Analysis Of The Willow Community Structure And Hydrarchy Succession Of Janghang Wetlands, A Ramsar Site In Korea

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Research Article

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Abstract

Wetlands are gradually being lost due to climate change and excessive development. As a consequence, it has become important to muster global cooperation to conserve wetlands. Janghang Wetland, registered as a Ramsar Wetland in May 2021, is located at the estuary of the Han River and is a biodiverse wetland with a dense willow tree community. However, problems with terrestrialization of Janghang Wetland have been raised in several years. This study investigated hydrosere status and the causes through the analysis of its plant community structure. It was found that the community for *Salix koreensis- Salix nipponica* takes up more than 90% of the entire vegetation for willow. As a result of analyzing the MIV correlation between *Salix koreensis* and *Salix nipponica* according to the distance from waterfront, *Salix koreensis* flourished more as it moved away from the river. Comparison for the growth of *Salix koreensis* and *Salix nipponica* by quadrat, showed that the *Salix nipponica* is affected by the tidal channel. Forest tree species such as *Rosa multiflora* and *Eleutherococcus sessiliflorus* were found in the shrub layer. The amount of precipitation and water level had been decreasing for the past 5 years. In the group dominated by *Salix koreensis*, the NaCl of the soil was higher than the optimal level for tree growth, while the NaCl in the group dominated by *Salix nipponica*, tended to be very close to '0'. In Janghang Wetland, *Salix nipponica* community is gradually being replaced by *Salix koreensis* community and it causes by terrestrialization.

1. Introduction

Wetland is an area where freshwater, brackish water, or saltwater permanently or temporarily covers the soil, and can be broadly divided into inland wetland and coastal wetland (RCS 2016, Kahlolo 2021). Riverside wetland is important in terms of habitat and species biodiversity for organisms as a buffer zone for two domains, the terrestrial ecosystem and aquatic ecosystem (R. Yapp 1922; Mitsch and Gosselink 2014; Lee et al. 2019). Wetlands have been damaged or reduced in size by various land use developments (Niering 1994; Keigo Nakamura 2006; Hong and Kim 2017), but their importance and ecological value started gaining recognition from the end of the 20th century (Magnusson 2004; Nassauer 2004; Stewant B. Rood 2019; Edo and Albrecht 2021). In addition, wetlands have been turned into dry areas by rapid climate change (Qiu et al. 1998; Mitsch WJ et al. 2013; Zaiyong Zhang et al. 2021), and wetland conservation has become an international issue (EAAFP 2019; DAWE 2019; Dayathilake 2021). In the recently amended Wetland Conservation Act of Korea, provisions on prevention of have been added (KRMGL 2021). Terrestrialization is defined as a water zone gradually turning into land or being covered by vegetation because of the elevation of riverbed (Yeo et al. 2009; Kim et al. 2014). Increase of vegetation in river may result in the loss of its ecological function (Williams 1978; Gurnell 2014; Kim and Kim 2019; Kim et al. 2020).

The estuary of Han River is a brackish water area with no estuary bank and is an ecological transition zone which occurs when freshwater meets saltwater. Located in this estuary, Janghang Wetland was designated as a National Wetland Protection Area in 2006 and was registered as a Ramsar site in May 2021 (Ahn 2012; Goyang-si 2019; RCS 2021). The willow community in Janghang Wetland provides food source, shelter, and habitat for wildlife including migratory birds, mammals, fish, amphibians, and insects (Bang et al. 2011; Markus-Michalczyk and Hanelt 2018), and provides citizens with waterfront views in the city (KME 2019). Willow communities prevent soil erosion during flood (Brunet and Astin 1997; Markus.M and D. Hanelt 2018) and absorb pollutants and heavy metals from water and soil (Vervaeke et al. 2003; Kuzovkina and Quigley 2005, KME 2014). Riparian trees help estimate the terrestrialization level of the river, calculate flooding frequency of the river, and manage the water flow of the river (Woo 2001; Pike and Scatena 2010; Cliff R. Hupp et al. 2016).

Terrestrialization in wetlands can be explained biologically by the process of hydrosere. This means gradually changing from underwater to land communities, and hydrosere in wetlands has four forms; Reed-swamp stage, Sedge-meadow stage, Woodland stage, and Forest stage (McGinnis 1918; Tayler 2019). In the Woodland stage, wetland plants decrease, shrubs layer and understory layer begin to flourish, and in the Forest stage, the canopy layer covers the entire vegetation. As for the vegetation of Janghang Wetland, Sedge-meadow and Reed-swam stages exist sequentially along the waterfront, and willow community spread out long in the direction of the river flow in the center of the wetland.

The representative tree species of Janghang Wetland are *Salix nipponica* and *Salix koreensis*. The species of *Salix* are indicator of river and wetland vegetation. They are also pioneer species that thrive in lotic environments and inhabit transition zones of wetlands and lands (Kuzovkina and Quigley 2005; Kim et al. 2013). The *S. nipponica* produces small, light seeds; develops multiple branches at the base of its stems; and grows in moist areas with intermittent flooding (Lee et al. 2002; Asaeda 2019). The *S. koreensis* is a deciduous broad-leaved tree as an indigenous of the Korea. It thrives around rivers or reservoirs and can grow up 20m in height and 80cm in width (Lee 2003; Kim and Kim 2014).

Lee (2000) divided the distribution level of *S. nipponica* and *S. koreensis* into four stages according to the height of the riverbed sediment (Lee et al. 2000). The first stage is when *S. koreensis* begin to inhabit the wetland. The second stage is when *S. koreensis* move in and two species coexist as the terrestrialization progresses. On the third stage, *S. koreensis* begin to dominate as *S. nipponica* gradually disappear. On the last stage, most of the *S. nipponica* population disappears and *S. koreensis* take over the habitat which becomes the climax forest (Lee et al. 2000). In addition, a study on the community characteristics of *Salix spp.* in the Nanji Wetland Ecological Park of Han River found that *S. nipponica* tend to dominate areas with high flooding frequency (Choi and Oh 2019), and *S. koreensis* tend to dominate areas with low flooding frequency or where terrestrialization has taken place (Park et al 2015).

