Secondary Succession and Natural Habitat Restoration in Abandoned Rice Fields of Central Korea

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Abstract

Floristic composition and soil characteristics (moisture, pH, nutrient contents) in abandoned upland rice paddies of different ages were analyzed to clarify the regenerative aspects of succession as a tool for habitat restoration. The study sites represented five seral stages: newly abandoned paddy fields; successional paddy fields abandoned for 3, 7, and 10 years; and a 50-year-old Alnus japonica forest. A vegetation sere was apparent in changes of dominant plant species in the order Alopecurus aequalis var. amurensis (annual grass), Aneilema keisak (annual forb), Juncus effusus var. decipiens (rush), Salix koriyanagi (willow), and Alnus japonica (alder) communities. These temporal stages resemble the spatial zonation of vegetation in local riparian floodplain ecosystems, indicating a hydrosere, with soil moisture decreasing over time. Age distributions and life forms of the dominant plant species support a “tolerance” model of secondary succession, in which the established species persist into later successional stages. Persistence of earlier colonizers led to a net cumulative increase in species richness and a more even distribution of species cover with increasing field age. Between 10 and 50 years, vegetation stabilizes as an alder community. Soil moisture content decreased steadily with paddy field age after an initial rise immediately after their abandonment, whereas pools of organic matter, N, P, K, Ca, and Mg, increased with field age. The pace and direction of recovery of native vegetation and natural soil properties in these abandoned rice paddies resembled classic old field succession, a form of secondary succession that often serves as a template for guiding restoration efforts. Active intervention, in particular dismantling artificial levees, could accelerate the recovery process, but natural habitat recovery generally appears sufficiently robust to achieve “passive” restoration of this rare community without intervention.

Key words: abandoned paddy fields, hydrosere, Kyunggi-do, Korea, native seed sources, secondary succession, spatial scale of regeneration.

Introduction

Old field succession, the sequence of change in plant communities on abandoned agricultural lands, forms a large body of ecological research (Mueller-Dombois & Ellenberg 1974; Rejmánek 1990; Glenn-Lewin & van der Maarel 1992), and studies of old fields continue to yield new findings of interest to community ecology (e.g., Pickett 1982; Bazzaz 1987; Goldberg 1987; Inoue & Tilman 1988; Schmidt 1988; Osbornová et al. 1990; Holt et al. 1995). Models and observations of secondary succession can be highly pertinent to vegetation management in restoration ecology (Miles 1987; van der Maarel 1988), especially for those programs that seek to understand and promote successional processes for land reclamation and habitat recovery (Luken 1990; Niering 1990; Bradshaw 1992; Robinson & Handel 2000). Indeed, unmanaged successional processes may often rescue restoration projects, as in the case of wetland mitigation projects, whose success may rest on the natural dispersal and establishment of the native biota (Lowry 1990).

Abandoned after dry land farming, old fields in temperate zones naturally revert to woodland with such regularity they are rarely treated as subjects for woodland restoration but rather as templates for understanding rates and trajectories of community change. The potential for natural succession after abandoned wetland agriculture is less certain, and available literature is scarce. In a few phytosociological studies, changes in species composition in abandoned flooded agricultural fields have been inferred (Shimoda & Suzuki 1981; Shi-
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moda 1996; Kim & Nam 1998), but patterns of successional sequence have not been documented.

Rice paddy fields of temperate eastern Asia have generally increased in acreage to meet rising demand for food. In some cases, however, even in relatively populous countries such as Korea and Japan, abandoned rice paddy fields are not uncommon, particularly in less-productive upland regions. As a result of shifting economies, rural population exodus, and the development of high-yield rice varieties, a substantial number of traditional rice fields are no longer cultivated. In Japan, for example, hopes have been raised that abandoned rice fields can play a significant role in restoring lost wetland functions and in promoting conservation of biological diversity (Shimoda 1996). However, little information is available on the ecological impacts of rice paddy cultivation, in particular whether the disturbance associated with cultivation and altered soil drainage are severe enough to impede natural succession after abandonment. From the perspective of ecological restoration, it is important to determine whether successional processes will operate to return these sites to more natural states or whether a more active form of reclamation or rehabilitation is required (Bradshaw 1992; Dobson et al. 1997).

