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Author(s): Yasuyuki Kosaka, Shinya Takeda, Saysana Sithirajvongsa, and Khamleck Xaydala

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Plant Diversity in Paddy Fields in Relation to Agricultural Practices in Savannakhet Province, Laos[1]

Yasuyuki Kosaka, Shinya Takeda, Saysana Sithirajvongsa, and Khamleck Xaydala

Kosaka, Yasuyuki, and Shinya Takeda *(Graduate School of Asian and African Area Studies, Kyoto University, Kyoto, 606-8501, Japan; e-mail: kosaka@asafas.kyoto-u.ac.jp)*, **Saysana Sithirajvongsa and Khamleck Xaydala** *(Faculty of Forestry, National University of Laos, Vientiane, Lao PDR; e-mail: forestfc@laopdr.com)*. Plant Diversity in Paddy Fields in Relation to Agricultural Practices in Savannakhet Province, Laos. *Economic Botany* 60(1):49–61, 2006. *This paper reports a study of paddy vegetation in central Laos. Plants were inventoried and vegetation types classified. Relationships between vegetation and agricultural practices were identified. A total of 184 wild herbaceous species and 17 cultivated species were recorded in two villages. Of the wild species, 19 were used by local people, four were rare species, and three were major weeds. Paddy vegetation was arranged in order of water regime from shorter to longer hydroperiod by DCA. The factors contributing to high species diversity were: (1) the presence of species unique to different paddy types; (2) the presence of remnant species from original vegetation; and (3) the impact of agricultural practices. Thus, at this study site, multiple plant species coexisted in paddy fields under various agricultural practices, and some species were essential sources of food or were used in other ways to support the subsistence livelihoods of local residents.*

Key words: Agriculture, beneficial species, harmful species, human-managed ecosystem, Laos, rare species, rice cultivation, water regime, weed.

Agricultural landscapes have attracted increasing attention in connection with the general rise of concern about the conservation of biodiversity (e.g., Gall and Orians 1992; Pimentel et al. 1992). The predominant agricultural land use throughout much of Asia is paddy farming for the monoculture cultivation of rice, and some studies have examined plant biodiversity in paddy fields (e.g., Bambaradeniya et al. 2004).

Although subject to repeated human disturbance, such as flooding, plowing, or weeding, many plant species persist within the paddy landscape. Shimoda (2003) revealed high plant diversity in a paddy field compared with vegetation in an abandoned field. Ikeda and Miura (2002) showed that many endangered wetland plants survived in paddy fields subject to traditional agricultural practices in Japan. However, the composition of weed species assemblages in paddy fields is rapidly changing due to factors such as increased use of herbicides, changes in plowing and fertilizer practices, changes in cropping systems (off-season cropping after rice harvest is becoming less common), and environmental change by creation of well-drained paddy fields (Shimoda 2003).

Weeds are a major constraint on crop production, yet they may be regarded as an important component of the agroecosystem (Marshall et al. 2003). In addition, many plants in paddy fields are useful. Datta and Banerjee (1978) reported that of 158 paddy weed species collected in West Bengal, 124 were regarded as useful according to available literature. Yamaguchi and Umemoto (1996) focused on weeds on paddy levees and pointed out their various functions for food, medicine, prevention of soil erosion, livestock feed, landscaping, and aesthetic plants. Moreover, the ecology and conservation

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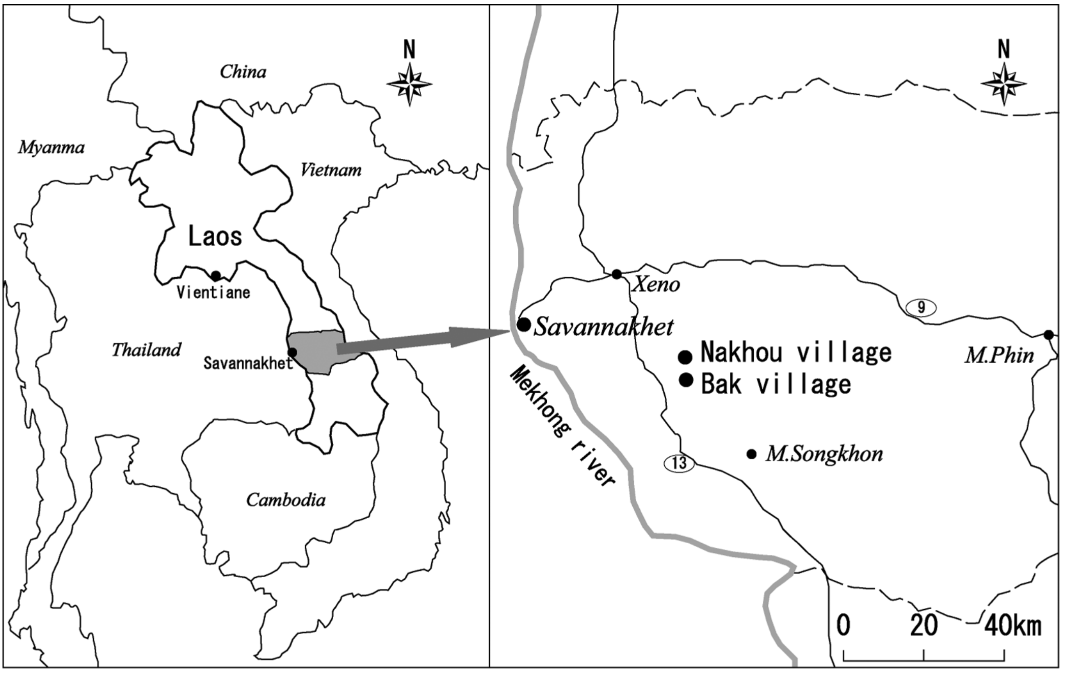

Fig. 1. Map of the study site in Savannakhet Province, Laos.

of wetlands has received much attention (Gopal and Sah 1995). Thus, there is an urgent need to carry out floristic surveys in paddy fields, which harbor many wetland plants, especially in regions where the flora is not well documented.

