Floristic study of the bryophytes of an evergreen broad-leaved forest in the vicinity of Baekyaki Oreum in Gujwa-Seongsan Gotjawal, Jejudo Island

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ABSTRACT: This study presents a survey of the bryophytes of evergreen broad-leaved forest near Baekyaki Oreum in Gujwa-Seongsan Gotjawal in the eastern part of Jejudo Island, Korea. A total of 53 taxa belonging to Bryophyta (11 families 26 genera 39 species) and Marchantiophyta (9 families, 9 genera 14 species) were determined, and the liverwort index was found to be 26.4%. The predominant life-form was the mat type. The rates of bryophytes dominating at mesic to hygric sites were higher than those of bryophytes, which were mainly observed in xeric habitats. These values indicate that the forest areas in this study area have a high density level. Upon an investigation of the substrates, bryophytes on rocks were most diverse. It was also found that volcanic rock masses of various sizes lay scattered over the study area and offer numerous micro-habitats for bryophytes. This is related to the characteristics of Gotjawal. We consider that more detailed studies should be conducted on regional scales to establish the bryophyte flora of Gotjawal and the evergreen broad-leaved forests of Jejudo Island.

Keywords: bryophyte, Gujwa-Seongsan Gotjawal, liverwort index, life-form

Jejudo Island was formed by volcanic activity and has unique topological and geological features. In this unique volcanic terrain, forests established on lava flow are scattered around the island, known as “Gotjawal,” a newly coined compound word coming from dialects spoken on Jejudo Island (Jeju Special Self-Governing Province, 2009; Yoon, 2014). Recently, it has become known that Gotjawal is an area inhabited by various plants and animals where unique and various types of ecosystems are also sustained; the area also contains natural waterways of the type necessary to recharge underground water, and it has high preservation value (Jeon et al., 2012; Kang et al., 2013; Yoon, 2014; Jeong, 2015). However, few floristic studies of bryophytes have been conducted, except for those concerning on Seonheul Gotjawal (Dongbaek-dongsan) in the northeastern part of the island by Yim et al. (2013), on Aewol Gotjawal (Subtropical Forest of Nabeup-ri) in the northwestern area by Yim and Hyun (2018), and on Hangeyeong Gotjawal (Cheongsu-ri) in the southeastern part of the island by Yim et al. (2019).

The area and range of the Gotjawal terrain have not yet been established (Jeon et al., 2015). According to Song (2000), who first described Gotjawal, Gotjawal can be divided into four major types of terrains. These were termed Gujwa-Seongsan, Jocheon-Hamdeok, Hangeyeong-Andeok, and Aewol. The Jeju Special Self-Government Province (2009) adds Gyorae-Hannam Gotjawal to the four terrains, making the total five (Fig. 1). Among them, the Gujwa-Seongsan Gotjawal terrain is suggested to be divided into four lava flow areas: Jongdal-Handong Gotjawal, Sehwa Gotjawal, Sangdo-Hado Gotjawal, and Susan Gotjawal (Song, 2000). It has been considered that these lava flows were formed by four corresponding Oreum (a small extinct volcanic cone in Jejudo Island). The Jongdal-Handong Gotjawal lava flow is distributed from Dongjeong Oreum to the coastal lowlands 30 m above sea level toward Handong-ri, over a total length of 11 km. The Sehwa Gotjawal lava flow starts at Darangshi Oreum and is distributed over a total length of 4.7 km. The Sangdo-Hado Gotjawal lava flow is distributed over a total length of approximately 5.6 km,
starting from Yongnuni Oreum and ending near Jimibong Oreum. Finally, the Susan Gotjawal lava flow starts around the vicinity of Gungdaeik Oreum 50 m above sea level in the western area of the village of Susan-ri, running for more than 5.5 km (Song, 2000). However, Ahn et al. (2015) found that Gujwa-Seongsan Gotjawal was formed by four sequential eruptions at Donggeomun Oreum. The lava flows from the first eruption are distributed in parts of Jongdal-Handong Gotjawal, Sangdo-Hado Gotjawal, and Sehwa Gotjawal. The second flows are distributed along the direction of Sangdo-Hado among the three forked flows of the first lava flows. The third flows are distributed from Jongdal-Handong Gotjawal to the vicinity of the Bijarim Forest, and the fourth flows are distributed from the south of Donggeomun Oreum toward the east. These lava flows are located in the vicinity of Baekyaki Oreum and are widely known as Baekyaki Oreum Gotjawal or Susan Gotjawal. In this area, evergreen broad-leaved forests are linearly distributed along the uneven terrain and unlike other Gotjawal terrains, the dominant tree species are not evergreen oaks but plants of the family Lauraceae. It has also

