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교육학석사 학위논문

**Soil Seed Bank as a Base for the
Conservation and Management of
Janggun Wetland, Habitat of
Insectivorous Plants**

식충 식물의 서식지인 장군습지의 보전과 관리를
위한 기초로서의 토양 종자 은행

2021년 8월

서울대학교 대학원
과학교육과 생물전공
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지도 교수 김 재 근

이 논문을 교육학석사 학위논문으로 제출함
2021년 6월

서울대학교 대학원
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2021년 7월

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Abstract

In the montane wetland, habitats of various wildlife including insectivorous plants, hydrological properties could change significantly with climate change, resulting in change of vegetation structure. Insectivorous plants replenish nutrition from insects and this distinctive life style makes these plants valuable to preserve. Janggun wetland, one of the representative montane wetlands in Republic of Korea, is valuable because insectivorous plants including *Utricularia yakusimensis* and several endangered species inhabit this wetland. However, insectivorous plants in the wetland are in danger of extinction due to the decrease of water level. This study was conducted to figure out the species composition and the germination characteristics of seeds of insectivorous plants by seed bank analysis in Janggun wetland. Ten points in the wetland were selected and three layers of soil were collected by depth in May 2020. A vegetation survey was conducted with 10 quadrats installed around points where sediment soils were selected, in August 2020. A mesocosm experiment was set with the collected soils from June to October and emerged individuals were identified and charted consistently. Total 5,820 individuals of 29 species appeared in seed bank, and *Eriocaulon cinereum* was the most abundant species in seed bank. In addition, the number of emerged individuals decreased as the depth of seed bank deepens. Shannon – Wiener diversity index of seed banks in annual plants increased in the deeper seed bank. Regardless of the depth of seed bank, community overlap indices between seed banks and aboveground vegetation of the wetland were relatively high in annual plants than perennials. In perennial plants, diversity indices were mostly high due to the lack of

dominant species. The insectivorous plants, unlike the absence in the wetland vegetation, *U. yakusimensis*, *Utricularia racemosa*, and *Drosera rotundifolia* appeared in seed banks where the shoots of *Molinia japonica* were rare and ground was inundated. It is thought that light and water level conditions for the germination and growth of insectivorous plants have not been satisfied in Janggun wetland, because of water level decrease and the formation of dominant communities of *M. japonica*. This study proved the possibility of reemergence of insectivorous plants from soil seed bank if the proper management about water and *M. japonica* is provided. Seed bank study for understanding distribution, germination characteristics, and the lifespan of seeds of various species is expected to be used for the conservation of species diversity of Janggun wetland, the management of montane wetlands, and the conservation of insectivorous plants.

Keyword: annual plant, insectivorous plant, Janggun wetland, perennial plant, species composition, water level decrease

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I. Introduction

Wetland, one of the most valuable ecosystems in the world, has unique traits from other ecosystems. As the ecotone between terrestrial and aquatic ecosystems, wetland is the habitat of a variety of organisms including wetland plants (Kim and Kim 2016, Hong and Kim 2017). There are even some endangered species in the wetlands, including insectivorous plants. In addition to the advantage that wetland is the repository of biodiversity, wetland produces lots of biomass, prevents aquatic ecosystems from water pollution, and regulates flood (Mitsch and Gosselink 2015). Furthermore, wetland contributes to the production of nitrogen molecules, participating in the nitrogen cycle (Bowden 1987).

Montane wetlands located in temperate zone have characteristics of low temperature, low pH, thick peat layer, and inundated soil (Kim et al. 2014). Due to these properties, montane wetlands are considered as important ecosystems where specific organisms have been adapted to the distinctive environment. Because there are steep mountainous terrains mostly in the country, montane wetlands were rarely formed in Korea (Kim 2009). In addition, as montane wetlands in Korea are likely to have precipitation and groundwater as the major water source, their hydrological properties are mostly affected by precipitation regime (Kim 2009). Distribution and growth of some wetland plant species, which have been specifically adapted to the environment of montane wetlands, could be affected by the environmental change of montane wetlands.

Soil seed bank is defined as the group of seeds which are dormant but germinative in the soil (Bigwood and Inouye 1988). Soil seed bank could improve

the understanding of diversity of vegetation, restoration after disturbance, and early vegetation formation. (Haag 1981, Galatowitsch and van der Valk 1996, Brock and Rogers 1998, Harwell and Havens 2003). Particularly, seed bank experiment enables to observe almost all species present through whole growth period, providing the opportunity to identify potential biodiversity in the ecosystem (Galatowitsch and van der Valk 1996). The composition of germinated species from seed bank is also affected by the reproductive traits of each species, such as amount of seed production and seed lifespan (Bossuyt and Honnay 2008).

Reproductive properties of plant species are mainly affected by their lifespan and habitat environment (Yang and Kim 2016). Annual plants reproduce and maintain their populations by seeds. Hence, population dynamics of annual plants could be affected mainly by its reproductive traits on the seed production and dispersion (Min 2005). On the other hand, perennial plants can maintain populations by not only seed production but also propagules (Leck et al. 1989). As wetland develops, aerial vegetation of annual species is predicted to decrease where perennial species increase, especially vegetative perennial species (Noon 1996). Therefore, seed bank experiment could reveal the potential biodiversity of annual species and enhance the understanding of the previous vegetation of the wetland.

One of the most distinctive species in montane wetlands is insectivorous plant. Insectivorous plants, which gain nutrition from small insects and protozoa, are different from other ordinary plants in the way to live and grow, and the number of insectivorous plant species is extremely limited (Choi 2019). Getting nitrogen from insects, insectivorous plants inhabit the acidic wetlands which are oligotrophic by poor decomposition of organic matter (Hill 1972, Heslop-Harrison 1989). In the montane wetlands in Korea, it is known that there are 2 families 4 genera 13 species

of insectivorous plants, including *Utricularia yakusimensis*, *U. racemosa*, *U. bifida* and *Drosera rotundifolia* (Choi 2019). They have high scarcity of distribution and habitat because they usually prefer oligotrophic habitat such as bogs and fens (Hill 1972, Heslop-Harrison 1989). Insectivorous plants in Korea seem to be threatened by the environmental changes of montane wetlands (NIBR 2012, Cho and Lee 2016).

Janggun wetland is one of the representative montane wetlands in Korea with *Molinia japonica* as a dominant plant species (Choi et al. 2021). It has high species diversity, where 250 plant species have been observed (Korean Wetlands Society 2017). Especially, the inhabitation of insectivorous plants of Lentibulariaceae such as *U. yakusimensis*, *U. racemosa*, *U. bifida* and *D. rotundifolia* had been identified (Lee et al. 2012). In recognition of the importance and value, there has been a recent call to the Ministry of Environment for designation of Janggun wetland as a wetland preservation area (Kwon 2011). However, water table decrease in Janggun wetland by changes in precipitation pattern has been observed for recent years (Son 2020). Furthermore, this water level change could lead to changes of vegetation structures, especially the distribution of relatively rare plant species such as insectivorous plant (Hong and Kim 2017).

