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Analysis of the Water Level Change for the Conservation of Janggun Montane Wetland

산지습지 보전을 위한 금정산 장군습지의 수위 변화 분석

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Recently, global climate change has caused temperature rise along with changes such as precipitation pattern change. Wetlands, ecotones of terrestrial and aquatic ecosystems, possess high level of biodiversity, and many indigenous organisms which are dependent on the wetlands' water levels. Therefore, prediction of wetland water levels is an indispensable factor in efforts to preserve wetlands and their biodiversity. Evapo-transpiration is the sum of evaporation from water and ground surfaces into the atmosphere and evaporation from plants to the atmosphere, and is one of the major factors that influence the hydrological cycle and water levels of the wetlands. In this study, total of three water level meters were installed in 10 X 10 quadrates in 3 different locations within the Janggun wetlands, Mt. Keumjung, to analyze water level change. Precipitation and water level data were collected via precipitation, temperature, and humidity meters along with the 3 water level meters installed along waterways from May 2017 until September 2019. Based on collected biomass, water level and precipitation data, a multiple regression analysis was conducted. The current study aims to present a method which enables utilization of tangible biological data such as biomass of wetland vegetation in hydrological analysis, e.g. evapo-transpiration analysis. If prediction of water level changes is enabled by the regression formula presented in the current study, it can be used as baseline material for wetland preservation.

Keywords: Biomass, Evapotranspiration, Montane wetlands, Precipitation, Water level

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Ⅰ. Introduction

Lately, the call to preserve wetland ecosystem is gaining traction due to its significance as the ecotone between terrestrial and aquatic biomes. Because of its unique characteristics, wetlands create an intricate and abundant environment that provides habitat for various wetland species (Hong and Kim 2017). Such provision of habitat for various wildlife is made possible by the plethora of different kinds of vegetation that act as producers in the wetland ecosystem. Furthermore, it is proven that wetland serves as to the high productivity of the ecosystem, the aesthetical value of the wetlands, and the water purification process.

Because the Republic of Korea has steep mountainous terrain, wetlands mostly form around rivers. It is almost impossible for peatlands form, and they can only rarely be seen in wetlands in high mountain ranges (Kim 2009). However, due to the characteristics of the terrain, the size of these peatlands are very small. Montane wetlands are part of the forest and wetland that are adjoined with nearby forests, in which various ecological actors such as hydrological factors, vegetation, and animals from ecosystems in the vicinity of the montane wetlands are organically connected with each other (Geathwaite 1995, Joseph 2000).

Due to the environmental significance of the wetlands and recent climate change, the importance of preserving mountain wetlands is becoming more prominent. Recently, climate change resulted in pattern differences such as subsequent rise in temperature and irregular precipitation patterns. These changes in pattern make it difficult to maintain the optimal amount of water discharge needed to preserve the natural functions of the wetlands. Lack of hydrological inflow and discharge causes the natural functions of the wetlands to deteriorate, which leads to change in vegetation, worse water quality, decrease in water levels, and other detrimental consequences (Hong and Kim 2017). Therefore, it is important to maintain the amount of inflow and water levels in the wetlands, and accurate predictions on wetland water level changes are crucial in preserving and restoring wetland ecosystems (Oh et al. 2017).

To prevent the detrimental change in wetland ecosystems' function and structure caused by climate change, one needs to understand the role of water, one of the major components of the wetland ecosystem. One field of study that can be utilized to understand the wetland water system is hydrology. Hydrology explores how water movement influence the environment and the impact of hydraulic phenomena in general. Understanding hydrology is important in order to better one's understanding of the wetland ecosystem, which possesses aquatic ecological elements. Hydrology studies the flow of water in the atmosphere and on land, and the circulation of water from land to the atmosphere is called the hydrologic cycle (Kim 2010). Numerous factors such as precipitation, evapotranspiration, etc., play a role in the hydrologic cycle. In mountain wetlands, major sources of water inflow are precipitation and also have connections to groundwater (Mitsch and Gosselink 1993). Major sources of water outflow include water flowing underground and evapotranspiration. However, most recent studies interpret such water balances solely from the perspective of hydrology, and do not consider biological factors. It is known that there is a correlation among underground water outflow, proliferation of plants, and water levels (Dacey and Howes 1984, Ursino et al 2004, and Marani et al 2006). In this context, considering biological factors which play a major role in evapo-transpiration and the wetland ecosystem is needed.

Evapotranspiration is one of the main discharge factor from montane wetlands, and it is also a form of measure which takes water evaporation from vegetation and other miscellaneous surfaces such as water surfaces, soil, snow, ice, etc., into consideration. However, due to its complexity and linkage to the biological factors, evapotranspiration is known to be one of the most challenging hydrologic parameters to estimate (Hulsmas et al. 2007). In a water level prediction model, evapotranspiration can be considered as the element that takes biological factors into account. Notable biological indices used to calculate evapotranspiration include the leaf area index and soil mulch (Kim et al. 2013, Kim 2010, Chung et al. 2014). Such biological indices are simplifications of a particular wetland's characteristics or its vegetation composition, and are one of the main factors that lower the accuracy of evapotranspiration calculation. In the case of evapotranspiration, there are studies that utilize the leaf area index. however, these studies only discuss wetland coverage or canopy type and do not take species composition or actual leaf area into consideration.

Wetland dependent plant species are heavily influenced by wetland water levels, and if optimal water levels are not maintained, these plants would have difficulty germinating and settling down. Furthermore, proper saturation in wetland is crucial for many wetland species such as amphibians, inverterbrates, and plants in which the water level provides breeding grounds or it provides adequate conditions for reproduction (Brooks and Hayasi 2002).

Therefore, the current study sought to comprehensively analyze change in water levels according to change in precipitation patterns, the subsequent change in vegetation, and how difference in vegetation contribute to water level changes by studying the Janggun wetlands in Mt. Keumjung. Janggun wetland in Mt. Keumjung is one of the recently discovered peatlands with thick peat layers, and should be considered as a preservation site due to its uniqueness and value as a montane wetland. However, the Ministry of Environment has not yet designated Janggun wetland as a wetland preservation area, and the area is currently subject to road development and other ventures that hinder preservation.

The current research was performed to study the effects of climate change on mountain wetlands with the Janggun wetlands in Keumjung mountain, Busan, as the subject of study. In order to comprehensively understand the montane wetland ecosystem, I focused on water level and biological factors, specifically plants, which are closely related to evapo-transpiration. The research questions are:

1) What are the influence of change in precipitation patterns on water levels?

2) What are the influence of biological factors (biomass, leaf area)

on wetland water levels?

3) What are the precipitation and biological factors needed to maintain the water levels of wetlands?

Ⅱ. Materials and methods

1. Study sites

The current study was conducted in the Janggun wetlands near the summit of Mt. Keumjung, Kyungsangnam-do. The wetland is located at latitude 35.293, longitude 129.053, between 550~660m above sea level (Figure 1).