In mountainous central Korea, the flat and gently sloping floodplains beside rivers and streams have been traditionally used for wet rice farming (Lee et al. 2000a, 2000b). Recently, however, rapid growth of urban areas has now overtaken many old rice fields, some of which lie abandoned on the fringes of suburban districts (Lee et al. 2000b). In Korea, as elsewhere, old-field succession on dry lands follows a typical progression from herbaceous to woody vegetation (Ok 1984; Ku 1994; Lee & Kim 1995a, 1995b). However, no information is available on the potential for succession in fallow rice paddies. In this study we looked for evidence of succession in central Korea. We also sought evidence for general mechanisms of succession comparable with those observed in old fields and other better-studied examples of secondary succession.

In abandoned lowland rice paddy fields, more active management is required to initiate successional processes for several reasons. First, the extent and magnitude of disturbance is much greater, with larger average field size and mechanized cultivation, in contrast to smaller, manually cultivated upland paddies. Second, native seed sources are remote because most of the surrounding areas are dominated by cultivated fields or suburban development. Third, poor drainage and a high water level inhibit the progress of succession (Yabe & Numata 1984). We hypothesized that abandoned upland paddy fields would be more likely to undergo secondary succession, due to their smaller sizes, nearby native seed sources, and better drainage. Our principal objective was to ascertain the need for intervention to promote the regenerative aspects of succession (van der Maarel 1988) as a tool for habitat restoration in abandoned upland rice paddy fields.

Methods

Study Area

Sample sites were located in Seongnam-si (37°20’ N, 127°9’ E) and Kuri-si (37°35’ N, 127°7’ E) in Kyunggi-do, central Korea. Si and do are administrative units corresponding to city and province, respectively. Study sites, ranging in altitude from 30 to 220 m, were located at the urban fringes of both cities. Parent rock of the study areas is alluvium from nearby mountain slopes, primarily derived from gneiss (Geological and Mineral Institute of Korea 1973), yielding a fine silt-loam soil texture. The continental climate of this region produces warm rainy summers and cold dry winters. Mean annual temperature is 11.5°C and precipitation, 1,300 mm (Korea Meteorological Administration 1990).

Study sites were grouped into five stages: 0-, 3-, 7-, and 10-year post-abandonment paddy fields and Alnus japonica (alder) forests estimated at 40 years of age. The ages of the falls were determined from interviews with local farmers combined with ring counts of woody species established in the older fields. Data from 12 study sites were used in all analyses. One site from each of the three youngest paddy fallow stages was studied, and two sites at the 10-year-old stage were studied, one in Seongnam-si and one in Kuri-si. Based on published criteria, all sites selected in this study could be classified as wet fields (Shimoda & Suzuki 1981; Matsumura et al. 1988; Okkuro et al. 1996; Shimoda 1996). However, wet fields can be further subdivided, based on plant species composition (Shimoda & Suzuki 1981; Yabe & Numata 1984; Shimoda 1996). The remaining seven sampling sites were located in stands of alder forest, four in Seongnam-si and three in Kuri-si.

Soils of the forests growing along streams near the abandoned paddy fields were formed from the same parent alluvium as the paddy field soils and were similar in texture. Research in Japan has characterized the A. japonica forest as a climax forest of montane wetlands (Nakagoshi et al. 1996) and riparian ecosystems (Okuda & Sasaki 1996). Therefore, we considered the seven forest sites to represent relatively late successional stages to be used as reference sites here. Increment borer samples indicated a 40-year mean age for mature trees in the seven stands. Previous observations have indicated that A. japonica first appears in paddy falls after 10 years (Lee, unpublished data). Based on stand locations and records of previous land use, we inferred that these

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alder stands were growing on former paddy fields that had been abandoned for approximately 50 years.

