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Research article

Mowing: A cause of invasion, but also a potential solution for management of the invasive, alien plant species *Erigeron annuus* (L.) Pers

Uhram Song[a,*,1], Deokjoo Son[b,1], Changku Kang[c], Eun Ju Lee[b], Kyoo Lee[d], Jeong Soo Park[d]

[a] Department of Biology and Research Institute for Basic Sciences, Jeju National University, Jeju 690-756, South Korea
[b] School of Biological Sciences, Seoul National University, Seoul 151-747, South Korea
[c] Department of Bioscience, Mokpo National University, Cheonggye-myeon, Muan, Jeollanam-do, 58554, South Korea
[d] National Institute of Ecology, Seocheon 325-813, South Korea

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ABSTRACT

Erigeron annuus is one of the major invasive, alien plants in Korea, and therefore research to manage (control) this invasive plant is essential. In this research, studies were conducted to determine the mechanisms by which *E. annuus* became the dominant plant at a landfill site and to develop management strategies for this alien plant. Because the seeds and seedling stage did not have superior adaptations to disturbed soil, demonstrate allelopathy, outcompete other species, or show rapid growth, the disturbance from mowing was likely the primary reason for the dominance of *E. annuus*. The areas without mowing showed a significant decrease in the coverage of *E. annuus*, whereas the mowed (managed) areas showed a significant increase. Additionally, mowing once increased the weight of reproductive organs by 50% and suppressed the growth of native species. Thus, the primary factor in the invasion of the alien species *E. annuus* was mowing, and, to control such an invasion, areas should be protected from mowing. Additionally, with selective mowing that targeted only *E. annuus*, mowing three times produced only approximately 10% of the reproductive organ biomass compared with that of the control. Because the flower stalk of *E. annuus* was relatively tall compared with that of native species in early summer, selective mowing might also provide a solution to control invasions of *E. annuus*. Therefore, with improved ecological understanding of the site and species, mowing of the right target during the optimal season and at an appropriate frequency is an environmental friendly solution to the management of *E. annuus*.

1. Introduction

The threat of alien species invasions to native species and biodiversity has become a major focus of ecological research. Many human activities, including agriculture, recreation, and transportation, promote both the intentional and accidental spread of species across their natural dispersal barriers (Kolar and Lodge, 2001). Invasive alien plants reduce species richness, and loss of diversity is not only a primary concern in ecology (Knops et al., 1999) but also closely related to global environmental and economic concerns (Lodge, 1993), which makes research on alien plant invasion an important issue. Moreover, research on invasive alien plants is essential to understand the dynamics of ecological communities and to predict ecological and economic impacts in guiding restoration. Predicting the species that are most likely to be alien invaders is a long-standing goal of ecologists (Kolar and Lodge, 2001); however, recently, with the effects of invasions becoming more extensive, research on mitigation and management strategies has become a priority. Therefore, research is actively being conducted to identify the interactions that affect invasive alien plant dispersal and the general causes of dispersal (Esler and Milton, 2007; Harris et al., 2009). Additionally, to avoid damage caused by alien plant invasion, a lot of previous research focused on preventing introduction in the belief that "the best offense is a good defense" (Mehta et al., 2007). However, with invasions now inevitable through numerous pathways, the management of invasive species has assumed greater importance. Management of invasive plants begins with an optimal detection strategy (Mehta et al., 2007) followed by control methods. Management protocols based on education (Mehta et al., 2007), competition with native species (Hoffmann et al., 2002), and simple removal (Erskine Ogden and Rejmánek, 2005) have been studied as methods to control the invasions of alien species. The management of invasive plants was recently extended to modeling (Lee et al., 2009), using decision-making models or those for predictions of future distributions of vegetation. *Erigeron annuus* (L.) Pers. is originally from northern America, is

* Corresponding author.
E-mail addresses: uhrami@gmail.com, uhrami@jejunu.ac.kr (U. Song).
[1] Co-first author.

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frequently observed in cities, in enclosed fields, and along county roadsides (Lee, 1980), and is one of the major invasive plants in Korea (Lee and Kim, 1991). *Erigeron annuus* is a biannual plant and a successional winter annual (Regehr and Bazzaz, 1979). The anti-germination constituents (5-butyl-3-oxo-2,3-dihydrofuran-2-yl)-acetic acid, 3-hydroxy-pyran-4-one, and two cinnamic acid derivatives have been isolated from *E. annuus* (Oh et al., 2002), together with other phenolic constituents (Lee and Seo, 2006), showing the potential for allelopathy. *Erigeron annuus* is now one of the dominant plants at the research site, the Sudokwon Landfill in Korea, which is one of the oldest sites dominated by *E. annuus*, (Song, 2010). The indications are that *E. annuus* will continue to dominate future vegetation at the landfill. Therefore, research on methods to manage (control) this invasive plant is essential. Additionally, *E. annuus* naturalized rapidly to become one of the dominant plant species in Korea (Kang and Shim, 2002), and is now found nationwide (Lee et al., 1992) where it competes with native species. *E. annuus* is now one of the major weeds in crop fields (Kim et al., 2008), and it reduces biodiversity by dominating fields (Lim et al., 2009). However, how it became a successful invader is still unclear. *E. annuus* likely has a competitive edge, possibly because of the increased survival of its seeds, rapid seedling and rosette stages, and/or allelopathic activity. It is important to determine the reason for its successful invasion to prevent and control further invasion. Therefore, the objectives of this research were to determine the reasons for the dominance of *E. annuus* at the research site and to identify management and control strategies for this plant. First, vegetation at the research site was monitored to confirm whether the site was under invasion or had already been invaded by *E. annuus*. Then, a series of experiments designed to study competition with native species, allelopathy effects, photosynthesis, and resistance to management activities were implemented to find what could be the major reason of invasion. Then, the effects of mowing, which is suspected to be one of the main reasons for dominance, were verified by monitoring vegetation changes with and without mowing. Finally, using mowing as a controlling method, we identified environmental friendly and efficient management strategies.