This study was conducted to manage and restore the willow colonies through the analysis of the *Salix spp.* community structure of Janghang Wetland of the estuary of Han River.

2. Material And Method

2.1. Study Site

The Han River is located in the central part of the Korean Peninsula, which is 459□ long and 75.70m wide on average. It encompasses 34,674□ of river basin, making up 23% of the land area of South Korea (KME 2014, HFRCO 2021). The main course of Han-river is formed by the confluence of the Namhan River and the Bukhan River near Paldang Dam. It flows through the center of Seoul and meets the Imjin River at its estuary (HRFCO 2019; Korea Ministry of Environment 2014). Janghang Wetland, located at the upstream of the estuary of Han

River, covers a broad span of multiple administrative districts, including Sinpyeong-dong, Deokyang-gu, Goyang-si; Janghang-dong, Ilsandong-gu; and Songpo-dong, Ilsanseo-gu. Its latitude and longitude are 37˚ 38' 17" N and 126˚ 45' 47" E. The wetland is approximately 7.6 km long and 0.6 km wide. The land area is 2.7㎢, and its tidal flat covers 4.79㎢, making up the total area of 7.49㎢ (KME 2021).

According to a terrain map from the year 1978, Janghang Wetland consist of two alluvial islands (MOLIT 2009, KME 2021). After the construction of the Singok Submerged Weir in 1988, the flow rate of the downstream area decreased and the amount of sediment increased, which resulted in the connection of two islands (Lee and Hwang 2006). Afterwards, the land area has increased due to artificial factors such as the construction of Jayu Road in 1990 and has become a sandbar (Goyang-si 2018).

The vegetation zone of Janghang Wetland is divided into waterside meadow, willow colony, and agricultural land. The willow colony accounts for more than 20% of the total vegetation cover of Janghang Wetland (Goyang-si 2019). The willow community has multiple vegetation layers such as herbaceous layer, shrub layer, understory layer and canopy layer, providing habitat for various plants and animals (Johnson 1976; Keddy 2010; Ahn et al. 2014; Stanek 2021). It is located on the border of Seoul and Goyang along the Han River and serves as an ecological network, connecting each green corridor of the city. In addition, it provides the four functions of provision, regulation, culture, and support services of ecosystem services. For instance, it offers wetland for citizens to be used as a field site for education (Fisher et al. 2009; Bae et al. 2012; Oh 2016; Schmutz 2018).

The documentary survey was conducted by referring to the historical data on the Han River development project in Goyang area and analyzing the satellite pictures of the study area which are from the year 1984 to 2018(GEM 2018). The field survey was conducted a total of 10 times in the growing season, which was from June 2018 to May 2019. Based on the satellite image, the location of the willow community was identified, and study sites including farmland, eco trail, and tidal channel were selected along the flow of the Han River. Then they were divided into six regions for survey, ranging from the letter A to F, at an interval of 200 to 300m. Each survey region includes in 4–6 quadrats, and the survey points were indicated by their district names and plot numbers. The total number of quadrats was 30 (Fig. 1).

2.2. Plant Community

2.2.1 Survey Method

Belt-Transect method and the Quadrat method were applied to determine the distance from the willow community to the riverside of Han River. The vegetation of the community was surveyed by placing 10m × 10m quadrat on each plot and dividing the vegetation into canopy, understory, and shrub layer. The height and diameter at breast height (DBH) were measured for each tree of the canopy and understory layer, and the height and crown width were measured for each tree of the shrub layer.

2.2.2 Data Analysis

The Importance Value (IV) of Curtis and McIntosh (1951) was calculated for each layer based on the population and DBH to compare the dominance of species appearing at each quadrat. The IV was divided by

2 after adding up the relative density and the relative coverage, and the Mean Importance Value (MIV) was calculated by weighting each layer differently (Park 1985).

IV = (Relative Density + Relative Coverage) / 2

MIV= {(3 × IV in Canopy layer) + (2 × IV in Understory layer) + (1 × IV in Shrub layer)} / 6

Based on the MIV of each tree species in surveyed quadrats, the community was classified by TWINSPAN (Two-way Indicator Species Analysis) (Hill 1979). The starting point of the willow community is 450m away from the riverside of the Han River. Considering the characteristics of riverside wetland, the distance from each quadrat to the Han River waterfront and the tidal channel as summarized in order to understand the relationship between the water environment factors and the tree community structure in the quadrats. Correlation analysis on the MIV of tree species in each survey area and the distance to the Han River waterfront and the tidal channel were carried out. The distances were divided by 3 at a straight-line from the Han River waterfront to the survey areas, and grouped into S1, S2 and S3. R-studio (4.0.4) was used for this correlation analysis. Based on those groups, the tree community structure was analyzed according to the distribution of MIV, population, DBH and height for *salix spp*. in each quadrat (Harcombe and Marks 1978).

2.3. Environmental Factors

2.3.1. Water level and Precipitation

The annual average water level and precipitation before the flowering season from 2009 to 2017 are shown on the websites of the Korea Meteorological Administration and the Korea Water Environment Information System (KMA 2018: KWAEIS 2018). The vegetation status according to the weather factors and water environment was estimated based on the result.

