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Temperature-dependent performance of competitive native and alien invasive plant species

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ABSTRACT

To assess the likely impacts of environmental change, the responses of two well-known invasive plant species, native *Pueraria lobata* and alien *Humulus japonicus*, to differences in growth temperature were studied in South Korea. Habitat preferences, physiological responses such as photosynthetic rates and chlorophyll contents, growth rates, and nutrient contents were quantified for each species. A competition experiment was conducted to evaluate the temperature preferences of the two species. All results indicated that the alien species *H. japonicus* can take advantage of elevated temperatures (35 °C) to enhance its competitive advantage against the native species *P. lobata*. While *H. japonicus* took advantage of elevated temperatures and preferred high-temperature areas, *P. lobata* showed reduced performance and dominance in high-temperature areas. Therefore, in future, due to global warming and urbanization, there are possibilities that *H. japonicus* takes advantage of elevated temperature against *P. lobata* that could lead to increased *H. japonicus* coverage over time. Therefore, consistent monitoring of both species especially where *P. lobata* is dominated are required because both species are found in every continents in the world. Controlling *P. lobata* requires thorough inspection of *H. japonicus* presence of the habitat in advance to prevent post *P. lobata* management invasion of *H. japonicus*.

1. Introduction

Problems caused by invasive plant species are increasing; indeed, such species cause severe disruption to both natural and managed ecosystems (Weber, 2003), reduction in native diversity, changes to nutrient pools and alteration of ecological and evolutionary processes (Dostál et al., 2013). Biological invasion has become an important issue for the conservation of biological diversity. Invasive plant species threaten native ecosystems by outcompeting native species and altering disturbance regimes; they also threaten human-managed systems such as agriculture, rangelands, and forests (Bradley et al., 2010). Biological invasions may increase with climate change (Bradley et al., 2010), as changing precipitation and temperature conditions are likely to increase the risk of invasion. In particular, increases in temperature may accelerate the invasive expansion of plants (Walther et al., 2009; Wang et al., 2011) by affecting growth, reproduction, resource allocation, and interactions between species (Wang et al., 2011). Since controlling these invasions has become very important, understanding which factors and plant traits play key roles in successful invasion by plants is important for management. However, despite some efforts, various authors have indicated that generalizations regarding invasions are somewhat elusive (Myers and Anderson, 2003). It is unlikely that a single factor or a few factors can explain why certain plant species are successful invaders. Therefore, improving our ability to make predictions about biological invasions requires focused studies on specific invaders (Myers and Anderson, 2003). Also, it is important to verify the effects of each potential environmental factor that might be related to successful invasion by the target species.

The target plant species of this research, kudzu [*Pueraria lobata* (Willd.) Ohwi] and Japanese hop (*Humulus japonicus* Siebold. & Zucc.), are often considered as invasive plant species around the world; both are also invasive in Korea. *P. lobata* is a perennial vine which has invaded many parts of the world and is considered to be a pest species (Koike et al., 2004; Weber, 2003). The Invasive Species Specialist Group (ISSG) identified it as one of the world's 100 worst invasive alien species (Lowe et al., 2000). The *P. lobata* vine has become a major threat to native ecosystems in the southern United States and is expanding its geographic range northwards (Bradley et al., 2010). The kudzu's rapid elongation,

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high photosynthetic rates, nitrogen fixation, and frequent rooting at stem nodes make the species an aggressive competitor that alters forest biodiversity and nitrogen cycles (Forseth and Innis, 2004). The *P. lobata* vine is considered as fast growing plant (Kim et al., 2012) in Korea that covers disturbed areas rapidly. *H. japonicus* is also an invasive species in the United States (Kaufman and Kaufman, 2013) and some parts of Europe (Balogh et al., 2008; Brunel et al., 2010). *H. japonicus* can survive in floodplains and along stream banks, but also thrives in disturbed areas such as roadsides and urban lots (Brunel et al., 2010). *H. japonicus* is a fast-growing plant that forms dense stands and outcompetes native species (Balogh et al., 2008). Also, *H. japonicus* pollen is highly allergenic (Song et al., 2012).