Vegetation Analysis

The vegetation survey was carried out from May to September 1993. Plant cover was measured in 26 quadrats of $1 \times 1$ m in herb-dominated sites (0–3 years post-abandonment), 23 quadrats of $5 \times 5$ m in shrub-dominated sites (7–10 years post-abandonment), and one quadrat of $20 \times 20$ m in each of the seven alder stands. Cover class data were collected by species (Braun-Blanquet 1964) and summed over all species in a quadrat and transformed to importance value (Klaudisová & Osbornová 1990). Ordinal cover was converted to the median value of percent cover range in each cover class, and the summed cover values for each species were divided by total cover of all species to calculate an importance value (relative abundance estimated from cover). Rank-abundance curves, which graphically depict patterns of species diversity and dominance (Magurran 1988; Kent & Cocker 1992), were constructed for each study site and combined in a single figure for comparison.

A potential vegetation sere was determined by analyzing changes in species composition and importance value of dominant species and species composition at each post-abandonment stage. Differences in species composition with field age were analyzed with detrended correspondence analysis ordination (Hill 1979). Size structure in woody plant populations was also compared among later stage (7 and 10 years) fields and alder stands.

Soil Properties

Three soil samples were taken in each of the four paddy field sites (0 to 10 years post-abandonment) and one each in the seven alder stands. Soil samples were collected from May to July 1993. Air-dried samples were used for analysis of physicochemical properties. Soil water content was obtained by subtracting weight of soil dried at 105°C for 48 hr from that of fresh soil. Organic matter content was determined from ash-free dry weight after ignition in a muffle furnace of 600°C for 4 hr. Laboratory 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). Total nitrogen was measured with the micro-Kjeldahl method (Jackson 1967). Exchangeable P was extracted in 1N ammonium fluoride (pH 7.0) solution, and K, Ca, and Mg were extracted in 1N ammonium acetate solutions (pH 7.0). Exchangeable P, K, Ca, and Mg contents were measured by inductively coupled plasma atomic emission spectrometry (ICP; Shimadzu ICPQ-1000) at the Inter-University Center for Natural Science Research Facilities in Seoul National University, Korea (Allen et al. 1986).

Results

Plant Species Composition and Field Age

Species richness, evenness, and diversity generally increased with age. The dominant plant species at each of the five post-abandonment stages were *Alopecurus aequalis* var. *amurensis* (annual grass), *Aneilema keisak* (annual forb), *Juncus effusus* var. *decipiens* (rush), *Salix koriyanagi* (willow), and *Alnus japonica* (alder), respectively (Fig. 1). *Alopecurus aequalis* var. *amurensis* was the dominant species in the youngest paddy field, but its importance value rapidly declined in older paddy fields. In contrast, *Aneilema* rarely occurred in the newly abandoned paddy field but was dominant in the 3-year-old field. *Juncus* was well represented in the 3-year-old abandoned field and continued to increase to a maximum in the 7-year-old field, apparently declining thereafter, as judged from its lower importance value in the 10-year field. *Salix* (willow) first appeared in the 7-year-old field and was a dominant species in the 10-year-old paddy field, although the importance value decreased compared with field age because many more species were present in the older field. Finally, *Alnus* appeared in only the 10-year-old paddy field and formed pure stands in a nearby montane riparian ecosystem (50 years, Fig. 1).

![Figure 1. Differences in importance values of the dominant species at each stage after abandonment.](image-url)
The two major detrended correspondence analysis ordination axes indicate several trends. On axis I, vegetation samples follow an ordered temporal sequence, with some overlap among 7- and 10-year-old samples (Fig. 2). Changes in species composition thus appear to follow a progressive successional trend. Most of the measured soil properties are strongly correlated with axis I, and consequently more than half of this result can be explained by this axis (Table 1).

Axis II groups younger sites (0-, 3-, and 7-year-old abandoned paddy fields) together, but two separate groupings appear for both 10-year-old abandoned paddy fields and for the alder stands (Fig. 2). One explanation for this pattern is greater variance in species composition with field age. However, a topographic explanation seems more likely. Samples clustered in the lower left of the diagram were taken in Seongnam-si, at elevations of 180 to 220 m; samples that cluster in the upper left were taken in Kuri-si, at 30 to 40 m. Elevation differences may be related to many environmental factors, including soil moisture content, leading to differences in species composition. A number of species typically associated with wetter sites, such as Carex dispalata, Arthraxon hispidus, and Impatiens textori in the 10-year-old fields and I. textori, Salix koreensis, and Athyrium niponicum in alder forests, appeared only in Kuri samples. More mesic species, such as Athyrium yokoscense, Spiraea prunifolia for. simpliciflora, and Setaria glauca in the 10-year-old fields and Weigela hortensis, Disporum sessile, and Euonymus alatus var. ciliato-dentatus in the alder stands, appeared only in our Seongnam-si samples.