The purpose of this study is to figure out the species composition of seed banks in Janggun wetland and to identify the presence of insectivorous plants in seed bank. The research questions are:

- 1) What species appear in seed banks in Janggun wetland?
- 2) Are there any differences in species diversity indices of seed banks by depth in annual and perennial plants?
- 3) Are there insectivorous plants in seed bank?

To achieve the goal, seed bank experiment was conducted and species

composition in seed banks were analyzed by the depth of soil. It is expected that this study will enable to identify species composition of seed bank in Janggun wetland especially about insectivorous plants and to establish management method for the restoration of the population of insectivorous plants in the wetland.

II. Materials and methods

1. Study site

Janggun wetland is a montane wetland located in Mt. Geumjeong, Yangsan City, Gyeongnam Province, Republic of Korea (35°17'32.43" N, 129°03'17.33" E, 565 m asl) (Fig. 1). Substrate consists of peat and is acidic and mostly anaerobic (Choi et al. 2021). The wetland is located near the ridge of the mountain and major water source might be surface flow and ground water (Ryan et al. 2014, Mitsch and Gosselink 2015, Kim and Kim 2016). The annual average temperature of Janggun wetland in 2020 was $15.1 \pm 0.4^{\circ}\text{C}$ (mean \pm SE) and daily mean temperature was highest in August as $27.9 \pm 0.2^{\circ}\text{C}$. The annual total precipitation of the wetland in 2020 was 1892.5 mm (Korea Meteorological Administration 2020). Rainfall was concentrated from June to August.

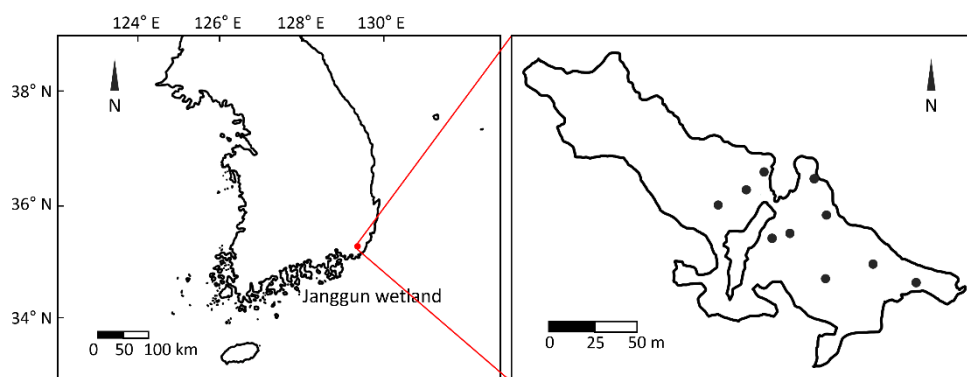


Fig. 1. The location of Janggun wetland and the spots of sampling quadrats in the wetland. The dots indicate the quadrats.

2. Field survey

Total 10 quadrats in 2 m × 2 m were established in the wetland (Fig. 1). Seed bank samples of each quadrat were collected in May 2020. Sediment soil samples were collected using soil auger with a diameter of 8 cm. In each quadrat, sediment soil samples were taken at five spots and three layers of 0 ~ 5 cm depth (Shallow), 10 ~ 15 cm depth (Medium), and 20 ~ 25 cm depth (Deep) at each spot and five samples at the same layer were mixed together. Therefore, three samples in each quadrat and a total of 30 samples were collected. Total volume of sediment soil taken from the wetland was 37,699 cm³. The samples were stored until June of the year of collection at 4°C before the experiment. Vegetation survey was conducted at 10 quadrats in August 2020. Density and coverage of emerged species were measured.

3. Experimental design and procedure

The collected sediment soil samples were used in a germination experiment at a greenhouse with open walls in Seoul National University (N37°27', E126°57'). A mosquito net was placed in the greenhouse to prevent the inflow of external seeds, and temperature and relative humidity logger (HOBO pro v2, Onset, USA) was installed inside the greenhouse and the measurement was conducted every hour during the experiment. Mix of sand and topsoil in a 2:1 volume ratio were used as the base soil. In order to eliminate any seeds or propagules, the base soil was heated for 6 hours at 105°C. To provide proper conditions for germination of each species, wet conditions maintaining -2 to 0 cm of water level from soil surface and inundated

conditions maintaining more than 2 cm of water level were created for each sample. The water level was maintained with inner and outer tray for each sample, by watering to the outer tray at least once a week during the experiment. Each inner tray (41.0 cm × 24.5 cm × 11.5 cm) was filled with base soil about 3 cm height, and sediment soil was evenly spread to about 2.5 mm height. Then inner tray was placed in the outer tray (59.0 cm × 38.5 cm × 14.0 cm) (Fig. 2). Germinated individuals were removed after identification once a week (Lee 2003). In the case of seedlings with a difficulty of identifying, they were transplanted at the other pots and grown until it showed the distinctive traits which could be identified. The experiment was conducted until October.

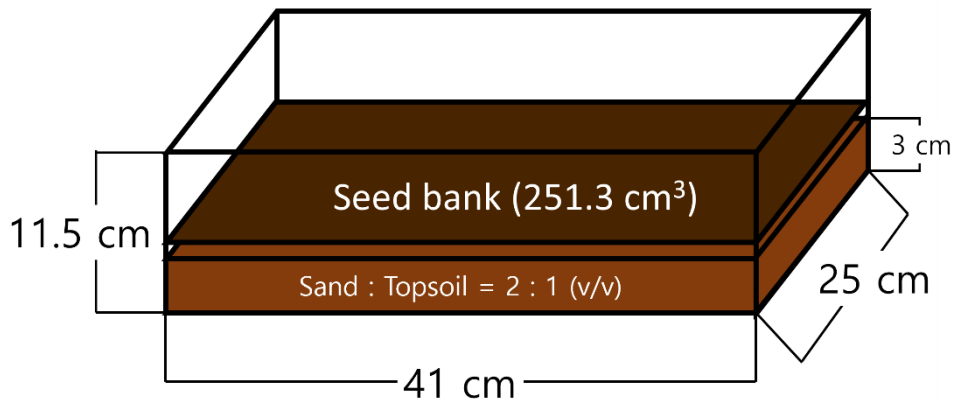


Fig. 2. Schematic diagram of seed bank experiment. The outer tray was not expressed in this figure.