There have been several reports published on the herbaceous species composition of paddy fields in mainland Southeast Asia. Heckman (1974) reported the seasonal succession of species in Laos. Tomita et al. (2003a; 2003b) found differences in weed vegetation in response to cultivation method and watering regime. However, overall floristic composition and species richness associated with paddy fields and paddy levees have received little attention. In this context, the plant diversity of an area is not merely a measure of the number of species occurring, but also reflects the dependence of the indigenous communities on that plant resource (Jain 2000).

This study was performed on the flood plain of the Mekong River in central Laos, where paddy fields are the predominant land use. Significant wetland habitat forms an integral and fundamental part of the agricultural and natural landscape of this region (Daconto 2001:1). The local people do not use herbicides and still collect various plants from paddy fields for use in their daily lives. The purposes of this study were twofold: (1) to create an inventory of and classify paddy vegetation, and (2) to describe relationships between paddy vegetation and agricultural practices.

Site Description and Methods

Site Description

The field survey was carried out at Nakhou village (16°29'N, 105°09'E, 140 m a.s.l.) and Bak village (16°27'N, 105°09'E, 160 m a.s.l.), Champhone District, Savannakhet Province, Laos (Fig. 1). Savannakhet Province is located in central Laos. Average annual minimum and maximum temperatures are 21.6°C (December) and 29.4°C (April). The mean annual rainfall is 1473 mm. The rainy season (May–October) and dry season (November–April) rainfalls are 1299.2 mm and 173.8 mm respectively. In Savannakhet Province, 8% of the land is occupied by paddy fields (NOFIP 1992), and 80% of the households are engaged in paddy cultivation (UNDP 1998:7).

The villages are located on different parts of the same contiguous slope, with paddy fields beginning in the lowlands of Nakhou village and extending upslope to central Bak village. Shifting cultivation is performed on the higher land of Bak village. Some springs were found in Bak village on the boundary between the paddy field zone and the shifting cultivation zone. Nakhou village was established more than 100 years ago. It has a population of 1,594 people, mostly ethnic Lao-Lum people, belonging to the Tai-Kadai ethnolinguistic family (Sisouphanthong and Taillard 2000), in 252 households. The majority of the land is dedicated to paddy fields, and all households are engaged in paddy cultivation. Bak village is believed to have existed for more than 200 years and has a population of 1,852 people, mostly ethnic Lao-Lum, in 327 households, with 60% of the land occupied by paddy fields. Ninety percent of the households are engaged in paddy cultivation, the rest in shifting cultivation.

Selection of the Survey Plots

The local people at the study sites classify paddy fields into four types based on topography, field location, and the subsequent water regime. Hillside paddy fields (*na khok*) occur on lower and upper slopes and are rain-fed. Home-side paddy (*na tin ban*) is cultivated on flat land and lower slopes adjacent to houses and is rain-fed. Lowland paddy (*na tham*) fields occur on flood terraces, parts of which are flooded in the rainy season and can only be cultivated in the dry season when the water level falls. Wet paddy (*na beung*) refers to fields on valley bottoms and foot slopes; water from springs is used to irrigate these fields throughout most of the year.

According to a preliminary interview survey, rainy season cropping is carried out by plowing in May, with transplanting occurring in June and harvesting in October. Soil improvement is mainly achieved by applying manure and rice husks with relatively light use of chemical fertilizer. Chemical herbicides and pesticides are not used. After the rice is harvested, water buffaloes and cattle graze in paddy fields, except in those lowland and wet paddy fields that are also cultivated in the dry season following insufficient rainy season yield. The survey also found that home-side paddy is the most fertile because nutrient-rich water flows into it from the surrounding houses. Lowland and wet paddy are moderately fertile, while lowland paddy along streams is at risk of floods. Hillside paddy was

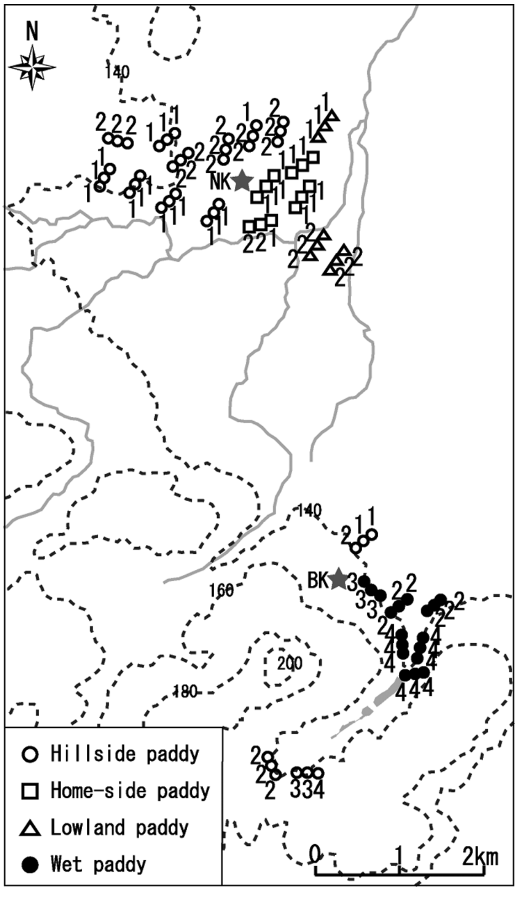

Fig. 2. Distribution of 78 quadrats and their vegetation types at Nakhou (NK) village and Bak (BK) village, Savannakhet Province, Laos. Numbers (1–4) represent vegetation types obtained by TWINSPAN classification of species assemblages within quadrats.

found to be generally less fertile, and the rice yield from this paddy type is usually low unless fertilizer is applied. The rice yield within the study site was found to be 1–3 t/ha, but subject to considerable variation depending on land quality, fertilizer application, and weather. Most of the rice yield is used for self-consumption.