2.3.2. Soil Property

For the analysis on soil property, soil sample for each willow community was collected three times in the same quadrat. Using the soil analysis method of the Korea Forestry Promotion Institute, the soil particle size, pH, organic and inorganic matter content of the collected samples were analyzed to figure out if they are suitable for plant growth (Byeon 2009).

3. Results

3.1. Topography Variations

According to the satellite photo of 1984, Janghang Wetlands consisted of two islands; however, when the Singok Underwater Weir was completed in 1988(GEM 2018), it was made up of three islands (Fig. 2). The satellite photo of 1998 shows the sign of vegetation development, and the map from the year 2008 clearly indicates a considerable growth of overall vegetation. By 2013, the river area near Ilsan Bridge decreased significantly while the land area gradually increased. Since then, the land area has nearly doubled from 2013 (3.69 ㎢) to 2018 (6.66 ㎢) (Fig. 2). In a previous study by Ahn, the vegetation growth point was located 50 m from the waterside before 2006(Ahn et al. 2012). That point where the willow community is located, was around 150m until 2008. The distance was around 450m in 2018, being tripled in ten years. It has been found that herbaceous plants such as reeds are inhabiting in the space between the waterside and the willow community.

3.2. Plant Community

3.2.1. Community Classification

The population of Salix spp. that were identified from the investigation of 30 quadrats was 446 in total including the individuals found in understory layer. There were 286 for *S. nipponica*, 148 for *S. koreensis*, and 4 for *S. pseudolasiogyne*. Based on the MIV of the trees found in each quadrat, the tree communities were classified by applying the TWINSPAN method (Fig. 3). The indicator species of the first level was *S. nipponica* and it was classified into two groups depending on the presence of the species. It is divided into two groups for the 29 quadrats with *S. nipponica* and 1 quadrat, A13 without *S. nipponica*. The *S. koreensis* and *S. pseudolasiogyne*. were found in the canopy layer of quadrat A13. The second indicator species was *S. koreensis*, and it made appearance in the remaining 26 quadrats except for A11, A12, and B27. *S. nipponica* and *S. koreensis* were found in common in those 26 quadrats, and it is assumed that most of the tree communities in Janghang Wetlands are composed of two species.

3.2.2. Correlation Analysis for MIV and Distance from the Riverside

In order to compare the water environment factors with growth characteristics of *S. nipponica* and *S. koreensis*, the correlation analysis was conducted on the MIV of each tree species and the distance from the riverside to the willow community (Table 1). The factors are two kinds, the distance from Han River and distance from tidal channel to each quadrat (Fig. 4). Since the groundwater level of the survey district is highly variable depending on the measurement point and season, the distance from the Han River waterfront to the willow community was set as an analysis factor. The consequence of the correlation analysis showed that the distance from the riverside to the willow community and the MIV of *S. nipponica* has a negative correlation of 30.09% and that of *S. koreensis* has a positive correlation of 45.01%. The correlation between MIV of *S. nipponica* and *S. koreensis*, and the distances from the willow community to the riverside and tidal channel were 16.37% and 22.38%, respectively, indicating a rather low correlation. Since the location of tidal channel has no regularity unlike the distance from the Han River as confirmed from aerial photograph in Fig. 4(NGII, 2018), the sum of the two waterfront distances was added to the analysis item. The correlation between the MIV of *S. nipponica* and *S. koreensis* was high in the sum of the two types of waterfront distances. The MIV of two species showed a strong negative correlation of 85.66%, indicating that *S. nipponica* flourishes near the riverside while *S. koreensis* dominates as the distance from the riverside increases. In addition, the density of *S. koreensis* in quadrat was inversely proportional to the density of *S. nipponica*.

Table 1
Correlation Analysis for the MIV of *salix spp*. species for Each Community by Distance from Han River and Tidal Channel to the *Salix* Community

	Distance from Han River	**Distance from Tidal channel**	**Distance for River + Tidal channel**	**MIV of *Salix nipponica***	**MIV of *Salix koreensis***
Distance from Han River	1				
Distance from Tidal channel	-0.30007	1			
Distance for River + Tidal channel	0.83016	0.28271	1		
MIV of *Salix nipponica*	-0.30098	-0.16377	-0.39837	1	
MIV of *Salix koreensis*	**0.45014**	0.22382	**0.58345**	-**0.85665**	1

3.2.3. MIV of Salix spp. by Quadrats

Willow communities begin to emerge at 450m point away from the riverside. They were grouped into S1, S2, and S3 depending on the distance from each quadrat to the riverside (Table 2). The average distance from the waterfront was 483.00m for S1, 537.38m for S2, and 612.44m for S3. In the S1 group (450m-510m), which is the closest group to the waterfront, there were 3 quadrats (B27, A11, A12) with the MIV of *S. nipponica* being 100.00%. There were 13 quadrats in the S2 group (511m ~ 570m). Among them, 2 quadrats where *S. pseudolasiogyne* appeared were A13 and A14. The only quadrat with the MIV of *S. nipponica* being 0% was A13. The MIV of *S. koreensis* was higher than the MIV of *S. nipponica* in 9 quadrats, and the MIV of two species were both 50% in the remaining 4 quadrats. Among 9 quadrats in S3 (571m-660m), there were 8 quadrats where the MIV of *S. koreensis* was higher than that of *S. nipponica* The only remaining quadrat, C20, was where the MIVs of both species were 50%. The MIV is a value obtained by adding up the dominance value of tree species in canopy, understory, and shrub layer. Since *S. nipponica* dominates mostly understory layers due to its growth nature, its MIV is relatively lower than that of *S. koreensis*. Although each of the layer was given a weighting, the MIVs of *S. nipponica* and *S. koreensis* do not show a significant difference because of the high population density of *S. nipponica*

Table 2 The MIV of *Salix spp.* for each community by distance to Han River and Tidal channel