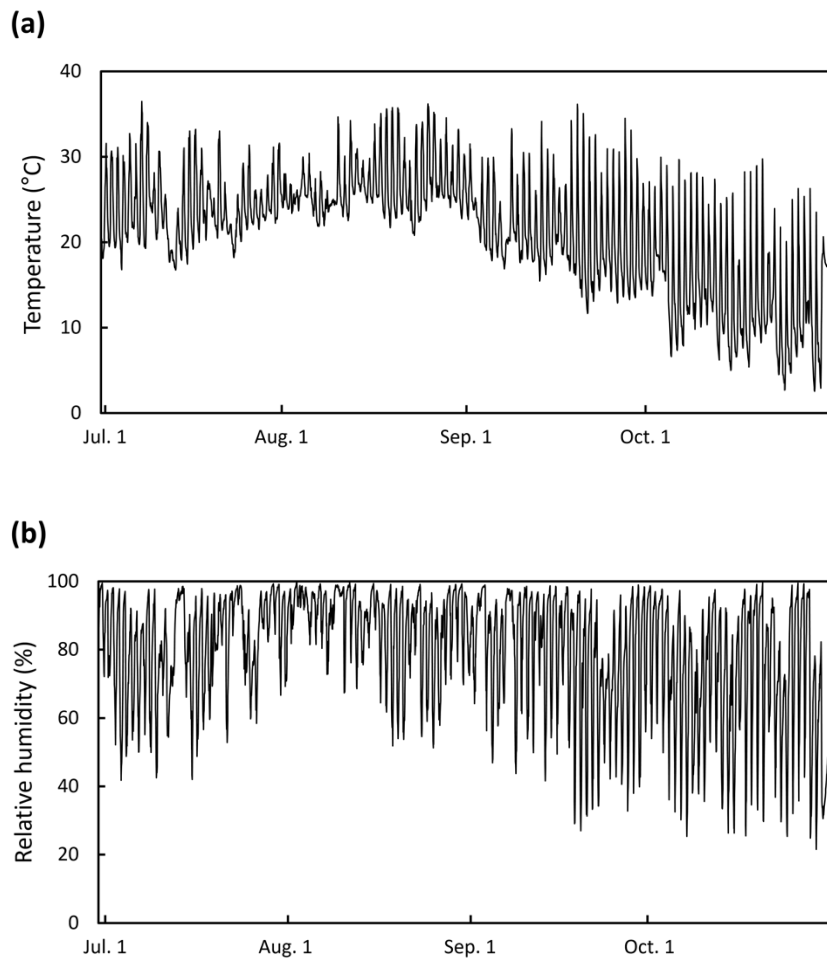


Fig. 3. Temperature **(a)** and relative humidity **(b)** in the greenhouse during the period of experiment.

4. Statistical analyses

To identify the difference of species richness and diversity between shallow, medium, and deep soils, one-way analysis of variance (ANOVA) and Duncan's post-hoc test were conducted with R (ver. 3.6.3) (R Core Team 2018). Tests were performed with 0.05 significance level.

Species composition and the number of individuals of each species in seed bank were compared with vegetation in wetland using Shannon-Wiener diversity index (H') and community overlap index (R_o) (Horn 1966). Each index was calculated by the following equations:

$$H' = -\sum p_i \log p_i$$

$$R_o = \frac{H'_{max} - H'_s}{H'_{max} - H'_{min}}$$

Where p_i is the number of individuals of i^{th} species divided by the number of total individuals. H'_{max} and H'_{min} mean Shannon – Wiener maximum and minimum similarity index between two communities respectively, and H'_s means Shannon – Wiener diversity index about combined species of two communities.

III. Results

1. Species composition in seed bank

A total of 29 species 5,820 individuals germinated in seed bank in Janggun wetland (Fig. 4, Table 1). The number of annual plants was 5,469 individuals, which showed about 15 times more than the number of perennial plants, 351. In the inundated condition, floating macrophytes, *Lemna perpusilla* Torr. appeared in several samples, but they were excluded in the data for further analysis because of the difference of life-form. In annual plants, the most common species was *Eriocaulon cinereum* with 4,401 individuals and second common species was *Erigeron annuus* with 515 individuals. Among insectivorous plants, 99 individuals of *U. yakusimensis* appeared. In perennial plants, 119 individuals of *Rhynchospora fujiana* Makino and 113 individuals of *Schoenoplectiella juncooides* appeared the most. *Molinia japonica*, dominant species in Janggun wetland, only showed 38 of germinated individuals. Two insectivorous plants, *U. racemosa* and *D. rotundifolia* appeared with 15 individuals and one individual each. The family with the largest number of species appeared was five from Poaceae, followed by four from Scrophulariaceae and three from Cyperaceae. Among them, Cyperaceae showed the most and largest germinated individuals with 394 individuals, followed by 193 in Scrophulariaceae and 89 in Poaceae.

Table 1. The list of species and family, lifespan, and life form of each species emerged in seed banks.

Species	Family	Lifespan	Life form*
<i>Eriocaulon cinereum</i>	Eriocaulaceae	Annual	OBW
<i>Eriocaulon sikokianum</i>	Eriocaulaceae	Annual	OBW
<i>Molinia japonica</i>	Poaceae	Perennial	FACW
<i>Isachne globosa</i>	Poaceae	Perennial	OBW
<i>Arundinella hirta</i>	Poaceae	Perennial	OBU
<i>Alopecurus aequalis</i>	Poaceae	Annual	FACW
<i>Digitaria violascens</i>	Poaceae	Annual	OBU
<i>Pycnus sanguinolentus</i>	Cyperaceae	Annual	FACU
<i>Rhynchospora fujiiiana</i>	Cyperaceae	Perennial	OBW
<i>Schoenoplectiella juncoides</i>	Cyperaceae	Perennial	OBW
<i>Erigeron annuus</i>	Asteraceae	Annual	OBU
<i>Centipeda minima</i>	Asteraceae	Annual	FAC
<i>Lindernia dubia</i>	Scrophulariaceae	Perennial	FAC
<i>Lindernia procumbens</i>	Scrophulariaceae	Annual	FAC
<i>Deinostema violacea</i>	Scrophulariaceae	Annual	OBW
<i>Mazus pumilus</i>	Scrophulariaceae	Annual	FACU
<i>Commelina coreana</i>	Commelinaceae	Annual	OBU
<i>Utricularia yakusimensis</i>	Lentibulariaceae	Annual	OBW
<i>Utricularia racemosa</i>	Lentibulariaceae	Perennial	OBW
<i>Drosera rotundifolia</i>	Droseraceae	Perennial	OBW
<i>Persicaria sagittata</i>	Polygonaceae	Annual	FACW

<i>Plantago asiatica</i>	Plantaginaceae	Perennial	OBU
<i>Hypericum laxum</i>	Clusiaceae	Annual	FAC
<i>Oxalis corniculata</i>	Oxalidaceae	Perennial	OBU
<i>Cerastium fontanum</i> subsp. <i>vulgare</i>	Caryophyllaceae	Annual	OBU
<i>Cardamine flexuosa</i>	Brassicaceae	Annual	FACW
<i>Trigonotis peduncularis</i>	Boraginaceae	Annual	OBU
<i>Typha</i> spp.	Typhaceae	Perennial	OBW
<i>Alnus japonica</i>	Betulaceae	Perennial	FACW

* OBW: Obligate wetland plant; FACW: Facultative wetland plant; FAC: Facultative plant; FACU: Facultative upland plant; OBU: Obligate upland plant (Choung et al. 2012).