A total of 26 sample plots were selected in paddy fields representing all four paddy types. In June 2003, one quadrat (1 m × 1 m) per plot was established for a preliminary survey. Subsequently, three quadrats per plot (including the initial quadrats) were established for a total of 78 quadrats (Fig. 2), which were assessed for plant species presence and abundance in July, September, October, December of 2003 and March of 2004, as described in the following section on data collection.

Data Collection

The rice agroecosystem can be divided into three broad habitat types, namely the field, the levee, and the ditch (Chandrasena 1988). In this study, herbaceous species (spermatophytes and pteridophytes) in fields and on levees were targeted. Throughout this paper, we refer to species as either cultivated, i.e., planted and managed by villagers, or wild, i.e., those that grow wild and are not cultivated, regardless of the species' natural distribution or origin.

The quadrat method was used to determine the composition and coverage of wild species in fields. Coverage (%) and height (highest individual in quadrat) of each species as well as water depth (average of several measurements in quadrat) were recorded in each quadrat. In addition, when unrecorded species were observed outside the quadrats during the survey period, their names were added to the inventory. For wild species on levees, semi-quantitative data (few, scattered, or abundant; Heckman 1974) were obtained by direct observation at several places in each paddy type because the various microhabitats (shore, flat part, and grassland; Yamaguchi and Umemoto 1996) prevented us from establishing quadrats. The name and habitat of cultivated species were recorded when observed. The collected plants were identified in the Faculty of Forestry, National University of Laos, Vientiane, Laos, and in the Forest Herbarium of the Royal Forestry Department, Bangkok, Thailand (BKF). Nomenclature of sampled plants followed Ho (1999–2000), Santisuk and Larsen (1997–2002), and Smitinand and Larsen (1970–1996). Voucher specimens were lodged in the herbarium of the Faculty of Forestry, National University of Laos.

We interviewed one key informant and several farmers in each village to determine the local names and uses of sampled plants as well as the rice cropping system (cropping seasons, fertilizer application, water management, weed control, yield, grazing after harvest).

Data Analysis

The quadrat data for species in fields were subject to two-way indicator species analysis using the computer program TWINSPAN (Hill 1994) and to detrended correspondence analysis (DCA) using the computer program DECORANA (Hill 1994). The relative abundance value was determined for the species with maximal coverage (%) in each quadrat during the survey period. TWINSPAN split the quadrats dichotomously based on species abundance data and was used to identify patterns in the vegetation classification.

DCA extracts the compositional gradients from the species-quadrats data matrix. Species richness, diversity, and dominance were determined for each paddy type by calculating species richness (number of species per quadrat), Shannon diversity index (Shannon and Weaver 1949), Simpson dominance index (Simpson 1949), and evenness index (Pielou 1966). The evenness index is a measure of how evenly species are distributed in a particular community. In addition, the number of unique species, i.e., species that were recorded in only one paddy type, was counted. The importance of species was estimated using an index of specific value (ISV; Pinder and Rosso 1998), defining species with value >0.2 as the dominant species (Tomita et al. 2003b):

$$\mathrm{ISV}i = \frac{\sum_{j=1}^{N} rk_{i,j}}{\sum_{j=1}^{N} rk_{max\ j}}$$

where rk_{ij} indicates the rank of species i in quadrat j, N indicates the number of quadrats, and $rk_{\max j}$ indicates the rank of the most abundant species in quadrat j.

All wild species both in fields and levees were categorized by life-form (annual herb or perennial herb) and water adaptability (hydrophyte, hygrophyte, or mesophyte), based on field observation and available literature, such as Chandrasena (1988), Harada, Shibayama, and Morita (1993), HEAR (2004), Ho (1999–2000), Kasahara (1959), Ohtaki and Ishido (1980), Santisuk and Larsen (1997–2002), Shimizu (2003), Smitinand and Larsen (1970–1996), Tomita et al. (2003b), and Weerakoon and Gunewardena (1983). In this paper, the definition of exotic species follows Fiedler and Jain (1992), i.e., non-native species that have established viable populations within a community. Such species exist within a community

TABLE 1. FLORISTIC CHARACTERISTICS OF HERBACEOUS SPECIES IN FIELDS AND ON LEVEES AT NAKHOU VILLAGE AND BAK VILLAGE, SAVANNAKHET PROVINCE, LAOS[1]

	In Fields	On Levees	In Common	Total
Wild species				
No. of families	17	37	22	47
No. of genera	23	78	42	116
No. of species	25	97	62	184
No. of hydrophytes	11	0	2	13
Cultivated species				
No. of families	7	6	0	13
No. of genera	10	7	0	17
No. of species	10	7	0	17
No. of hydrophytes	0	0	0	0

[1] "In Fields" and "On Levees" indicate the species that occur only in each of those habitats. "In Common" means species that occurred both in fields and on levees.

only through the influence of human activities and were determined according to HEAR (2004), Kasahara (1959), and Shimizu (2003). Rare species were determined according to the classification of Santisuk and Larsen (1997–2002) and Smitinand and Larsen (1970–1996).

