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# Successional Changes in Seed Banks in Abandoned Rice Fields in Gwangneung, Central Korea

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**ABSTRACT**: In order to understand the role of seed banks for restoration, seed banks in abandoned rice fields in the Gwangneung National Arboretum, central Korea were investigated using the seedling emergence method. The study sites represented three stages: an initial stage dominated by forbs such as *Persicaria thunbergii* and *Juncus effuses* var. *decipiens*, a middle stage dominated by *Salix*, and a late stage dominated by *Quercus aliena* and *Prunus padus* (in nearby riparian forest chosen as a reference stand). DCA ordination arranged the stands according to the number of years since abandonment. CCA ordination identified the dominant environmental variables correlated most closely with Axes 1 and 2 as $Mg^{2+}$ (intraset correlation was 0.827) and $K^+$ (intraset correlation was −0.677), respectively. Species richness and diversity decreased from the initial stage (H'=2.61) to the middle (H'=1.79) and late (H'=0.75) stages. A total of 49 species (/$m^2$) and 18,620 seedlings (/$m^2$) emerged out of the seed bank samples. The DCA ordination and similarity analysis detected a large discrepancy between the composition of the actual vegetation and the seed bank. We conclude that the contribution of seed bank to restoration is low. However, seed bank may help the recovery of forbs after disturbance. Some of our results are consistent with the tolerance model of succession whereas others follow the trajectory of the facilitation model. More research on succession will be required to understand the underlying mechanisms.

***Key words***: Abandoned rice fields, Gwangneung, Restoration, Seed bank, Succession

## INTRODUCTION

In Asian countries where people depend on rice as a food source, most floodplains of rivers and streams have been transformed to rice fields (Lee et al. 2006). Until the late 20th century, rice fields were rarely abandoned because rice production was not adequate to meet demand. In recent years, however, people are moving in large numbers from rural areas to urban areas (Lee et al. 2002). As a result, inaccessible and terraced rice fields are being increasingly abandoned. Only highly productive and easily accessible rice paddy remains in cultivation (Tasser et al. 2006). Therefore, frequent opportunities for habitat restoration occur as a result of land abandonment (Young 2000).

Seed banks are defined as the ungerminated but viable seeds that can remain dormant for periods ranging from several years to several decades in the soil until environmental conditions are appropriate for germination (Grime 1989, Simpson et al. 1989). Plants usually delay germination by permitting their seeds to enter a dormant state, forming a seed bank (Baskin and Baskin 1998). The species composition of seed banks is affected by the established vegetation, seed longevity, regeneration strategies of individual species, and surrounding environmental conditions (Harper 1977). Seed banks can significantly affect vegetation diversity, revegetation of disturbed areas, and initial vegetation composition. Thus, they have been examined in studies of succession, vegetation history, and seed germination properties (van der Valk and Davis 1979, Haag 1981, Galatowitsh and van der Valk 1996, Brock and Rogers 1998, Harwell and Havens 2003). Seed banks are an important factor affecting the reestablishment of vegetation in disturbed areas (e.g. van der Valk and Pederson 1989, Chambers and MacMahon 1994, Zabinski et al. 2000). Nowadays, the study of seed banks is an important feature of the basic surveys for wetland restoration (Kim and Ju 2005). Understanding the role of seed banks is also important in the design of restoration projects (Richter and Stromberg 2005).

In Korea, there have been very few studies of the abandoned rice fields. Lee et al. (1998) clarified the vegetation sere and the underlying mechanisms by analyzing soil environmental factors and vegetation in abandoned rice fields at different time intervals after abandonment, and Lee et al. (2002) clarified the regenerative aspects of succession as a tool for habitat restoration.

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Studies of seed banks have also been very rare in Korea. Kim and Ju (2005) studied soil seed banks in an ecological preserve area in Seoul and Kim and Lee (2005) clarified the role of seed banks in the establishment of vegetation in landfills.

The purposes of this paper are to 1) analyze the species diversity and composition of seed banks in abandoned rice fields, 2) examine the relationship between the soil seed bank and the actual vegetation, 3) verify successional changes, and 4) evaluate the possibility of using the existing seed bank for restoration.

