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이학석사학위논문

Effects of Water Level and Temperature on
Competitive Interaction between Invasive
and Native Wetland Plants

수위와 온도 차이가 습지의 침입종과 자생종
경쟁 관계에 미치는 영향 연구

2012년 8월

서울대학교 대학원

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**Effects of Water Level and Temperature on
Competitive Interaction between Invasive
and Native Wetland Plants**

A Thesis Presented

By

Shin, Minjoo

Advised by Assoc. Prof. Dr. Eun Ju Lee

**In partial fulfillment of the requirements for the degree of
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at the

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Seoul National University
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Effects of Water Level and Temperature on Competitive Interaction between Invasive and Native Wetland Plants

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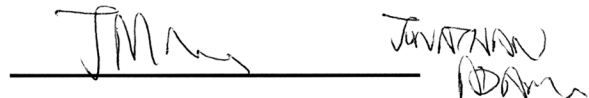
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Abstract

Effects of Water Level and Temperature on Competitive Interaction between Invasive and Native Wetland Plants

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Riparian areas are vulnerable to invasion because regular floods decrease the competitive interaction and provide many kinds of microhabitats for species. *Lythrum salicaria* is a well-known aggressive invader of wetlands in North America but is a native species in Korea. There are reports about natural habitats of *Lythrum salicaria* at the riparian area in some parts of Korea, however, none of them reports that it dominates the community. *Panicum dichotomiflorum* is invasive in Korea but native in North America and *Phragmites australis* is native in Korea. I compared the characteristics of three species among different treatments to measure fitness of each species at several flooding conditions and elevated temperature. I hypothesize that *Lythrum salicaria* will most sensitive to different condition and have the lowest position in competition.

To compare different properties on different environmental condition, I divided experimental sets to two temperature and three water level conditions. The sets at elevated temperature were placed in the greenhouse and the mean temperature inside the greenhouse was about 2°C higher than outside. The height of *Panicum dichotomiflorum* wasn't affected by temperature change while the height of *Lythrum salicaria* and *Phragmites australis* were

significantly higher in elevated temperature than in ambient temperature.

Three different water levels (dry, wet and flooding condition) were set for studying water supply and flooding effects. There was no difference between wet treatment and flooding treatment but plants at dry treatment didn't grow up well than other water treatments. *Lythrum salicaria* and *Phragmites australis* showed significant difference between dry and other conditions while *Panicum dichotomiflorum* didn't. It indicates that two species are more sensitive to water condition, especially at elevated temperature.

Three species were investigated separately or planted together to watch the competitive effects. *Lythrum salicaria* was affected most by competition. There was no difference between the kinds of which species it competes with. The interaction between climate factors and competition had different influences with species. *Panicum dichotomiflorum* showed more competitive properties than other two species.

In conclusion, *Lythrum salicaria* was most sensitive to environmental variations and *Panicum dichotomiflorum* and *Phragmites australis* were less sensitive to environmental factors. The stable precipitation pattern of the United States could affect to the wide distribution of *Lythrum salicaria*. If climate changes, however, *Panicum dichotomiflorum* and *Phragmites australis* which showed more competitive ability than *Lythrum salicaria* may replace the wetlands community and alter the plant distribution in wetlands.

Keywords: invasive plants, climate change, *Lythrum salicaria*, *Phragmites australis*, *Panicum dichotomiflorum*

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I . Introduction

Plants invasion and climate change

Biotic invasion is considered as a global problem which threatened biodiversity and change distribution of lots of species (Vitousek, D'Antonio, Loope & Westbrooks, 1996; Mack *et al.*, 2000; Thomas *et al.*, 2004). As anthropogenic changes increase species movement to non-native niche, more and more invasive species threatens native species and ecosystem (D' Antonio, 1993; Thompson, Hodgson, Grime & Burke, 2001). Although there are some debates whether invasive species are really harmful to the ecosystem or not (Farnsworth & Ellis, 2001; Mahaney, Smemo & Yavitt, 2006), it is certain that invasive species change native habitats and have influence on the ecosystem. In Korea, Ministry of Environment designated 13 ecosystem threatening invasive species and tries to control the balance between native and invasive species. Worldwide, Invasive Species Specialist Group (ISSG) developed a list "100 of the world's worst invasive alien species (2004)" to aware of the risks of harmful invasions.

It is important to predict the change of plants distribution because it could change the rates of nutrient cycling in terrestrial ecosystems and alter tropical structure of community (D'Antonio & Vitousek, 1992; Zavaleta, 2000). Climate changes that could influence plant invasion include rising temperature, altered precipitation, increased atmospheric CO₂ and nitrogen decomposition (Richardson *et al.*, 2000; Thuiller, 2007; Vila *et al.*, 2007; Bradley *et al.*, 2009; Blumenthal, Wilcove & Ziska, 2010). This is the reason why researches on the relation between plant invasion and climate are needed.

Many ecologists arouse the importance of researching plant invasions linking to climate change (Dukes & Mooney, 1999; Weltzin, Belote & Sanders, 2003; Vilà *et al.*, 2007; Bradley, Blumenthal, Wilcove & Ziska, 2010). Recently, Bradley (2010) compared impacts of global change on invasive plant species and insisted there were interacting effects between different elements of global change such as CO₂ elevation and warming, N deposition and precipitation. Competition experiment between C3 and C4 plants at different level of drought stress and CO₂ concentration gave certain evidence that changing environmental factors would change competitive ability between species (Marks & Strain, 1989). Har-Edom and Sternberg (2009) showed that decreasing precipitation made native plant communities more resistant to an invasive plant which is weak to low water condition. Manea and Leichman (2010) focused on elevated CO₂ and designed competition experiment between native and invasive plants under two different CO₂ condition. If precipitation increases, ornamental species which are restricted their habitats by water limitation could be more aggressive to wide region (Har-Edom & Sternberg, 2009). Researches on the interactions between climate change and plant invasion, however, have been seldom published.

Riparian areas like wetland are considered weak place to invasion (Casanova & Brock, 2000; Bradley *et al.*, 2010). Regular floods decrease the competitive interaction and provide many kinds of microhabitats for various species (Hood & Naiman, 2000). Different water regime and changing precipitation could have major effect on plant community in wetland (Casanova & Brock, 2000). Newly created environmental condition caused by changing precipitation could facilitate plant invasion (Bradley *et al.*, 2010). Harworth-Brockman (1993) studied effects of flooding difference on seedling of *Lythrum salicaria* which is a major invasive wetland plant in North America to control the population of the plant.

Study about flooding effects on *Lythrum salicaria* seedling (Haworth-Brockman & Murkin, 1993) indicates that shallow flooding has no difference on plant growth. After established, flooding didn't have little effect on seedling survival. However, some invasive species show significantly greater ability to survive than noninvasive species on different water regimes (Levine & Stromberg, 2001; Krecher & Zedler, 2004). Kercher and Zedler (2004) compared physical traits of invasive and noninvasive plant on different water regime and their results supports that invasive plants are less sensitive to flooding than habitat specialists.

Plants-plants interaction on invasion

Competition is one of the natural processes which determine the response of communities to environmental change, such as climate change, N deposition and habitat fragmentation (Reader & Bonser, 1993; Howard & Goldberg, 2001). For example, when N deposition changes, nutrient availability would be altered and resources could be decreased. Then, one species could be winner in resource competition and the number of looser species would be decreased (Wedin & Tilman, 1996; Blumenthal *et al.*, 2008).

When new species are introduced to new ecosystem, they have to compete with native species which have similar ecological niche (Goldberg, 1990). If introduced species become dominant in the community, individuals of native species would be decreased. The reason of success in invasion is commonly considered the superior competitive ability of invasive species in same ecological niche (Gaudet & Keddy, 1995; Nernberg & Dale 1997). The mechanism of invasion is based on difference in competitive ability so if researching on the reason of differences can provide a solution for harmful

invasion caused by changing environmental conditions (Callaway & Achehoug, 2000).

Lythrum salicaria is a perennial wetland plant which is on the list of ISSG. It is a well-known aggressive invader of wetlands in North America (Stuckey, 1980). It introduced to North America from Eurasia and spread to whole region of the U.S. rapidly (Stuckey, 1980). Riparian areas are vulnerable to invasion because regular floods decrease the competitive interaction and provide many kinds of microhabitats for various species (Hood & Naiman, 2000). Because *Lythrum salicaria* is considered as one of the worst invasive plants of North American wetland, many studies investigated effects of *Lythrum salicaria* on North American wetland vegetation (Morrison, 2002; Hager, 2004; Houlahan & Findlay, 2004). Like other invasive species, there are still some debates whether *Lythrum salicaria* invasion negatively impact on North American wetlands (Farnsworth & Ellis, 2001; Mahaney, Smemo & Yavitt, 2006). It has been recorded that *Lythrum salicaria* lives in the riparian area of Kangwon-do and Southern part of Nakdong River according to 'detailed wetlands survey in inland Korea' by Ministry of Environment but none of reports said that it dominated the community where they found. It is very contrastive phenomena to the case of North America.

Phragmites australis is a perennial wetland plant and very common native monocot in Korea. *Panicum dichotomiflorum* is an annual wetland plant and originated from North America. It spreads through the riverside of Korea. Two species were observed at the habitat of *Lythrum salicaria* in Korean wetland and all three species lives on the boundary of land and river. I chose those two species to research the competitive ability of *Lythrum salicaria*. *Lythrum salicaria* is invasive in North America but native in Korea, *Panicum dichotomiflorum* is invasive in Korea but native in North America and

Phragmites australis is native in Korea. Both *Lythrum salicaria* and *Phragmites australis* are perennial and propagate by rhizome but *Panicum dichotomiflorum* does not. So competition experiments of three species could provide results which can explain the reason why *Lythrum salicaria* dominate in North America but not in Korea.

Hypothesis and Purpose of research

Selecting those three species and using three different environmental conditions, I focused to study relation between species and interaction of invasion and climate factors, especially temperature and water regime.

Here, I suggest a hypothesis: flooding before establishing will affect to survival of species and *Phragmites australis* and *Panicum dichotomiflorum* will show greater ability to survive than *Lythrum salicaria*. Water level changes randomly in Korea so the difference of species would cause different distribution of plants. Also, *Phragmites australis* and *Panicum dichotomiflorum* will be at dominant position in competition experiments, which indicates that growth of *Lythrum salicaria* could be disturbed in Korea, but in North America where it is considered as exotic plants, it could spread easily by establishing new interaction with native species.

The central aim of the research was to find the main cause of dominance in competition between three wetland plants and predict the change on distribution for future climate. To catch the change of fitness of each species at different environmental conditions, different water supply and temperature was treated to each set of plants. Competition experiment was conducted to find dominant species at different environmental conditions. Results of

research were expected to offer confirmed data of ecological state and characteristic of three species.