(a) Annual plants

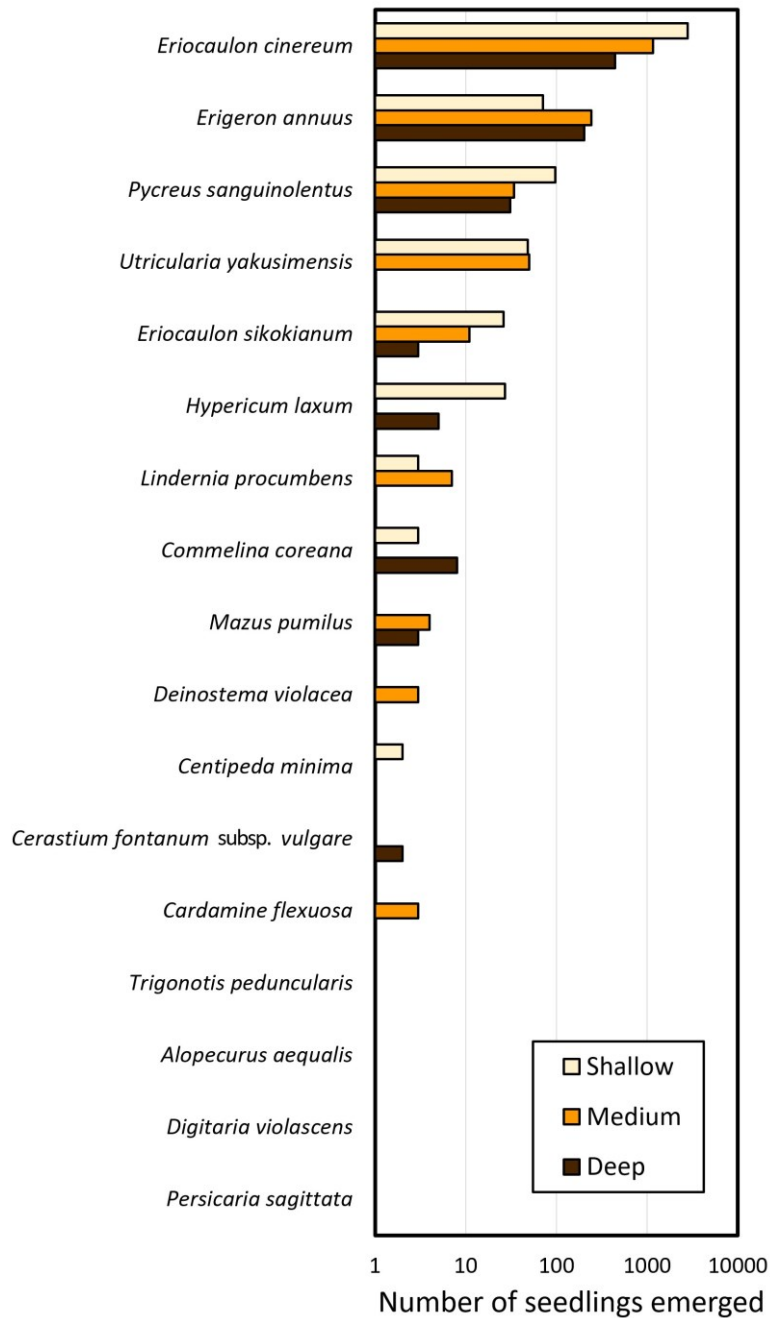


Fig. 4. Emerged seedling number of each species of annual (a) and perennial (b) plants in three layers of seed banks.

(b) Perennial plants

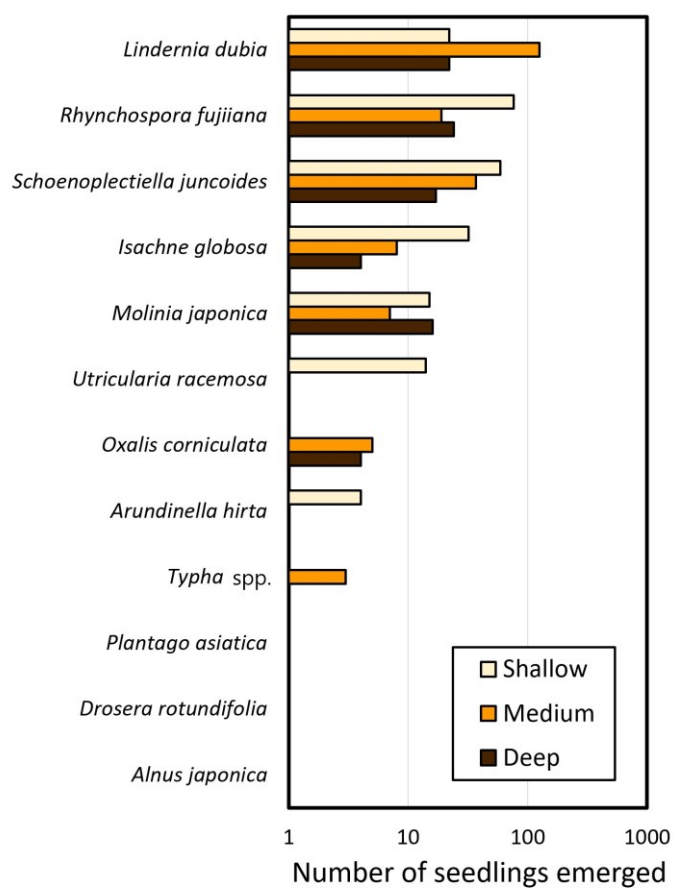


Fig. 4. Continued.

2. Species diversity of seed banks in annual and perennial plants

Comparing the density of germinated individuals according to the depth of collected soil showed that the largest number of individuals germinated in the shallow layer, followed by medium layer, and the smallest amounts of individuals in deep layer soil in the both cases of annual and perennial plants (Fig. 5). The average seedling density in the sediment soil in the shallow layer statistically differed from those in the medium and deep layer. The average seedling density of annual plants for each depth was about 15, 20, and 11 times higher than of perennial plants, respectively.

