaceae H. Klinggr. 리본이끼과				
<i>Metzgeria lindbergii</i> Schiffn.	리본이끼	Mats	L	GSP036
Radulaceae Müll. Frib. 부채이끼과				
<i>Radula japonica</i> Gottsche ex Steph.	부채이끼	Mats	P	GSP112
<i>Radula oyamensis</i> Steph.	치너부채이끼	Mats	LP	GSP173
Frullaniaceae Lorch 지네이끼과				
<i>Frullania ericoides</i> (Nees) Mont.	초록지네이끼	Mats	LP	GSP020
<i>Frullania inflata</i> Gottsche	물가지네이끼	Mats	X	GSP163

Table 1. Continued.

Taxa	Korean name	Life-form	Substrate	Voucher No. (Eun-Young Yim-)
<i>Frullania muscicola</i> Steph.	참지네이끼	Mats	LP	GSP083
Lejeuneaceae Cavers 작은귀이끼과				
<i>Acrolejeunea pusilla</i> (Steph.) Grolle & Gradst.	사슴주름이끼	Mats	P	GSP311
<i>Cololejeunea japonica</i> (Schiffn.) Mizut.	세모귀이끼	Mats	P	GSP003
<i>Lejeunea japonica</i> Mitt.	작은귀이끼	Mats	L	GSP069
<i>Trocholejeunea sandvicensis</i> (Gottsche) Mizut.	둥근귀이끼	Mats	LPX	GSP010
Lophocoleaceae Müll. Frib. ex Vanden Berghen 두끝벼슬이끼과				
<i>Heteroscyphus argutus</i> (Nees) Schiffn.	아기비늘이끼	Mats	L	GSP237
<i>Heteroscyphus coalitus</i> (Hook.) Schiffn.	큰비늘이끼	Mats	P	GSP268
<i>Heteroscyphus planus</i> (Mitt.) Schiffn.	비늘이끼	Mats	LPS	GSP033
<i>Lophocolea minor</i> Nees	아기두끝벼슬이끼	Mats	L	GSP023
Plagiochilaceae Müll. Frib. & Herzog 날개이끼과				
<i>Plagiochila furcifolia</i> Mitt.	비자날개이끼	Tall turfs	L	GSP024
<i>Plagiochila ovalifolia</i> Mitt.	둥근날개이끼	Tall turfs	L	GSP331
<i>Plagiochila sciophila</i> Nees ex Lindenb.	아기날개이끼	Tall turfs	L	GSP118
Anthocerotophyta Rothm. ex Stotler & Crand. -Stotler 각태류식물문				
Notothyladaceae (Milde) Müll. Frib. ex Prosk. 짧은빨이끼과				
<i>Phaeoceros carolinianus</i> (Michx.) Prosk.	마당빨이끼	Mats	P	GSP445

L, epilithic; P, epiphytic; X, epixylous; S, on the soil.