### Table 1. Correlation coefficients between environmental factors and stand scores of DECORANA ordination.

<table>
<thead>
<tr>
<th>Environmental Factors</th>
<th>Axis I</th>
<th>Axis II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content (%)</td>
<td>-0.34**</td>
<td>-0.02</td>
</tr>
<tr>
<td>pH</td>
<td>0.30*</td>
<td>0.09</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>-0.91**</td>
<td>0.18</td>
</tr>
<tr>
<td>Total nitrogen (%)</td>
<td>-0.70**</td>
<td>-0.09</td>
</tr>
<tr>
<td>Available phosphorus (ppm)</td>
<td>-0.73**</td>
<td>0.05</td>
</tr>
<tr>
<td>Exchangeable potassium (ppm)</td>
<td>-0.90**</td>
<td>0.27*</td>
</tr>
<tr>
<td>Exchangeable calcium (ppm)</td>
<td>-0.69**</td>
<td>0.30*</td>
</tr>
<tr>
<td>Exchangeable magnesium (ppm)</td>
<td>-0.37**</td>
<td>0.21</td>
</tr>
<tr>
<td>Elevation (m)</td>
<td>-0.21</td>
<td>0.85**</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td>0.92</td>
<td>0.36</td>
</tr>
<tr>
<td>Variance proportion (%)</td>
<td>52.70</td>
<td>73.25</td>
</tr>
</tbody>
</table>

*Significant at 5% level.
**Significant at 1% level.

### Plant Species Diversity and Field Age

Rank-abundance relationships (Fig. 3) reveal two trends of net increases in species diversity. First, species richness generally increased with field age, indicating an accumulation of additional species over time. Second, the degree of dominance, determined by the steepness of the curves, declined with field age. At each successive interval, the relative abundance of an average species was higher, indicating a more even distribution of space occupancy.

![Figure 2. Ordination (DECORANA, Hill 1979) of the 56 vegetation samples representing all sites.](image)

![Figure 3. Rank-abundance curves of plant species grouped by site ages (time since abandonment). Importance values are derived from relative cover estimates from 56 quadrat samples taken among the five age categories.](image)
Size Distributions of Dominant Woody Plants

Salix koriyanagi (willow) populations sampled in the 7-year-old field exhibited a narrow size distribution, with most stems in intermediate size classes (Fig. 4A).

In samples from the 10-year-old abandoned paddy field (Fig. 4B) a few large willows stand out, whereas most stems remain in smaller size classes. Alder population in the 10-year-old field consisted of young trees of small size and exhibited a reverse J-shaped size distribution. Alder stems sampled in the forest stands (Fig. 4C) show a normal distribution pattern, with a high peak around the median size.

Soil Properties and Field Age

Soil moisture content appeared to increase rapidly after abandonment and then eventually decline (Fig. 5A). In contrast, soil pools of organic matter, total N, and exchangeable K tended to increase over field age, up to 10 years (Fig. 5, C–F). Available P, exchangeable Ca and Mg contents, and pH also tended to increase with field age, except for a decline in one early stage (Fig. 5, B, E, G, and H). But extrapolating from forest stand data, long-term trends in accumulation may vary among the different nutrients.

Discussion

Restoration and Secondary Succession

One of the most important considerations in ecological restoration is the pace of change from a degraded site toward a more desirable community/ecosystem (Bradshaw 1992). A fundamental characteristic of secondary succession in general, and old-field succession in particular, is the relatively brief period of early community development (Glenn-Lewin & van der Maarel 1992). The science of restoration ecology could achieve considerable progress if more efforts were made to document how secondary successional processes function in different post-disturbance settings, with an eye toward accelerating early regenerative phases (Bradshaw 1989).