II. Materials and Methods

1. Experimental setting

The experiment was set up at Songgok-ri, Moga-myeon, Icheon-si, Gyeonggi-do on April, 2011. It was conducted under different conditions of water supply and temperature. A set of flooding experiment was composed of 18 treatment combinations: 6 species categories (*L. salicaria*, *P. dichotomiflorum*, *P. australis*, *L. salicaria* × *P. dichotomiflorum*, *P. dichotomiflorum* × *P. australis*, *P. australis* × *L. salicaria*¹) and 3 water condition (dry, wet, and flooding). Dry condition² was similar with upland conditions so watered twice a week but normally kept in dry soil. Wet condition was kept saturated with water but the water level was not over the surface of pots. The water level was kept over 10cm (about 11cm~13cm) from pots for flooding condition (Chun, Kim & Moloney, 2010). To investigate the competition effects, a seedling of a species was planted per a pot for individual experiments, while a seedling of two species was planted in a pot to contain two different kinds of plants per a pot for competition experiments.

To examine the influence of difference in temperature, each set of water level experiments was placed in 2 different temperature conditions: ambient and elevated temperature. One set of experiments was set inside the greenhouse which designed for elevated temperature, while the other was set outside the greenhouse which designed for ambient temperature (Figure 1).

¹ Symbol ‘ × ’ means that two species were planted together.

² This treatment was not designed for drought stress but the expression ‘dry’ was used to compare with the others.

Environmental factors, such as humidity and light intensity, were maintained same. The outside setting was covered by vinyl top to adjust the light intensity and to minimize the rain fall effect. Other environmental factors like wind, insects and other microenvironment were not controlled during the experiments.

In summary, there were 36 different kinds of experiments (6 different species categories, 3 different water levels, and 2 different temperature conditions). Species categories were gathered with same categories to minimize the interruption of other species. Each sort of experiments was replicated 5 times.

Mature seeds of *L. salicaria*, *P. dichotomiflorum* and *P. australis* were harvested at each species habitat on November, 2010. The seeds were dried at room temperature (20°C) and stored in a cold room (4°C) for experiments.

Seeds were germinated in 50-cell trays on April, 2011. The germinated seedlings were transplanted into plastic pots (15cm diameter, 15cm height). Pots were filled with two types of commercial organic soils {Nongwoo Bio-Farm – coco peat (10~15%), peat moss (13~18%), vermiculite (50~60%), zeolite (6~9%), diatomaceous earth (8~13%), pH – 4.5~5.8, EC – 1.3~2.7 ds/m, TN – 1,200~2,500 mg/kg, P₂O₅ – 300~600 mg/kg and Seoul Bio-Baroker - coco peat (40~45%), peat moss (25~35%), perlite (10~14%), vermiculite (8~10%), zeolite (8~13%), pH – 5.5~7.0, EC ≤ 300, NO₃-N ≤ 300 ppm, NH₄-N ≤ 200 ppm, P₂O₅ – 18~25 mg/kg } which mixed 1:1 ratio.



Figure 1. Experimental setting. (A) The whole view of study site; (B) Ambient temperature experiments on outside; (C) Wet and flooding treatment was set in tanks.

2. Climate factors

2.1 Climate measurements

Data loggers (HOBO U12-012, On Set, MA, USA) with sensors (TEL-7001, Telaire, CA, USA) were placed to record temperature. Temperatures were recorded once an hour. Data were separated by Day (06:00 - 18:00) and Night (18:00 – 06:00). Soil water content and temperature were measured using an ECH₂O logger (Em50, DECAGON Devices, WA, USA).

2.2 Analysis of soil

Soil samples were taken from pots of each environmental treatment for *L. salicaria*. After air-dried in shade, each sample (5g FW) were put into 100mL Kjeldahl flask with 1mL 60% HClO₄, 5mL HNO₃ and 0.5mL H₂SO₄ and gradually heated at Block digester until white smoke came out. Ten to fifteen minutes later, flasks were cooled to room temperature and added distilled water. The extracts were filtered with filtering paper (Whatman No. 42) then amounts of exchangeable cations (Na⁺, Mg²⁺, K⁺, Ca²⁺) measured using by Atomic Absorption Spectrophotometer (Perkin-Elmer 3110).

3. Analysis of plants

3.1 Physical analysis

The height of each planted species was measured once in every month from June to September. Plants were harvested in September 23th. Total aboveground biomass of each plant was measured after drying at 80°C for 48hrs in drying oven.

3.2 Chemical analysis

3.2.1 Photosynthetic pigment content

Photosynthetic pigments of each species were extracted during 8 hr in the dark using dimethyl sulfoxide (DMSO) in water bath at 65 °C (Hiscox & Israelstam, 1979; Tait & Hik, 2003). The absorbance of the photosynthetic pigments was measured by UV/visible spectrophotometer (Spectrmamax Plus 384, Molecular Devices, CA, USA) at 665nm and 649nm. Photosynthetic pigment concentrations were calculated using following equation (Wellburn, 1994).

$$\text{Chlorophyll a} = 12.25A_{665\text{nm}} - 2.79A_{649\text{nm}}$$

$$\text{Chlorophyll b} = 21.50A_{649\text{nm}} - 5.10A_{665\text{nm}}$$

3.2.2 Total soluble sugar

Plant samples were ground to a fine powder in liquid nitrogen, homogenized in 80% ethanol, and incubated for 30 min. After 5 min centrifugation (13,000g), the supernatant was collected and evaporated using a centrifugal evaporator (CVE-100, EYELA, Tokyo, Japan). Samples were resuspended in 1.5 mL distilled water, incubated for 30 min, and centrifuged 5min (13,000g). The 200μL of supernatant was collected and mixed with 1mL of anthrone reagent (Van Hanel, 1968). The absorbance was measured by UV/visible spectrophotometer (Spectrmamax Plus 384, Molecular Devices, CA, USA) at 620nm.

3.2.3 C/N ratio

To determine the C and N content of plant, dried leaves and stems of each species were milled then analyzed with an Automatic Elemental Analyzer (Flash EA 1112; Thermo Fisher Scientific).

4. Statistical analysis

A one-way ANOVA was performed to identify significant difference among water level treatments. The *t*-test was used to assess the statistical significance of temperature treatments. The interacting effects among different factors were examined using two-way or three-way ANOVA. Tukey's honestly significant difference (HSD) post hoc contrasts were used to determine differences among different levels within factors. SPSS (IBM SPSS Statistics 19; 2010 SPSS, Inc., an IBM company) was used for all the statistical analysis with a *P*-value of 0.05 for testing the hypothesis.

III. Results

1. Climate factors

Mean temperature in the greenhouse which was designed for elevated temperature (E-T) was clearly higher than outside which designed for ambient temperature (A-T). To clarify the distinction, temperature data were divided into day (06:00-18:00) and night (18:00-06:00). The mean temperature of day in the greenhouse (E-T) was about 5°C higher than outside of the greenhouse (A-T), while the mean temperature of night in the greenhouse was slightly higher than outside (Figure 2).

The water content of wet and flooding treatment were 3 to 4 times higher than that of dry treatment (Table 1 Water content and temperature of soil on July). The exchangeable cations (Na^+ , Mg^{2+} , K^+ , Ca^{2+}) contents on soil had no significant differences between different conditions (Figure 3).

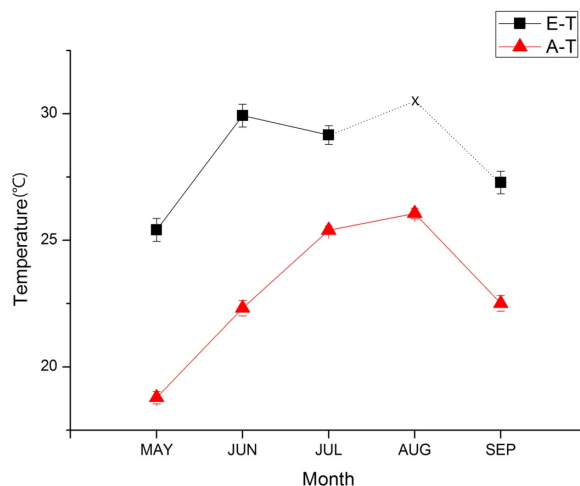
Table 1 Water content and temperature of soil on July

		Water content (%)	Temperature (°C)
A-T	dry	20.7±0.45	25.9±0.15
	wet	74.6±0.02	27.3±0.12
	flooding	61.7±0.16	27.9±0.10
E-T	dry	22.1±0.54	25.1±0.13
	wet	76.9±0.01	25.0±0.07
	flooding	X*	X*

X*: Data of flooding treatment in the greenhouse (E-T) were lost due to the malfunctioned data logger.

Mean ± SE values are given. (N=5).

(A)



(B)

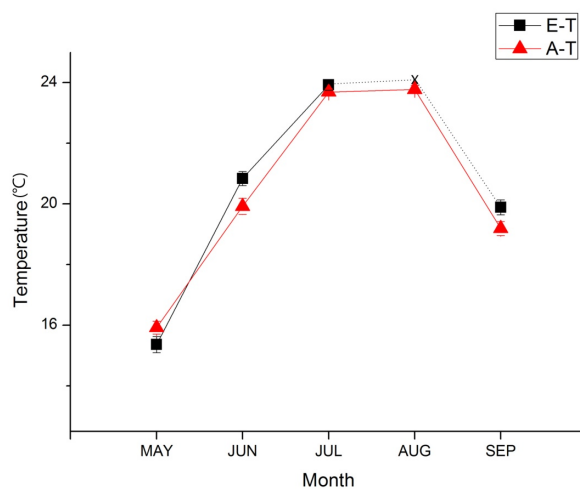


Figure 2. Monthly average temperature of (A) day (06:00-18:00) and (B) night (18:00-06:00). Error bars indicate \pm standard error. Data in the greenhouse on August were lost due to the malfunctioned data logger. X and dotted line were estimated through the average of other month data.