Fig. 1. Map showing the location of the study area and distribution of the Gotjawal terrains, Jejudo Island, Korea. Gotjawal terrains designated by the Jeju Special Self-Governing Province (1997) are indicated by the colored areas.

Fig. 2. Pictures showing the characteristics of the evergreen broad-leaved forest in the vicinity of Baekyaki Oreum in Gujwa-Seongsan Gotjawal, Jejudo Island. A. Panoramic view of the evergreen forest from the top of Baekyaki Oreum. B. Vegetation. C. Bryophytes on rocks. D. Bryophytes on bark.
been found that the deciduous trees such as *Celtis sinensis* Pers. and *Mallotus japonicus* (L. f.) Mu?ill. are mixed throughout this forest. In addition, in the lower layer of the forest, the ratio of exposed rocks is high, and ferns, such as *Arachniodes aristata* (G. Forst.) Tindale, *A. standishii* (T. Moore) Ohwi, and *Crepidotomes latealatum* (Bosch) Copel grow, as do flowering plants such as *Ardisia crenata* Sims, *A. japonica* (Thunb.) Blume, and *Rubus buergeri* Miq. The adjacent area is used as pasture, where *Miscanthus sinensis* Andersson, *Ligustrum obtusifolium* Siebold & Zucc., *Euonymus alatus* (Thunb.) Siebold, and *M. japonicus* etc. are densely distributed. The secondary forest of deciduous broad-leaved trees formed around this area is dominated by *Pourthiaea villosa* (G. Forst.) Tindale, *Arachniodes aristata* (G. Forst.) Tindale, *C. sinensis* latealatum (G . Forst.) Tindale, *A. standishii* (T. Moore) Ohwi, and *Crepidotomes latealatum* (Bosch) Copel.

The purpose of this study was to investigate the bryophyte flora of the evergreen broad-leaved forest in the vicinity of Baekyaki Oreum in Gujwa-Seongsan Gotjawal. Furthermore, this study contributes to the literature on the bryophyte flora of Gotjawal and evergreen broad-leaved forests on a regional scale and provides basic data pertaining relevant indicator species.

**Materials and Methods**

**Field surveys**

Field surveys were conducted in an evergreen broad-leaved forest in the vicinity of Baekyaki Oreum in Gujwa-Seongsan Gotjawal, with an area of approximately 75,453 m² (Fig. 1), four times from August of 2011 to August of 2018. The study area is located between Donggeomeuni Oreum, Baekyaki Oreum, and Jwabomi Oreum and belongs to Jongdal-ri, Gujwa-eup, Jeju-si, and Seongeup-ri, Pyoseon-myeon, Seogwipo-si.