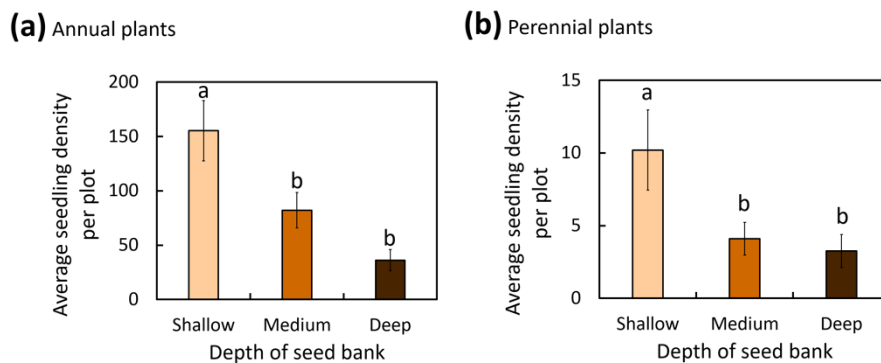
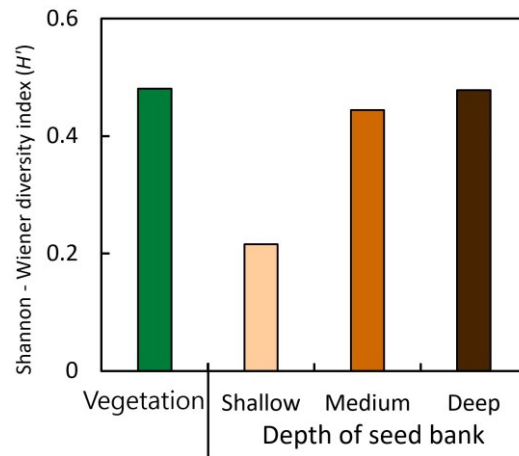


Fig. 5. Average seedling density of annual **(a)** and perennial **(b)** plants in shallow, medium, and deep layers. Vertical bars show standard error for each depth. Different letters indicate statistically different sub - groups by Duncan's post - hoc test ($p < 0.05$).

In annual plants, among Shannon - Wiener diversity indices (H') of aboveground vegetation in August was 0.48 (Fig. 6a). The species diversity indices of seed banks were lower than index of aboveground vegetation, increasing with the depth of seed banks (0.22 in shallow, 0.44 in medium, and 0.48 in deep layer, respectively). Comparing the community overlap index (R_o) between seed banks by depth and wetland vegetation in August, the depth with the highest community overlap was shallow, and the deeper the depth of the seed bank, the lower overlap index (shallow = 0.66, medium = 0.60, deep = 0.59) (Fig. 6c).

On the other hand, in the case of perennial plants, H' of seed bank of medium layer showed the highest value of 0.69 and the index of aboveground vegetation was the lowest, 0.26 (Fig. 6b). Also, indices of perennial plants in seed banks were higher than those of annual plants. However, community overlap indices were lower than those of annual plants and the index of seed bank in shallow layer was the lowest (shallow = 0.36, medium = 0.47, deep = 0.55) (Fig. 6d).

(a) Annual plants



(b) Perennial plants

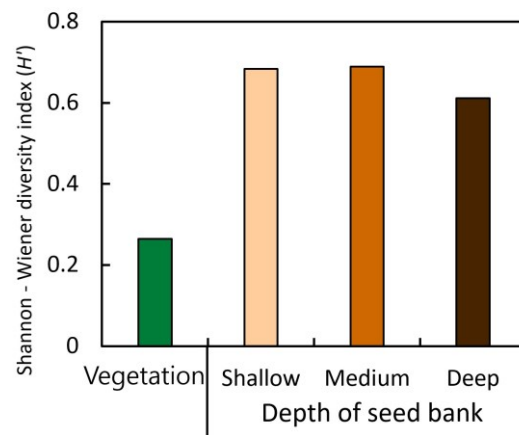
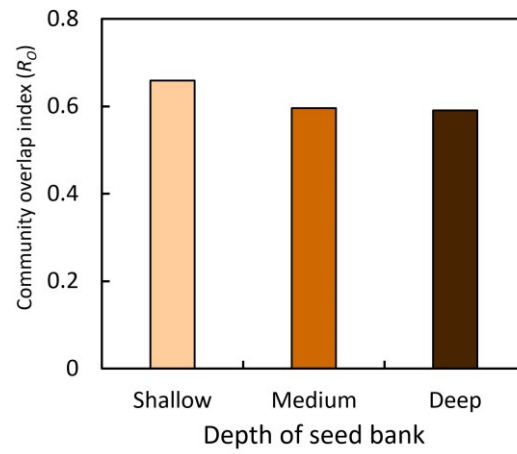


Fig. 6. Shannon – Wiener diversity index of aboveground vegetation in August and seed banks in shallow, medium, and deep layers of annual **(a)** and perennial **(b)** plants. Community overlap index between each seed bank in shallow, medium, and deep layers and aboveground vegetation in August of annual **(c)** and perennial **(d)** plants.

(c) Annual plants



(d) Perennial plants

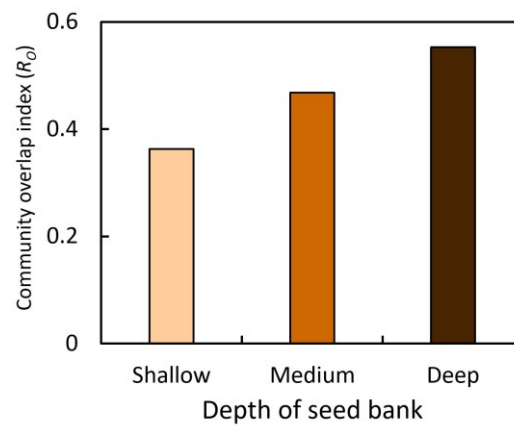


Fig. 6. Continued.

3. Temporal dynamics of seedling emergence and the presence of insectivorous plants in seed bank

In the result of the germination periods for each seed, the largest number of species germinated in July and September, with slight differences in species germinating during each period (Fig. 7). In the case of annual plants, the most frequently found species, *E. cinereum*, always germinated actively during the experiment, and *E. annuus* and *Lindernia dubia* also germinated during the entire period. *Commelina coreana*, *Cardamine flexuosa*, *Persicaria sagittata* only appeared in June and July, and no germinated individuals were observed afterward. In the case of perennial plants, *Rhynchospora fujiiiana*, and *Oxalis corniculata* germinated actively, and many monocotyledons such as *Schoenoplectiella juncoides* and *Isachne globosa* appeared. Three insectivorous plants, *U. yakusimensis*, *U. racemosa*, and *D. rotundifolia* were not observed in the wetland but appeared in seed banks (Fig. 4). The seedlings of *U. yakusimensis* were first observed in August, and the seedlings of *U. racemosa* and *D. rotundifolia* were observed from September (Fig. 7).