Community for *DR	Quadrat Code	D.R (m)	*D.T (m)	*S. nip.*	*S. kor.*	*S. pse.*	***R.mul.*	*M. alb.*	*E. ses.*	*L. obt.*
S1	B27	451	53	**100.00**	-	-	-	-	-	-
450~510m	D01	460	70	41.67	50.00	-	**8.33**	-	-	-
	D02	470	90	40.00	**60.00**	-	-	-	-	-
	A11	470	21	**100.00**	-	-	-	-	-	-
	D03	495	106	27.69	55.64	-	-	-	**16.67**	-
	A12	503	30	**100.00**	-	-	-	-	-	-
	B28	505	28	40.00	**60.00**	-	-	-	-	-
	E06	510	30	**64.27**	35.73	-	-	-	-	-
S2 511~570m	D04	511	130	40.00	**60.00**	-	-	-	-	-
	A14	520	18	32.55	46.03	**15.17**	-	-	-	**6.25**
	F24	520	50	40.00	**60.00**	-	-	-	-	-
	A13	524	37	-	**50.00**	**50.00**	-	-	-	-
	D05	530	60	33.33	50.00	-	**16.67**	-	-	-
	F21	531	70	33.33	50.00	-	**16.67**	-	-	-
	B29	539	34	40.00	**60.00**	-	-	-	-	-
	F25	540	20	47.02	46.00	-	-	**6.98**	-	-
	C15	546	96	40.00	**60.00**	-	-	-	-	-
	B30	547	59	56.65	43.35	-	-	-	-	-
	C16	551	90	40.00	**60.00**	-	-	-	-	-
	C18	561	88	50.00	50.00	-	-	-	-	-
	C17	566	82	50.00	50.00	-	-	-	-	-
S3	F26	571	43	40.00	**60.00**	-	-	-	-	-
571~660m	F22	580	10	40.00	**60.00**	-	-	-	-	-
	E07	597	10	49.36	50.64	-	-	-	-	-
	E08	607	15	40.00	**60.00**	-	-	-	-	-
	E09	615	20	35.90	**64.10**				-	-
	C19	620	55	40.00	**60.00**	-	-	-	-	-
	E10	631	23	40.64	42.70	-	-	**16.67**	-	-

	C20	632	45	50.00	50.00	-	-	-	-	-
	F23	660	38	40.00	**60.00**	-	-	-	-	-

* D.R.: Distance from Han River to survey plots, D.T.: Distance from Tidal channel to survey plots

***R.mul.: Rosa multiflora, M.alb.: Morus alba, E.ses.: Eleutherococcus sessiliflorus, L.obt.: Ligustrum obtusifolium*

In the S1 group, the MIV of *S. nipponica* tends to be high, which means that *S. nipponica* are dominant in the group. In most quadrats of S2 and S3, which are located at a distance further than 511m from the Han River, showed a high MIV of *S. koreensis*. It means that *S. koreensis* thrives and *S. nipponica* diminishes as it gets further away from the waterside. In S2 and S3 group, where *S. koreensis* dominates, a large number of withered *S. nipponica* individuals have been found. Through the MIV analysis, it is assumed that *S. nipponica* and *Salix koreensis* will continue to compete in the canopy and understory layer.

In addition, comparative analysis on the MIV of *S. nipponica* and *S. koreensis* was conducted with species shrub layer (Table 3). The MIV of *S. koreensis* was more than 50% higher in the quadrats where *Rosa multiflora*, *Eleutherococcus sessiliflorus* were found. And it was found that the MIV of *S. koreensis* was relatively low in the quadrats and the MIV of *S. nipponica* tended to be high where *Morus alba*, which is well adapted to wet environment.

Table 3
The MIV of quadrats with new species in shrub layers

Species in Shrub Layer	***R. Mul.***			***M. alb.***		***E. ses.***	***L. obt***
Quadrat Code	D01	D05	F21	E10	F25	D03	A14
MIV of *S. nip.*	41.67	33.33	33.33	40.64	47.02	27.69	32.55
MIV of *S. kor.*	50.00	50.00	50.00	42.70	46.00	55.64	46.03

3.2.4. Growth Condition for *Salix spp*. per Quadrats

The averages number of individuals, DBH and height for each quadrat in S1, S2, and S3 group were calculated (Table 4). Based on the outcome, it is possible to estimate the growth status and environmental characteristics of each group (Kang 2019). The average distance to the riverside from each quadrat of the group was 483m for the S1 group, 537m for the S2 group, and 612m for the S3 group. The average distance to the tidal channel was 54m for the S1 group, 64m for the S2 group, and 29m for the S3 group. The tidal channel exists everywhere around the Han River, regardless of the distance from the group to the riverside. The average distance from the tidal channel to the S3 group, which is located far from the riverside, was the lowest among all groups at 29m. Consequently, it has been confirmed that the average number of *S. nipponica* per quadrat was high in the S3 group. And the average number and DBH of *S. koreensis* per quadrat were high in that group. In the case of *S. nipponica*, the average number of individuals and height per quadrat was high but the DBH was relatively low in the S3 group. The high number of individuals and low

DBH of *S. nipponica* in S3 may attribute to the fact that *S. nipponica* continue to reproduce under the influence of the surrounding tidal channel but are unable to sustain itself for long.