**Identification, nomenclature and arrangement of taxa**

The samples collected in the investigated area were identified at the species level with macroscopic morphology and microscopic features using relevant literature (Iwatsuki and Mizutani, 1972; Inoue, 1974, 1976; Choe, 1980; Noguchi, 1987, 1988, 1989, 1991, 1994; Gao et al., 1999; Iwatsuki, 2001; Li et al., 2001; Wu et al., 2002; Cao et al., 2003). Voucher specimens were deposited in the herbarium of the Warm Temperate and Subtropical Forest Research Center in Korea (WFRC). Only one collection number per taxon was cited to avoid repetition on the floristic list. The nomenclature and arrangement of the taxa utilize the systems proposed by Goffinet et al. (2009) and Crandall-Stotler et al. (2009) for mosses and liverworts, respectively.

**Life-forms and substrates**

The life-forms of the bryophytes in the study area were estimated using Mägdefrau (1982), and they were found to be on the floristic list for each taxon. The records of substrates for each taxon were included in this list.

**Number of bryophyte taxa and liverwort index**

We compared the number of taxa and the liverwort index of the evergreen broad-leaved forest in the vicinity of Baeakyaki Oreum with other localities based on the available literature [i.e., Deogyusan Mt. (Choi et al., 2010; Yoon et al., 2011), Sobaeksan Mt. (Korea National Park Research Institute, 2016a), Gayasan Mt. (Korea National Park Research Institute, 2016b), Taebaeksan Mt. (Korea National Park Research Institute, 2018), Jirisan Mt. (Korea National Park Research Institute, 2019a), Sokrissan Mt. (Korea National Park Research Institute, 2019b), Dongbaek-dongsan (Yim et al., 2013), Subtropical Forest of Nabeup-ri (Yim and Hyun, 2018), and the evergreen broad-leaved forest of Cheongsu-ri at Hangyeong Gotjawal (Yim et al., 2019)]. The liverwort index, which is based on the fact that liverworts and hornworts tend to prefer more humid conditions compared to mosses, was calculated as follows (Nakanishi, 2001):

\[
\text{Liverwort index} \times 100 = \frac{\text{No. of liverworts} + \text{No. of hornworts}}{\text{Total no. of liverworts}} \times 100
\]

**Results and Discussion**

**The number of taxa and the liverwort index**

A total of 53 taxa belonging to Bryophyta (11 families 26 genera 39 species) and Marchantiophyta (9 families 9 genera 14 species) were determined (Appendix 1). A comparison of the results of the numbers of taxa indicated that the evergreen broad-leaved forest in the vicinity of Baeakyaki Oreum has a larger area than the Subtropical Forest of Nabeup-ri, but also has lower species diversity (Table 1).

The liverwort index is based on findings indicating that liverworts and hornworts tend to prefer more humid conditions than mosses. Therefore, it is useful to compare air humidity levels between different sites (Nakanishi, 2001). The liverwort index of the evergreen broad-leaved forest in the vicinity of Baeakyaki Oreum showed a humidity level of 26.4%, demonstrating that the air humidity of investigated area was lower than all of the mountain and Gotjawal areas, apart from the evergreen broad-leaved forest of Cheongsu-ri (Table 1). We consider that more detailed studies of the bryophyte flora of Korea should be conducted on a regional scale.
Remarkable species

*Plagiochila shangaica* Steph. (Hae-an-nal-gae-i-ikki), Choi et al. (2012), newly reported from Korean flora, was found in this study area (Fig. 3). This liverwort inhabits moist rocks on Jejudo Island, Oenarodo Island and Geojedo Island, among others, and is distributed in China, Japan, and Vietnam (Choi, 2013; Shu et al., 2017). The centers of diversity of *Plagiochila* are in Southeast Asia and the Neotropics (So, 2001). *P. shangaica* is designated and managed as a rare plant in Japan (Ministry of the Environment Government of Japan, 2020). The habitat of this species was unknown except for Andeok Valley on Jejudo Island, and this marks the first time it has been found in Gotjawal terrains thus far. Therefore, it is considered that research on this species as a climate change indicator species and rare plant is necessary.