In Korea, the two species are also very weedy and grows fast to compete with each other in many places (Kang et al., 2012; Kim et al., 2012; Song, 1996) including one of the field site, the Sudokwon landfill in Korea. *P. lobata* is a native species of Korea, while *H. japonicus* is believed to have been introduced a few centuries ago from Japan. As they are both fast growing vines, they both form dense stands and compete with each other in floodplains, stream banks, and disturbed areas. *P. lobata* and *H. japonicus* co-occur in many areas, showing that they share similar habitats (Kim et al., 2007; Park et al., 2010). In Japan, where both species are native, they are also in competition (Tokuoka et al., 2011). However, in urban areas, only *H. japonicus* is reported to be increasingly invasive or weedy and to disturb ecosystems (Cho et al., 2008; Han et al., 2004; Jin et al., 2013; Park and Kang, 2010; Song et al., 2012). Therefore, *H. japonicus* may be better able to exploit the elevated temperatures and levels of carbon dioxide found in urban areas than *P. lobata*. However, at one of the study site, the Sudokwon landfill in Korea, where the two species compete, *P. lobata* is dominant where canopy coverage is high and expands into open areas, while *H. japonicus* is dominant in open areas and expands into closed-canopy areas (Song, 2010) though seedling of two species were found in both open areas and canopy closed areas. The seeds of two species are introduced on both areas but who becomes dominant depends on canopy coverage. This might mean that *P. lobata* is sensitive to soil moisture content; however, both species can live on slopes (Han et al., 2004) where the soil moisture content is usually low. Also, *P. lobata* was introduced to the United States to reduce soil erosion in disturbed areas (Forseth and Innis, 2004; Hickman et al., 2010), indicating that this species can establish itself on bare and arid soil. Therefore, differences in temperature, rather than in soil moisture content, between open- and closed-canopy areas could be major factors resulting in the different invasion/growth patterns shown by the two species. Based on this observation, the elevated temperature in urban areas could also be an important factor allowing *H. japonicus* to dominate there; carbon dioxide levels may not be important. Therefore, in this research, temperature-dependent ecophysiological responses of the co-occurring invasive plant species *P. lobata* and *H. japonicus* are studied. The environmental conditions of actual habitats of both species were compared and greenhouse and outdoor experiments with different temperature were studied to monitor temperature-dependent responses of *H. japonicus* and *P. lobata*.

2. Materials and methods

2.1. Canopy coverage, soil moisture, and photosynthetic rates in the field

In field experiment, actual habitat conditions of *P. lobata* and *H. japonicus* were monitored. Canopy pictures of patches where *P. lobata* and *H. japonicus* were dominant were taken in September 2006 to monitor whether plants prefer open canopy areas or closed canopy areas. The study site was the Sudokwon landfill in Korea (37° 34′ 52″ N and 126° 37′ 29″ E); 6 years before the research took place, the site had been reclaimed, so it consisted of large slopes and fields. Pictures were taken from 30 cm above the main roots or center of *P. lobata* and *H. japonicus* patches with areas exceeding 2 × 2 m (50 replicates each). To find the main root of *P. lobata*, roots between stems and those that could be pulled up by hand were excluded. For *H. japonicus*, because several individuals were in each 2 × 2 m patch, pictures were taken from the middle of the patch. The line transact method was used to find the next patch. In July 2007, to exclude the effects of herbaceous plants on canopy coverage, pictures were taken from 1.5 m above the ground (20 replicates each). Pictures were taken using a semi-fisheye lens (HD-3031PRO, Raynox, Japan) and a digital camera. Canopy coverage was estimated from the pictures, after digital processing and analysis, by using the software image J program (National Institutes of Health, USA) (Breitsameter et al., 2013). Soil samples were collected at the same place, when canopy pictures were taken (20 replicates). The soil was dried for 48 h at 105 °C to measure its moisture content.

In 2008, to verify whether canopy coverage preferences of two species were related to temperature and temperature dependent performances, the photosynthetic rates of *P. lobata* and *H. japonicus* at the same study site with high temperature (35 °C) and low temperature (25 °C) were measured using a portable photosynthetic measurement system (Li-6400, Li-cor Biosciences; flow rate = 500 μmol/s and 400 ppm CO_2). The temperature was selected because the leaf temperature in shade, where *P. lobata* dominates in June was 24.6 ± 0.2 °C (mean ± SE of ten replicates) and the leaf temperature open canopy area where *H. japonicus* dominates was about 33.9 ± 0.5 °C (mean ± SE of ten replicates) for *P. lobate* when measured by Laser Targeting Infrared Thermometer (DT-8860b, CEM, China). The leaves at the middle of the vine were selected for measurement. The photosynthetic rates were first measured in June (at 25 °C), but it was difficult to maintain the temperature of the leaf chamber to 35 °C at that time. Therefore, the photosynthetic rates of the same individuals were measured again at 35 °C in September.

2.2. Greenhouse experiment

A greenhouse experiment was introduced to compare responses of *P. lobata* and *H. japonicus* by elevated temperature. Seedlings of *P. lobata* and *H. japonicus* were established in experimental pots in late June 2009 (six replicates per treatment and species), in commercial growing soil (Sunshine Mix #5, Sun Gro Horticulture, Canada). The seedlings were grown for 1 month in the pots (14 cm upper diameter and 15 cm height) in growth chambers. Thereafter, the pots were moved into a greenhouse and an open field at Seoul. The plants were irrigated every day and were harvested in late September. The temperature at two sites was measured using a thermometer with a data logger (HOBO H9; Onset Computer, USA). The chlorophyll content of the leaves was measured using SPAD-502 (Minolta Co., Japan) in July to avoid any damage, and then measured again in September using the DMSO extraction method (Hiscox and Israelstam, 1979). Leaves at the middle of the vine were selected for measurement. The photosynthetic rates of *P. lobata* and *H. japonicus* were measured in early September, inside (35 °C) and outside (25 °C) the greenhouse. The actual temperature of inside the greenhouse was less than 32 °C when measured, but temperatures were unified with previous field experiment. The C and N contents of plant leaves were analyzed using an elemental analyzer (Flash EA 1112; Thermo Electron Co., USA). Plants were harvested and washed with distilled water; moisture was wiped off with laboratory paper towels before measurement of fresh weight.