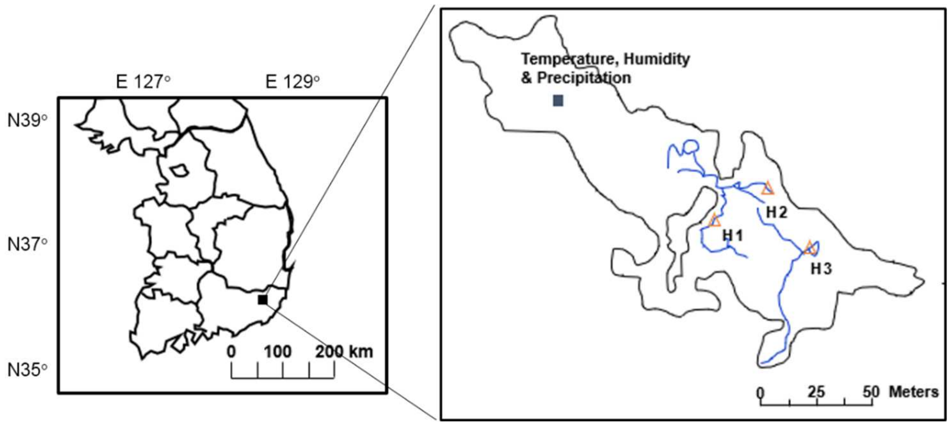

Figure 1. (a) Location of Janggun wetland in South Korea. (b) Location of the Mini weather station and 3 water level meters (H1, H2, and H3) within the Janggun wetland.

2. Hydrological and weather factors

Total of 3 water level meters (ecotone^{wm} Water Level Logger, Remote Data Systems, Inc) were installed: one (H1) on the 2nd of March 2017 and two (H2, H3) on the 5th of May 2017. Analyses shown in the current study were based on data collected by the water level meters from the day of their respective installations until September 30, 2019. The data was collected at hourly intervals. Also a mini weather station was set up in the Janggun wetlands at December 6, 2016, in order to accurately gauge the temperature, humidity, precipitation (Figure 1).

3. Biological factors

In order to examine the plant distribution around water level meter, vegetation map was drawn in a 10 m X 10 m quadrat. For *Molinia japonica* being the major dominant species of Janggun wetland, we categorized it into three groups by its height: *Molinia japonica* S (Height < 90 cm), *Molinia japonica* M (90 cm < Height < 120 cm), and *Molinia japonica* L (120 cm < Height).

I collected the aboveground biomass from a 40 cm x 40 cm quadrat from each plant communities based on the vegetation map at the end of the plants' life cycle, around the end of September to early in October. The samples were dried in a dry-oven of 80°C for 48 hours, and then I measured the dry biomass. In addition, monthly aboveground biomass from May to October were estimated based on Gorme et al (2012).

I measured leaf surface area to determine the biological factors that contribute to water level changes in August, 2019 when the plant's biomass was at its peak. In a scale of 40 cm X 40 cm quadrat of each plant community, I counted the number of each species. I collected 3 individuals of each species and measured the surface areas of the leaves and stems using a portable leaf area meter (LI-3000C, LI-COR Bioscience, Lincoln, NE).

4. Determination of season

The change in seasons were analyzed based on the standards (seasonal threshold) proposed by Byungsung Lee (1979). Lee's seasonal threshold has been utilized in the South Korea for various researches on climate change of specific regions (Maeng et al. 2014). Daily average temperature for the start of spring is 5°C and above, for summer 20°C and above, for autumn below 20°C, and for winter below 5°C (Table 1). The temperature determining the weather was based on the 9 days moving average data of daily mean temperatures. The dates were recorded in Julian date format, with 365 days in between the 1st of January and the 31st of December.

Table 1. Definition of the Starting Date of each season and the Seasonal Length (Lee 1979)

Season	Definition of the Starting Date of Season	Definition of the Seasonal length
Spring	The initial day when the average temperature rises by more than 5 °C and does not fall again	From the beginning of spring to the day before the beginning of summer
Summer	The initial day when the average temperature rises by more than 20 °C and does not fall again	From the beginning of summer to the day before the beginning of fall

Table 1 continued.

Autumn	The initial day when the average temperature drops below 20 °C and then doesn’t rise again	From the beginning of fall to the day before the beginning of winter
Winter	The initial day when the average temperature drops below 5 °C and then doesn’t rise again	From the beginning of winter to the day before the beginning of spring

5. The concept and types of extreme weather events

In order to effectively compare the 3 years’ meteorological data, the concept of extreme weather events was used. Extreme weather events are the average of weather events that occur outside of a specific period of time, and this average itself was denominated as extreme (IPCC 2001). For example, if a precipitation event occurs outside of the previously established precipitation time period, the event itself would be regarded as extreme. The World Meteorological Organization (WMO) acknowledged the importance of quantifying extreme weather events and recently released “Guidelines on Analysis of extremes in a changing climate in support of informed decisions for adaptation (WMO 2009)”. In the guideline, the Expert Team on Climate Change Detention and Indices (ETCCDI) defined extreme indices in order to comprehend the extreme weather conditions and climate change shown by collected data, and explained the extreme characteristics of the 27 temperature and climate related indices. One of the important aspects of the index concept is to calculate the number days that exceed the specified annual breaking point. In order to assess extreme weather events, the breaking point is based on percentiles. The reason to opt for a percentile-based breaking point instead of a set breaking point is because the number of days that exceed the percentile breaking point are more evenly distributed, and give more significant results when conducting localized analysis. The current paper selected 7 indices related to precipitation and temperature of the 27 temperature and climate related indices defined by the ETCCDI (Table 2).

Table 2. The description of 5 ETCCDI precipitation and temperature related indices of extremes (WMO 2009).

ID	Description	Unit
$SDII$	Simple daily intensity index	$\frac{mm}{day}$
$R50$	Number of heavy precipitation days	$days$
$R80$	Number of very heavy precipitation days	$days$
CDD	Consecutive dry days	$days$
$RX1day$	Max 1-day precipitation amount	mm
$RX5day$	Max 5-day precipitation amount	mm

(1) $SDII$ (Simple Daily Intensity Index)

SDII can be calculated with the equation shown below. In the formula RR_{wj} is the total daily precipitation of the days which precipitation was occurred $w(RR \geq 1mm)$ during time period j, W is the number of wetting rain days during period j, and is calculated as follows.

$$\boldsymbol{SDII_j = \frac{\sum_{w=1}^{W} RR_{wj}}{W}}$$

(2) $R50mm, R80mm$ (Number of days precipitation over 50mm, 80mm)

Indices related to precipitation can be defined as number of days' precipitation was the same or exceeded 50mm, 80mm. Here RR_{ij} is total daily precipitation on the ith day of time period j, (and the number of days RR_{ij} is the same or exceeds 50mm, 80mm)

$$\boldsymbol{RR_{ij} \geq 50mm, 80mm}$$

(3) CDD

CDD is defined as the number of consecutive days during which precipitation was the same or below $1mm$. RR_{ij} is total daily precipitation of the ith day of time period j, and the number of consecutive days RR_{ij} is the same or below 1mm.

$$\boldsymbol{RR_{ij} < 1mm}$$

(4) $RX1day, RX5day$

These can be calculated with the equation below. Here, RR_{kj} is total precipitation of 1 or 5 consecutive days in interval k within time period j. RX1day or RX5day is determined by setting the maximum of 1 or 5 consecutive days precipitation amount.

$$\boldsymbol{RX1day_j \ \ or \ \ RX5day_j} = \mathbf{max}(\boldsymbol{RR_{kj}})$$

6. Water level analysis

To assess the correlation between water level and precipitation, I extracted and analyzed the peaks from the data where there was an increase or a decrease in water levels. The analysis was made by considering the sum of the precipitation amount of a precipitation event that occurred prior and during the increase in water levels as 1 unit of precipitation per change in water levels.