RESULTS

GENERAL CHARACTERISTICS OF SAMPLED PLANTS AND PADDY FIELD TYPES

A total of 184 wild species, representing 116 genera and 47 families, were recorded (Table 1). Cyperaceae (30 spp.), Poaceae (29 spp.), and Scrophulariaceae (22 spp.) were the dominant families overall. Rare species recorded were *Drosera indica* L. (on levees), *Stylidium kunthii* Wall. (on levees), *Stylidium tenellum* Sw. ex Kunth. (both in fields and on levees), and *Stylidium uliginosum* Sw. ex Willd. (on levees). Among the wild species, a total of 43 were exotic species from Africa, America, Australia, India, or Madagascar. In addition, a total of 17 cultivated species representing 17 genera and 13 families were recorded (Table 1).

Diversity and other characteristics of the four paddy types are shown in Table 2. Of the wild species in fields, the number was greatest in hillside paddy (52) and least in wet paddy (27), with each paddy type including several unique species. Of the wild species on levees, the number was greatest in hillside paddy, which included multiple unique species.

CLASSIFICATION AND ORDINATION OF SAMPLE QUADRATS

From the analysis of wild species in fields, we obtained four vegetation types from the classification of the 78 quadrats (Fig. 3). At the first level division, group A and B corresponded to water regime. All quadrats in group A were subject to a long dry period during the year, whereas group B was composed of quadrats flooded throughout most of the year. The indicator species was *Limnophila geoffrayi* Bonati

TABLE 2. PLANT DIVERSITY AND OTHER CHARACTERISTICS OF HILLSIDE, HOME-SIDE, LOWLAND, AND WET PADDY FIELDS AT NAKHOU VILLAGE AND BAK VILLAGE, SAVANNAKHET PROVINCE, LAOS.

Paddy Type Mean Water Depth	Hillside 0–4 cm	Home-side 0–4 cm	Lowland 0–3 cm	Wet 6–18 cm
Wild species in fields				
No. of families	23	23	18	17
No. of genera	39	42	32	24
No. of species	52	49	38	27
No. of unique species	8	9	5	7
Species richness[1]	11.5 ± 4.8^b	17.2 ± 3.8^a	13.4 ± 2.8^b	7.8 ± 3.8^c
Shannon's index	3.03	3.03	3.01	2.53
Simpson's index	0.07	0.07	0.06	0.11
Evenness index	0.75	0.77	0.82	0.74
Wild species on levees				
No. of families	37	21	21	18
No. of genera	81	48	44	41
No. of species	125	62	57	59
No. of unique species	49	2	9	11

[1] Entry of species richness (number of species per quadrat) is mean ± standard error. Numbers in the same row followed by the same letter are not statistically different (α=0.05).

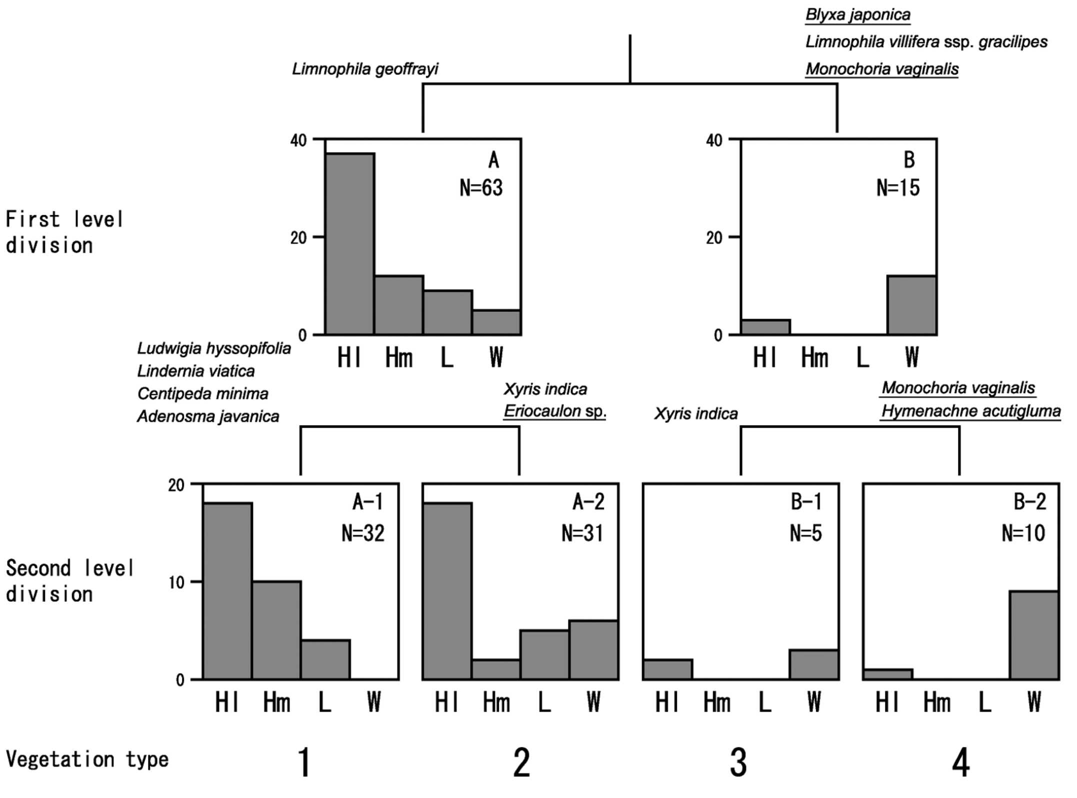

Fig. 3. TWINSPAN classification of 78 vegetation quadrats at Nakhou village and Bak village, Savannakhet Province, Laos. Plant names represent the indicator species for each division. Species with underlines are hydrophytes. Bars indicate the number of quadrats in the respective paddy types, such as hillside paddy (Hl), home-side paddy (Hm), lowland paddy (L), and wet paddy (W).