Table 4 The average population, DBH and height of *S. nipponica* and *S. koreensis* per quadrat

Group	Num. of Quadrats	*A.D.R	*A.D.T.	Total Population		Per Quadrat			
						Average of Population		Average of DBH	
				S. kor.	***S. nip.***	***S. kor.***	***S. nip.***	***S. kor.***	***S .nip.***
S1	8	483.00	**53.50**	27	77	3.38	**9.63**	19.78	**17.96**
S2	13	536.69	**64.15**	73	97	5.62	**7.46**	19.34	**18.27**
S3	9	612.44	**28.78**	46	97	5.11	**10.78**	20.85	**15.53**

*A.D.R.: Average Distance from Han River, A.D.T.: Average Distance from the Tidal Channel

3.3. Environmental Factors

3.3.1. Water level and Precipitation

Change in water level at the Han River estuary measured by Haengju Bridge Water Observatory and monthly precipitation data provided by Korea Meteorological Administration were comparatively analyzed by year (Fig. 5). The growth of willows in low arctic Tundra may be subjected to drought stress due to the increase of temperature and the decrease of precipitation in summer (Magdalena 2020). The growth of willows in temperate zone is affected more by the precipitation from January to March than the average annual precipitation (Lee et al. 2012; Kim et al. 2013; Choi and Jun 2019; Kim and Kim 2020). The water level by each year of 10 years up until the previous year of the survey was compared to each other. It was 231.60mm in 2011 and 210.26mm in 2017, decreasing by more than 20mm (Table 5). The amount of precipitation between January and March decreased gradually to 11mm in 2011, went up drastically to 22.30mm in 2013, and gradually decreased again to 15.30mm. The water level, which controls water balance, groundwater flow, and salt water movement, also affects vegetation. The soil moisture and salinity can be estimated from the vegetation cover condition (Taree 1992; Horton 2001; Yali Chi and Jingli Shao 2005). The longer the drought period or the lower the amount of precipitation, the more difficult it becomes for wetland-adapted tree species to grow, and the easier it becomes for xeric adapted invasive tree species to grow (Annemarie G. Garssen et al. 2014). As the water level and precipitation continued to decrease for 5 years from 2014 (Table 5), it is considered that *S. nipponica*, which had steadily grown from the shrub layer to the understory layer, has declined in the number, while *S. koreensis* has rapidly grown to the canopy layer.

Table 5
The annual average water level change by each year at Seoul and Goyang-si

Year **Water (mm)**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Water level (Goyang-si Deokyang-gu)	205.59	221.30	231.60	211.63	**219.48**	**201.16**	**196.90**	**207.76**	**210.26**
Precipitation of *Jan.-Mar. month (Seoul-Gyeonngi)	16.30	28.60	11.00	15.60	**22.30**	**12.80**	**15.80**	**15.30**	**18.40**

3.3.2. Soil Properties

In order to understand the chemical characteristics of the soil for each group of quadrats of Janghang Wetlands, they were divided into the S1 group, which is dominated by *S. nipponica*, and the S2 and S3 group, both of which are dominated by *S. koreensis*. And then comparative analysis on multiple soil properties including pH, organic content, nitrogen content, available phosphoric acid, and cation exchange capacity (CEC) was carried out (Table 6). The soil particle size of each quadrat was either silt or silt loam, with silt content ranging from 70 to 83%, sand content ranging from 17 to 23%, and clay content ranging from 3.7 to 8.5%. Organic content, total nitrogen content, available phosphoric acid, electrical conductivity (EC) and NaCl content of the soil either exceeded or failed to reach the standard level for tree growth. Among them, total nitrogen content and available phosphoric acid did not display differentiated numerical value.

Organic content of wetland soil normally increases in inverse proportion to flooding frequency (Craft 1988). However, in the case of Janghang Wetlands, its overall organic content seems to be low due to the influence of the tidal channel. There was no particular difference in the organic content among each group of S1, S2, and S3, so it is estimated that the organic content does not significantly affect the growth of *S. nipponica* and *S. koreensis*. Electrical conductivity (EC) is an indicator that comprehensively displays the concentration of ions and salt in the soil, and can estimate the salinity in an indirect way (Byeon 2009). While the EC of the standard level for tree growth is less than 0.4 (dS/m-1), it ranged from 0.33 to 0.73 (dS/m-1) in S1 group and 1.20 to 1.58 (dS/m-1) in S2 and S3 group. The values of S2 and S3 group were 2.5 times higher than the value of S1 group. The NaCl content ranged from 0.006–0.009% in B27, B28, and E06 quadrat of S1 group where *S. nipponica* is dominant. This is much lower than the standard value of 0.05% for tree growth. On the other hand, among the five quadrats dominated by *S. koreensis*, the NaCl content of F21, F22, and F25 quadrat NaCl content was higher than the standard level for tree growth. The NaCl content of F23 and F24 quadrat were 0.043% and 0.049% respectively, which were close to the maximum value (0.05%) for tree growth. The outcome of soil analysis may indicate that salt accumulates more as it gets further away from the riverside, which in turn affects the growth of *S. nipponica*.

Table 6. The comparison for soil analysis as to classification groups by distance from riverside

Properties for Soil Analysis (unit)	*Suitable standard value for tree growth	Group for S1			Group for S2 & S3				
		B27	B28	E06	F21	F22	F23	F24	F25
pH	5.5 6.5	6.6	6.6	6.9	6.5	6.0	6.7	6.3	6.2
* O.M.(%)	≥ 3.0	**1.24**	**1.65**	**1.84**	**0.53**	**0.58**	**1.21**	**0.58**	**0.73**
T.N.(%)	≥ 0.25	**0.114**	**0.134**	**0.149**	**0.049**	**0.079**	**0.108**	**0.078**	**0.089**
*A.P.(mg/kg-1)	60<A.P.<200	**251.2**	**236.3**	**224.9**	172.1	167.6	**201.3**	**258.1**	177.9
CEC(cmol/kg-1)	12 20	8.14	8.51	8.43	5.94	5.72	7.99	5.50	6.31
K+(cmol/kg-1)	0.25 0.50	0.40	0.39	0.46	0.30	0.26	0.30	0.37	0.33
Ca2+(cmol/kg-1)	2.5 5.0	4.50	**5.08**	4.67	2.83	3.36	4.35	2.84	2.90
Mg2+(cmol/kg-1)	≥ 1.5	2.14	2.82	3.21	2.65	1.75	2.74	1.96	2.53
EC(dS/m-1)	**< 0.4**	0.33	**0.73**	**0.47**	**1.58**	**1.44**	**1.25**	**1.20**	**1.30**
NaCl(%)	**< 0.05**	0.007	0.009	0.006	**0.058**	**0.057**	**0.049**	**0.043**	**0.052**