Life-forms

We estimated the life-forms for each taxon in the study area, as presented in Table 2. The predominant life-form was the mat type (19 species, 35.8%), followed by the weft (18 species, 34.0%), tall turf (10 species, 18.9%), fan (3 species, 5.7%), tail (2 species, 3.8%), and short turf types (1 species, 1.9%). 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 rates of mostly pleurocarpous bryophytes (the mat, weft, fan, and tail life forms) dominating at mesic to hygric sites amounted to 79.2%, whereas mostly acrocarpous bryophytes (the tall turf and short turf life forms), mainly observed in xeric habitats, amounted to 20.8% (Fig. 2, Appendix 1). These values indicate that the forests in this study area have high density levels.

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**Table 1. Comparisons of the bryophyte species richness levels and liverwort indexes of the evergreen broad-leaved forest in the vicinity of Baekyaki Oreum and other localities.**

| Locality | Area (km²) | No. of species | Liverwort index |
|----------|------------|----------------|-----------------|
| Evergreen broad-leaved forest in the vicinity of Baekyaki Oreum (Gujwa-Seongsan Gotjawal) | 0.075 | 53 | 26.4 |
| Dongbaek-dongsan (Seonheul Gotjawal) | 1.420 | 85 | 27.0 |
| Evergreen broad-leaved forest of Cheongsu-ri (Hangyeong Gotjawal) | 0.501 | 72 | 23.6 |
| Subtropical Forest of Nabeup-ri (Aewol Gotjawal) | 0.034 | 63 | 30.2 |
| Jirisan Mt. | 483.022 | 218 | 49.5 |
| Sobaeksan Mt. | 322.011 | 236 | 41.9 |
| Deogyusan Mt. | 231.650 | 311 | 40.8 |
| Sokrisan Mt. | 274.766 | 130 | 42.3 |
| Gayasan Mt. | 76.256 | 173 | 37.6 |
| Taebaeksan Mt. | 70.052 | 275 | 38.9 |

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Fig. 3. *Plagiochila shangaica* Steph. found in the study area.
We estimated the substrates for each taxon to investigate the distribution pattern. The numbers of taxa according to the substrate are presented in Table 3. Upon an investigation of the substrates, bryophytes on the rocks were found to be most diverse, at 49 taxa, followed by bark (19 taxa) and decayed tree and soil (10 taxa, each). These results appear to stem from the fact that volcanic rock masses of various sizes are scattered over the study area, offering numerous micro-habitats for bryophytes due to one of the characteristics of Gotjawal, i.e., the presence of rocks of various sizes that are scattered randomly (Fig. 2C, D).

Table 2. Number of taxa and percentage composition according to the life-forms of bryophytes in the study area.

| Life-forms          | No. of taxa (%) |
|---------------------|-----------------|
| Xeric habitat type  | 11 (20.8)       |
| Short turfs         | 1 (1.9)         |
| Tall turfs          | 10 (18.9)       |
| Mesic to hygric site type | 42 (79.2) |
| Tails               | 2 (3.8)         |
| Fans                | 3 (5.7)         |
| Mats                | 19 (35.8)       |
| Wefts               | 18 (34.0)       |
| **Total**           | **53 (100.0)**  |

Table 3. The number of taxa according to the substrate in the study area.

| Substrate            | No. of taxa |
|----------------------|-------------|
| Specific to only one substrate |            |
| Epilithic            | 28          |
| Epiphytic            | 1           |
| Epixylous            | 1           |
| On the soil          | 1           |
| Common to two or more substrates |         |
| Epilithic and epiphytic | 9          |
| Epilithic and on the soil | 2          |
| Epilithic and epixylous | 1          |
| Epiphytic and epixylous | 1          |
| Epilithic, epiphytic and epixylous | 2          |
| Epilithic, epiphytic and on the soil | 2          |
| Epilithic, epiphytic and on the soil | 1          |
| Epilithic, epiphytic, epixylous and on the soil | 4          |
| **Total**            | **53**       |