(hygrophyte) for group A and *Blyxa japonica* (Miq.) Maxim. ex Aschers. (hydrophyte), *Limnophila villifera* Miq. ssp. *gracilipes* (Craib ex Hoss.) Yamazaki (hygrophyte), and *Monochoria vaginalis* (Burm. f.) Presl (hydrophyte) for group B.

At the second level division in group A, most quadrats in home-side paddy were placed into subgroup A-1, whereas all quadrats in wet paddy were placed into subgroup A-2. Quadrats in hillside and lowland paddy were placed into both subgroups. Indicator species for A-1 were *Ludwigia hyssopifolia* (G. Don) Exell. (hygrophyte), *Lindernia viatica* (Kerr ex Barnett) Philcox (mesophyte), *Centipeda minima* (L.) A. Br. & Aschers. (mesophyte), and *Adenosma javanica* (Bl.) Koord. (mesophyte), indicating rather dry conditions. A-2 quadrats were characterized by the existence of *Xyris indica* L. (hygrophyte) and *Eriocaulon* sp. (hydrophyte), indicating wet conditions. In group B, most quadrats in wet paddy were placed into subgroup B-2, characterized by *Monochoria vaginalis* (hydrophyte) and *Hymenachne acutigluma* (Steud.) Gilliland. (hydrophyte), indicating a longer period of flooding in B-2 than in B-1, which was characterized by *Xyris indica* (hygrophyte).

The four vegetation types obtained by the TWINSPAN classification were arranged along DCA axis 1 in order from type 1 to type 4 (Fig. 4). In addition, there was a gradient in paddy types across axis 1 (Fig. 4a). Home-side and lowland paddy scored lower, whereas wet paddy scored higher. Hillside paddy was distributed widely along axis 1 in an order corresponding to the water regime (Fig. 4b). Quadrats with a long dry period had the lowest scores and those flooded almost throughout the year had high scores.