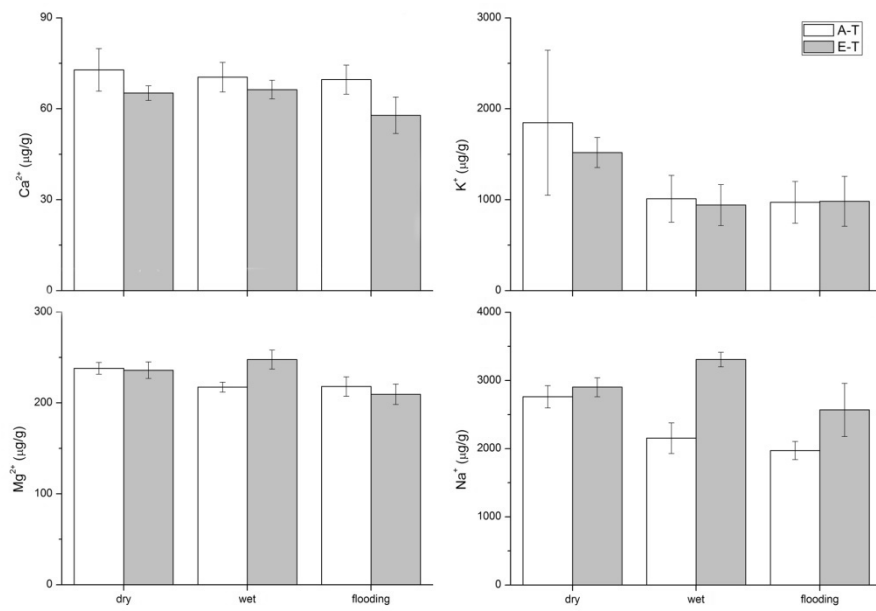


Figure 3. Chemical properties of soil of *Lythrum salicaria* at the last harvest in September, 2012. Error bars indicate ± standard error (N=3).

2. Effects of climate factors

2.1 Physical analysis

Plant Height

All three species' height was significantly different at flooding treatment on September (Table 2). Although there were no statistically significant difference at other water level, it is certain that plant height in E-T was higher than in A-T, especially in *L. salicaria*.

To see the growth pattern of three species, monthly average height of plants were compared in each temperature condition. Generally, plants at water sufficient condition grew taller than dry condition.

There was no significant difference in height of *L. salicaria* in ambient temperature at the end of experiments; however, in elevated temperature, plants at water sufficient condition grew significantly taller than at dry condition (Figure 4). In ambient condition, plants placed at water sufficient condition show significant difference in height in July, even though it became a slight difference in the end. In elevated temperature, there was a definite difference of height between dry and water sufficient condition from the beginning to the end of experiments; plants height between two different water sufficient conditions – wet and flooding- were almost similar.

P. dichotomiflorum was similar in the aspect of difference between dry and water sufficient condition, but there were no significant difference in both ambient and elevated temperature at the end of experiments (Figure 5). In ambient condition, plants at water sufficient condition grew well than dry condition until August. In elevated condition, the difference between water sufficient and dry condition can be seen in the graph, but it doesn't have

statistical significance except data of August. The plants height at flooding condition is even taller than those at wet condition in August.

Unlike other two species, *P. australis* shows significant difference only at the beginning of experiment in ambient temperature (Figure 6). While other two species at dry condition have the lowest height over the span of experiments even there is no statistical significance, *P. australis* at dry condition has the lowest height only in June, the early part of experiments. In elevated condition, however, it is clear that *P. australis* at water sufficient condition grew much taller than those at dry condition. In the graph, the height of plants at flooding condition is a little higher than wet condition but there is no statistical significance.

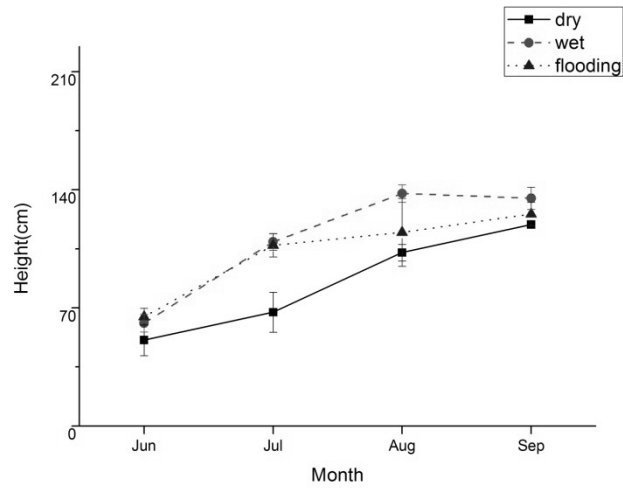
Table 2 Plant height of *Lythrum salicaria*, *Panicum dichotomiflorum*, and *Phragmites australis* in September, 2012

Height (cm)				
		<i>Lythrum salicaria</i>	<i>Panicum dichotomiflorum</i>	<i>Phragmites australis</i>
dry	A-T	119.4 ±1.2 ^a	202.9±13.9 ^a	153.6±8.5 ^a
	E-T	132.9 ±6.7 ^a	222.5±10.4 ^a	156.0±17.3 ^a
	A-T	135.0 ±6.6 ^b	250.6±12.4 ^a	161.8±11.0 ^a
wet	E-T	185.2 ±8.2 ^a	278.2±24.0 ^a	159.4±12.1 ^a
	A-T	125.7 ±6.9 ^b	176.7±28.8 ^b	167.0±9.6 ^b
flooding	E-T	182.8 ±10.7 ^a	280.7±10.5 ^a	204.6±13.0 ^a

Mean ± SE values are given.

Means with different letters within a column are significantly different at P<0.05 using Tukey's honestly significant difference (HSD) test (N=5).

(A)



(B)

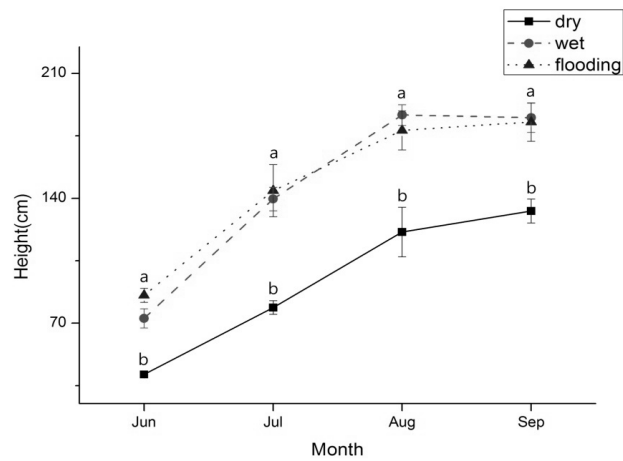
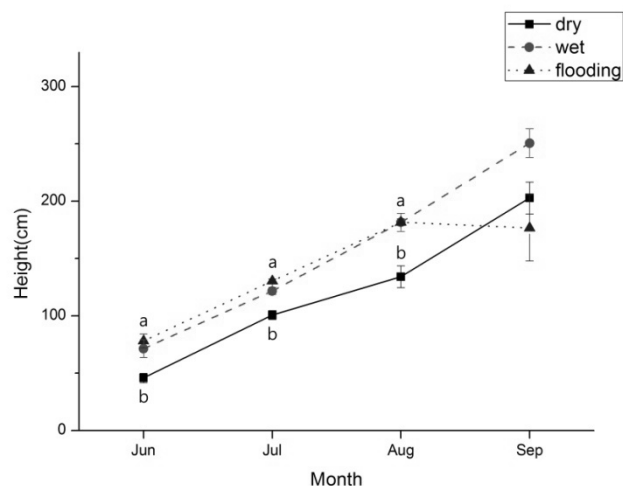


Figure 4. Monthly average height of *Lythrum salicaria* from June to September, 2012. Plants height at different water level in same temperature treatment: (A) ambient temperature, (B) elevated temperature. Bars(\pm SE) with different letters are significantly different at $p < 0.05$ using Tukey's honestly significant difference (HSD) test (ANOVA, $N=5$).

(A)



(B)

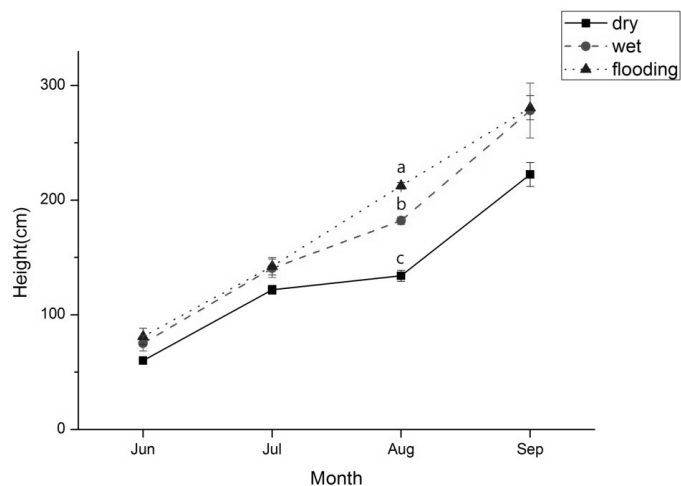
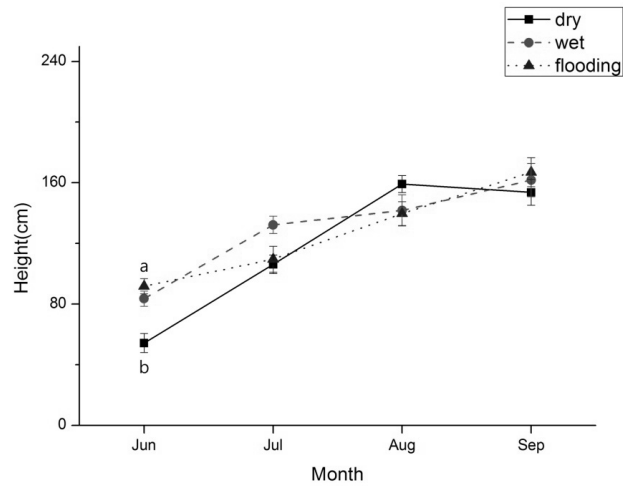


Figure 5. Monthly average height of *Panicum dichotomiflorum* from June to September, 2012. Plants height at different water level in same temperature treatment: (A) ambient temperature, (B) elevated temperature. Bars(\pm SE) with different letters are significantly different at $p < 0.05$ using Tukey's honestly significant difference (HSD) test (ANOVA, $N=5$).

(A)



(B)

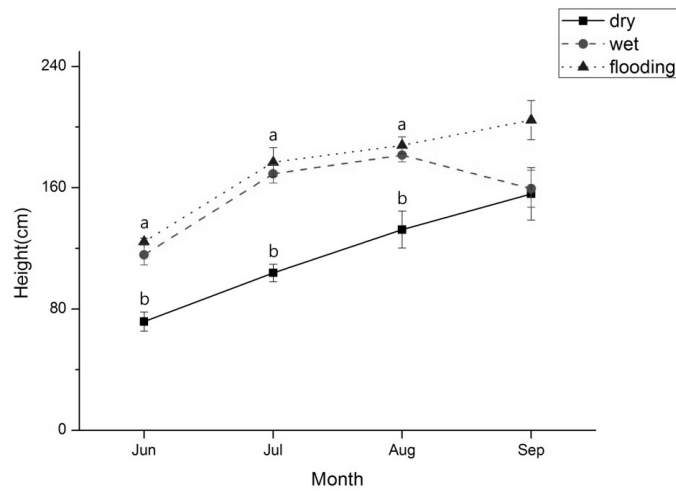


Figure 6. Monthly average height of *Phragmites australis* from June to September, 2012. Plants height at different water level in same temperature treatment: (A) ambient temperature, (B) elevated temperature. Bars(\pm SE) with different letters are significantly different at $p < 0.05$ using Tukey's honestly significant difference (HSD) test (ANOVA, $N=5$).