* Suitable standard value: Standard value for tree growth proposed by National Institute of Forest of Science,

O.M.: Organic matter, A.P.: Available phosphate

4. Discussion

The vegetation that inhabits along rivers and wetlands varies depending on the water environmental factors such as the rate of flow and water level of the floodplain, inundation period, and the number of days with precipitation (Michelle 2000; Rood 2005; Hillman 2016; Jung 2018). It is also hugely affected by water level fluctuation (Markus-Michalczyk 2014). In the case of Seoul and its metropolitan area in Korea, the water level and annual average precipitation drastically decreased over the past five years since 2012. Through the analysis on MIV of tree species, it was confirmed that *S. koreensis* is dominant as it gets further away from the riverside and *S. nipponica* is dominant near the tidal channel and riverside. In the case of *S. nipponica*, even in the S3 group which is far from the riverside, the number of individuals increased, but their DBH was low. Thus, it is estimated that *S. koreensis* tolerates the dry environment better than *S. nipponica* does and is affected by the soil moisture condition as well as the groundwater level (Mukherjee 2020).

For the second environmental factor, it was estimated that *S. nipponica* declined and *S. koreensis* prospered as the precipitation decreased especially before the flowering period, which lowered the reproduction rate of *S. nipponica* and prolonged dry condition (Lio et al. 2019). A number of forest tree species were found in the shrub layer of the willow community in Janghang Wetlands, indicating the severity of terrestrialization (Lee et al. 2019). It is caused by a combination of the physiological characteristics of each tree species; microscopic climatic factors including the seasonal precipitation index; and the soil environment (Joe and Song 2011). As a result of analyzing the tree community structure based on the biological hydrarchy succession mentioned in the introduction, Janghang Wetlands has already transitioned from the Woodland stage to the last stage, the Forest stage. As to the 4th stage of the terrestrialization process in the *salix* spp. community (Lee et al. 2012), the willow community in Janghang Wetlands seems to be in the 3rd stage of terrestrialization, in which *S. nipponica* decline and *S. koreensis* flourish. Although the importance and value of the willow community was acknowledged, there was a lack of literature review which are comparable to the willow community in the Janghang Wetlands of the past. The time of terrestrialization was estimated by checking the change in the area of sedimentation and vegetation through satellite images.

The increase of the size of willow community in Janghang Wetlands is confirmed through the annual topographical change, and the study on the characteristics of *S. nipponica* and *S. koreensis* in Janghang Wetlands can be a useful baseline data. In addition, in the investigation of the herbaceous layer in the willow community, many halophytes such as *Carex scabrifolia*, *Bolboschoenus planiculmis*, *Calamagrostis epigeios*, *Phacelurus latifolius* and *Plantago lanceolate* were found, so the salinity in the soil could be an important factor (Vandersande 2001). Accumulation of salt in soil after evaporation of moisture in the soil can cause fatal damage to sensitive plants (Kratsch 2008; Paudel et al.2018; Feng 2020; Haraguchi & Sakaki 2020; Chapman 2021; Martina Baaij et al. 2021).

In particular, long-term monitoring of change in salinity and water level can predict the potential population decline of plant species at an early stage (M. Adeleye et al. 2021), so intensive management of target species can prevent from extinction. For the efficient use by human, the physiological characteristics of *Salix* spp. tree were artificially improved to match the surroundings (Hangs R. D. 2011), and an appropriate environment is managed to preserve native species (Korea Water Resources Association, 2019). Flow rates, aquatic topographical mechanisms, water quality and ecological conditions are key indicators of maintaining optimal wetland habitat (Swanson et al. 2017; Mukherjee 2019). This study, like the latter, focuses on the growth of *S. nipponica*, a representative wetland plant of the floodplain, and has significance in evaluating the wetland environment.

5. Conclusion

According to the analysis of the community structure of the *Salix* community in Janghang Wetlands, two tree species, *Salix nipponica* and *Salix koreensis*, are constantly competing to expand the vegetation area. The dead trees of *S. nipponica* in understory layer, which grows naturally in intermittent flooded areas, are found, and the rapid growth of *S. koreensis* in canopy layer is a stage in which terrestrialization has already taken place. The cause of terrestrialization in this study was estimated to change the sedimentary area and to be decreased in precipitation and water level due to climate change. The water level gradually decreased due to the increase in the sedimentary area and the decrease in precipitation, and it is believed that the initial Woodland stage progressed rapidly to the Forest stage in recent years. In order to maintain the value of Janghang Wetlands, it is necessary to focus on improving the problems related to the moisture content in the soil and the water environment. Changes in soil moisture content and groundwater level can be roughly estimated by referring to the growth status of *S. nipponica* in Janghang Wetlands. Further studies on the distribution of dead trees and physiological characteristics of salt tolerance and drought stress of *S. nipponica* should be conducted. *S. nipponica* thrive in riverside floodplains, which can act as an ecological indicator of the environmental condition of wetlands. In order to conserve wetlands, both detailed research on the tree community structure and monitoring of flora and vegetation of wetlands need to be conducted.