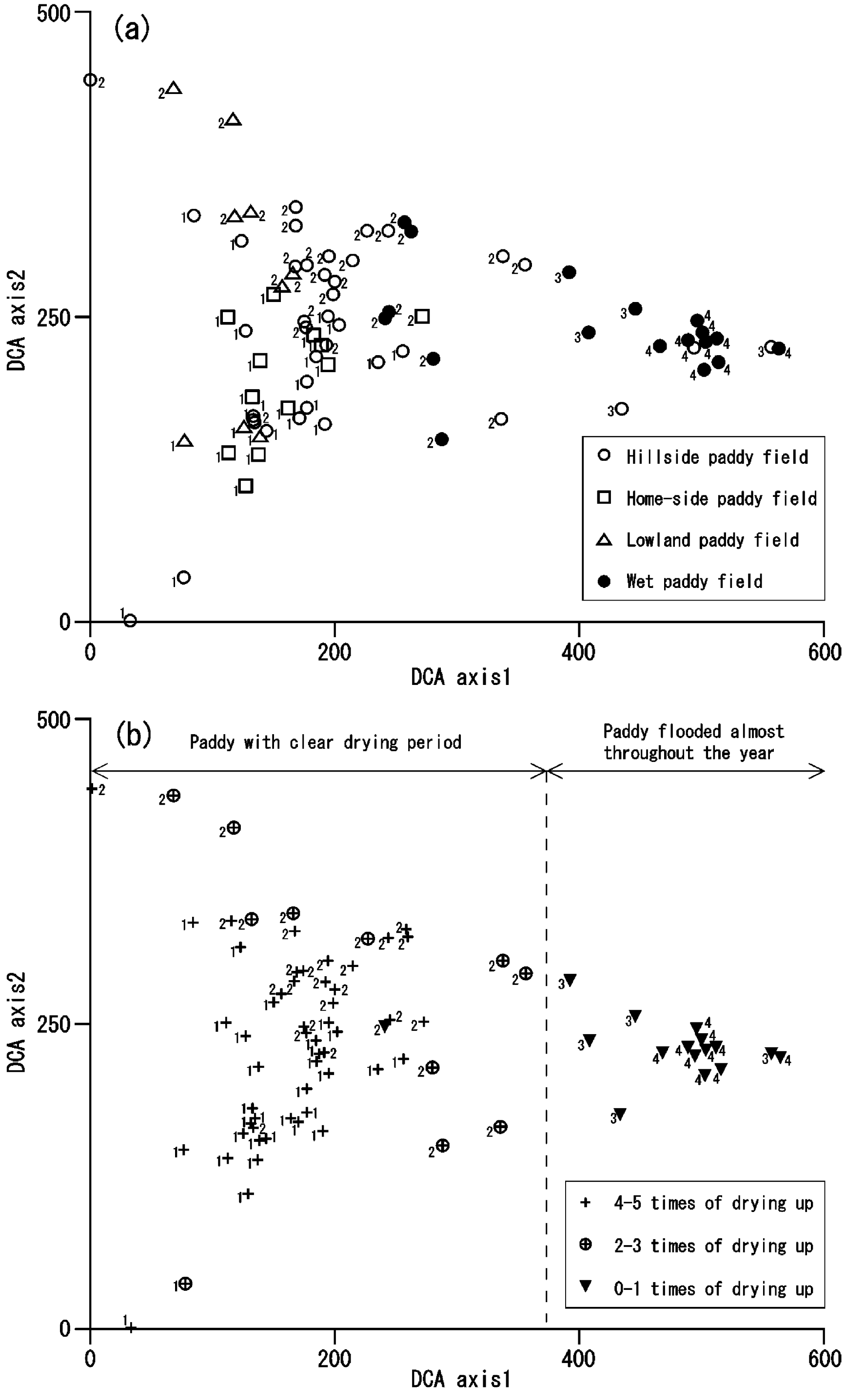

Fig. 4. Scatter diagram of the first two axes of DCA ordination of 78 vegetation quadrats for (a) paddy type and (b) hydroperiod (represented by the frequency of drying up during the survey period) at Nakhou village and Bak village, Savannakhet Province, Laos. Numbers 1, 2, 3, and 4 correspond to vegetation type obtained by TWINSPAN classification.

Agricultural Practices and Their Impact

Paddy vegetation was strongly influenced by agricultural practices. Some kinds of human impacts affected plant distribution on a broad scale. For example, flooding and plowing caused a clear difference between field habitat and levee habitat. Among the 184 wild species recorded, 25 species (13.6%) grew only in fields, 97 (52.7%) only on levees, and 62 (33.7%) both in fields and levees (Table 1). In addition, species composition varied with microhabitat on the levees, such as near the waterline, on the flat crown, and on a side-slope. Although many species tended to grow near the waterline and side-slope, only a few species, such as *Desmodium heterophyllum* (Willd.) DC. and grasses, survived on the flat crown, which was subject to continuous trampling. Moreover, the effect of livestock grazing after harvesting was pronounced. According to the interview survey and field observation, water buffaloes and cattle grazed almost all herbaceous species.

Other kinds of impacts occurred site-specifically with different frequency and intensity. *Fimbristylis miliacea* (L.) Vahl, *Ludwigia hyssopifolia*, and *Limnophila villifera* ssp. *gracilipes* were recognized as the most harmful weeds by villagers. *Fimbristylis miliacea* and *Ludwigia hyssopifolia*, however, were removed by manual uprooting during the peak of the rainy season when growth was most vigorous. On the other hand, *Limnophila villifera* ssp. *gracilipes* often covered wet paddy fields throughout the off-season of rice cultivation. Such fields were first weeded with hoes before plowing, consuming much time and labor. Repairing of paddy levees also seemed to affect species composition. For example, perennial herbs such as *Osbeckia chinensis* L., *Sida rhombifolia* L., and *Waltheria indica* L. grew on levees made of laterite, which require infrequent repair, whereas annuals were dominant on levees made of erodible sandy soil, which require frequent repair.

Useful Plants

A total of 19 wild species were directly used by villagers for food and other purposes (Appendix). We recorded 11 edible species: *Amaranthus viridis* L., *Blyxa japonica*, *Colocasia esculenta* (L.) Schott., *Glinus oppositifolilus* (L.) DC., *Justicia balansae* Lind., *Kaempferia galanga* L., *Limnophila geoffrayi*, *Lygodium* sp., *Marsilea crenata* Presl, *Monochoria vaginalis*, and *Smilax* sp. Of these, *Limnophila geoffrayi* and *Marsilea crenata* were not only dominant in paddy fields, but were also found to be important herbs in the local diet and were sold in markets. *Limnophila geoffrayi* has a fragrant smell and is an essential herb for the popular Lao dish *keng noomai* (bamboo shoot soup). Because the species only grows in paddy fields in the rainy season, plants are dried and kept for the dry season when live plants are not available. *Colocasia esculenta* grew wild on the shore of paddy levees. *Glinus oppositifolius* was sold in markets in the dry season, when other wild edible plants were scarce.

Local people used five species for medicines. A decoction of *Amorphophallus* sp. tubers was used for malaria. A decoction of leaves and roots of *Elephantopus scaber* L. was consumed orally for a stomachache. A paste of fresh leaves of *Eupatorium odoratum* L. was applied on wounds as an astringent. A decoction containing *Scoparia dulcis* L. roots, *Sida rhombifolia* roots, and *Imperata cylindrica* (L.) Beauv. var. *major* (Nees) Hubb. (which was not found in paddy field areas in this study site) roots was consumed orally for irregular menstruation. *Adenosma javanica* and *Ludwigia hyssopifolia* were used as pig feed. *Cyperus pilosus* Vahl was collected at the end of the rainy season and used as the raw material for mat weaving in Nakhou village. Floating plants, such as *Salvinia cucullata* Roxb. and *Salvinia natans* (L.) All., were not used directly, but were considered useful for maintaining lower water temperature in paddies. Moreover, almost all species were utilized as forage for water buffaloes and cattle.

Among the 17 cultivated species, 15 were edible plants that were apparently domesticated from wild species. *Allium ascalonicum* L., *Anethum graveolens* L., *Arachis hypogaea* L., *Brassica rapa* L. var. *chinensis* (L.) Kitam., *Citrullus lanatus* (Thunb.) Mats. & Nak., *Cucumis sativus* L., *Ipomoea batatas* (L.) Lam., *Vigna unguiculata* (L.) Walp. var. *sesquipedalis* (L.) H. Ohashi, and *Zea mays* L. were planted after rice (*Oryza sativa* L.) harvesting in home-side and lowland paddy fields where water was available nearby. *Canna edulis* Ker., *Capsicum frutescens* L., *Cleome gynandra* L., *Mentha* *aquatica* L. var. *aquatica*, and *Ocimum basilicum* L. were planted in small vegetable gardens on broadened paddy levees in the rainy season. At Nakhou village, *Cyperus corymbosus* Rottb. was planted in pools within the homestead and also in small marshes adjacent to paddy fields. It was collected twice a year for use in mat weaving. *Hymenocallis littoralis* (Jacq.) Salisb. was an important species; used in Buddhist ceremonies and for medicine, it was often planted in home gardens and was also found on paddy levees. Straw from rice plants was kept after threshing and used as feed for water buffaloes and cattle in the rainy season, a period in which they are excluded from grazing in paddy fields. Rice husks were used as feed for chicken, ducks, and fish.