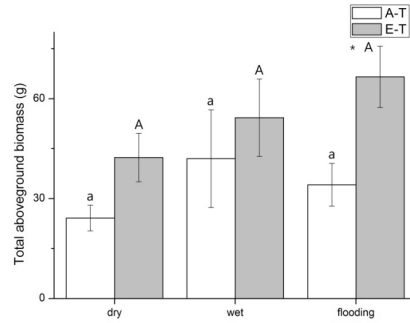
Total aboveground biomass

The pattern of total aboveground biomass differs from the pattern of plants height. *P. dichotomiflorum* doesn't show any statistically significant difference among 6 different experimental treatments, although the biomass in elevated temperature is a little higher than in ambient temperature in the graph (Figure 7B).

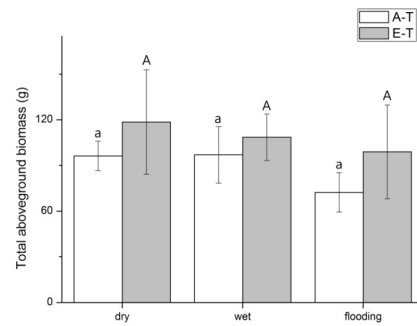
Total aboveground biomass of *L. salicaria* and *P. australis* shows significant differences at flooding water level (Figure 7A, 7C). At flooding condition, aboveground biomass of both species in elevated temperature was heavier than those in ambient temperature. *P. australis* at water sufficient condition show higher biomass value in the graph, but there is no significant difference among water level. Total aboveground biomass of *L. salicaria* in ambient temperature also doesn't show statistical difference; however, that in elevated temperature has statistically significant difference. It shows the highest value of weight at wet condition whereas plants at dry condition have the lowest value of weight.

Comparing three species, the pattern of each species is quiet different even though the difference has no statistical significance. In elevated temperature, *L. salicaria* shows the highest aboveground biomass at wet condition, however, the highest value of *P. dichotomiflorum* is the value at dry condition and that of *P. australis* is the value at flooding condition.

(A)



(B)



(C)

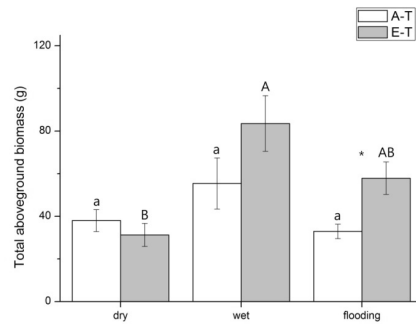


Figure 7. Total aboveground biomass of (A) *L. salicaria*, (B) *P. dichotomiflorum*, and (C) *P. australis*. Data are represented with mean \pm standard error. Asterisks indicate temperature treatment differences, and different letters indicate water level treatment differences ($P < 0.05$, $N = 5$) for ambient (lower case) and elevated (upper case) temperature.

2.2 Chemical analysis

2.2.1 Photosynthetic pigment content

Chlorophyll content shows different trend among species. There is no critical difference in chlorophyll content of *L. salicaria* (Table 3). Temperature difference couldn't have effects on chlorophyll content of *P. dichotomiflorum*, neither; however, dry condition increased chlorophyll content of *P. dichotomiflorum* in general (Table 4). The difference was clearer in elevated temperature than in ambient temperature. In contrast, water level treatments didn't have effects on chlorophyll content of *P. australis* (Table 5). *P. australis* was influenced by temperature differences; Elevated temperature significantly increased chlorophyll content of *P. australis*.

Interaction between temperature and water level treatment did not significantly affect the chlorophyll content of all three species ($P > 0.05$, respectively).

Table 3 Chlorophyll a, chlorophyll b, and total chlorophyll content of *L. salicaria*.

		Chlorophyll a		Chlorophyll b		Total Chlorophyll	
<div>Temperature</div>		A-T	E-T	A-T	E-T	A-T	E-T
Water level	dry	8.37±1.34	9.68±0.32	4.04±0.07	5.21±0.37	12.99±0.30	16.51±1.28
	wet	7.46±0.20	9.41±0.76	4.53±0.69	5.20±0.10	14.57±2.30	16.81±0.48
	flooding	9.02±0.52	8.73±1.01	4.83±0.23	4.59±0.51	15.65±0.85	15.05±1.72
ANOVA result	T	NS	NS	NS	NS	NS	NS
	W	NS	NS	NS	NS	NS	NS
	T x W	NS	NS	NS	NS	NS	NS

*P<0.05; **P<0.01; NS: P>0.05; Mean ± SE values are given.

Means with different letters within a column are significantly different at P<0.05 using Tukey's honestly significant difference (HSD) test (N=5).

T, temperature treatment; W, water level treatment; T x W, temperature and water level treatment; NS, not significant

Table 4 Chlorophyll a, chlorophyll b, and total chlorophyll content of *P. dichotomiflorum*.

		Chlorophyll a		Chlorophyll b		Total Chlorophyll	
Water level	Temperature	A-T	E-T	A-T	E-T	A-T	E-T
	dry	11.22±0.94	12.42±0.98 ^a	5.70±0.60	6.39±0.51 ^a	19.13±1.73	21.26±1.68 ^a
	wet	8.94±0.72	9.10±0.04 ^b	4.73±0.36	4.69±0.00 ^b	15.44±1.22	15.59±0.05 ^b
	flooding	9.82±0.19	7.98±0.88 ^b	5.17±0.03	4.10±0.41 ^b	16.93±0.25	13.65±1.46 ^b
ANOVA result	T	NS		NS		NS	
	W	**		**		**	
	T x W	NS		NS		NS	

*P<0.05; **P<0.01; NS: P>0.05; Mean ± SE values are given.

Means with different letters within a column are significantly different at P<0.05 using Tukey's honestly significant difference (HSD) test (N=5).

T, temperature treatment; W, water level treatment; T x W, temperature and water level treatment; NS, not significant

Table 5 Chlorophyll a, chlorophyll b, and total chlorophyll content of *P. australis*.

		Chlorophyll a		Chlorophyll b		Total Chlorophyll	
Water level	Temperature	A-T	E-T	A-T	E-T	A-T	E-T
	dry	8.54±0.86	10.51±0.18	4.87±0.35	5.16±0.18	16.03±1.15	17.26±0.60
	wet	9.31±0.67	10.11±0.36	4.39±0.41	5.44±0.09	14.62±1.43	18.03±0.30
	flooding	9.25±0.78	10.93±0.34	4.79±0.42	5.55±0.12	15.87±1.36	18.63±0.53
ANOVA result	T	**		*		*	
	W		NS		NS		NS
	T x W		NS		NS		NS

*P<0.05; **P<0.01; NS: P>0.05; Mean ± SE values are given.

Means with different letters within a column are significantly different at P<0.05 using Tukey's honestly significant difference (HSD) test (N=5).

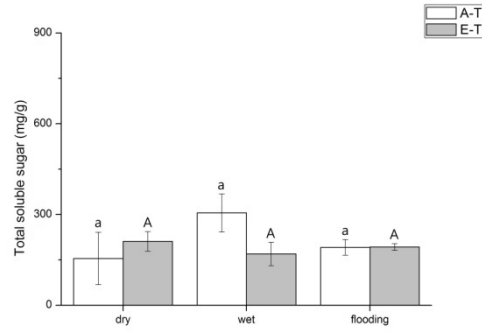
T, temperature treatment; W, water level treatment; T x W, temperature and water level treatment; NS, not significant

2.2.2 Total soluble sugar

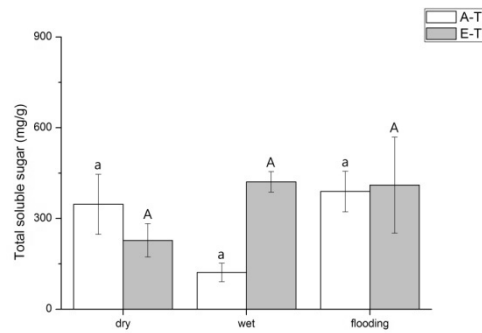
Total soluble sugar content basically differs among each species; *L. salicaria* has a small quantity of total soluble sugar while *P. australis* has a large quantity of total soluble sugar, relatively (Figure 8).

Total soluble sugar content of *L. salicaria* wasn't affected by both temperature and water level (Figure 8A). Although total soluble sugar content of *P. dichotomiflorum* was significantly different between A-T and E-T at wet condition, overall content didn't have significant differences among different treatments (Figure 8B). The content of *P. australis*, however, was affected significantly by water level (Figure 8C); flooding treatment increased total soluble sugar content of *P. australis*. It was particularly noticeable in elevated temperature and the *P*-value between water sufficient condition –wet and flooding condition- was even lower than the *P*-value between dry and flooding condition.

(A)



(B)



(C)

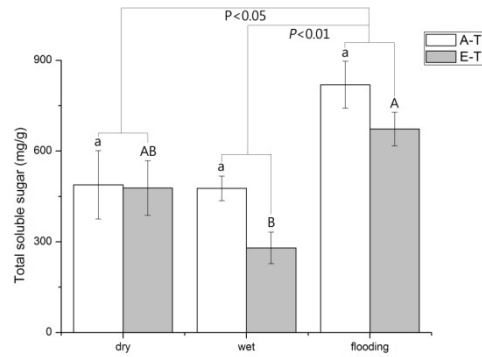


Figure 8. Total soluble sugar content of (A) *L. salicaria*, (B) *P. dichotomiflorum*, and (C) *P. australis*. Data are represented with mean \pm standard error. Different letters indicate water level treatment differences ($P < 0.05$, $N = 5$) for ambient (lower case) and elevated (upper case) temperature.

2.2.3 C/N ratio

There are no significant differences on C content for all treatments while N content differs from species to treatments, respectively (Table 6). N content of dry condition for *L. salicaria* was significantly higher than water sufficient conditions. Although not much as *L. salicaria*, N content of dry condition for both *P. dichotomiflorum* and *P. australis* was significantly higher than water sufficient conditions, too. C/N ratio shows different pattern from C or N content of plants. For *L. salicaria*, only C/N ratio of wet condition in elevated temperature was significantly higher than others. For *P. australis*, C/N ratio of wet condition in ambient temperature was significantly high while that of dry condition in elevated temperature was significantly low.