Declarations

Supplementary Information

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Figures

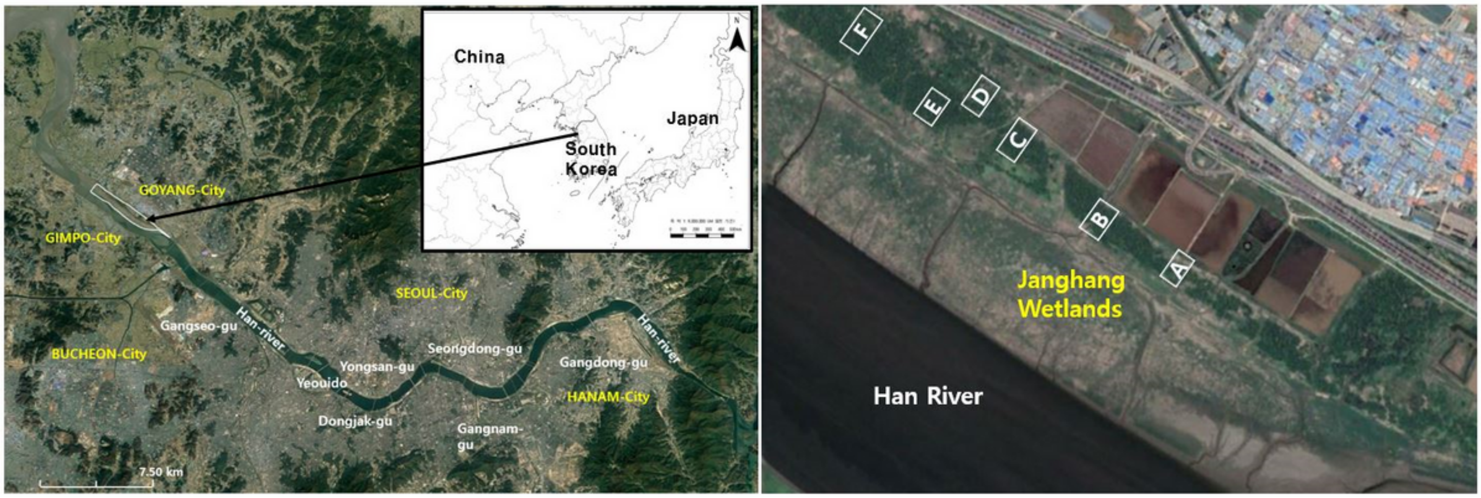

Figure 1

The survey sites (A, B, C, D, E, F) and location on the map for Janghang wetlands

Year	1984	1988	1998	2008	2013	2018
Area Length (km)	4.16 + 5.46	4.58 + 5.58 + 2.80	14.40	14.48	15.10	16.50
Area Extent (km^2)	0.72 + 1.20	1.0 + 1.52 + 0.31	2.78	3.10	3.69	6.66
Number of Island	2	3	-	-		-

Figure 2

The satellite photograph and area size of the Janghang Wetlands from 1984 to 2018

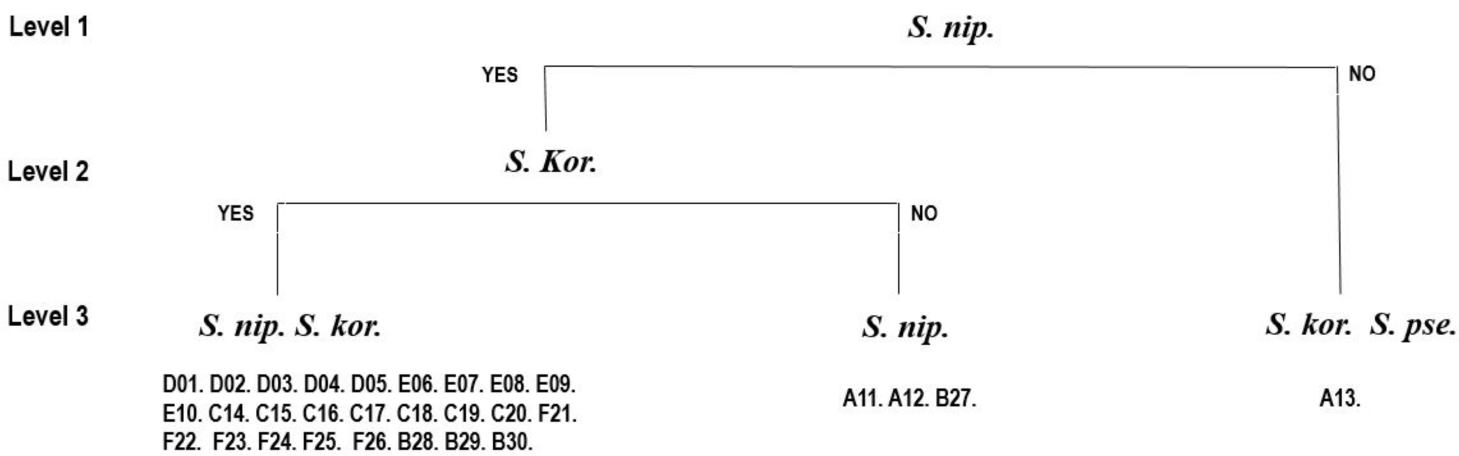

Figure 3

The dendrogram of classification by TWINSPAN for tree community in Janghang Wetlands