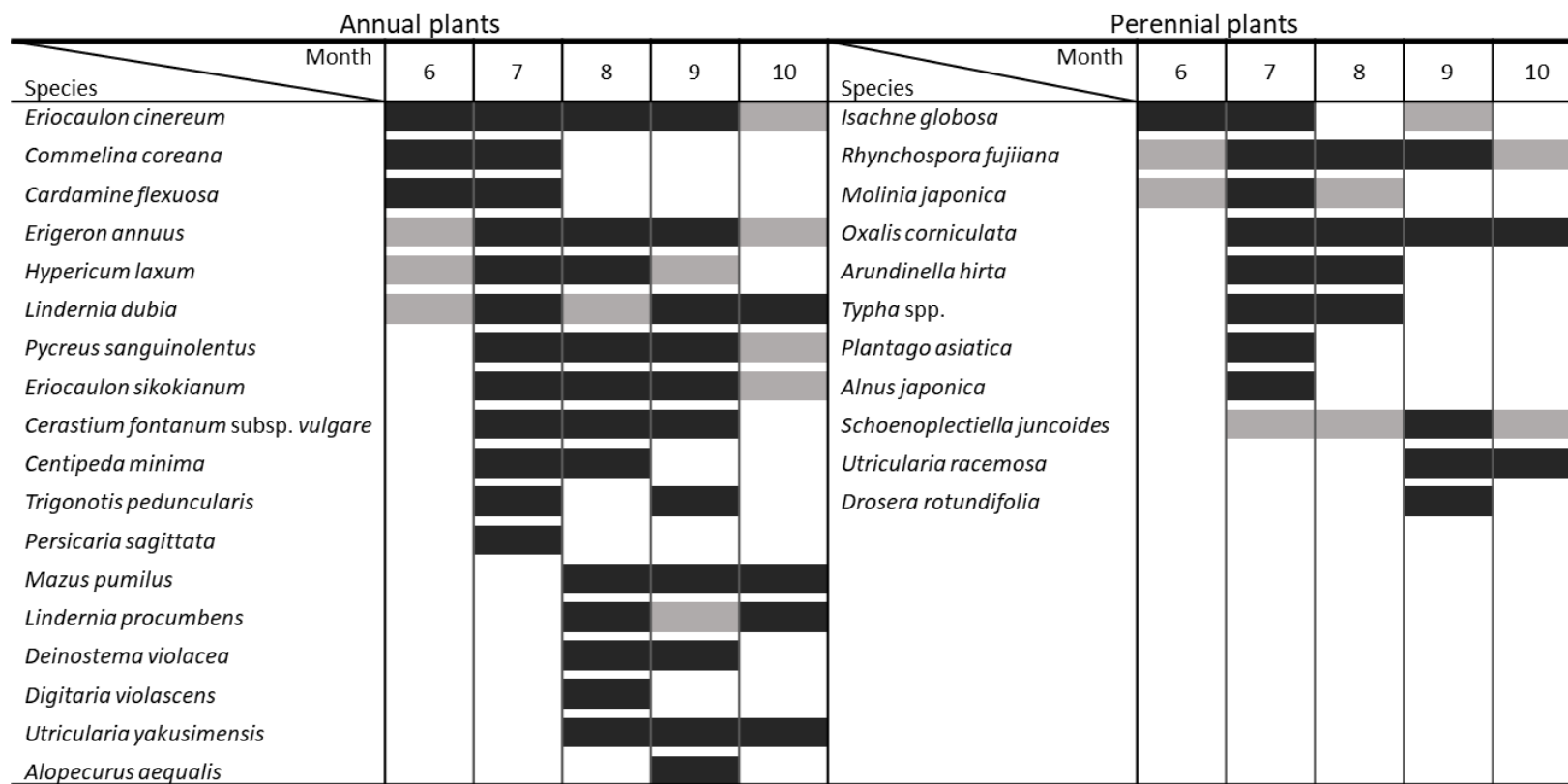


Fig. 7. The germination period of each annual and perennial plant species. Squares filled with dark gray and light gray indicate more than 10% of total germination in each species and less than 10% of total germination in each species, respectively.

IV. Discussion

1. Species composition in seed bank

In this study, total 5,820 individuals of 29 species germinated in the seed banks of Janggun wetland (Fig. 4). The most abundant species in seed bank was *E. cinereum* in annual plants. In contrary, the most dominant species in vegetation was *M. japonica*. It is known that when perennial Poaceae plants dominate aboveground in the wetland, it is not easy that the vegetation of aboveground matches that of underground seed bank (Leck et al. 1989, Kim and Ju 2005). This could result from the way *M. japonica* maintains its population. *Molinia japonica* reproduces by seeds, but like other Poaceae plants, it develops population by vegetative reproduction mostly (Albert et al. 2015). This property makes the seeds of *M. japonica* rarely observed in seed bank (Leck et al. 1989). Therefore, dominant species of seed bank, *E. cinereum* was different from the dominant species of aboveground vegetation in Janggun wetland, *M. japonica*.

2. Species diversity of seed banks in annual and perennial plants

As the result of comparing the characteristics of seed banks collected from three different depths, the number of seedlings decreased in the deeper soil seed bank rather than the shallower soil seed bank (Fig. 5). Seeds in the deeper sediment soil are regarded as the older seeds than in the shallower sediment soil with decreased viability and germination probability. This would mean that seeds of perennial plants tend to be less viable and have shorter lifespan. In addition, the number of seedlings of perennial plants were far less than that of annual plants (Fig. 5). In the case of perennial plants, the species found in seed banks were mainly Poaceae, Cyperaceae, and woody plant. Woody plants have a lower appearance rate in seed banks, which could be caused by higher rate of intake and decomposition of fruit and seed (Leck et al. 1989). Moreover, some perennial Poaceae and Cyperaceae plants have rhizome, which could be efficient for expansion of populations. It is thought that perennial plants inhabiting Janggun wetland tend to depend on the vegetative propagation for the maintenance of their populations after settlement in the wetland.

Shannon – Wiener diversity index of emerged species in seed bank was higher in perennial plants than annual plants. In annual plants, diversity index increased as the depth of seed bank increased (Fig. 6a). The small diversity index of seed banks in annual plants seems to be due to the presence of a large number of *E. cinereum*, resulting low species evenness. On the other hand, aboveground vegetation seems to have lower diversity index due to low species richness. Community overlap index between seed banks by depth and aboveground vegetation, the value decreased as depth deepened in annual plants (Fig. 6c). Compared with

perennial plants, the current vegetation structure and the community structure of seed banks of annual plants were quite similar regardless of the depth of seed banks. It is thought that the annual plants in Janggun wetland tend to produce seeds well and maintain their own germination and growth rate. Therefore, in order to preserve the diversity of annual plants in Janggun wetland, management of the excessive expansion of dominant species, *M. japonica*, seemed to be needed (Choi et al. 2021).