Figure 9 more focuses on C/N ratio on each environmental treatment. C/N ratio of *P. dichotomiflorum* doesn't have any significant difference among treatments. Statistical difference was obvious at *L. salicaria*. C/N ratio of *L. salicaria* shows significant differences among water levels as well as temperature treatments. *L. salicaria* at wet condition had high C/N ratio in both ambient and elevated temperature. At wet condition, plants in elevated temperature had significantly higher C/N ratio than those in ambient temperature.

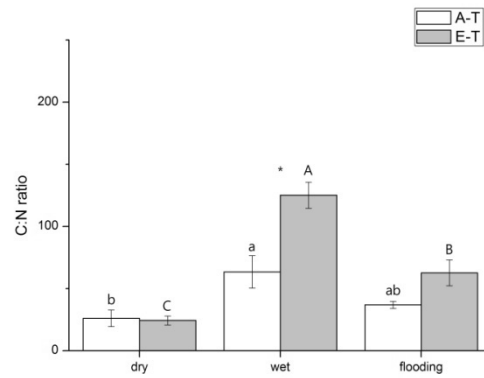
Table 6 Carbon, Nitrogen, and C/N ratio of plant after harvesting

		<i>L. salicaria</i>			<i>P. dichotomiflorum</i>			<i>P. australis</i>		
		Carbon	Nitrogen	C/N ratio	Carbon	Nitrogen	C/N ratio	Carbon	Nitrogen	C/N ratio
A-T	dry	422.80±7.88 ^a	18.22±3.86 ^a	26.04±6.71 ^b	418.86±1.99 ^a	15.41±3.39 ^{abc}	29.54±5.39 ^a	417.69±1.01 ^a	9.28±1.78 ^{ab}	48.15±8.25 ^{ab}
	wet	411.66±3.69 ^a	7.03±1.33 ^b	63.42±13.00 ^b	419.19±3.50 ^a	16.11±0.54 ^{abc}	26.08±0.81 ^a	409.08±3.84 ^a	4.75±0.30 ^b	86.75±4.94 ^a
	flooding	409.64±1.91 ^a	11.27±1.00 ^{ab}	36.83±2.91 ^b	416.16±4.67 ^a	17.83±1.19 ^{ac}	23.52±1.38 ^a	403.71±5.06 ^a	5.90±0.75 ^b	70.95±9.85 ^{ab}
E-T	dry	422.83±6.75 ^a	18.01±2.16 ^a	24.34±3.61 ^b	420.59±3.75 ^a	19.55±1.64 ^a	21.79±1.64 ^a	416.71±5.06 ^a	12.26±0.88 ^a	34.35±2.55 ^b
	wet	418.09±6.77 ^a	3.39±0.29 ^b	125.06±10.52 ^a	430.20±7.58 ^a	5.62±2.21 ^b	148.16±91.91 ^a	418.02±4.98 ^a	7.93±1.89 ^{ab}	59.91±15.55 ^{ab}
	flooding	418.67±5.88 ^a	7.03±1.05 ^b	62.63±10.47 ^b	416.65±10.89 ^a	8.16±3.26 ^{bc}	74.59±31.68 ^a	416.01±1.86 ^a	5.52±0.66 ^b	77.60±9.45 ^{ab}

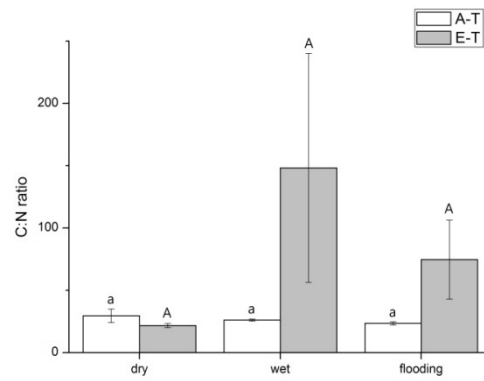
Mean ± SE values are given.

Means with different letters within a column are significantly different at P<0.05 using Tukey's honestly significant difference (HSD) test (N=3).

(A)



(B)



(C)

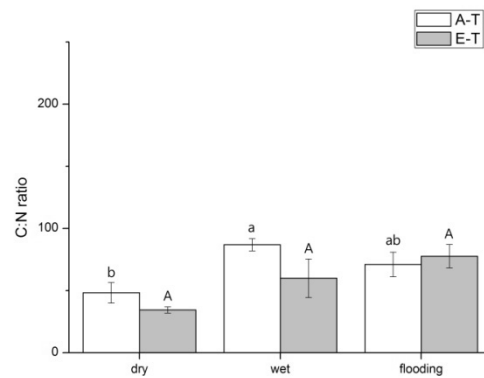


Figure 9. C/N ratio of (A) *L. salicaria*, (B) *P. dichotomiflorum*, and (C) *P. australis*. Data are represented with mean \pm standard error. Asterisks indicate temperature treatment differences, and different letters indicate water level treatment differences ($P<0.05$, $N=3$) for ambient (lower case) and elevated (upper case) temperature.

3. Effect of Competition

To see competition effects on growth of plants, physical factors were compared using three-way ANOVA (Table 7). Interaction among all three factors -competition, water level and temperature- in both height and total aboveground biomass didn't have significant effects on all species.

P. dichotomiflorum didn't have influenced by interaction between competition and temperature. The interaction between competition and water level in both height and biomass was significant, however, although competition effect was not. *L. salicaria* was significantly affected by competition in both height and biomass. The interaction of competition with water level or temperature had significant effects on biomass of *L. salicaria* but not on height.

Table 7 P values from three-way ANOVA for *L. salicaria*, *P. dichotomiflorum*, and *P. australis* on September

	<i>L. salicaria</i>		<i>P. dichotomiflorum</i>		<i>P. australis</i>	
	Height	Biomass	Height	Biomass	Height	Biomass
Competition	***	**	NS	NS	NS	***
Water level	***	**	**	NS	NS	*
Temperature	***	NS	**	NS	**	NS
C x W	NS	**	**	**	NS	NS
C x T	NS	***	NS	NS	NS	***
W x T	**	NS	NS	NS	NS	NS
C x W x T	NS	NS	NS	NS	NS	NS

*P<0.05; **P<0.01;***P<0.001; NS: P>0.05

C, Competition treatment; T, temperature treatment; W, water level treatment; NS, not significant

The three-way ANOVA were performed with plant height and biomass, respectively.

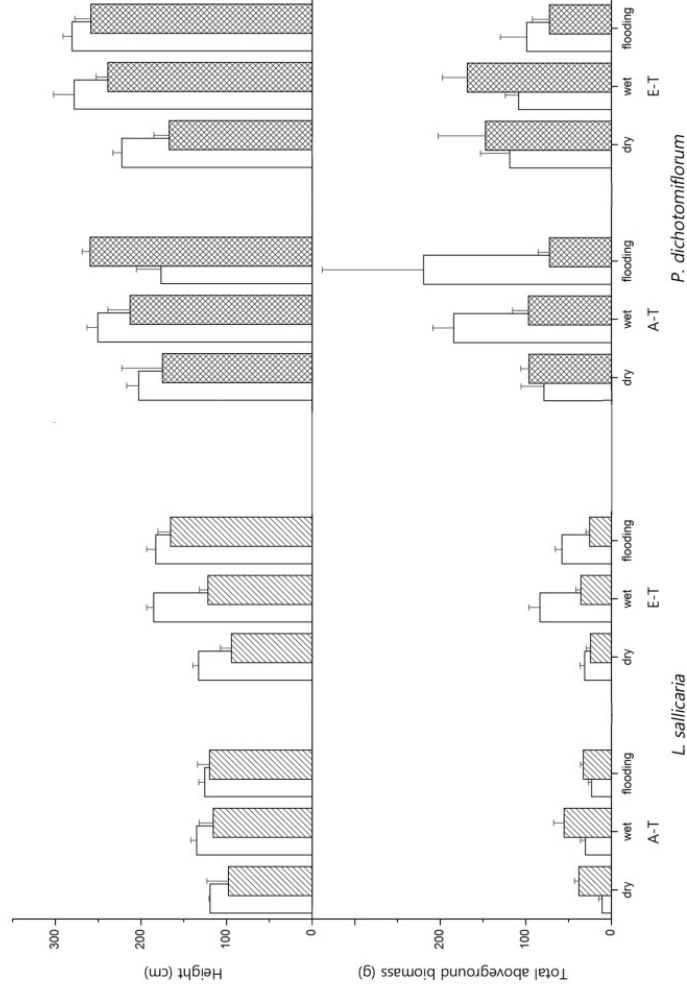


Figure 10. Total aboveground biomass and plant height for individual and competition experiments of *L. salicaria* and *P. dichotomiflorum*. □, plants grown individually; ▨, plants grown with *P. dichotomiflorum*. Data are represented with mean \pm standard error (N=5).

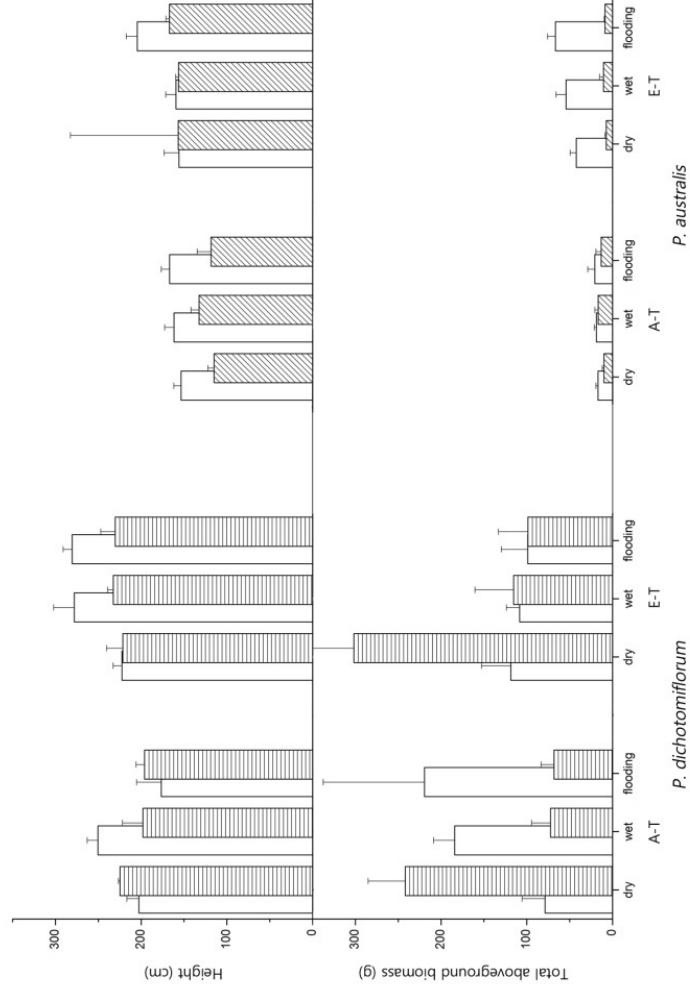


Figure 11. Total aboveground biomass and plant height for individual and competition experiments of *P. dichotomiflorum* and *P. australis*. \square , plants grown individually; \square (hatched), plants grown with *P. dichotomiflorum*; \square (solid grey), plants grown with *P. australis*. Data are represented with mean \pm standard error (N=5).