Discussion

Characteristics of Species Composition Compared with Other Areas in Asia

The number of wild herbaceous species (87 in fields, 159 on levees, and 184 in total) recorded at only two villages was large compared with other areas in Asia. Kasahara (1959) recorded 191 paddy weeds from all over Japan. A study of paddy weeds in west Sri Lanka (658 fields in 329 villages from four districts) reported 136 species (75 in fields and 116 on levees; Chandrasena 1988). Tomita et al. (2003b) recorded 96 species (78 species were identified) from 179 rain-fed paddy fields with a wide range of rainfall, topography, soil, and hydrological conditions in northeast Thailand. The number of exotic species at the current study site was 43. This compares with 96 in Japan, 39 in west Sri Lanka, and 25 in northeast Thailand.

Many of the common wild species in fields in this study site were also common in northeast Thailand (Tomita et al. 2003b), where paddy fields were classified into seven types: direct dry-seeded fields with rich, medium, and poor water conditions; transplanted fields with rich, medium, and poor water conditions; and fallow fields. Dominant species (ISV>0.2) in at least one paddy type were: *Alysicarpus vaginaris* (L.) DC., *Cynodon dactylon* (L.) Pers., *Cyperus difformis* L., *Cyperus pulcherrimus* Willd. & Kunth, *Digitaria ciliaris* (Retz.) Koel., *Digitaria elongata* (Trin) Spring, *Echinochloa colonum* (L.) Link., *Fimbristylis miliacea*, *Ludwigia adscendens* (L.) Hara., *Ludwigia hyssopifolia*, *Melochia corchorifolia*, *Panicum repens*, and *Paspalum scrobiculatum* L. Ten of these species were also recorded in the present study, and, of these, *Fimbristylis miliacea*, *Ludwigia hyssopifolia*, and *Melochia corchorifolia* were dominant. Considering that *Fimbristylis miliacea* and *Ludwigia hyssopifolia* were found to be dominant in almost all types of paddy fields in northeast Thailand (Tomita et al. 2003b), they seem to be widespread from northeast Thailand to central Laos.

On the other hand, other species that were dominant in our study site, (*Adenosma javanica, Blyxa japonica, Centipeda minima, Cyperus haspan, Digitaria fuscescens, Glinus hernarioides, Limnophila geoffrayi, Limnophila villifera* ssp. *gracilipes, Lindernia viatica, Monochoria vaginalis, Rotala indica*, and *Utricularia aurea*) were not recorded in northeast Thailand (Tomita et al. 2003b). Although the topography, climate, flora, and fauna of the Mekong Valley in Laos and northeast Thailand are similar (Heckman 1974), this result suggests that some herbaceous species display site-specific dominance.

Effect of Water Regime on Paddy Vegetation

The results of the classification and ordination indicated that the water regime of paddy fields influenced the paddy vegetation in this study site. It has been pointed out that wetland vegetation is influenced not only by hydroperiod but also by water chemistry, availability of moisture in the soil during the dry season, and soil fertility (Goslee, Brooks, and Cole 1997; Pinder and Rosso 1998). In this study, water and soil quality were not investigated. Despite this limitation, it will be important to conduct provisional classification of paddy vegetation and subsequent identification of indicator species. The identification of more indicator species could lead to the development of a useful tool for wetland research and management because hydrological monitoring is often both expensive and time-consuming (Goslee, Brooks, and Cole 1997).

Factors Contributing to High Species Diversity

The mosaic distribution of different types of paddy fields was considered the most important factor contributing to species diversity. Higher species diversity at the field scale was associated with fields receiving less water, i.e., homeside, lowland, and hillside paddy (Table 2). A general reduction in plant diversity with increasing hydroperiod has also been reported from studies of wetlands (e.g., Pinder and Rosso 1998). However, wet paddy also contributed to the overall species richness in this study site because the species composition was different from other types of paddy fields. Consequently, the existence of various species unique to the different paddy types enhanced the local species diversity (Table 2). However, paddy fields are artificial wetlands (Lu 1995), and the water regime is managed by humans. As is often the case with paddy fields in Japan (Shimoda 2003), the paddy field flora will be simplified by the homogeneity of the water regime resulting from irrigation and drainage.

The presence of remnant species from the original vegetation also contributed to species diversity. For example, *Elephantopus scaber*, *Habenaria rostellifera* Reichb. f., *Kaempferia galanga*, and *Smilax* sp. are forest species, and *Drosera* spp. and *Utricularia aurea* Lour. occur in natural wetlands. These species may be regarded as temporary weeds: they occur in newly established fields but gradually decline and eventually disappear (Kasahara 1954). However, the paddy fields in this study site contained fields aged from 10 years to more than 100 years, and remnant species were recorded even on the levees of the older fields.

Human impacts were considerable. Human-made habitats contributed to the high species diversity, e.g., by harboring many species specializing in either field or levee habitat (Table 1). Livestock grazing and the various activities relating to rice cultivation appeared to prevent the paddy vegetation from undergoing succession to meadows of grasses or sedges. Shimoda (2003) revealed the high plant diversity in paddy fields by comparing herbaceous vegetation in paddy with that of abandoned fields. The study also showed that succession to meadows in abandoned fields can be prevented by human management such as mowing and maintenance of ditches (Shimoda 2003). Although mowing was not carried out in this study site, it is considered that the grazing of water buffaloes and cattle played a similar role to mowing.