## STUDY AREA AND METHODS

The study area was located in the Gwangneung National Arboretum, central Korea (Fig. 1, 37° 42' 36"～47' 41" N and 127° 8' 20"～11' 58" E). This area is in a cool-temperate broadleaved forest region (Lim et al. 2003). Mean annual precipitation and temperature were 1,365 mm and 11.3℃, respectively (Forest Practice Research Center, internal data file). The study area includes fields that have been abandoned for various numbers of years. We examined fields in three developmental stages: an initial stage dominated by forbs such as *Persicaria thunbergii* and *Juncus effuses* var. *decipiens*, a middle stage dominated by *Salix*, and a late stage, exemplified by a nearby riparian forest chosen as a reference stand, dominated by *Quercus aliena* and *Prunus padus*. All study sites in the three stages of succession are located within 200 m of each other, at an elevation of 100 m above sea level. Therefore, those sites do not vary substantially in environmental factors except developmental stage.

Vegetation surveys were performed from April to September 2006 in 29 plots, including 10 study plots in the initial stage, 9 in the middle stage, and 10 in the late stage. Quadrats of 10 × 10 m and 1 × 1 m were used for stands dominated by trees and forbs, respectively. Field surveys were carried out using quadrat and point methods in stands dominated by trees and forbs, respectively (Barbour et al. 1999).

Seed bank data were collected using the seedling emergence method. We sampled the soil in March 2006 before germination occurred. A total of 75 samples were obtained including 25 samples from each stage. After removal of the litter layer, topsoil was collected using a soil auger with a volume of 157 $cm^3$ (19.625 $cm^2$ surface area × 8 cm depth) from ten random points within the quadrats (1 × 1 m) and those ten soil cores were pooled to produce one sample (ter Heerdt et al. 1996). The aboveground vegetation at the sampling sites was also recorded. The samples were not sieved, because the coarse materials include seeds (Kim and Lee 2005). The soil samples were thinly spread on a mixture of vermiculate, peat moss, and pearlite in plastic trays (length 49 cm, width 33 cm, depth 8 cm). The trays were randomly placed in a plant nursery in Seoul

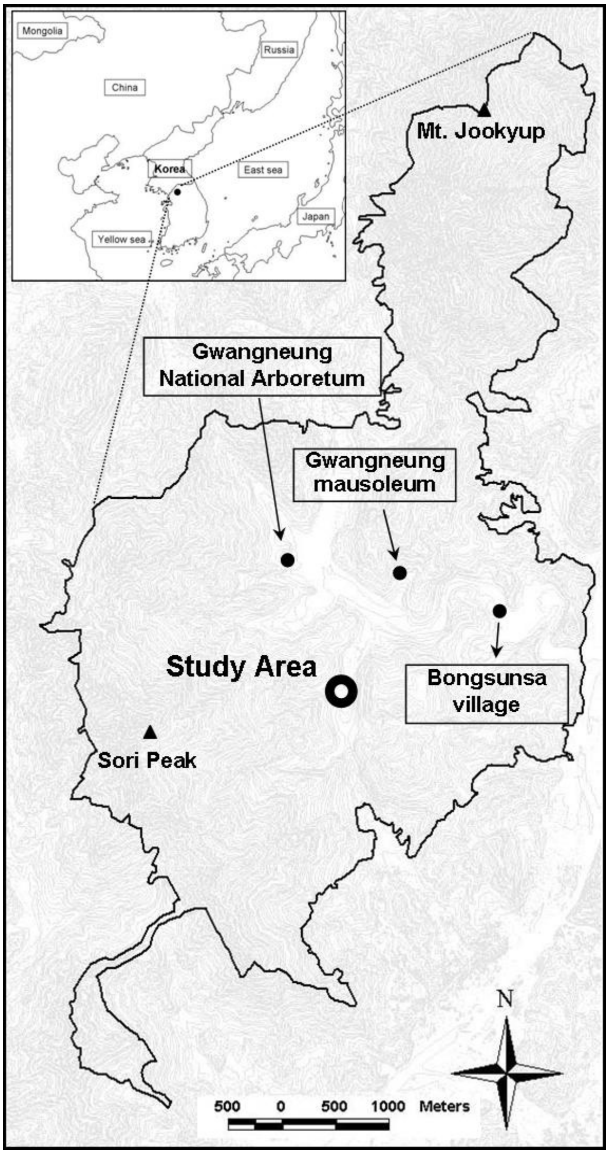


Fig. 1. Map showing the study areas. The marginal line indicates the boundary of Gwangneung national arboretum.