Retention Time (RT) refers to the time elapsed between the water level reaching its peak value and decreasing back. Therefore, rate of water level increase is the rate of change when the water levels reach their peak or the value of time needed until the water levels reach their peak. Rate of water level decrease, on the other hand, is the average rate of change when water levels revert back to base levels after reaching peak levels or the amount of time it took for the water level to decrease back to base level.

7. Statistical analysis

In order to find out the relationship between water level and other factors such as precipitation and biological factors, multiple regression analysis was performed. The multiple regression analysis was performed for each hydrological factor and biological factors by backward selection method to estimate the water level change. The analysis was conducted at 0.05 significance level by using SPSS version 22.0.

Ⅲ. Results

1. Climate

1.1. Temperature and Season length

The change in temperature from January 1, 2017 until September 30, 2019 is shown in Figure 2. Starting date of each season was based on the annual temperature data (Figure 2 a). The winter between 2017 and 2018 (winter of 2017) lasted 80 days, while the winter between 2018 and 2019 lasted 73 days. In the case of autumn, the duration has shortened from 104 days to 74. Spring lasted for approximately 80 ~ 91 days which decreased each year for three years consecutively. Finally, the duration of summer consistently increased from 97 days to 133 to 140 days according to the data collected till September 30, 2019. Furthermore, the starting date has moved up earlier for past three years (Figure 2 b).

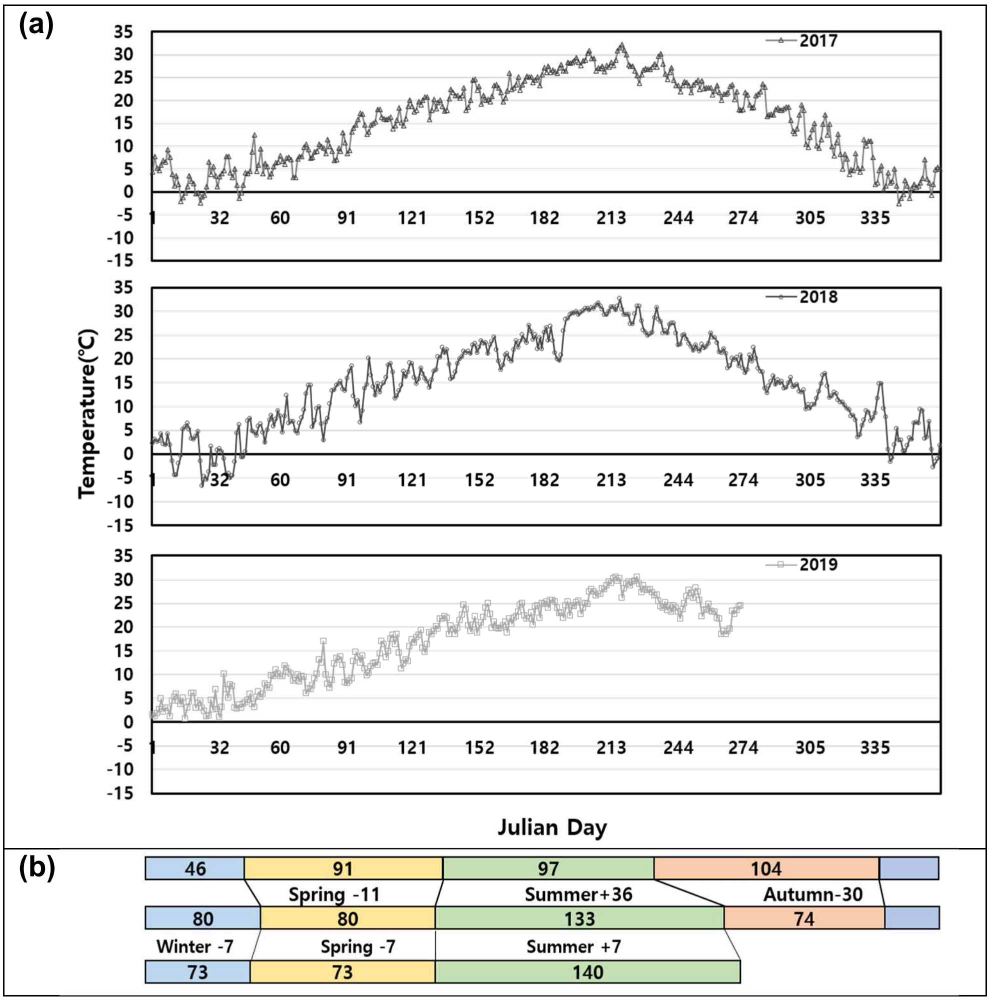

Figure 2. Annual Temperature Change (a) and Change in Seasonal Length (b)

In case of spring and summer, the temperature was stable. However, autumn and winter showed up to 1.6°C temperature change. Between the winters of 2017 and 2018, the temperature of winter 2018 was approximately 1°C lower than that of 2017, and the average temperature of autumn also dropped by approximately 3.5°C compared to the previous year (Figure 3). To sum up, there was the steady increase in the duration of summer and the average temperature of each season has not showed any pattern.

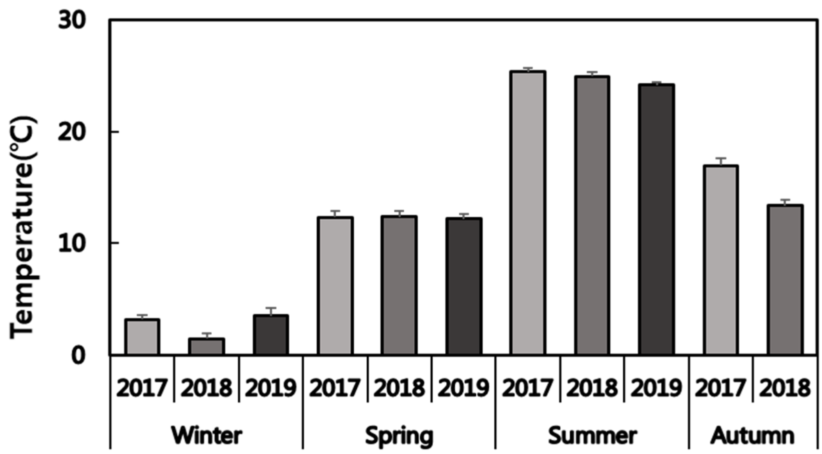

Figure 3. Average Temperature of Winter, Spring, Summer, Autumn in 2017, 2018, and 2019 (mean ± SE)

1.2. Precipitation and ETCCDI Indices

In 2017 annual precipitation was at 753.1mm, which is less than 50% of 2018’s 1450.6mm or 2019’s 1500.7mm as of 30th of September (Figure 4). The recorded national average of the cumulative precipitation from January to May of 2017 was 181.50mm, which is the second lowest since 1973 (Bang et al. 2018).