Secondary succession is a complex multifactorial process (Halpern 1989; Bazzaz 1990; Glenn-Lewin & van der Maarel 1992; Peet 1992), difficult to generalize (van Hulst 1992; McCook 1994). Ecological processes that drive succession include propagule dispersal, interspecific interactions, life history variation, biomass accumulation, and nutrient mineralization. Some of these processes were evident in the sequential changes in the plant communities and soil properties we investigated, during the chronosequence from cultivated rice paddy to native woodland.

Succession cannot always be counted on to promote habitat restoration, as when dispersal is dominated by aggressive weedy species (Bradshaw 1989) or when natural source populations are small and distant (Robinson & Handel 2000). A large number of species colonized, as shown in other regional riparian studies.

Figure 4. Frequency distribution of diameter classes of major woody plants appeared in (A) 7-year-old abandoned paddy fields, (B) 10-year-old abandoned paddy fields, and (C) 50-year-old alder forest stands.
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However, in our study the major plant species that colonized disperse by wind and/or water, and therefore connections to natural floodplain populations in this montane riparian network are likely to be strong. For example, willow and alder, which dominate older successional paddy fields, have buoyant wind-dispersed seeds that also float downstream, rapidly colonizing streambanks and floodplains (Young & Young 1992; Okuda & Sasaki 1996).

The extent of ecological damage is another important consideration. Rice cultivation in the sites studied had been traditionally conducted at small scales in naturally wet soils. Where dispersal, patch dynamics, or other spatially dependent processes contribute to successional change, rates of succession should rise inversely with the spatial extent of disturbance (van Hulst 1992; McCook 1994; Holt et al. 1995). Furthermore, the artificial levee systems used are simple earthen berms that erode rather quickly, and thus a natural floodplain dynamic might return in a relatively brief period of time.

The ecological consequences of nutrient depletion and artificial flooding and draining cycles could have produced long-lasting soil disruption, but in this case a 50-year chronosequence suggests that at least nutrient pools and plant species diversity recover within a few decades. Experience in Japan indicates that the disruption by rice cultivation to natural marsh ecosystems is relatively short-lived, judging from the capacity for natural marshland vegetation to regenerate (Shimoda & Suzuki 1981; Yabe & Numata 1984; Shimoda 1996). In such cases at least, degradation was not severe enough to prevent secondary succession.

Chronosequence of Paddy Field Succession

As with old-field succession, and secondary succession in general, life history differences accompanied shifts in species composition. *Alopecurus aequalis var. amurensis*, the dominant species in the newly abandoned paddy field, is highly adapted to an agricultural calendar. An annual grass, it germinates in early spring and completes its life cycle at the onset of rice planting. *Aneilema*, dominant in the 3-year-old abandoned paddy field, is an annual forb but with a life cycle that spans

Figure 5. Changes of soil moisture, pH, and nutrient contents with years after abandonment. Values are means of three samples per site in 0- to 10-year-old abandoned paddy fields and one per site in alder stands.
the growing season. The perennial rush, *Juncus*, was dominant in the 7-year-old paddy field, and willow shrubs were dominant in the two 10-year-old paddy fields, which included young populations of alder trees. Greater dominance of the longer-lived species in older fields implies a strong role for competition (Egler 1954; Connell & Slatyer 1977). On the other hand, species diversity was greater in older paddy fields, indicating some mitigation of competition, perhaps due to their more structurally complex plant communities or to commensurate changes in their soil properties.

The vegetation differences among successively older paddy fields resemble the spatial zonation of vegetation in riparian floodplains (Lee 1996a). Species composition of *Alopecurus* and *Aneilema* communities established in the younger (0- and 3-year) fallow paddy fields was similar to that surrounding nearby stream pools, whereas vegetation in the older (7- and 10-year) fields corresponded to nearby floodplain and streambank zones, respectively (Lee 1996a). The alder forest community in Japan is considered a climax community of montane wetlands (Nakagoshi et al. 1996), riparian zones (Okuda & Sasaki 1996), and marshes (Yabe & Numata 1984). The same alder species appears to be the dominant canopy species in similar habitats of central Korea (Lee et al. 2000b).