In perennial plants, on the other hand, the diversity index for aboveground vegetation was the lowest, while indices of seed banks showed relatively high values over 0.6 (Fig. 6b). Perennial Poaceae plants being dominant in the wetland inhibit the growth of other plants by occupying spaces and resources through vegetative reproduction (Kim and Ju 2005). This made various perennial plants which are present in the wetland not grow well, causing low species richness and evenness. In addition, community overlap indices from three layers of depth were lower than those of annual plants, and index of seed bank from shallow sediment soil was the lowest (Fig. 6d). There were not many *M. japonica* in soil seed bank, and the rest of the species appeared at a similar level in the seed banks. Unlike *M. japonica* which is a facultative wetland plant, other perennials in Poaceae and Cyperaceae, such as *I. globosa*, *R. fujiana*, and *S. juncooides* differ in type from *M. japonica*, the obligate wetland plant (Choung et al. 2012). Thus, it could mean that they would be less suitable to the current wetland environment than *M. japonica*, because *M. japonica* makes the environment more proper for itself by producing tussock and litter layer (Choi et al. 2021).

3. Presence of insectivorous plants in seed bank

Among insectivorous plants, seedlings of *U. yakusimensis*, *U. racemosa*, and *D. rotundifolia* were identified (Fig. 4). Though these species have not been found in Janggun wetland, it is thought that their seeds or propagules were present in the seed bank. During the experiment, *U. yakusimensis* began to appear in August, and *U. racemosa* and *D. rotundifolia* were observed from September (Fig. 7). For dormancy-breaking of *D. rotundifolia*, low temperature and wet condition for 12 weeks are required and then temperature of 20 ~ 30°C and light are needed (Cho and Lee 2016). Considering this property, the relatively late time of emergence of *D. rotundifolia* seems to be after dormancy-breaking of seed.

There has been observed water level decrease due to reduced precipitation in Janggun wetland for recent years (Son 2020). It could be said that *D. rotundifolia* was not observed in the wetland because the wet condition for 12 weeks which is necessary for the germination of seed has not been satisfied. In addition, the growth characteristics of *Utricularia* includes shallow water level (< 20 cm) and oligotrophic water (Ceschin et al. 2020). Therefore, it is thought that two species of *Utricularia* could not be observed in the wetland because there was improper water level for the growth of *U. yakusimensis* and *U. racemosa* due to the decrease of water level.

Drosera rotundifolia needs about 54.7% of relative light intensity (Cho and Lee 2016), and *Utricularia* including *U. yakusimensis* and *U. racemosa* grow in the environment with sunny sites (~ 1500 $\mu\text{mol}/\text{m}^2\text{s}$) (Ceschin et al. 2020). In Janggun wetland, *M. japonica* forms tussocks and large amounts of dead litter. Water level decrease from continuous drought could cause the expansion of *M. japonica*

population whose aboveground height is relatively taller (Son 2020), which may make the environment where insectivorous plants cannot acquire enough light at the ground surface, below shoots of *M. japonica*. Therefore, there were several possible causes of recent disappearance of insectivorous plants at aboveground vegetation in Janggun wetland.

V. Conclusion

This study identified species composition diversity, and the presence of insectivorous plants by seed bank in Janggun wetland. Total 29 species appeared in seed bank, and the number of germinated seedlings decreased as the depth of seed bank deepens. The formation of dominant communities of *M. japonica* in the wetland seemed to make annual plants germinate at a low rate and the environment be less proper for the growth of perennial plants in the wetland. In this study, insectivorous plants, *U. yakusimensis*, *U. racemosa*, and *D. rotundifolia*, were not found in the wetland, while they emerged in seed bank. Decrease of water level in the wetland observed recently seemed to cause an inadequate environment for the germination and growth of insectivorous plants. The management of excessive expansion of *M. japonica* and maintenance of water level in Janggun wetland could enable the reemergence of insectivorous plants which are in danger of disappearance in the wetland.

References

- Albert A, Brisson J, Belzile F, Turgeon J, Lavoie C (2015) Strategies for a successful plant invasion: the reproduction of *Phragmites australis* in north-eastern North America. *J Ecol* 103(6): 1529-1537
- Bigwood DW, Inouye DW (1988) Spatial pattern analysis of seed banks: an improved method and optimized sampling. *Ecology* 69: 479-507
- Bossuyt B, Honnay O (2008) Can the seed bank be used for ecological restoration? An overview of seed bank characteristics in European communities. *J Veg Sci* 19: 875-884
- Bowden WB (1987) The biogeochemistry of nitrogen in freshwater wetlands. *Biogeochemistry* 4: 313-348
- Braun-Blanquet J (1932) Plant sociology. Fuller GD, Conrad HS (translators). McGraw-Hill, New York, 439p
- Brock MA, Rogers KH (1998) The regeneration potential of the seed bank of an ephemeral floodplain in South Africa. *Aquat Bot* 61: 123-135
- Ceschin S, Bellini A, Traversetti L, Zuccarello V, Ellwood NTW (2020) Ecological study of the aquatic carnivorous plant *Utricularia australis* R. Br. (Lentibulariaceae). *Aquat Ecol* 54(1): 295-307
- Cho JS, Lee CH (2016) Dormancy and germination characteristics of round-leaved sundew (*Drosera rotundifolia* L.) seeds native to Korea. *Korean J Plant Res* 29(5): 564-573
- Choi YE (2019) A study on the characteristics of the environment and vegetation of carnivorous plants habitats in Geogum-do islands of Goheung counties, Jeollanam-do. *The Journal of Korean Island* 31(1): 215-234
- Choi YS, Park HJ, Kim JG (2021) Effects of soil water content and light intensity on the growth of *Molinia japonica* in montane wetlands in South Korea. *J Ecol Environ* 45(1): 1-7
- Choung YS, Lee WJ, Jo KH, Min BM, Hyun JO, Lee GS (2012) Categorizing vascular plant species occurring in wetland ecosystems of the Korean peninsula. Center for Aquatic Ecosystem Restoration, Chuncheon
- Galatowitsch SM, van der Valk AG (1996) The vegetation of restored and natural prairie wetlands. *Ecol Applic* 6: 102-112

- Haag RW (1981) Emergence of seedlings of aquatic macrophytes from lake sediments. *Can J Bot* 61: 148-156
- Harwell MC, Havens KE (2003) Experimental studies on the recovery potential of submerged aquatic vegetation after flooding and desiccation in a large subtropical lake. *Aquat Bot* 77: 135-151
- Heslop-Harrison Y (1989) Carnivorous plant. In: Gould JL (ed) *Life at the edge. Readings from scientific American*. W. H. Freeman Pub. Co., New York, pp 99-160
- Hill EP (1972) Litter size in Alabama cottontails as influenced by soil fertility. *J Wildl Manage* 36: 1199-1209
- Hong MG, Kim JG (2017) An analysis of trends in wetland function assessments and further suggestions. *J Wet Res* 19(1): 1-15
- Horn HS (1966) Measurement of “overlap” in comparative ecological studies. *Am Nat* 100(914): 419-424
- Kim HS, Kim JW (2016) Hydrology of wetlands. In: Ahn KS, Kim HS, Kim JG (ed) *Wetlands*. Life Science Publishing Co., Seoul, pp 22-59
- Kim JG (2009) Ecological characteristics of *Sphagnum* fens in Mt. Odae: I . Sowhangbyungsna-neup. *Journal of Korean Wetlands Society* 11(1): 15-27
- Kim JG, Ju EJ (2005) Soil seed banks at three ecological preservation areas in Seoul. *Korean J Ecol* 28(5): 271-279
- Kim T, Yang B, Lee J, Yang H, Park S, Lee J, Lee J, Baek C, Lim J, Kang N, Park J (2014) A study on soil characteristics for conservation and management of mountain wetlands(I). *Natl Inst Environ Res*, Incheon
- Korea Meteorological Administration (2020) <https://www.weather.go.kr/w/index.do>. Accessed 11 June 2020
- Korean Wetlands Society (2017) Evaluation of effect on ecosystem and plan for preservation of water level result from the decline of water level in Janggun wetland
- Kwon K (2011.01.17) Gyeongnam, to promote designation of Janggun wetland in Yangsan city as Ramsar wetland. *The Kyunghyang Shinmun*. Accessed 5 July 2021. <https://m.khan.co.kr/local/Yeongnam/article/201101172232325#c2b>
- Leck MA, Parker VT, Simpson RL (1989) *Ecology of soil seed banks*. Academic press,