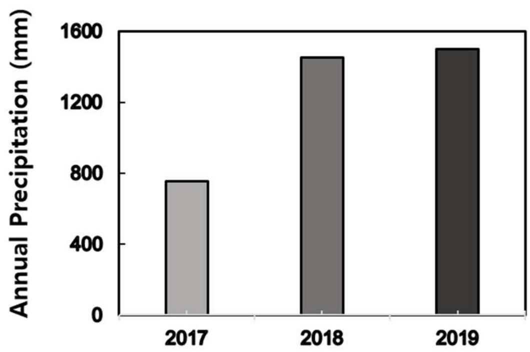

Figure 4. Annual precipitation in 2017, 2018, and 2019. 2019's data was collected until 30th, September.

SDII in 2017 was also low, with 2 days in the case of R50 and 1 day for R80 (Table 3). CDD was 58 days, which is the highest out of the 3 years, and RX1dl was at 122.2, RX5 at 131.9. This indicates that there was less than 10mm of rain during the 4 days before and after a day of intensive rainfall. Weather data in 2018 and 2019 up until September 30 showed similar patterns. CDD showed some deviation but it can be attributed to the fact that weather data during dry season, from October and onwards, were left out. In 2019, there was heavy rain until September, and with frequent torrential rain periods, RX1day and RX5day numbers in 2019 were higher than those in 2018. From these numbers, it can be inferred that the precipitation pattern in 2019 had more torrential rain periods than 2018.

Table 3. The calculate result of ETCCDI Indices (SDII, R50, R80, CDD, RX1day, RX5day) in 2017, 2018, and 2019

ID	2017	2018	2019
$SDII\ (\frac{mm}{day})$	14.597	23.753	23.821
$R50\ (days)$	2	8	8
$R80\ (days)$	1	3	3
$CDD\ (days)$	58	41	14
$RX1day\ (mm)$	122.2	195.8	234.3
$RX5day\ (mm)$	131.9	266.3	349

The histogram of non-rainfall duration showed each year's precipitation characteristics (Figure 5). In 2017, on top of being mostly dry throughout the year, a high frequency of non-rainfall duration era that lasted for 15 days or more (Figure 5 a). Total of 101 days lasted dry for at least 15 days consecutively. 2018 also had frequent dry seasons that lasted for 15 days or longer but fairly less than 2017 (Figure 5 b). In 2019, there were no instances when periods of no rainfall lasted 15 or more days up until the 30th of September, but showed high frequency of periods with no rainfall for 5 or less days (Figure 5 c).

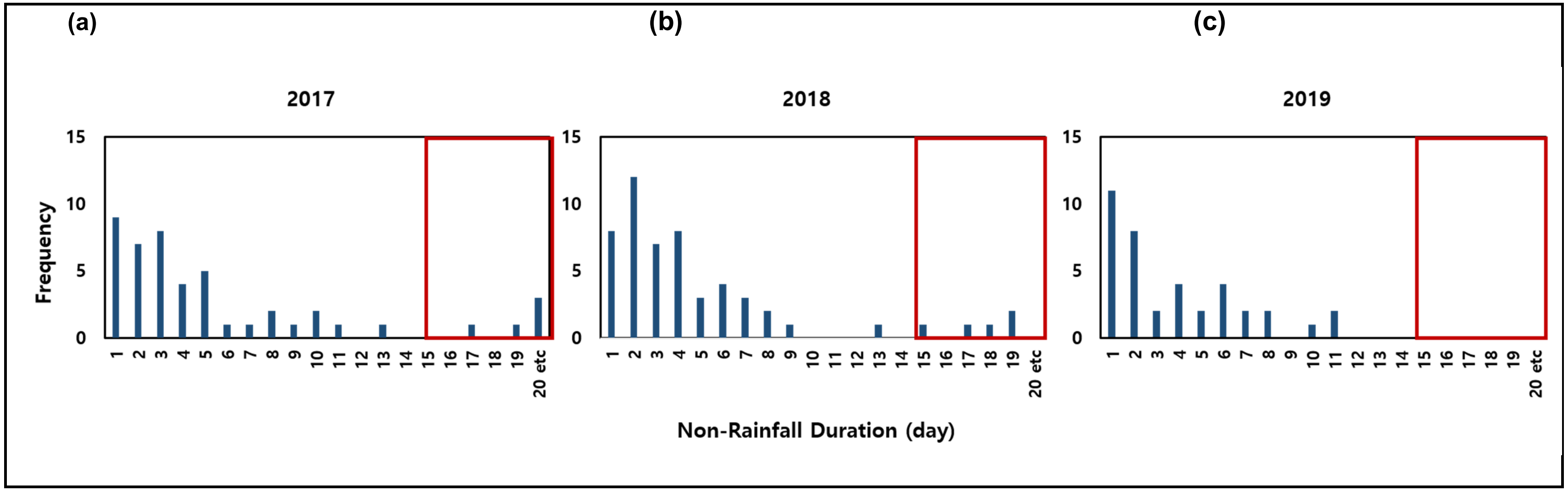

Figure 5. The frequency distribution of Non- Rainfall Duration Days in 2017, 2018, and 2019. The red box indicates the data of 15days or more non-rainfall duration dates.

In 2017, significant water level changes caused by rainfall events were recorded by water level meters H1 and 3, and H3 in particular showed notable water level changes (Figure 6 a). However, as water level meter 2 did not record any increase in water levels since the dry season in May, water level recovery in the area may be difficult if the period of no rainfall persists for 15 or more days.

In 2018 all three water level meters showed relatively significant increase in water levels following rainfall events. H3 showed higher peak levels compared to other water level meters. Water levels maintained –300 mm and above for 2 months after the torrential rain period during September and October (Figure 6 b).

The data from 2019 shows that water levels did not rise above –300 mm until April, when there is relatively less precipitation. However, H3 still recorded high peak levels relative to the rainfall events. Due to the torrential rain periods that started in July, water levels maintained –300 mm or more for approximately 3 months (Figure 6 c).