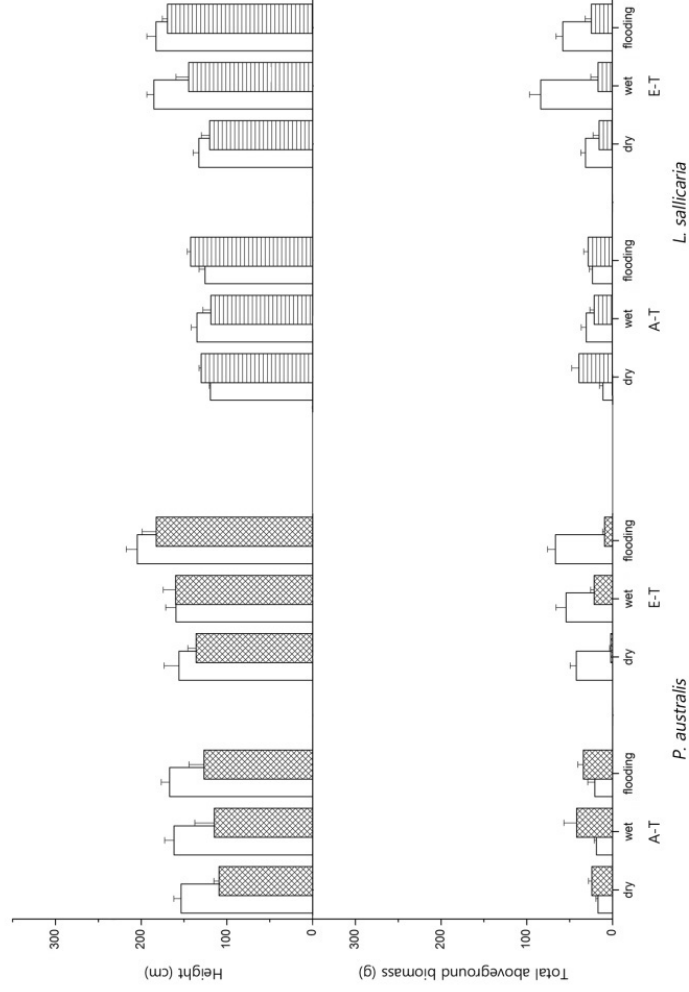



Figure 12. Total aboveground biomass and plant height for individual and competition experiments of *P. australis* and *L. salicaria*. , plants grown individually; , plants grown with *L. salicaria*; , plants grown with *P. australis*. Data are represented with mean \pm standard error (N=5).

IV. Discussion

1. Effect of temperature

Generally, elevated temperature facilitates the height growth of plants (Veteli *et al.*, 2002). Temperature strongly influences initiation and expansion of roots, leaves and other organs and higher temperatures accelerate rate of organ initiation as well as shorten the duration of expansion (Morison & Lawlor, 1999). The height of *P. dichotomiflorum* was not affected by temperature change. *L. salicaria* and *P. australis* grew significantly higher in elevated temperature than in ambient temperature.

Chlorophyll content of *P. australis* was affected by temperature while the other species were not. Plants convert light energy to chemical energy from photosynthesis. The first step of photosynthesis is to absorb light energy using chlorophyll, so chlorophyll content is highly related with photosynthetic ability of plants. High temperature could affect photosynthetic ability by changing chemical reaction or structural organization (Pastenes & Horton, 1996). Some articles show that leaf cells which contain chlorophylls are damaged and the rate of photosynthesis is decreased at extremely high temperature (Chu, Aspinall & Paleg, 1974; Chabot & Chabot, 1977). However, their experiments were designed to continuously maintain the temperature over 40°C. The rate of photosynthesis increase as temperature increase up to 35°C (Lafta & Lorenzen, 1995; Pastenes & Horton, 1996). Chlorophyll content of *P. australis* was increased significantly in elevated temperature at all kinds of water treatments.

Carbon and Nitrogen content are related to productivity of plants. C/N ratio is generally affected by elevated temperature and atmospheric CO₂ concentration (Kim & You, 2010). Tashiro and Wardlaw (1991) reported nitrogen reduction in kernel in high temperature treatments. *P. australis* wasn't affected by temperature on its C/N ratio. The temperature influences the C/N ratio of *L. salicaria* especially on water sufficient condition. N content of *P. dichotomiflorum* was affected by elevated temperature but C/N ratio wasn't significantly different. It indicates that the productivity of *L. salicaria* is decreased when temperature increase.

2. Effect of water level

Water condition is a major factor which has influence on plants growth. Wetlands are intermediate zone between land and open water system, so species which live in wetland usually get a constant supply of water. Drought stress decreases growth of wetlands plants affecting the plants physiological ability (Touchette, Uannacone, Turner & Frank, 2007). The difference in drought adaptations among species attribute to interspecific availability of plants community (Yin *et al.*, 2005). *L. salicaria*, *P. dichotomiflorum* and *P. australis* were affected significantly by water condition.

All three species grew taller at water sufficient condition. There was no difference in height between wet and flooding condition. They were more affected by water condition before July than after July. After a month of experimental setting, most plants grew significantly higher than water level at flooding treatments. Casanova and Brock (2000) reported that depth is the least important factor which affects the plant community. Research about effects of flooding on *L. salicaria* seedlings also support the data that flooding fewer than 30cm doesn't significantly affect the height of plants (Haworch-Brockman & Murkin, 1993). The seedlings were flooded before they grew up to 10cm in this research. I expected that there would be effects on growth and survival of seedlings but there weren't. It is considered that three species have high tolerance to flooding at seedling stage.

Because plant is sensitive to decreasing water potential, water stress reduces total biomass as well as plant growth (Ryan, 1991). Total biomass of *L. salicaria* and *P. australis* were affected by water supply while *P. dichotomiflorum* wasn't. Two species showed significant difference in their biomass between dry and water sufficient condition and both were sensitive to temperature only at flooding condition.

Water deficient doesn't alter chlorophyll content when duration is short even it is acute (Sanchez, Hall, Trapani & Hunau, 1982; Schlemmer, Francis, Shanahan & Schepers, 2005). However, when dry condition is maintained longer, chlorophyll level is reduced and photosynthetic ability rate is modified (Sanchez, Hall, Trapani & Hunau, 1982). Chlorophyll content of *P. dichotomiflorum* was decreased significantly at dry condition. The difference was more obvious in elevated temperature. The chlorophyll lost at dry condition is caused by lost of the mesophyll cells (Alberte & Thornber, 1977).

N content of plants is decreased by water deficient stress because water stress affect nutrient uptake of plants (Sanchez, Hall, Trapani & Cohen de Hunau, 1982). *L. salicaria* showed the most sensitive to water condition on N content. Comparing other two species, water difference didn't have effect on N content of *P. dichotomiflorum*. Therefore, if the water level of habitat changes, *L. salicaria* could be negatively affected by it and lose to competition with other species.

3. Effect of competition

The interaction between water level and competition was not significant on *P. australis*, indicating that the competitive ability of *P. australis* was not affected by water availability. By contrast, the interaction between water level and competition was significant on *P. dichotomiflorum*. The interaction between temperature and competition was significant in *L. salicaria* and *P. australis*. These indicate that *P. australis* was more affected by competition with other plants at elevated temperature than at ambient temperature, whereas *P. dichotomiflorum* was more affected by competition with other plants in dry condition than in water sufficient condition. Therefore, *P. dichotomiflorum* would be on dominant position among three species if temperature increases, whereas *P. australis* would be on dominant position if water condition changes to more drought condition. In both case, *L. salicaria* would take the lowest position in competition with other plants.

The biomass of *P. dichotomiflorum* was increased at dry condition when it competed with *P. australis* but the height was not different. Increasing biomass of *P. dichotomiflorum* was caused by lateral growth rather than vertical growth (height).

Water supply alters competitive interactions (Bazzaz & Carlson, 1984). The photosynthetic pathway of C4 plants have more effective CO₂ fixing rate so C4 plant can maintain high photosynthetic rate minimizing the water loss (Salisbury & Ross, 1978). C4 plants have high water use efficiency so grow well at dry condition. They have competitive advantages under high temperature as well as water stress. (Gifford, 1974; Redmann, 1975; Doliner & Jolliffe, 1979). *P. dichotomiflorum* is a C4 plant (Kim *et al.*, 2011) so it could be dominant at drought stress (Doliner & Jolliffe, 1979).

4. Plant invasion and Climate

Generally, *P. dichotomiflorum* wasn't affected much by environmental variations. It means *P. dichotomiflorum* is less sensitive to environmental changes. Moreover, *P. dichotomiflorum* may take the advantageous position for competition than other two species because it is a C4 plant. If the environment changes in sudden, *P. dichotomiflorum* could adapt to the change rapidly and become stable in its distribution while others couldn't.

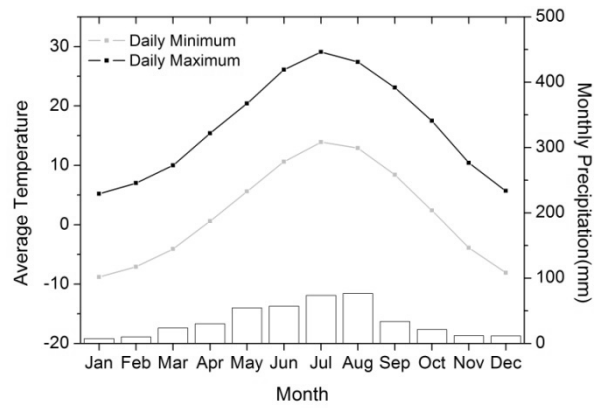
P. australis also showed less sensitive to environmental differences. *P. australis* was more affected by elevated temperature than *P. dichotomiflorum*. Chlorophyll content is a major difference in temperature effect between *P. australis* and *P. dichotomiflorum*. It may be caused by the physiological difference that *P. australis* use C3 CO₂ fixing cycle. The increasing chlorophyll content in elevated temperature of *P. australis* could indicate that increasing temperature will not have negative effect on *P. australis* by decreasing photosynthetic rate.