Some rare species were recorded in this study site. It is considered that even a slight change in the paddy environment may lead to their extinction because their habitat or the number of individuals was limited. Even currently common species in paddy fields could drastically decrease in number if herbicide use is adopted (Smitinand and Larsen 1985). Some of the common wetland species in this study site—*Blyxa japonica*, *Ceratopteris thalictroides* (L.) Brongn., and *Salvinia natans*—are regarded as important for conservation in Japan, where herbicides are widely used in paddy fields (Ikeda and Miura 2002). Although wetlands have disappeared at alarming rates throughout the world (Mitsch and Gosselink 2000), it is apparent that herbicide-free paddy fields play a role in providing habitat for various wetland plants.

Biodiversity and Agricultural Productivity

It has been suggested that harmonizing agricultural productivity with biological diversity should be the ultimate goal of the analysis of paddy vegetation (Tomita et al. 2003a). In this study, an overall species inventory was conducted first as the basic groundwork. The relationship between paddy vegetation and subsistence livelihoods was described by identifying exploited (and cultivated) species, beneficial species, rare species, and harmful species (major weeds). This kind of provisional classification assists in the analysis of the interactions between agricultural practices and organisms (Gall and Orians 1992). Yet these interactions were not always confined within neat definitions. For example, even weed species harmful to rice production were useful as feed for livestock. In addition, agricultural intensification and innovation has begun to affect this study site, a place where previously only subsistence agriculture had been conducted. For example, irrigation with electric pumps was introduced to some of the lowland paddy fields at the beginning of 2004, enabling a second crop each year. The number of households using chemical fertilizer and powered tillage equipment will increase, although it is now still small. These changes will lead to increases in rice yield. However, the relationship between paddy vegetation and people's livelihoods may also change, though to what extent is unclear. Maintaining biological diversity is essential for productive agriculture, and ecologically sustainable agriculture is essential for maintaining biological diversity (Pimentel et al. 1992). Therefore, further study on paddy vegetation is necessary to provide the knowledge required to maintain both agricultural productivity and biological diversity.

Conclusion

In this study site, paddy fields comprised not just a homogenous landscape producing merely rice, but also harbored many plant species, including exploited species, beneficial species and rare species. The water regime varied with different types of paddy field from shorter to longer hydroperiod, influencing the paddy vegetation. The presence of species unique to the different paddy types (hillside, home-side, lowland, and wet paddy) was considered the greatest factor contributing to the high species diversity. The presence of remnant species from the original vegetation, such as forest species or natural wetland species, was also significant. Moreover, agricultural practices influenced the species composition. Human-made habitats contributed to high species diversity by harboring many species specializing in field or levee habitat. Human activities such as flooding and plowing, weeding, repairing paddy levees, and livestock grazing prevented paddy vegetation from making the succession to homogenous meadows of grasses or sedges. Thus, multiple plant species coexisted in paddy fields under various agricultural practices, and some of these species were essential as local food or for subsistence livelihoods. This kind of analysis of the interaction between vegetation and agricultural practices makes an important contribution to the understanding of biological diversity in human-managed ecosystems.

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APPENDIX. LOCAL NAME OF USEFUL WILD SPECIES AT NAKHOU VILLAGE AND BAK VILLAGE, SAVANNAKHET PROVINCE, LAOS.

Scientific Name	Family	Local Name	Use
Justicia balansae Lind.	Acan	*Phak ka taa*	Food
Amaranthus viridis L.	Amar	*Phak hom*	Food
Amorphophallus sp.	Arac	*Ka bouk paa*	Medicine
Colocasia esculenta (L.) Schott.	Arac	*Kok bon*	Food
Elephantopus scaber L.	Ast	*Khi fai nok khoum*	Medicine
Eupatorium odoratum L.	Ast	*Nya kiu/Nya falang*	Medicine
Cyperus pilosus Vahl	Cyp	*Pheu naa*	Mat weaving
Blyxa japonica (Miq.) Maxim. ex Aschers.	Hydr	*Nee poua*	Food
Sida rhombifolia L.	Mal	*Nya khat*	Medicine
Marsilea crenata Presl	Mars	*Phak ven*	Food
Glinus oppositifolius (L.) DC.	Moll	*Phak dang khom*	Food
Ludwigia hyssopifolia (G. Don) Exell.	Onag	*Kok kadian*	Feed
Monochoria vaginalis (Burm. f.) Presl	Pont	*Phak i hin*	Food
Lygodium sp.	Schi	*Phak kout kapom*	Food
Adenosma javanica (Bl.) Koord.	Scr	*Nya pheun*	Feed
Limnophila geoffrayi Bonati	Scr	*Phak ka nyeng*	Food
Scoparia dulcis L.	Scr	*Nya khai hao*	Medicine
Smilax sp.	Smil	*Kheua kheuang*	Food
Kaempferia galanga L.	Zin	*Van toup moup*	Food

Families: Acan, Acanthaceae; Amar, Amaranthaceae; Arac, Araceae; Ast, Asteraceae; Cyp, Cyperaceae; Hydr, Hydrocharitaceae; Mal, Malvaceae; Mars, Marsileaceae; Moll, Molluginaceae; Onag, Onagraceae; Pont, Pontederiaceae; Schi, Schizaeaceae; Scr, Scrophulariaceae; Smil, Smilacaceae; Zin, Zingiberaceae.