**S. nip.*: *Salix nipponica, S. kor.*: *Salix koreensis, S. pse.*: *Salix pseudolasiogyne*

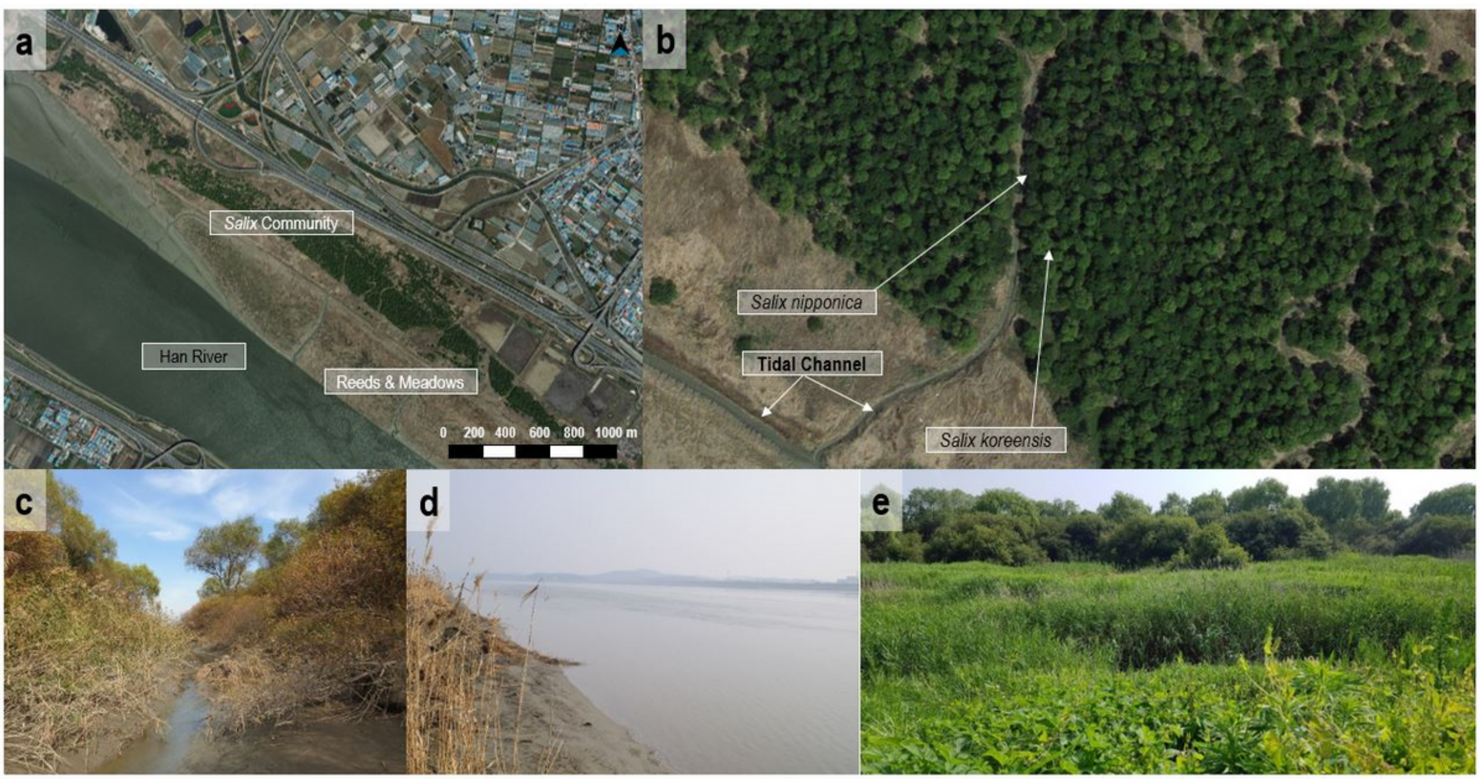

Figure 4

Salix community and Tidal Channel. **a** Aerial photograph of *Salix* community and Han River, **b** Distribution for *Salix nipponica* and *Salix koreensis*, **c** Tidal Channel in *Salix* Community, **d** Han River and Riverside, **e** Reeds and Meadows in Janghang Wetlands

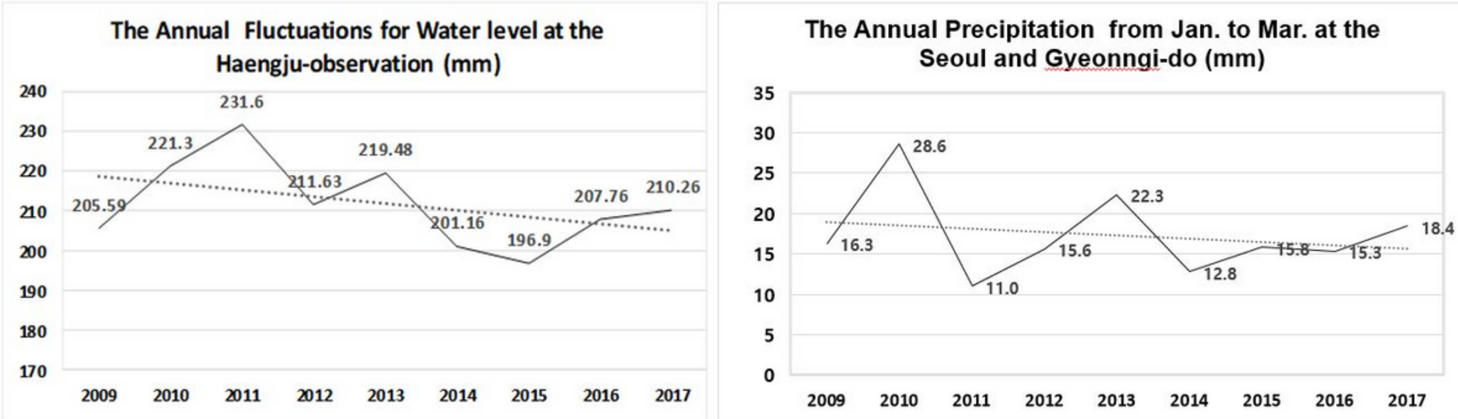

Figure 5

The change of water level and Precipitation for annual average by each year at Seoul-si and Goyang-si