L. salicaria is distributed in whole parts of North America. To compare the regional differences, I chose Colorado and Los Angeles where *L. salicaria* get a highly noxious weed grade by the United States federal government or a state (USDA, 2012). The precipitation of Colorado and Los Angeles are stable and distributed equally, whereas the precipitation of Seoul is irregular and concentrated in plant growing seasons (Figure 13). As *L. salicaria* was sensitive to environmental changes and negatively affected by different condition from ambient condition, stable precipitation could be the reason of wide spread in North America while not in Korea. *L. salicaria* which considered as an exotic species have to establish new interaction with other native species at new ecosystem. In the process, *L. salicaria* could spread

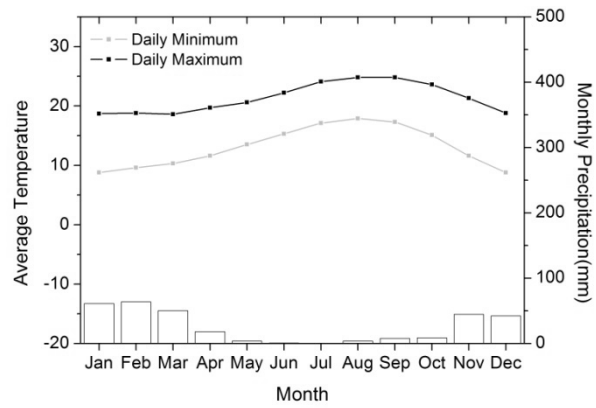
easily by setting dominant position than native species (Callaway & Aschehoug, 2000).

Earth's climate has experienced increasing average temperature approximately 0.8°C (Houghton *et al.*, 2001). Global warming could be an important determinant of the success of invasive species (Williams *et al.*, 2007). All three species were more sensitive on their physiological traits in elevated temperature. *P. dichotomiflorum* seems to take the dominant position in elevated temperature than other two species. Although *L. salicaria* is dominant in the wetland of the United States, *P. australis*, *P. dichotomiflorum* and other species which are stronger in adaptation to environmental change could occupy the wetlands community.

(A)



(B)



(C)

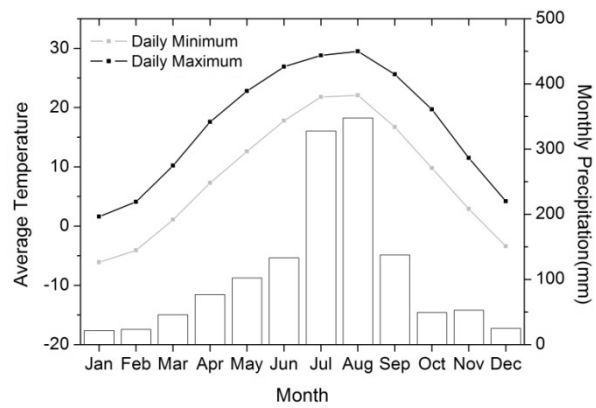


Figure 13. Monthly average temperature and precipitation for the 30-year period: (A) Colorado, (B) Los Angeles and (C) Seoul.

V. References

- Blumenthal D, Chimner RA, Welker JM and Morgan JA. 2008. Increased snow facilitates plant invasion in mixedgrass prairie. *New Phytologist* 179: 440-448.
- Boyley CW, Eichler LW and Madsen JD. 1999. Loss of native aquatic plant species in a community dominated by Eurasian watermilfoil. *Hydrobiologia* 415: 207-211.
- Bradley BA, Blumenthal DM, Wilcove DS and Ziska LH. 2010. Predicting plant invasions in an era of global change. *Trends in Ecology & Evolution*. 25(5): 310-318.
- Bradley BA, Oppenheimer M and Wilcove DS. 2009. Climate change and plant invasion: restoration opportunities ahead?. *Global Change Biology* 15: 1511-1521.
- Callaway RM and Aschehoug ET. 2000. Invasive plants versus their new and old neighbors: a mechanism for exotic invasion. *Science* 290:521-523.
- Carlsen TM, Menke JW and Pavlik BM. 2000. Reducing competitive suppression of a rare annual forb by restoring native California perennial grasslands. *Restoration Ecology* 8: 18-29.
- Casanova MT and Brock MA. 2000. How do depth, duration and frequency of flooding influence the establishment of wetland plant communities?. *Plant Ecology* 147: 237-250.
- Chabot BF and Chabot JF. 1977. Effects of light and temperature on leaf anatomy and photosynthesis in *Fragaria vesca*. *Oecologia* 26: 363-377.

- Chu TM, Aspinall D and Paleg LG. 1974. Stress Metabolism. VI. Temperature stress and the accumulation of proline in barley and radish. *Australia Journal of Plant Physiology* 1:87-97.
- Chun YJ, Kim CG and Moloney KA. 2010. Comparison of life history traits between invasive and native populations of purple loosestrife (*Lythrum salicaria*) using nonlinear mixed effects model. *Aquatic Botany* 93: 221-226.
- D'Antonio CM, Vitousek PM. 1992. Biological invasions by exotic grasses, the grass fire cycle, and global change. *Annual Review of Ecology, Evolution, and Systematics* 23: 63-87.
- D'Antonio CM. 1993. Mechanisms controlling invasion of coastal plant communities by the alien succulent *Carpobrotus edulis*. *Ecology* 74: 83-95.
- Dukes JS and Mooney HA. 1999. Does global change increase the success of biological invaders?. *Tree* 14(4): 135-139.
- Dukes JS. 2002. Species composition and diversity affect grassland susceptibility and response to invasion. *Ecological Applications* 12: 602-617.
- Farnsworth EJ and Ellis DR. 2001. Is purple loosestrife (*Lythrum salicaria*) an invasive threat to freshwater wetlands? Conflicting evidence from several ecological metrics. *Wetlands* 21(2): 199-209.
- Gaudet CL and Keddy PA. 1995. Competitive performance and species distribution in shoreline plant communities: a comparative approach. *Ecology* 76: 280-291.
- Hager HA. 2004. Competitive effect versus competitive response of invasive and native wetland plant species. *Oecologia* 139: 140-149.
- Har-Edom O and Sternberg M. 2010. Invasive species and climate change:

- Coryza canadensis* (L.) Cronquist as a tool for assessing the invasibility of natural plant communities along an aridity gradient. *Biological Invasions* 12(7): 1953-1960.
- Haworth-Brockman MJ and Murkin HR. 1993. Effects of shallow flooding on newly established purple loosestrife seedlings. *Wetlands* 13(3): 224-227.
- Hiscox JD and Israelstam GF. 1979. A method for the extraction of chlorophyll from leaf tissue without maceration. *Canadian Journal of Botany* 57(12): 1332-1334.
- Hood WG and Naiman RJ. 2000. Vulnerability of riparian zones to invasion by exotic vascular plants. *Plant Ecology* 148: 105-114.
- Houghton JT *et al.* 2001. Climate change 2001. The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, UK: Cambridge University Press.
- Houlahan JE and Findlay CS. 2004. Effect of invasive plant species on temperate wetland plant diversity. *Conservation Biology* 18(4): 1132-1138.
- Howard TG and Goldberg DE. 2001. Competitive response hierarchies for germination, growth, and survival and their influence on abundance. *Ecology* 82: 979-990.
- Kercher SM and Zedler JB. 2004. Flood tolerance in wetland angiosperms: a comparison of invasive and noninvasive species. *Aquatic Botany* 80: 89-102.
- Kim HR and You YH. 2010. Effects of elevated CO₂ concentration and increased temperature on leaf related-physiological responses of *Phytolacca insularis* (native species) and *Phytolacca americana*

- (invasive species). *Journal of Ecology and Field Biology* 33(3): 195-204.
- Lafta AM and Lorenzen JH. 1995. Effect of high temperature on plant growth and carbohydrate metabolism in potato. *Plant Physiology* 109: 637-643.
- Levine CM and Stromberg JC. 2001. Effects of flooding on native and exotic plant seedlings: implications for restoring south-western riparian forests by manipulating water and sediments flows. *Journal of Arid Environments* 49: 111-131.
- Mack RN *et al.* 2000. Biotic invasion: causes, epidemiology, global consequences, and control. *Ecological Applications* 10: 689-710.
- Mahaney WM, Smemo KA, and Yavitt JB. 2006. Impacts of *Lythrum salicaria* invasion on plant community and soil properties in two wetlands in central New York, USA. *Canadian Journal of Botany* 84(3): 477-484.
- Marks S and Strain BR. 1989. Effects of drought and CO₂ enrichment on competition between two old-field perennials. *New Phytologist* 111(2): 181-186.
- Morison JIL and Lawlor DW. 1999. Interactions between increasing CO₂ concentration and temperature on plant growth. *Plant, Cell and Environment* 22: 659-682.
- Morrison JA. 2002. Wetland vegetation before and after experimental purple loosestrife removal. *Wetlands* 22(1): 159-169.
- Nernberg D and Dale MRT. 1997. Competition of five native prairie grasses with *Bromus unermis* under three moisture regimes. *Canadian Journal of Botany* 75: 2140-2145.
- Pastenes C and Horton P. 1996. Effect of high temperature on photosynthesis

- in beans. *Plant Physiology* 112: 1245-1251.
- Reader RJ and Bonser SP. 1993. Control of plant frequency on an environmental gradient: effects of abiotic variables, neighbours, and predators on *Poa pratensis* and *Poa compressa* (Gramineae). *Canadian Journal of Botany* 71: 592-597.
- Richardson DM *et al.* 2000. Invasive alien organisms and global change: a South African perspective. Pages 303-349 in Mooney HA & Hobbs RJ, editors. *Invasive Species in the Changing World*. Island Press.
- Ryan MG. 1991. Effects of climate change on plant respiration. *Ecological Applications* 1(2): 157-167.
- Sanchez RA, Hall AJ, Trapani N and Cohen de Hunau R. 1983. Effects of water stress on the chlorophyll content, nitrogen level and photosynthesis of leaves of two maize genotypes. *Photosynthesis Research* 4: 35-47.
- Schlemmer MR, Francis DD, Shanahan JF and Schepers JS. 2005. Remotely measuring chlorophyll content in corn leaves with differing nitrogen levels and relative water content. *Agronomy Journal* 97: 106-112.
- Stuckey RL. 1980. Distributional history of *Lythrum salicaria* (purple loosestrife) in North America. *Bartonia* 47: 3-20.
- Tait MA and Hik DS. 2003. Is dimethylsulfoxide a reliable solvent for extracting chlorophyll under field conditions?. *Photosynthetic Research* 78(1): 87-91.
- Thomas CD *et al.* 2004. Extinction risk from climate change. *Nature* 427: 145-148.
- Thompson K, Hodgson JG, Grime JP and Burke MJW. 2001. Plant traits and temporal scale: evidence from a 5-year invasion experiment using native species. *Journal of Ecology* 89: 1054-1060.