Women's University to prevent invasion of other seeds from outside. Seedlings that emerged were identified to the species or genus level, and were removed after counting to promote the emergence of additional seedlings. If immediate identification was impossible, seedlings were transplanted to other pots to allow further growth.

Differences in species composition among study sites were analyzed with Detrended Correspondence Analysis (DCA, Hill 1979) and the relationship between species composition and soil properties was analyzed with Canonical Correspondence Analysis (CCA, ter Braak 1986) by using PC-ORD 4 (McCune and Mefford 1999). For the matrix of importance values, we conducted relativization by species column, and the results were subjected to Detrended Correspondence Analysis (DCA) for ordination (Hill 1979). Nomenclature followed Lee (1985), Park (1995), Ryang et al (2004), and the Korean Plant Names Index (2003).

Similarity between the actual vegetation and the seed bank was calculated using Sorensen's similarity index ($IS_s$; Greig-Smith 1983):

$$IS_s = (2C/A + B) \times 100$$

where $A$ is the number of species in the vegetation, $B$ is the number of species in the seed bank and $C$ is the number of species common to both.

Soil samples were collected and vegetation surveys were conducted in 29 plots. In each sample plot, five soil cores were taken from the top 10 cm. Soil samples were dried under shaded conditions in the laboratory for 10 days and sieved through 2 mm mesh. Before drying, a part of the soil samples was used to measure soil moisture content. Soil moisture content was calculated from the percentage of pure water weight of fresh soil, using the following equation:

$$SM\ (\%) = \frac{S_f - S_d}{S_f} \times 100$$

($S_f$ : soil weight before drying, $S_d$ : soil weight after drying)

The soil pH was measured with a bench top probe after mixing the soil with distilled water (1:5 ratio, w/v) and filtering the extract (Whatman No. 44 paper). The soil organic matter content was obtained by measuring the loss after ignition for four hours in a muffle furnace at 400℃. Total nitrogen was measured using the micro-Kjeldahl method (Jackson 1967). Exchangeable $K^+$, $Ca^{2+}$ and $Mg^{2+}$ contents were measured from an extract in 1N ammonium acetate solution at pH 7.0 by ICP (inductively coupled plasma atomic emission spectrometry; Shimadzu ICPQ-1000; National Institute of Agricultural Science and Technology 2000).

## RESULTS

### Change of Species Composition

The eigenvalues of Axes 1 and 2 from the DCA ordination based on the seed bank data were 0.493 and 0.188, respectively (Fig. 2). Older abandoned rice fields tended to fall on the left of Axis 1, and younger ones were on the right of Axis 1. The dominance of *Pilea mongolica* and *Bidens frondosa* increased from left to right on Axis 1, whereas that of *Carex neurocarpa* and *Pimpinella brachycarpa* decreased. The dominance of *Lipocarpha microcephala* increased from bottom to top on Axis 2, whereas that of *Eragrostis multicaulis* and *Stellaria alsine* var. *undulata* decreased.

The eigenvalues of Axes 1 and 2 from the CCA ordination based on the seed bank and soil data were 0.458 and 0.081, respectively (Fig. 3). The arrangement of stands was closely correlated with the order of $Mg^{2+}$, total-N, pH, organic matter, $K^+$, and $Ca^{2+}$. $Mg^{2+}$ showed the highest correlation with Axis 1, and $K^+$ showed the highest correlation with the Axis 2 (Table 1). Soil moisture content tended to decrease from the initial stage to the late stage (Fig. 4).