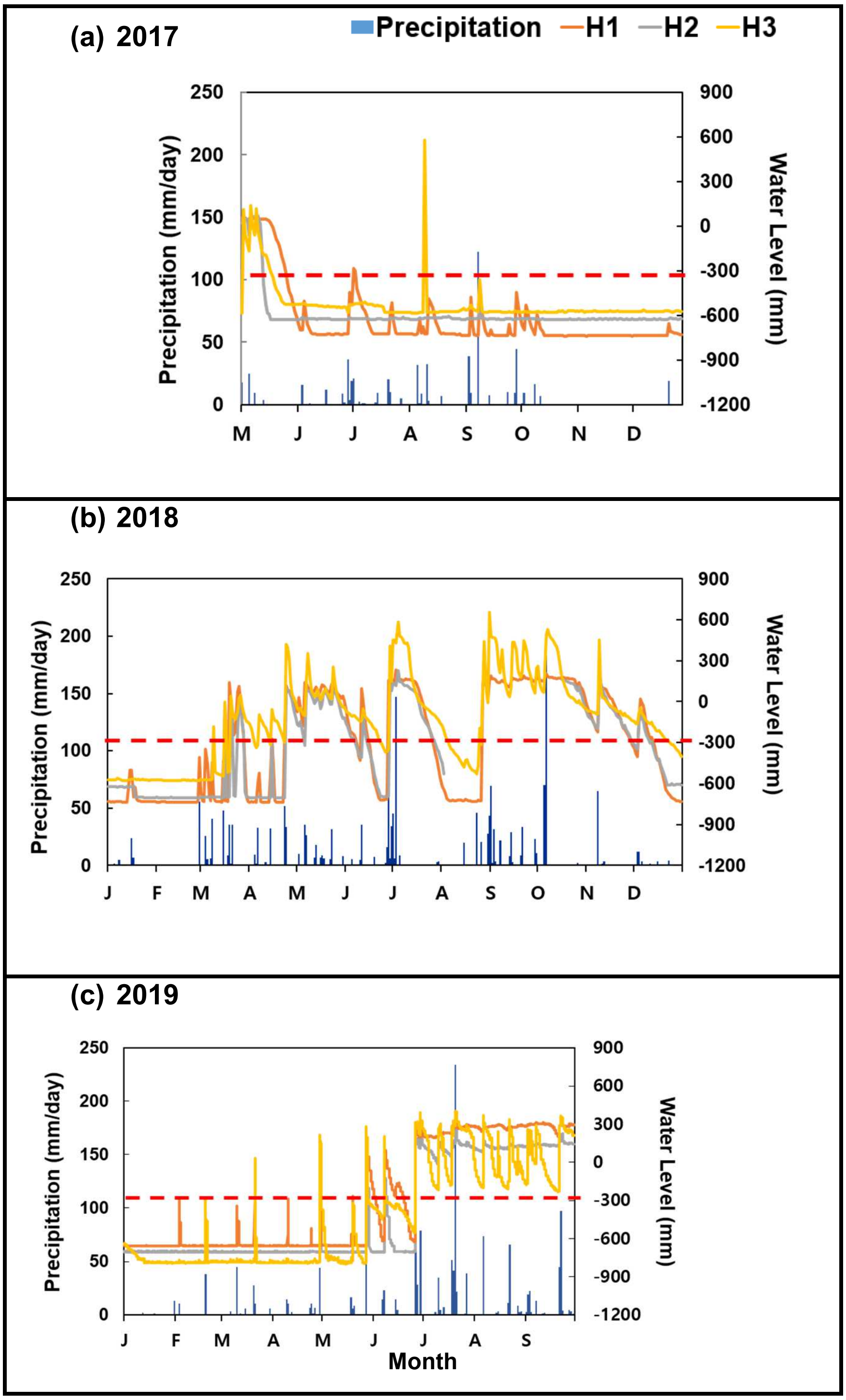

Figure 6. Annual data of Precipitation and Water Level Change pattern.

2. Biological data

Total biomass and leaf area of each H1, H2, H3 quadrat showed the same tendency (Figure 7). H3 quadrat had the highest biomass and leaf area whereas H1 quadrat had the lowest biomass and leaf area. This tendency also coincided with *M. japonica*'s dominance level in plant communities near the water level meters. For the quadrate of H1, various plant species with relatively low leaf surface and biomass, such as the *Isachne globosa*, coexist with the *M. japonica*. In the area around water level 3, however, there were no colonies that were not dominated by the *Molina japonica* (Appendix 1).

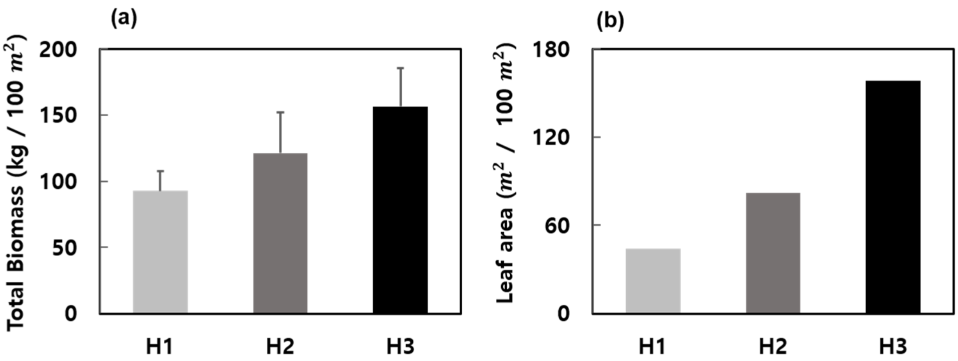

Figure 7. Total biomass and leaf area of each quadrat H1, H2, and H3. Biomass is the average of 3 years' data (mean ± SE).

3. Hydrological data

3.1. Daily water level change in Non-rainfall continued era

Daily water level changes for 1 week during period of 15 or more days with no perspiration were analyzed (Figure 8). Even though there were no precipitation, daily water levels continuously changed throughout the week on a daily period. Water level showed decrease with the sunrise and decrease with the sunrise respectively, though three water level meters showed different time period.

H1 showed the highest peak around 8:00 am and lowest peak around 10:00 pm, showing that water level decrease occurred for 14 hours per day in daylight and increase in water level started around sundown for 10 hours. H2 showed the highest peak in 9:00 am and the lowest peak around 5:00 pm, in which water level decreased for 8hours which is 6hours shorter than H1. H3 showed the highest peak in 10:00am and the lowest peak in 3:00 pm. H3 had the water level decrease for 5hours. The range of changes differed among water level meters. For water level meters 1 and 2, the range of fluctuation was 10.5mm per day, while water level meter 3 showed 14.5mm per day.

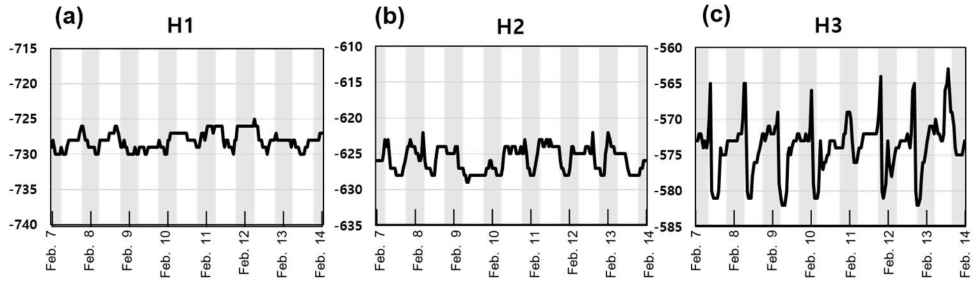

Figure 8. Water level change for a week in non-rainfall continued era.

3.2. Monthly water level change of different precipitation patterns

Single rainfall event of precipitation amount below 45mm was pointed out. After the sustained dry season of non-rainfall duration of more than 15days, all water level meters did not demonstrate the water level increase. Following a 45mm rainfall event after 15 days of non-rainfall, water level meter recorded an approximately 200mm increase in H1 but water level meters 2 and 3 did not show signs of increased water levels (Figure 9). There was also no increase in water levels after 10mm precipitation.