As in many other studies of succession, we substituted comparisons of different-aged fields in lieu of a long-term study of change in one or a few locations. This type of chronosequence approach has been criticized, in part because similar vegetation patterns can result from different processes (Austin 1981; Pickett 1989). However, in our case, both above- and belowground trajectories resembled natural floodplain dynamics (both spatial and temporal), and the (assumed) later stages closely resembled native riparian woodland (Lee 1996a; Okuda & Sasaki 1996). Therefore, at least with respect to dominant species at each stage examined, the chronosequence appears consistent with a general pattern of natural regeneration via succession.

**Soil Properties and Rice Paddy Succession**

The increases in soil organic matter, total N, available P, and exchangeable K, Ca, and Mg are generally comparable with trends observed in dry land old fields, including those studied in central Korea (Lee & Kim 1995a). In the recovery process of soil nutrient pool, a decline of several nutrients, such as available P, and exchangeable Ca and Mg in the earliest stage is due to the absorption by rapidly growing plants over the supply (Tamura et al. 1986). Soil moisture is typically low in recently abandoned paddy fields, because when water is drained for the final rice harvest it is not replenished (Shimoda 1997; Kim & Nam 1998). The abandoned paddy fields eventually accumulate water as the drainage system within paddy field breaks down. The development of wet soils would then facilitate establishment of *Aneilema* and *Juncus* and lead to the observed decline in *Alopecurus*. With time, however, as larger and longer-lived plants colonize the paddy fallows, successional changes may include a hydrosere (Mueller-Dombois & Ellenberg 1974), during which soil moisture gradually diminishes in concert with an increase in vegetation biomass and complexity.

Previous work on abandoned paddy fields in Korea (Kim & Nam 1998) and Japan (Shimoda & Suzuki 1981; Shimoda 1987, 1996) supports a hydrosere model of succession. Decreasing soil moisture can result from a reversion to more natural drainage patterns (Shimoda & Suzuki 1981) and an increase in evapotranspiration, as vegetation passes from grassland to shrub and forest stages. Studies of old paddy fields located on lowland plains have recognized various herbaceous communities, including tussock meadow (a seral stage in this study), as climax communities. In those sites, soil water levels tend to remain high, perhaps inhibiting establishment of trees and shrubs (Shimoda & Suzuki 1981; Yabe & Numata 1984; Shimoda 1987, 1996). The terrace systems in narrow mountain valleys of central Korea are better drained and are more likely to produce a hydrosere after abandonment.

**Conclusions**

Natural succession appears to function well as a passive form of restoration in this ecosystem. Just as removing dikes and other drainage impediments may be sufficient to renew natural vegetation dynamics in salt marsh communities (Niering 1990, 1994), simply allowing the artificial berms to erode away appears sufficient to promote a successional sequence. It is worth asking whether some form of intervention, such as reflooding paddy fields after abandonment, would stimulate or impede succession. For example, the period of early dominance by the agricultural weed *Alopecurus* might be shortened by accelerating the buildup of soil moisture. However, the apparent 10-year cycle from abandoned rice paddy to formative woodland seems relatively short, and the need for direct intervention appears doubtful. The availability of nearby native seed sources and their importance in secondary succession lead us to the conclusion that conservation efforts might be better spent protecting the native riparian ecosystems that make paddy field recovery possible. Our results are noteworthy in this regard, because *A. japonica* communities are now rare in Korea, as most were destroyed for agriculture. Continued recovery through
natural regeneration will contribute significant benefits for ecological diversity of Korea.

In Korea, as elsewhere, costly poorly designed land- scaping is often substituted for ecologically based land reclamation and habitat restoration (e.g., Lee 1996b; Lee & You 2001). In some cases, abandoned rice paddies near urban zones have been treated with intensive ad-hoc reforestation projects, using exotic species or inappropriate species and lacking a valid scientific basis (Cho et al. 1994). A better knowledge of natural recovery processes, in particular, rates and patterns of secondary succession, can provide a useful framework for less costly, more durable, and more natural forms of restoration.

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LITERATURE CITED


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*Title is a tentative translation for the original title written in Japanese by the authors.