### Changes in Species Diversity

Species rank-abundance curves and Shannon indices of the seed

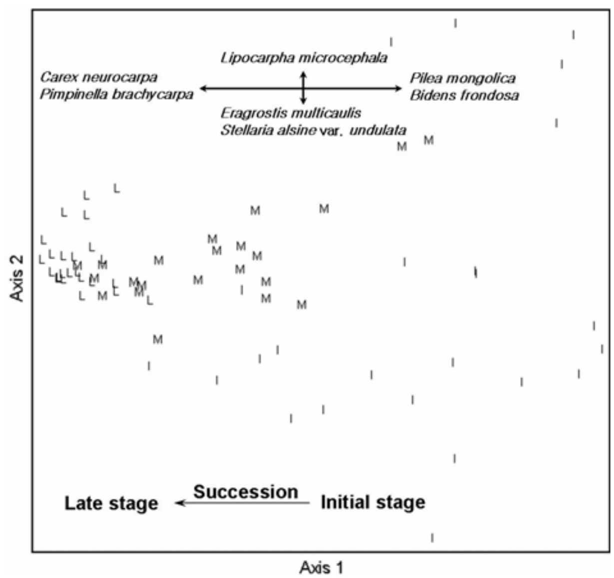


Fig. 2. DCA ordination of stands based on the seed bank data collected in rice fields of three successional stages, including the initial (I), middle (M), and late stages (L).

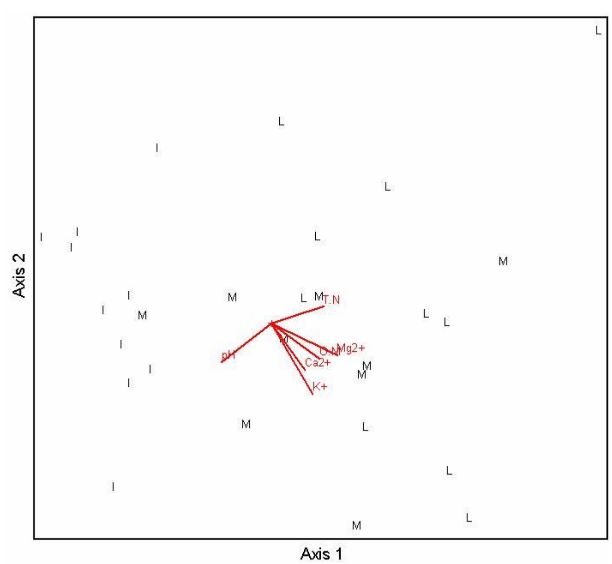


Fig. 3. CCA ordination based on seed bank and soil data collected in the rice fields of three successional stages, including the initial (I), middle (M), and late stages (L).

Table 1. Intraset correlations for six soil variables

| Variable | Axis 1 | Axis 2 |
|---|---|---|
| pH | −0.623 | −0.374 |
| Organic matter | 0.601 | −0.337 |
| Total-N | 0.655 | 0.163 |
| $K^+$ | 0.519 | −0.677 |
| $Ca^{2+}$ | 0.422 | −0.449 |
| $Mg^{2+}$ | 0.827 | −0.304 |

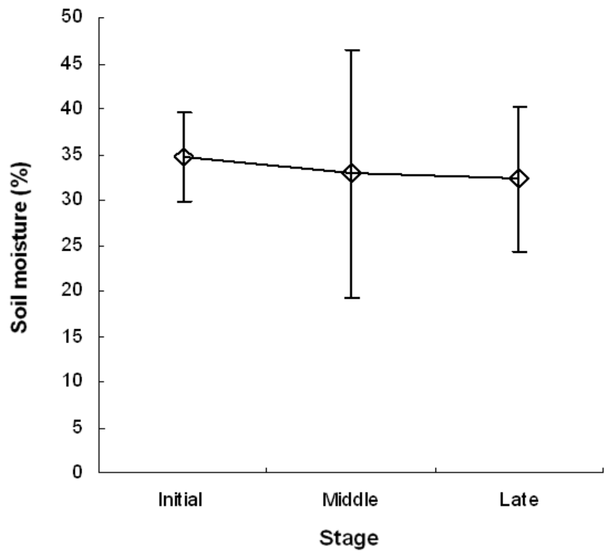


Fig. 4. Soil moisture contents based on soil data collected in abandoned rice fields in the initial, middle, and late stages of succession.