Substrate pattern

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| Epilithic and on the soil | 2          |
| Epilithic and epixylous | 1          |
| Epiphytic and epixylous | 1          |
| Epilithic, epiphytic and epixylous | 2          |
| Epilithic, epiphytic and on the soil | 2          |
| Epilithic, epiphytic and on the soil | 1          |
| Epilithic, epiphytic, epixylous and on the soil | 4          |
| **Total**            | **53**       |
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Appendix 1. Floristic list of bryophytes of evergreen broad-leaved forest in the vicinity of Baekyaki Oreum in Gujwa-Seongsan Gotjawal, Jejudo Island.

| Taxa | Korean name | Life form | Substrate | Voucher No. |
|------|-------------|-----------|-----------|-------------|
| Bryophyta Schimp. 선류식물문 | Fissidentaceae Schimp. 봉황이끼과 | Fissidens gymnogynus Besch. 작은봉황이끼 | Tall turfs L | SSG324 |
| | Bryaceae Schwägr. 은이끼과 | Rosulabryum capillare (Hedw.) J. R. Spence 철사이끼 | Short turfs L | SSG072 |
| | Mniaceae Schwägr. 참이끼과 | Mnium ambiguum H. Müll. 납작맥초롱이끼 | Tall turfs L | SSG178 |
| | | Plagiomnium acutum (Lindb.) T. J. Kop. 아기들덩굴초롱이끼 | Tall turfs LS | SSG016 |
| | | Plagiomnium cuspidatum (Hedw.) T. J. Kop. 들덩굴초롱이끼 | Tall turfs L | SSG006 |
| | | Plagiomnium vesicatum (Besch.) T. J. Kop. 큰잎덩굴초롱이끼 | Tall turfs L | SSG095 |
| | | Trachycystis microphylla (Dozy & Molk.) Lindb. 아기초롱이끼 | Tall turfs LP | SSG108 |
| | Bartramiaceae Schwägr. 구슬이끼과 | Philonotis fontana (Hedw.) Brid. 물가이끼 | Tall turfs S | SSG073 |
| | Thuidiaceae Schimp. 깃털이끼과 | Anomodon minor (Hedw.) Lindb. 푸른명주실이끼 | Tails LP | SSG168 |
| | | Claopodium aciculum (Broth.) Broth. 가시이끼 | Wefts L | SSG077 |
| | | Haplocladium angustifolium (Hampe & Müll. Hal.) Broth. 착은명주실이끼 | Wefts LPXS | SSG003 |
| | | Haplocladium microphyllum (Hedw.) Broth. 작은명주실이끼 | Wefts LP | SSG078 |
| | | Pelekium versicolor (Hornsch. ex Müll. Hal.) Touw 아기깃털이끼 | Wefts LPXS | SSG008 |
| | | Thuidium kanedae Sakurai 깃털이끼 | Wefts LPS | SSG007 |
| | | Thuidium pristocalyx (Müll. Hal.) A. Jaeger 푸른깃털이끼 | Wefts L | SSG081 |
| | | Thuidium subglaucinum Cardot 큰푸른깃털이끼 | Wefts L | SSG111 |
| | Brachytheciaceae Schimp. 양털이끼과 | Brachythecium buchananii (Hook.) A. Jaeger 긴양털이끼 | Wefts L | SSG083 |
| | | Brachythecium helminthocladium Broth. & Paris 긴양털이끼 | Wefts L | SSG261 |
| | | Brachythecium plumosum (Hedw.) Schimp. 날개양털이끼 | Wefts LP | SSG033 |
| | | Brachythecium populeum (Hedw.) Schimp. 양털이끼 | Wefts LXS | SSG005 |
| | | Brynia novae-angliae (Sull. & Lesq.) Grout 세로양털이끼 | Wefts L | SSG018 |
| | | Cirrhopiliferum piliferum (Hedw.) Grout 긴nut양털이끼 | Wefts L | SSG032 |
| | | Eurhynchium savatieri Schimp. ex Besch. 가지부리이끼 | Wefts LPXS | SSG087 |
| | | Rhynchosciadium pallidifolium (Mitt.) A. Jaeger 아기양털부리이끼 | Wefts LP | SSG153 |
| | Hypnaceae Schimp. 닼 jinting이끼과 | Callidium haldanianum (Grev.) H. A. Crum 풍이끼 | Wefts L | SSG048 |
| | | Pseudotaxiphyllum pohliaecarpum (Sull. & Lesq.) Z. Iwats. 볼간접주목이끼 | Mats LS | SSG096 |
| | | Pylaisiadelpha temnirostris (Bruch & Schimp. ex Sull.) W. R. Buck 무성아실이끼 | Mats P | SSG092 |
| | | Taxiphyllum aomoriense (Besch.) Z. Iwats. 겹찬주목이끼 | Mats L | SSG144 |
| | | Taxiphyllum taxirameum (Mitt.) M. Fleisch. 주목이끼 | Mats LPX | SSG058 |
Appendix 1. Continued.

