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Weed biodiversity and rice production during the irrigation rehabilitation process in Cambodia

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ABSTRACT

A phytosociological survey of weed species was conducted during the rainy season in 2008 in paddy fields at different distances from the main irrigation canal in the Kamping Puoy Irrigation Rehabilitation Area in northwestern Cambodia. The spatial variation in water depth was large between upstream (shallower) and downstream (deeper) paddies, which resulted in different weed, with many Poaceae and Cyperaceae species observed on levees in upstream and aquatic herbs in downstream paddies. Chemical fertilizer input levels were generally small and average rice yield was relatively low (ca. 2.3 t/ha). Traditional and less intensive weed management options such as hand weeding, mid-season tillage, and post-harvest straw burning were common, while the herbicide 2,4-D was also widely used. Weed species in the paddy ecosystem used by villagers included *Ipomoea aquatica*, *Nymphaea nouchali*, and *Monochoria vaginalis* (occasional, for human consumption) and graminoid species (frequent, for cattle feed in addition to rice straw). Greater inorganic fertilizer input was associated with a lower diversity of weed species, but grain yield and weed diversity indices had no negative relation among different locations. This survey revealed relatively small extent of intensification in the irrigation rehabilitation area in Cambodia, which led to high weed diversity, including numerous plant species available for use to support farmers' livelihoods in the area.

1. Introduction

Paddy fields provided various ecosystem services, such as (1) provisioning of rice grain, rice straw, and other plant species (i.e., weeds) and animals; (2) regulating air temperature and flood control; (3) cultural services of festivals and rituals associated with farming; (4) supporting nutrient cycles and disease control; and (5) preserving genetic diversity (Zedler and Kercher, 2005). Paddy fields were traditionally characterized by a rich flora, with more than 1800 plant species (both aquatic and terrestrial) associated with rice in southeast Asia (Moody, 1989; Soerjani et al., 1987), cropped using traditional methods, i.e., water flooding but with distinct ecological phases, incomplete leveling, heterogeneous microscale conditions, repetitive disturbance due to tillage, low fertilizer input, hand weeding without using synthetic herbicides (Fernando, 1993; Rao et al., 2007).

Cambodian paddy fields might be unique in that relatively few farmers adopted modern agricultural techniques, partly due to the country's long civil war (from 1970 to 1993). For example, the rate of fertilizer use was much lower than that in neighboring countries: 5 in Cambodia versus 133 in Thailand and 324 kg/ha in Vietnam, based on averages from 2002 to 2004 (Yu and Fan, 2009). The area devoted to dry-season fully irrigated rice was only 14% of the total cultivated area in Cambodia (JICA, 2010). The Cambodian government recently issued a national policy to increase rice production from 7.3 in 2010 to 9.1 Mt in 2015 by increasing the dry-season irrigated rice area from 385,000 in 2010 to 480,000 ha in 2015; the government also aimed to increase exports of unpolished rice from the estimated value (including unofficial transportation to its neighboring countries) of 2.06 in 2010 to 2.89 Mt in 2015 (RGC, 2010). In the future, Cambodia's rich weed biodiversity might decrease in those areas where modern agricultural techniques were widely introduced, such as paddy fields undergoing irrigation rehabilitation.

The aim of this study was to provide baseline data of weed flora for the assessment of possible trade-offs and synergies between weed biodiversity and rice production in Cambodian paddy fields

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under a scenario of shifting management schemes from traditional to modern methods (Supplementary Fig. 1). A hypothesis was proposed that the rice ecosystem was heterogeneous and level of production intensity was relatively low, which might allow up to some extent to increase rice yield without decreasing weed diversity and weed provision function of ecosystem services in the Cambodian paddy.

2. Material and methods

Cambodia had a tropical monsoon climate, with a dry season that lasts from December to May and a rainy season that lasts from June to November. The monthly maximum and minimum temperatures in Battambang province were 33.0 (in April) and 23.2 °C (in January), respectively, and the annual precipitation averaged 1368 mm.

The Kamping Puoy Irrigation Rehabilitation Area (KPIRA), located west of Battambang city in Battambang province of northwestern Cambodia (13°02′ N, 103°04′ E), was one of the largest irrigated paddy areas in Cambodia (ca. 2800 ha out of the ca. 5000-ha area were irrigated in 2008). The irrigation water came from the Kamping Puoy reservoir through irrigation canals, which were constructed during Pol Pot's regime from 1975 to 1979. The irrigation system did not function well, possibly due to poor design, and it was repaired by Italian and Japanese government agencies from 1998 to 2006 (Try, 2008). The goal of the rehabilitation project was to maximize the area that could be planted with rice during the dry season and hence to improve the system to permit cultivation of two rice crops.