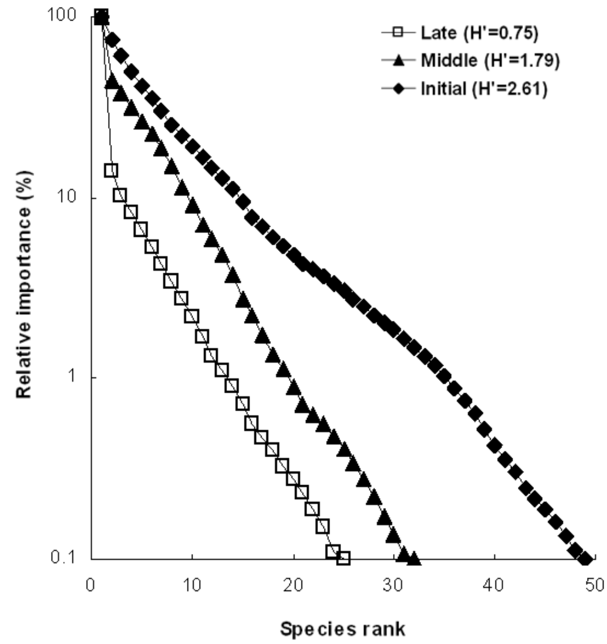


Fig. 5. Rank-abundance curves and Shannon indices (H') based on seed bank data collected in abandoned rice fields in the initial (I), middle (M), and late (L) stages of succession.

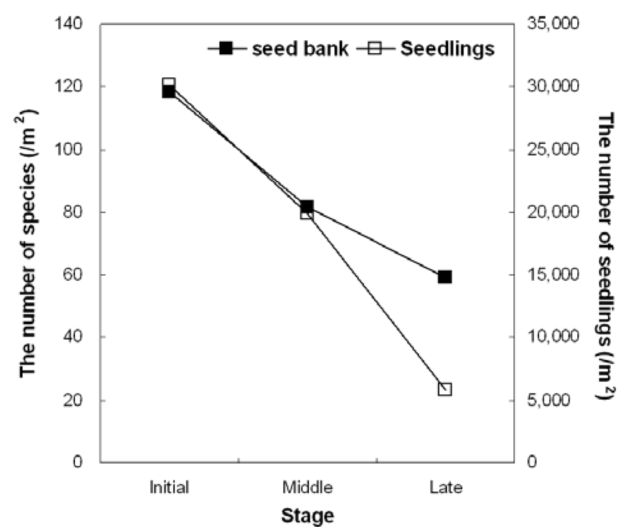


Fig. 6. Changes in the number of species represented in the seed bank and seedlings with advancing successional stage from the initial (I) to the middle (M) and late (L) stages.

banks are shown in Fig. 5. The initial stage showed the highest species richness and diversity (H'=2.61), and species richness and diversity decreased in the middle (H'=1.79), and late (H'=0.75) stages.

The total number of species in the seed bank and the number of seedlings appearing in the seed bank at each stage are shown in Fig. 6. A total of 49 species /$m^2$ and 18,620 /$m^2$ seedlings emerged. The highest number of species and seedlings germinated in the initial stage, and germination rates decreased with advances in the successional stage.

## A Comparison of Species Composition Based on the Seed Bank and Actual Vegetation Data

Fig. 7 shows the result of DCA ordination based on data from the seed bank and the woody vegetation. Eigenvalues of Axes 1 and 2 were 0.987 and 0.750, respectively. On Axis 1, there is a clear separation between on the seed bank and woody vegetation data. Stands based on seed bank data were concentrated on the left on Axis 1 and those using woody vegetation data tended to be arranged on the right of Axis 1. The dominance of *Quercus aliena* and *Styrax obassia* increased from the left to the right on Axis 1, whereas that of *Persicaria conspicua* decreased. The dominance of *Q. aliena* and *S. obassia* increased from the bottom to the top on Axis

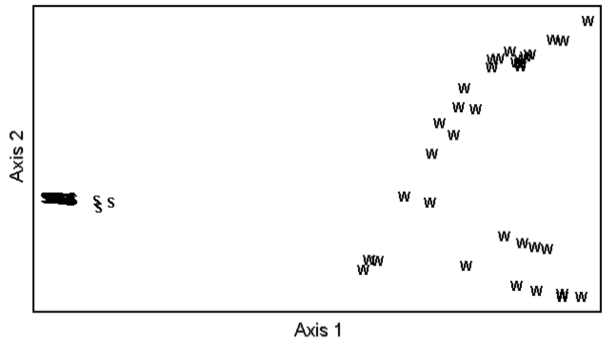


Fig. 7. DCA ordination of stands based on woody vegetation and seed bank data. W: woody vegetation, S: seed bank.