New York

- Lee SD, Kim JS, Kim MJ, No TH (2012) Ecological characteristics and management plan of Geumjeong mountainous wetlands in Mt. Geumjeong. *Pro Kor Soc Env Eco Con* 22(1): 86-90
- Lee TB (2003) *Colored Flora of Korea*. Hyangmunsa, Seoul
- Min BM (2005) Seed distribution and burial properties of *Suaeda japonica* in tidal-flat. *Korean J Ecol* 28(3): 141-147
- Mitsch WJ, Gosselink JG (2015) *Wetlands* 5th ed. John Wiley & Sons, Inc, New Jersey
- National Institute of Biological Resources (NIBR) (2012) *Red data book of endangered vascular plants in Korea*. Natl Inst Environ Res, Incheon
- Noon KF (1996) A model of created wetland primary succession. *Landsc Urban plan* 34(2): 97-123
- R Core Team (2018) *R: a language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna
- Ryan ME, Palen WJ, Adams MJ, Rochefort RM (2014) Amphibians in the climate vise: loss and restoration of resilience of montane wetland ecosystems in the western US. *Front Ecol Environ* 12(4): 232-240
- Son GY (2020) Analysis of the water level change for the conservation of Janggun montane wetland. Dissertation, Seoul National University
- Yang YY, Kim JG (2016) The optimal balance between sexual and asexual reproduction in variable environment: A systematic review. *J Ecol Environ*: 40-42

Abstract in Korean

식충 식물을 비롯한 다양한 동식물의 서식지인 산지 습지는 기후 변화에 따라 수문학적 특성이 크게 변화할 수 있고 이로 인해 식생 구조가 바뀔 수 있다. 식충 식물은 곤충을 섭취함으로써 양분을 얻는 방식을 취하며 독특한 생활 방식으로 인해 보존 가치가 높다. 국내 대표 산지 습지 중 하나인 금정산 장군습지는 자주땅귀개를 비롯한 식충 식물과 여러 멸종위기 동식물의 서식처로서 보전 가치가 높으나, 최근 습지 수위 저하로 인해 식충 식물의 절멸이 우려되는 상황이다. 본 연구는 장군습지의 종자 은행 분석을 통해 장군습지의 종 구성과 식충 식물의 종자 발아 특성을 이해하고자 하였다. 2020년 5월 습지 내 10곳을 선정하였고 깊이별로 세 층의 토양을 채집하였다. 2020년 8월에 같은 지점에 10개의 방형구를 설치하여 식생 조사를 수행하였다. 채집한 토양으로 6월부터 10월까지 메조코즘을 조성하여 지속적으로 출현 개체를 동정 및 기록하였다. 장군습지의 종자 은행에서는 총 29종 5,820개체가 출현하였으며 곡정초가 가장 많이 출현하였다. 또한, 채집한 종자 은행의 깊이가 깊을수록 발아한 개체수는 감소하였다. 일년생 식물에서 Shannon – Wiener 종다양성 지수는 종자 은행의 깊이가 깊어질수록 증가하였고, 습지 식생과 종자 은행의 군집 중복 지수의 값은 종자 은행의 깊이에 상관없이 상대적으로 높게 나타났다. 다년생 식물에서 종다양성 지수는 뚜렷하게 우점하는 종이 없어 대체로 높았다. 식충 식물의 경우 습지 식생에서는 발견되지 않았지만 습지 내 진퍼리새가 적고 물이 고이는 지점에서 채집한 종자 은행에서 자주땅귀개, 이삭귀개, 그리고 끈끈이주걱이 출현하였다. 장군습지 내에서 식충 식물의 발아와 생육에 필요한 빛과 수위 조건이 진퍼리새의 우점 군락 형성과 수위 저하에 의해 충족되지 못하고 있는 것으로 판단되었다. 본 연구는 식충 식물의 서식지로서 보호 가치가 큰 장군습지에 물과 진퍼리새의 관리가 적절히 이루어진다면, 토양 종자 은행으로부터 식충 식물이 다시 출현할 수 있음을 증명하였다. 종자들의 분포 및 발아 특성, 종자의 수명을 파악할 수 있는 종자 은행 연구는 장

군습지 생태계의 보존 및 산지 습지의 관리, 더 나아가 식충 식물의 보존을 위한 기초 자료로 활용될 수 있을 것이라 기대한다.

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주요어: 다년생 식물, 수위 저하, 식충 식물, 일년생 식물, 장군습지, 종 조성

Appendix

Appendix 1. The list of species observed and dominance levels (in Braun-Blanquet scale) of each species in aboveground vegetation in Janggun wetland.

Species	lifespan	Dominance level*
<i>Molinia japonica</i>	Perennial	5
<i>Persicaria sagittata</i>	Annual	2
<i>Eriocaulon cinereum</i>	Annual	1
<i>Euphorbia humifusa</i>	Annual	1
<i>Hypericum laxum</i>	Annual	1
<i>Rumex acetosa</i>	Perennial	1
<i>Schoenoplectiella juncooides</i>	Perennial	1
<i>Miscanthus sinensis</i>	Perennial	+
Cyperaceae spp. (a)	Perennial	+
Cyperaceae spp. (b)	Perennial	r
<i>Pinus densiflora</i>	Perennial	r
<i>Pycreus sanguinolentus</i>	Annual	r
<i>Carex dickinsii</i>	Perennial	r
<i>Vitis flexuosa</i>	Perennial	r
Cyperaceae spp. (c)	Perennial	r

* 5: 75 ~ 100% of coverage; 4: 50 ~ 75% of coverage; 3: 25 ~ 50% of coverage; 2: 5 ~ 25% of coverage; 1: < 5% of coverage with numerous individuals; +: < 5% of coverage with few individuals; r: < 5% of coverage with very few individuals (Braun-Blanquet 1932).