Plagiotheciaceae M. Fleisch.

*Plagiothecium euryphyllum* (Cardot & Thér.) Z. Iwats.  
Mats L SSG090  
Plagiothecium nemorale (Mitt.) A. Jaeger  
Mats LPX SSG002

Entodontaceae Kindb. 

*Entodon challenger* (Paris) Cardot  
Wefts L SSG089  
*Entodon sullivantii* (Müll. Hal.) Lindb.  
Wefts LPXS SSG009

Sematophyllaceae Broth.

*Sematophyllum subhumile* (Müll. Hal.) M. Fleisch.  
Mats X SSG093  
*Sematophyllum subpinnatum* (Brid.) E. Britton  
Mats PX SSG267

Neckeraceae Schimp.

*Neckera humilis* Mitt.  
Fans LP SSG013  
Pseudanomodon giraldii (Müll. Hal.) Ignatov & Fedosov  
Tails L SSG075  
*Thamnobryum plicatum* (Sande Lac.) Z. Iwats.  
Fans L SSG088  
*Thamnobryum subseriatum* (Mitt. ex Sande Lac.) B. C. Tan  
Fans L SSG004

Marchantiophyta Stotler & Crand. -Stotl.

Wiesnerellaceae Inoue  
*Wiesnerella denudata* (Mitt.) Steph.  
Mats L SSG102  
Dumontieraceae D. G. Long  
*Dumontiera hirsuta* (Sw.) Nees  
Mats L SSG103  
Metzgeriaceae H. Klinggr.  
*Metzgeria lindbergii* Schiffn.  
Mats LP SSG182

Pixellaceae Cavers  
*Pixella gracilima* Mitt.  
Mats L SSG220  
*Pixella grandiloba* Lindb.  
Mats L SSG143  
*Pixella vernicosa* Lindb.  
Mats L SSG001

Lejeuneaceae Cavers  
*Lejeunea japonica* Mitt.  
Mats LPS SSG204

Lophocoleaceae Müll. Frib. ex Vanden Berghen  
*Heteroscyphus argatus* (Nees) Schiffn.  
Mats L SSG099  
*Heteroscyphus planus* (Mitt.) Schiffn.  
Mats LP SSG186

Plagiochiaceae Müll. Frib.  
*Plagiochila ovalifolia* Mitt.  
Tall turfs L SSG046  
*Plagiochila sciophiola* Nees ex Lindenb.  
Tall turfs LX SSG214  
*Plagiochila shangaica* Steph.  
Tall turfs LP SSG107

Cephaloziellaceae Douin  
*Cephaloziella spinicaulis* Douin  
Mats L SSG148

Jungermanniaceae Rchb.  
*Jungermannia infusca* (Mitt.) Steph.  
Mats L SSG173

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