2, whereas that of *S. gracilistyla* and *S. integra* decreased.

Similarly, the DCA ordination based on seed bank and herbaceous vegetation data resulted in a clear separation between stands according to the source of the data (Fig. 8). However, the distance between stands based on the seed bank and herbaceous vegetation was shorter than that for the seed bank and woody vegetation. The Eigen values of Axes 1 and 2 were 0.953 and 0.483, respectively. Stands based on seed bank data were distributed on the left of Axis 1 and those from herbaceous vegetation data tended to be located on the right side of Axis 1. The dominance of *Persicaria filiformis* and *Corydalis ochotensis* increased from the left to the right on Axis 1, whereas that of *Galinsoga ciliate* and *Sagittaria pygmaea* decreased. The dominance of *Echinochloa crusgalli* var. *frumentacea* and *Adenocaulon himalaicum* increased from the bottom to the top on Axis 2, whereas that of *Athyrium yokoscense* and *Desmodium podocarpum* var. *oxyphyllum* decreased.

Based on the Sorensen's similarity indices, the similarity of the species composition in the seed bank and actual vegetation for the three stages ranged from 2.1% to 29.3%, and similarity decreased from the initial to the later stages (Table 2).

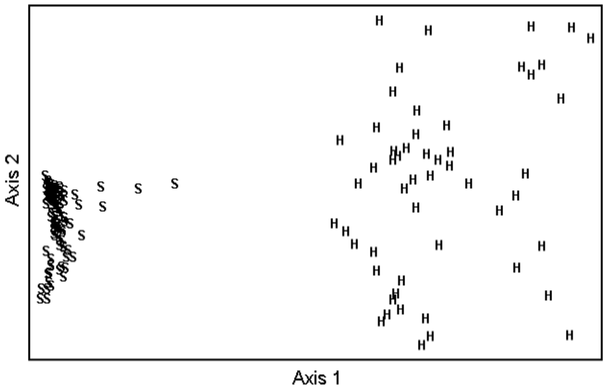


Fig. 8. DCA ordination of stands based on herbaceous vegetation and seed bank data. H: herbaceous vegetation, S: seed bank.

Table 2. A comparison of similarities between actual vegetation and seed bank data in abandoned rice fields of three successional stages

| Stage | I | M | L |
|---|---|---|---|
| Similarity (%) | 29.3 | 10.8 | 2.1 |

I: initial stage, M: middle stage, and L: late stage.

## DISCUSSION

### Analysis and Evaluation of Seed Banks

Seed banks were rich during the early stages of stand development or just after abandonment as shown in Figs. 5 and 6 (Oosting and Humpreys 1940, Livingston and Allessio 1968, Roberts et al. 1984). However, there was low similarity between the actual vegetation and the seed bank (Table 2, Figs. 7 and 8), which is similar to the results from other studies (Douglas 1965, Johnston et al. 1969, Thompson and Grime 1979, Rabinowitz 1981, Pratt et al. 1984, Hassan and West 1986, Bertiller 1992, Warr et al. 1994, Jutila 1998, Falinska 1999, Olano et al. 2002, Bossuyt et al. 2002, Kim and Lee 2005, Solomon et al. 2006, Roovers et al. 2006, Godefroid et al. 2006). These results imply that there is little similarity between the vegetation that may be recruited from the seed bank and the actual vegetation (Roovers et al. 2006).

The forest species that constitute the late successional stage are usually rare in the seed bank (Olano et al. 2002). Even in stable plant communities with a long history, many species appearing in the vegetation are absent from the seed bank (Thompson 2000). This could be due to the fact that their reproductive capacity is limited, while their large seeds are vulnerable to predation and decay, and have restricted longevity (Bekker et al. 1998). Another reason for the rich flora of early successional species is that early successional species produce overwhelming numbers of long-living seeds, whereas most forest species form a transient seed bank (Roovers et al. 2006). In addition, the abundance of earlier successional species in the seed bank could be due to the suppression of seedling emergence by litter in old forests (Amiaud and Touzard 2004).