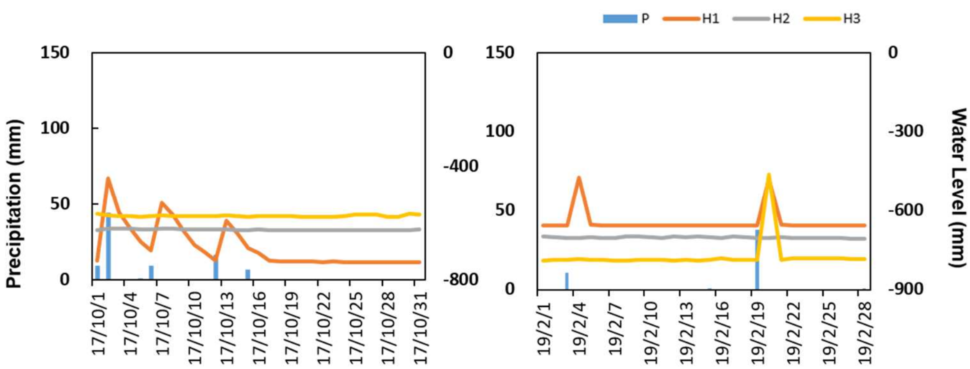

Figure 914. Daily Water level change in Janggun wetland in October and February.

In July, precipitation intensity was high and single rainfall event had more than 100 mm per day (Figure 10). This rainfall caused all three water meters' water level to rise and the rainfall following made the water level sustained fairly. However, H3 showed fluctuation than H1 and H2. Constant precipitation maintained the water level above the minimum water level of each H1, H2, H3.

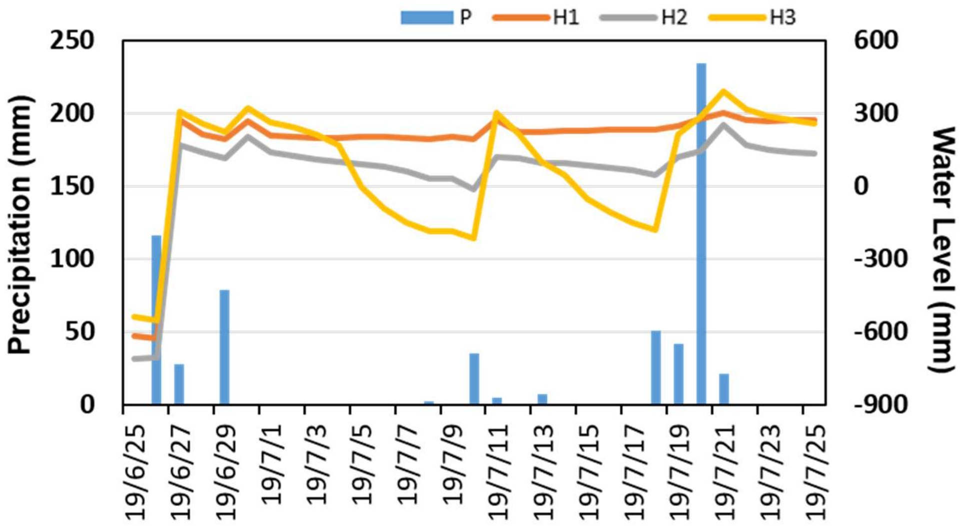

Figure 10. Daily water level change in Janggun wetland in July.

After precipitation and water level being higher than the minimum water level, the precipitation deters the water level decrease resulting in longer retention time (Figure 11).

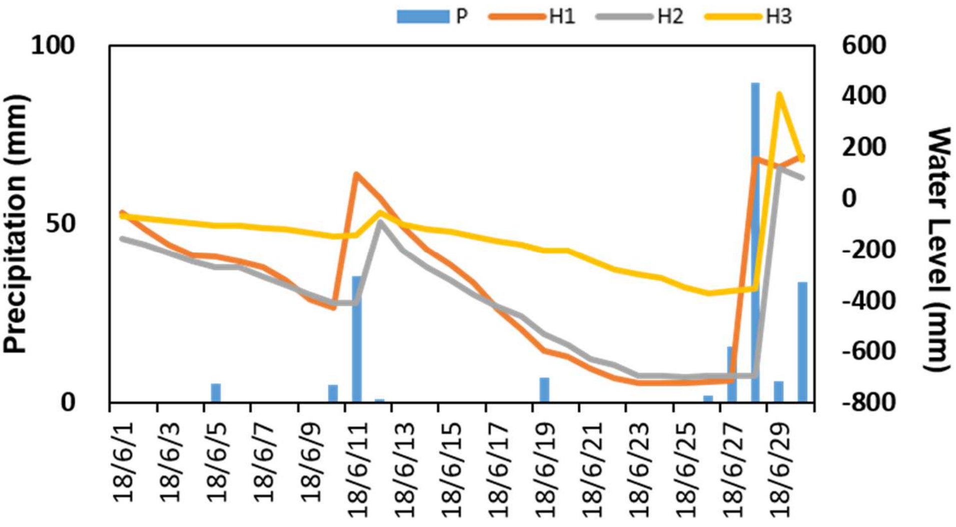

Figure 11. Daily water level change in Janggun wetland in June.

Ⅳ. Discussion

1. Climate and Biological Factors

Based on observation of temperature, season duration, and ETCCDI indices of the past 3 years, we confirmed that there were no discernible patterns regarding temperature among meteorological data for the past 3 years. However, in 2017, SDII values were the lowest out of the 3 years. R50 and R80 values of 2017 were also low, with 2 days and 1 day respectively. Yearly aggregate precipitation of South Korea in 2017 was only 50% of the yearly average precipitation. The yearly aggregate precipitation of Kyungsang-do, where the Janggun wetlands is located, was the lowest out of all the regions (Bang et al).

Longer and earlier Summer and Spring means flowering season for various plant species to occur faster. However, if stable water levels are not maintained after flowering and settlement, the plants' survivability may decrease. Therefore, the general paradigm shift of the seasons and weather can lead to change in plant species composition. The disruption may lead to extinction but at moderate levels, it may also lead to change in species dominance (Lee and Kim 2019). In Janggun wetland, the dominance of *Molinia japonica* is steadily increasing, and colony diversity is decreasing. *Molinia japonica,* being the common species in montane wetland (Hwang et al. 2014), is a perennial plant. Perennial plants have better survivability in various water levels (Grace and Wetzel 1981), *M. japonica* could have survived the extreme water level change in 2017, resulting in the increase of dominance.

Precipitation, one of the climate factors, is well known to have a significant impact on productivity of community or perennial plants. The quantity and temporal patterns of precipitation are crucial to the plant community (Pitt and Heady 1978), and increase in precipitation at certain level is known to result in total biomass of perennial plants (Zhoulin et al. 2014). Thus, precipitation pattern change as a result of global climate change can affect in plant species diversity as well as plant productivity.