2. Materials and methods

2.1. Site description

The Sudokwon Landfill in Incheon, South Korea, is one of the largest sanitary landfills in the world, with an approximate area of 20,000,000 m^2. The landfill has four sites for reclamation, and, now, the second reclamation site is accepting wastes (Sudokwon Landfill Site Management Corporation, 2013). Reclamation site 1, which was closed in 2001, has eight levels; each level accepted wastes and then was covered with soil, and a new level was formed for new reclamation. The geographic coordinates of the center point of the landfill are 37°34′52″ N, 126°37′29″ E. The average annual temperature and precipitation for this area during the years of research (2005–2009) were 12.5 °C and 1284 mm, respectively (Korean Meteorological Administration, 2010).

2.2. Vegetation monitoring and soil analysis

To determine whether *E. annuus* was invading the research site, quadrat sampling was used to monitor seasonal vegetation at the landfill. Detailed methods are described in Appendix 1 in Supplementary Materials. Vegetation at nine sites in the landfill was monitored to determine whether *E. annuus* was invading the landfill. Plants were identified based on 'Illustrated Flora of Korea' by Lee (1993). The importance of herbaceous vegetation was calculated according to Cottam and Curtis (1956). Methods for soil analysis are presented in Appendix 2 in Supplementary Materials.

2.3. Competition and allelopathy experiments

The survival rates and growth of seeds, seedlings and rossettes of *E. annuus* and the other dominant (*Glycine soja*) or artificially planted (*Aster koraiensis* and *Lotus corniculatus*) native species in the landfill were compared to uncover why *E. annuus* had a competitive edge over other species. Detailed methods are described in Appendix 3 in Supplementary Materials.

For the test of allelopathy, aqueous extracts from 200 g leaves and (or) roots of *Erigeron annuus* (L.) Pers, stirred with one liter of distilled water for 24 h, were used (Kil and Yun, 1992). The germination test was conducted in Petri dishes with filter paper wetted with the extracts (Patterson Iii and Olson, 1983). Twenty seeds were evenly dispersed in each dish. The Petri dishes were maintained in a growth chamber (HB-301L; Hanbaek Scientific Co., Korea) at 20 °C with 12 h of daylight. The germination rate was examined for 5 weeks (six replicates). Two native species, *Aster koraiensis* and *Lotus corniculatus* var. *japonicus*, were used in the germination test. To measure effects on seedling growth, ten seedlings of *Aster koraiensis* that germinated within two days were placed in Petri dishes (ten replicates), and 5 ml of extracts was added daily for a week. These dishes were maintained in the growth chamber under the same conditions as in the germination experiment. To prevent disturbance of shoot growth, the covers of the Petri dishes were not used; instead, extracts were used for the first week, and, after the first week, distilled water was added daily to prevent drying.

2.4. Effects of traditional management activities and photosynthetic rates

The landfill was under continuous management using traditional methods such as mowing, pulling out of weeds by hand, and planting native species. To determine whether these management practices were effective or could be effective in managing *E. annuus* invasion, 1 × 1 m quadrats were established in early March 2006, with approximately 10 cm buffer zone on each side. Eight treatments were employed: 1) control; 2) removal of above ground *E. annuus* using mowing); 3) removal of *E. annuus* and planting of *Aster koraiensis* Nakai (Re-Aster-P); 4) removal of *E. annuus* and planting of *Lotus corniculatus* var. *japonicus* Regel planted (Re-Lotus-P); 5) planting of *A. koraiensis* (Aster-P); 6) planting of *L. corniculatus* planted (Lotus-P); 7) spraying of *A. koraiensis* seeds (Aster-S); and 8) spraying of *L. corniculatus* seeds (Lotus-S). For 'planted' treatments, 20 individuals were planted in each quadrat. For 'seed sprayed' treatments, 30 ml of seeds was mixed with 100 ml of soil and then sprayed onto quadrats. Each treatment had five replicates. In May and September, the coverage of *E. annuus* and the other two species (*A. koraiensis* and *L. corniculatus*) in each quadrat was determined. Additionally, in March 2006 and 2007, the numbers of *E. annuus* in each quadrat were counted. In 2007, the photosynthetic rates of *E. annuus* and a native species, *Aster koraiensis* Nakai, continuously transplanted to landfill slopes, were determined to find out whether *E. annuus* had a high photosynthetic rate that would explain its invasion success. Detailed methods are described in Appendix 4.

2.5. Mowing experiments and reproductive organ weight differences after mowing

Ten quadrats (1 × 1 m) were established in level one, a level in which *E. annuus* was the most dominant species. By protecting 100 m^2 (5 × 20 m) in large quadrats (5 m is the width of the flattened area of level one), *E. annuus* in the ten quadrats was protected from mowing and was monitored from 2006 to spring 2009. Twenty other quadrats were established that were not protected from mowing. Two mowing treatments were examined, 1 and 2. Mowing 2 treatments were under the control of the landfill managers, and the area was mowed once in September 2006 and August 2007, twice in May and October 2008, and once in August 2009 by managers. The mowing 1 treatment was also not protected from the mowing activity of the landfill managers and