### Consideration on Succession Model Perspectives

Connell and Slatyer (1977) proposed three models or mechanisms by which succession may be driven. The facilitation model proposes that early successional species may improve their environments in such a way that new species of the next seral stage are at a competitive advantage and thus supplant species from the previous stage. The driving force behind succession in this model, therefore, is the reaction of the site to the plants growing on it. The tolerance model is a revision of Egler's IFC (Initial Floristic Composition) model, which suggests that all pioneer, seral, and climax species are present initially following disturbance. Some germinate and become established quickly, others germinate quickly but grow more slowly for a longer period, and others may become established still later. Larger, longer-lived, slower-growing species eventually outcompete small pioneer species and thus community dominance shifts and succession proceeds. The inhibition model de-emphasized biotic interactions such as competition, and suggested that all species resist invasion by competitors by preempting space and continue to inhibit invasion until they die or are damaged (Barbour et al. 1999).

Our results show that although all species did not emerge in the initial stage, species of the next stage were already invading in the current stage (Figs. 2 and 3). This result implies that the process of succession is continuous and thereby supports the tolerance model. But changes in the species composition were closely related to changes in the soil environment, which follows the trajectory of the facilitation model (Fig. 3). In fact, Walker and Chapin (1987) characterized the Connell-Slatyer models as simplistic, and suggested that succession is an inherently complex phenomenon driven by interactions among numerous mechanisms. Accordingly, no single model is sufficient to interpret our results for succession in abandoned rice fields. More studies of succession will be required to develop adequate models to explain the mechanisms driving plant succession.

### Implication of Seed Banks for Restoration

Ecological restoration is the return of a degraded ecosystem to a close approximation of its original state before disturbance (National Research Council (NRC) 1992). The goal of ecological restoration is to reestablish a functionally complete ecosystem (Stanturf et al. 2001), and methods for restoration are different depending on the degree of disturbance. There are three methods for ecosystem restoration: allowing natural recovery as a passive form of restoration, minimal intervention to accelerate succession, and constructive intervention such as planting trees and sowing seeds (Bradshow 1984).

Knowledge about the seed bank in these abandoned paddy fields will be crucial in guiding ecological restoration efforts. Seed banks can speed up secondary succession on abandoned bare soils such as old fields and some ruderal urban sites (Prach and Pyšek, 2001). Some studies have reported that the lack of desirable seeds is the key limiting factor when cultivated land is restored to its original grassland with diverse plant communities (Pywell et al. 2002, Walker et al. 2004). Our data on seed banks in abandoned rice fields indicate that herbaceous species are abundant but woody plants are very restricted. Identifying critical constraints is often the first step in ecological restoration of degraded ecosystems (Zhan et al. 2007).

Table 3. Total number of seeds and the number of *Salix* species seeds emerging in three stages of succession

| | I | M | L |
|---|---|---|---|
| The number of *Salix* seedlings (/$m^2$) | 43 | 155 | 0 |
| Total number of seedlings (/$m^2$) | 30,111 | 19,924 | 5,825 |

I: initial stage, M: middle stage, and L: late stage.

The DCA ordination indicated that the abandoned rice fields experienced successional change over time after abandonment (Figs. 2 and 3), but both the number of species and seeds decreased with advancing succession. Moreover, the numbers of the representative woody plant, *Salix* species, in the abandoned rice fields were highest in the middle stage and then very low in the late stage, when no *Salix* seedlings emerged. In addition, there was a large discrepancy between the species composition of the seed bank and that of the actual vegetation (Table 3). We conclude that the seed bank can be a useful source for the recovery of annual species following disturbance (Baskin and Baskin 1980); however, it is insufficient for the restoration of woody species. We suggest that restoration of abandoned rice fields can be accelerated by introducing *Salix* species, which are usually easy to establish with cuttings.

## ACKNOWLEDGMENTS

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