- Thuiller W. 2007. Climate change and the ecologist. *Nature* 448: 550-552.
- Touchette BW, Iannacone LR, Turner GE and Frank AR. 2007. Drought toperance wersus drought avoidance: a comparison of plant-water relations in herbaceous wetland plants subjected to water withdrawal and repletion. *Wetlands* 27(3): 656-667.
- Van Handel E. 1968. Direct microdetermination of sucrose. *Analytical Biochemistry* 22: 237-257.
- Veteli TO, Kuokkanen K, Julkunene-Tiito R, Roininen H and Tahvanainen J. 2002. Effects of elevated CO₂ and temperature on plant growth and herbivore defensive chemistry. *Global Change Biology* 8: 1240-1252
- Vilà M, Corbin JD, Dukes JS, Pino DJand Smith SD. 2006. Linking plant invasions to environmental change. Pages 115–124 in J. Canadell, D. Pataki, and L. Pitelka, editors. *Terrestrial ecosystems in a changing world*. Springer, Berlin, Germany.
- Vitousek PM, D'Antonio CM, Loope LL, Westbrooks R. 1996. Biological invasions as global environmental change. *American Scientist* 84(5): 468-478.
- Wedin DA and Tilman D. 1996. Influence of nitrogen loading and species composition on the carbon balance of grasslands. *Science* 274: 1720-1723.
- Wellburn AR. 1994. The spectral determination of chlorophylls a and b, as well as total carotenoids, using various solvents with spectrophotometers of different resolution. *Journal of Plant Physiology* 144: 307-313.
- Weltzin JF, Belote RT and Sanders NJ. 2003. Biological invaders in a greenhouse world: will elevated CO₂ fuel plant invasions?. *Frontiers in Ecology and the Environment* 1(3): 146-153.

- Williams *et al.* 2007. Warming and free-air CO₂ enrichment alter demographics in four co-occurring grassland species. *New Phytologist* 176: 365-374.
- Yin C, Wang X, Duan B, Luo J and Li C. 2005. Early growth, dry matter allocation and water use efficiency of two sympatric *Populus* species as affected by water stress. *Environmental and Experimental Botany* 53: 315-322.
- Zavaleta E. 2000. The economic value of controlling an invasive shrub. *A Journal of the Human Environment* 29: 462-467.

국문 초록

생물다양성 보존에 대한 관심이 증가함에 따라 다양성을 위협하는 주 요인 중 하나인 외래종의 침입 연구의 중요성이 대두되고 있다. 국가 간 교류가 증가하면서 외부에서 유입된 종들이 자생종을 위협하며 그 서식지를 넓히는 경우가 크게 증가하였다. 외래종의 경우, 대기 중 이산화탄소의 증가나 지구온난화, 서식지 파편화와 같은 환경 변화 등과 복합적으로 식물 분포에 영향을 끼치기 때문에 외래종의 침입 작용과 환경 요인들과의 관계에 관한 연구가 필요하다.

털부처꽃(*Lythrum salicaria*)은 우리 나라 자생종으로 1900년대 초반 유라시아에서 미국으로 도입된 후 급격하게 확산되었다. 자생지인 우리 나라에서는 강원도와 낙동강 지역 습지에서 서식하고 있으나 군락 내 우점종으로 보고된 곳은 없었다. 미국개기장(*Panicum dichotomiflorum*)은 털부처꽃과는 반대로 미국 자생종이며 우리 나라에 도입되어 하천 곳곳에 분포하고 있다. 갈대(*Phragmites australis*)는 우리나라 하천에서 가장 흔하게 발견할 수 있는 자생종이다. 털부처꽃은 부처꽃과로 다년생이며, 미국개기장은 일년생 벼과, 갈대는 다년생 벼과로 다양한 환경에 따른 생육 및 생리 특성 차이 연구를 통하여 환경이 변화했을 때 세 종의 적응도가 어떻게 달라지는 지 비교해 보고자 했다.

기후 변화에 따른 온도 상승에 대한 연구를 위하여 온실 밖과 온실 안에 각각 실험을 설치하였으며 온실 안팎의 기온은 평균 2°C 차이가 났다. 털부처꽃과 갈대는 상승된 온도에서 통계적으로

유의하게 키가 더 자랐으나 미국개기장의 경우 유의한 차이가 없었다.

물 공급과 침수에 따른 영향을 살펴보기 위하여 건조한 조건과 습윤한 조건, 침수 조건에서 각 식물들을 연구하였다. 침수 조건의 경우 토양 위 10cm정도로 수위를 유지하였으나 식물들의 특성이 습윤 조건과 차이가 나지 않았다. 털부처꽃과 갈대는 건조 조건과 수분이 풍부한 조건에서 키와 건중량에 유의한 차이를 보였으나 미국개기장은 그렇지 않았다. 이는 미국개기장에 비해 털부처꽃과 갈대가 더 수분 조건에 민감하게 반응함을 시사한다.

세 종의 생육에서 다른 종과의 경쟁이 미치는 영향 연구는 각각 두 종씩 한 화분에 함께 심어 실험하여 이루어졌다. 그 중 털부처꽃이 가장 경쟁의 영향을 많이 받았으며 미국개기장이 세 종 중에서는 경쟁에서 우위에 있는 것으로 드러났다. 어떤 종과 경쟁하느냐는 실험 결과에 차이를 주지 않고 단지 경쟁 여부만 유의한 차이를 나타냈다. 갈대는 상승 온도에서 경쟁의 영향을 많이 받았으며 미국개기장은 건조한 조건에서 경쟁의 영향을 많이 받았다.

주요어: 침입종, 기후 변화, 털부처꽃, 미국개기장, 갈대

학 번: 2010-23113

감사의 글

지난 2년간 지도해주시고 여러 방면에서 도움을 주신 이은주 교수님께 감사 드립니다. 부족한 점이 많았을 텐데도 끝까지 믿고 맡겨주셔서 무사히 논문을 마칠 수 있었습니다. 흔쾌히 논문 심사를 맡아 주시고 바쁜 와중에도 조언을 해주신 Bruce Waldman 교수님과 부족한 점을 날카롭게 지적해주셔서 수정, 보완할 수 있게 해주신 Jonathan Adams 교수님께도 감사의 말씀을 전합니다.

석사 학위를 하면서 학문적 소양을 넓히기도 했지만 실험실 생활을 하면서 좋은 선배님들과 사람들을 만난 덕분에 많은 것을 배우고 깨달았습니다. 주제를 잡고 실험 계획을 짜는 데 큰 도움을 주신 우람 선배, 굵은 일 할 때마다 힘써 도와주신 정수 선배, 논문 마무리를 잘 할 수 있게 조언을 많이 해주신 효혜미 선배, 이천 온실을 편하게 쓸 수 있게 배려해주신 의재 선배, 자주 뵙지는 못했지만 가끔씩 웃음 주신 규 선배, 함께 생활한 시간이 얼마 없음에도 매년 챙겨주시는 기훈 선배, 일본 가시기 전까지 재미있는 실험실 생활을 할 수 있게 해주신 호준 선배, 처음 들어와서 어리버리 했을 때 늘 챙겨주고 졸업하고 나서도 계속 신경 써준 새로미 선배, 논문 방향을 잡고 실험 중간중간 학문적 측면에서 많이 조언해주신 용성 선배, 앞뒤 생각 않고 별려놓은 일들을 같이 땀 빼며 하느라 고생 많이 한 지숙 언니, 더운 온실에서 일하기 힘들었을 텐데도 항상 웃으면서 도와준 영주 언니, 뒤늦게 들어와 함께 졸업하는 희주 언니, 실험실에 들어와 누구보다 바쁜 나날을 보내고 있는 덕주 언니와 정환 오빠. 모두들 고맙고 앞으로 하는 일 전부 다 잘 풀리길 바랍니다.

매번 귀찮았을 텐데도 흔쾌히 사다리 빌려주신 동물생태방 분들과 어색하지 않게 즐겁게 실험할 수 있게 도와주신 공주대 식물생태방 분들 덕분에 원활하게 실험을 끝마칠 수 있었습니다. 감사합니다.

자주 연락하고 살가운 성격이 아니라 내가 힘들 때만 뜬금없이 연락하는 데도 그 때마다 얘기 들어주고 울고 웃어준 친구들도 고맙습니다. 취준하느라 바쁠 텐데 힘들다고 얘기할 때마다 들어주고 공감해준 지희, 같은 500동에 있게 됐다고 좋아했는데 정작 자주 못보고 졸업하는 두리, 기숙사 같은 동에 살게 됐는데 자주 못 본 민정이, 자질구레한 부탁할 때마다 도와준 근배, 바쁘게

살고 있을 노유까지. 12기 아이들 모두 가끔씩 봐도 추억 팔이 하며 웃을 수 있게 해줘서 반갑고 든든했습니다. 많이 힘들었을 텐데 이겨내고 곳곳이 미래를 개척해나가는, 앞으로는 모든 일이 잘 풀릴 틈에 행은이에게 힘들 때 많이 도움이 되지 못한 것 같아 미안하고 고맙습니다. 약 일 년간 방을 같이 쓰며 편안하게 생활할 수 있게 해준 계심 언니, 고맙고 석사 생활 건강히 마치길 바랍니다. 논문 쓰느라 스트레스 받을 때 곤곤펀 덕분에 답답한 숨통이 트였습니다. 우리 둘 모두 무한히 아름다운 미래를 걸을 수 있길.

처음 석사 생활을 시작할 때는 의욕도 넘치고 무엇이든 하고 싶어했지만 반복되는 일상에 지쳐 조금은 나태해 진 것도 같습니다. 좀 더 명확해진 것도 있고 오히려 더 혼란스러워 진 것도 있지만 지난 2년의 생활이 제 인생에서 결코 의미 없고 후회되는 시간은 아니었다고 생각합니다. 학위를 따고 졸업을 하고 다시금 선택의 기로에 놓여있지만 2년 동안 얻은 것들을 발판 삼아 나아가면 어떤 것도 잘 할 수 있으리라 믿습니다.

처음 들어왔을 때부터 졸업을 앞둔 지금까지 든든한 언니로, 믿을 수 있는 동료로, 편한 친구로 함께 해준 희상 언니. 까다롭게 굴고 제멋대로였던 적도 많았는데 그럴 때마다 다 받아주고, 질질 끄는 저를 같이 이끌어 줘서 무사히 이 글을 쓰고 있습니다. 십 년, 이십 년 후에는 웃으며 지금을 추억하고 행복하고 즐거운 삶을 살고 있길 바랍니다.

부족한 저를 믿고 자랑스러워 해주신 할아버지, 할머니, 외할머니, 그리고 언제나 제 의견을 존중해주시고 믿어주신 아빠, 엄마 누구보다 감사하고 사랑합니다. 이제 제법 생각이 깊어진, 멋진 내 동생 동민이도 누나보다 훨씬 잘나가기라 믿습니다:)

마지막으로 직접 졸업 논문을 보여드리고 싶었는데 이제는 먼 곳에서 지켜보실 외할아버지, 감사합니다.