2. Water level change pattern

Generally, perspiration, surface water inflow, evapotranspiration, and discharge to groundwater are some of the main factors that influence change in water levels. These factors contribute to inflow and outflow and engage in complex interactions with each other to result in what we define as water level (Figure 12). To understand this hydrological cycle comprehensively, one should take into consideration the individual characteristics of water level meters and the aforementioned factors. In the case of precipitation, water level increase is not only proportional to the precipitation, but are also highly dependent on non-rainfall duration days prior and precipitation intensity. Moreover, in order for precipitation to directly impact on water level increase, there watershed in which water can be stored instead of being discharged as surface runoffs. If not, certain amount of precipitation may not impact water levels.

Lastly, discharge to groundwater may affect amount of outflow. This is relevant to permeability of the soil constitution of a wetland. For instance, the soil of the Janggun wetlands is mostly comprised of peat, which possesses high permeability and has a propensity to hold water. In this case, the amount of discharge to groundwater can be deemed as insignificant (Korean Wetlands Society).

H1, being the quadrat where watershed area being the largest, peatland layer depth the deepest. The low permeability allows peatland to hold the surface water within (Joseph H and Tim PB 2003). H1 had the highest water retention time. This mechanism is also the reason why the H1 water level meter is most sensitive to precipitation. Unlike H 2 and H 3, water level meter 1 shows increase and decrease in water levels even during an individual rainfall event minimum of 20mm. This is because water during rainfall events with low precipitation does not get discharged as surfaces runoff from the watershed but remain in watersheds in the vicinity of water level meter 1. Thus, water levels recorded by water level meter 1 is more directly influenced by precipitation inflow compared to that of other water level meters (Figure 6).

The monthly precipitation-water level shows that the 3 water level meters show different patterns for the same rainfall event (Figure 8). Generally, the water level meters show the same patterns for rainfall events that are 50mm or above per day (Figure 11). However, for rainfall events below 50mm per day, there were different patterns depending on the duration of dry season prior to the rainfall event and sustained intensity of the rainfall event. It can be assumed that these trends are caused by differences in watershed size, resulting H2 and H3 to discharge the water via surface runoff. In order to increase the water level of H2 and H3, single rainfall event consist of 50mm and above or two or more consecutive rainfall event with 20 mm / day above is needed.

First, the water level change within the day can be explained by the transpiration of plants. The water uptake by roots have been known to control water table movement in wetlands (Dacey and Howes 1984). This daily water level change was most high in H3 where the change in water level was 10.5mm in average. This coincides with the biomass and leaf area result where the biomass and leaf area could indicate that H3 has possibly higher evapotranspiration than others.

Judging by the fact that these points in time repeat themselves, it can be inferred that significant factors necessary for water level increase are 1) Non-rainfall duration days lasting for 15 or more days, and 2) Sustained precipitation.

The area near water level meter, has soil that is rich with well-developed organic sediment layers. On the other hand, areas around water level meter 2 were mostly comprised of clay sand, had the smallest water watershed. Areas near water level meter 3 displayed mixed characteristics with an intermediate-size of watershed. In cases where the soil is mostly comprised of clay sand, we assessed that moisture circulation was difficult, and therefore water levels decreased as much as water lost by evapotranspiration.

Water level change showed different pattern for following categories.

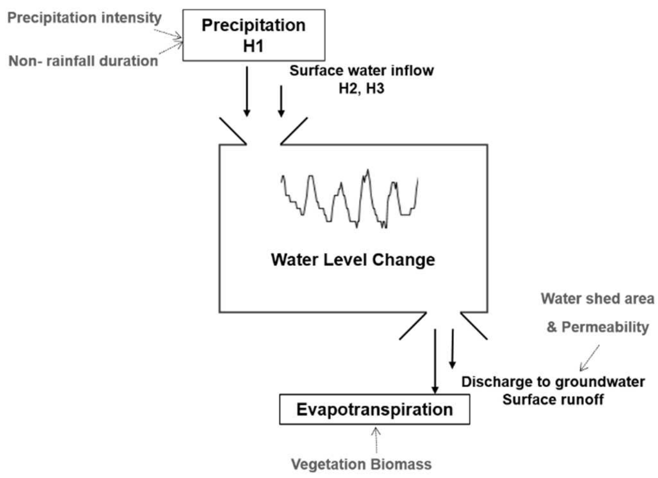

Figure 12. Schematic diagram representing the factors effecting on water level change.

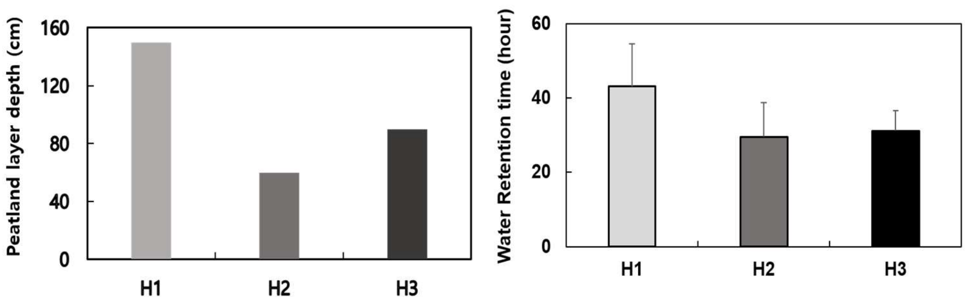

Figure 13. Peatland layer depth and water retention time of H1, H2, and H3. Retention time was the average throughout 3 years (mean ± SE).

3. Construction of univariate multiple regression of Water level change and Precipitation and biomass

According to backward selection method, statistical significance of linear model of Water level decrease slope was the highest when Precipitation, Precipitation duration date and biomass were selected as variables (p = 0.023).

$$\boldsymbol{W_{IN}} = \mathbf{94.39 - 0.404AGBM - 0.114}\boldsymbol{P_i}, \mathbf{-1.003}\boldsymbol{P_{day}}, (\boldsymbol{p} = \mathbf{0.182})$$

$$\boldsymbol{W_{DC}} = \mathbf{-7.733 + 0.74AGBM + 0.002}\boldsymbol{P_i}, \mathbf{-1.761}\boldsymbol{P_{day}}, (\boldsymbol{p} = \mathbf{0.033})$$

(W_{IN} = Increasing slope of water level (mm / hr) AGBM = Above ground biomass (kg / 100 m$^{2)}$, P_i = Precipitation intensity (mm / day), P_{day} = Precipitation duration day (day))

To comprehensively explain the water level increase and decrease, aboveground biomass, precipitation intensity, precipitation duration day were selected to develop generalized linear models. The slope of water level increase showed positive correlation with the above ground biomass. Biomass is the representative trait to show the plants' growth and it also coincides with the leaf area (Mitsch and Gosselink 2000). Evapotranspiration (ET) is known to account more than half of the water discharge in various ecosystems (Lu et al. 2003), and the regional hydrological cycle could be easily altered by ET. ET is a main factor that connects the biological and hydrological processes and studies have made an effort to predict the ET (Sun et al. 2011). Leaf area index (LAI)was introduced to measure empirical ET by diving each sites via dominant plant community's canopy and assigning each index accordingly (Allen et al. 1994). The biomass showing positive correlation with water level decrease explains the linkage between the biomass and evapotranspiration resulting in water level decrease.

Water level decrease and precipitation intensity had positive correlation and negative correlation with precipitation duration date. This explains that precipitation duration date, representing the consecutive days of rainfall event, deters the water level decrease. This can indicate that the frequency of consecutive rainfall events is crucial to maintain water level for the wetland ecosystem.

Ⅴ. Conclusion

I conducted this study in order to figure out the relationship between climate change, hydrological features and vegetation in montane wetland, specifically in Janggun montane wetland. We analyzed the relationship between precipitation and water level change, considering the biomass in order to link the hydrological process with biological process. Water level, precipitation, and the biomass have been collected within three years. Water level change pattern differed among water level meters due to its watershed area, peatland layer, and biomass which comprehensively altered the evapotranspiration and surface runoff. Multiple regression analysis showed correlation between water level change and biomass and precipitation factors. This study can be used as references to predict the water level in montane wetlands. This could be used as a data and resource in order to conserve Janggun wetland and other montane wetlands.

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Appendix 1. Annual vegetation data of 2017, 2018 and 2019. Community name, area and biomass are provided.

Year	**Water meter ID**	**Community name**	**Community area(m^2)**	**Community Biomass(g)**
2017	H1 - a	*Phragmites japonica*	1	1220.9
	H1 - b	*Molinia japonica*	31	97252.3
	H1 - c	*Leersia japonica*	14	9311.8
	H1 - d	*Scirpus juncoides – Molinia japonica*	34.75	26818.3
	H1 - e	*Scirpus juncoides – Rhynchospora chinensis*	15	5620.3
	H1 - f	*Isachne globosa – Scirpus juncoides*	4.25	2410.5
	H2 – a	*Molinia japonica*	48.4	20730.3
	H2 – b	*Molinia japonica*	9	12309.8
	H2 – c	*Juncus diastrophanthus*	1.6	149.2
	H2 – d	*Scirpus juncoides*	4.3	1387.8
	H2 – e	*Molinia japonica - Scirpus juncoides*	36.7	25703.8

	H3 – a	*Molinia japonica*	74.5	93427.7
	H3 – b	*Scirpus juncoides*	10.25	8736.8
	H3 – c	*Scirpus wichurae – Juncus effusus*	6.75	4237.3
	H3 – d	*Scirpus wichurae*	3.75	4450.1
	H3 - e	*Leersia japonica - Scirpus wichurae*	4.75	4261.6
	H1 – 1	*Molinia japonica*	28	71991.5
	H1 – 2	*Leersia japonica*	4.5	3181.8
	H1 – 3	*Scirpus juncoides*	13.4	7111.2
	H1 – 4	*Molinia japonica*	11.7	9692.7
2018	H1 – 5	*Molinia japonica*	26.4	21542.4
	H1 – 6	*Phragmites japonicus*	1.8	3004.3
	H1 - 7	*Scirpus juncoides - Molinia japonica*	14.2	16561.6
	H2 - 1	*Molinia japonica*	16.7	22217.3
	H2 - 2	*Molinia japonica*	45.6	70164.2

	H2 - 3	*Molinia japonica*	16.1	45208.8
	H2 - 4	*Molinia japonica*	21.6	10064.3
	H3 - 1	*Scirpus wichurae*	16.6	25437.4
	H3 - 2	*Molinia japonica*	10.6	17701.3
	H3 - 3	*Molinia japonica*	66.3	156381.0
	H3 - 4	*Molinia japonica*	6.5	12512.1
2019	H1 - 1	*Molinia japonica*	53.5	3990.4
	H1 - 2	*Molinia japonica – Miscanthus sineesis*	4.4	1176.9
	H1 - 3	*Molinia japonica - Isachne*	4.4	462.9
	H1 - 4	*Isachne – Carex heterolepis*	4.4	81.9
	H1 - 5	*Miscanthus sineesis*	3.9	894.1
	H1 - 6	*Molinia japonica*	8.7	1162.9
	H1 - 7	*Molinia japonica – Scirpus juncoides*	8.6	262.9
	H1 - 8	*Scirpus juncoides*	3.9	1292.8

	H1 - 9	*Scirpus juncoides – Calamagrostis epigejos*	3.8	801.0
	H1 - 10	*Scirpus juncoides*	4.4	150.0
	H2 – 1	*Molinia japonica*	13.7	1367.3
	H2 - 2	*Molinia japonica*	9	1149.0
	H2 - 3	*Molinia japonica - Miscanthus sineesis*	4.8	848.4
	H2 - 4	*Molinia japonica - Miscanthus sineesis*	2.8	643.9
	H2 - 5	*Miscanthus sineesis*	1.1	288.3
	H2 - 6	*Molinia japonica*	68.6	11275.7
	H3 - 1	*Molinia japonica*	77	12802.7
	H3 - 2	*Molinia japonica – Scirpus wichurae*	9.1	154.2
	H3 - 3	*Molinia japonica*	4.4	522.1
	H3 - 4	*Molinia japonica – Calamagrostis epigejos*	9.5	762.9

국문 초록

산지습지 보전을 위한 금정산 장군습지의 수위 변화 분석

전세계적인 기후변화에 따라 온도 상승뿐만 아니라 강수패턴의 변화가 야기되고 있다. 습지는 육상생태계와 수생태계의 전이지대로서 높은 생물다양성을 가지고 있으며 다수의 생물종들이 습지의 수위에 의존성을 가진다. 따라서 이러한 생물다양성 및 습지를 보전하기 위해서 수위를 예측하는 것은 매우 필수적이다. 증발산량이란 수표면이나 지표면에서 대기중으로 증발되는 증발량과 식물에서 일어나는 증산량의 합으로 수문순환 및 수위에 영향을 미치는 주요 요소 중 하나이다. 본 연구에서는 금정산 장군습지를 대상으로 3개의 10 m X 10 m 방형구에 각각 수위계를 설치하여 각 수위계별 수위 변화를 분석하고자 하였다. 물길을 따라 설치된 총 3개의 수위계 및 강우량 및 온도 습도계를 통해 강우량 및 수위 데이터를 2017년 5월부터 2019년 9월까지 수집하였다. 3개의 수위계는 각각 다른 식생 분포를 가지고 있어 같은 강우사상에 대해 다른 수위 변화 양상을 보였다. 측정된 생물량을 바탕으로 강수량 및 생물량에 따른 수위 변화에 대한 선형 회귀식을 얻을 수 있었다. 본 연구는 증발산량과 같은 수문학적 분석에 습지 식물의 생물량이라는 실질적인 생물학적 데이터를 활용할 수 있는 방안에 대

해 제시하는 것에 그 의의가 있다. 뿐만 아니라 본 연구에서 도출한 회귀식을 통해 강수량에 따른 수위 변화 예측이 가능해진다면 장군 습지를 비롯한 산지습지의 보전을 위해서 기초 자료로 쓰일 것이라 기대된다.

주요어 : 강수 패턴, 다중회귀, 산지습지, 생물량, 수위 변화, 증발산량

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