The study site was the downstream 950-ha zone of KPIRA, located about 12 km from the Kamping Puoy reservoir. The irrigation system in the 950-ha zone was rehabilitated by the grassroots Kusanone scheme of the Japan International Cooperation Agency (JICA) from 2001 to 2003, and dry-season rice production was only partly implemented between 2003 and 2008.

In the 950-ha zone, six secondary irrigation canals and six secondary drainage canals (ca. 1–3.5 km long) were connected to the main irrigation and drainage canals. Twenty-eight paddy fields were selected from 140 fields along two secondary canals (D2-1 and D2-7), with D2-1 located about 3.4 km upstream of D2-7 along the main canal (N2). The main and secondary irrigation and drainage canals were not lined with concrete. The paddy fields were grouped into upstream (U), midstream (M), and downstream (D) paddies based on their distance from the main canal along the secondary canals D2-1 and D2-7: D2-1 upstream (1U; 0.3 km, 4 selected from 31 fields), D2-1 midstream (1M; 1.2 km, 6 selected from 38 fields), D2-1 downstream (1D; 2.4 km, 6 selected from 29 fields), D2-7 upstream (7U; 0.1 km, 4 selected from 8 fields), D2-7 midstream (7M; 0.8 km, 4 selected from 20 fields), and D2-7 downstream (7D; 1.6 km, 4 selected from 14 fields). The paddy areas along D2-1 were rehabilitated earlier than those along D2-7. By 2008, farmers only grew a single crop per year in 7D, 7M, 1D, whereas two crops were grown annually in the other fields.

Environmental variables, rice and weed growth variables and weed species were collected in two quadrats per field (each 2 m × 2 m) in 28 fields at 2-month intervals from August 2008 (planting time during the rainy season) to February 2009 (after harvest), for a total of 224 quadrats, while agronomic management variables were collected for each field (Supplementary Table 1). The quadrats were established toward the middle of each field to minimize the influence of edge effects, and their locations were determined by means of GPS (eTrex Legend HCx; Garmin Corporation, Olathe, KS, USA). The same quadrats were used for the five observations from August to February. Mean and standard deviation for all the environmental, rice and weed growth, and management variables were calculated for each of the six paddy groups (1U, 1M, 1D, 7U, 7M, 7D) from the measurements of quadrats or fields.

2.1. Environmental variables

As an indicator for water availability and microtopography, the depth of the standing water was determined in all quadrats. Soil moisture was measured by a CS620 HydroSense water content probe (Campbell Scientific, Logan, UT, USA) and soil hardness by a soil compaction meter (Fujiwara, Tokyo, Japan). Water and soil pH were measured by a Twin B-212 pH meter (Horiba, Kyoto, Japan). In each quadrat, the maximum height of rice plants and weeds was measured using a pole. The coverage of rice and weed within each quadrat was visually assessed by Braun-Blanquet (1964) scale: + = <1, 1 = 1–5, 2 = 6–25, 3 = 26–50, 4 = 51–75, and 5 = 76–100%.

2.2. Agronomic management variables

The owners and managers of the 28 surveyed paddy fields in Ta Kream and Poy Svay villages were interviewed about their management practices, including planting methods (transplanting or direct seeding), organic and inorganic fertilizer types and application rates, herbicide use (yes or no), hand weeding (yes or no), traditional weed control method (i.e., mid-season tillage) (yes or no), crop residue management after harvest (i.e., burning) (yes or no), and rice yield. Rice yield was also estimated from the samples from each field to confirm agreement with the interviewed values.

2.3. Weed data analysis

Voucher specimens were collected for each plant species, as well as for unidentified species with low frequency and low coverage. Identification of species was based on Dy Phon (2000), Harada et al. (1996), and Kadono (1994) using specimens at the Bangkok Forest Herbarium.

All vegetation data were converted into mean cover classes to improve the normality and homogeneity within groups (McCune and Grace, 2002). The dominance values in the Braun-Blanquet scale were therefore converted into the following mean cover classes: + = 0.5, 1 = 3, 2 = 15, 3 = 37.5, 4 = 62.5, and 5 = 87.5%.

The life forms of the species were divided into five categories based on Reimer (1984): (1) emergent graminoids (*e-g*), whose roots and basal portions grow beneath the surface of shallow water but whose leaves and stems were primarily in the air and that were grasslike herbaceous plants with leaves that were mostly narrower than their length (i.e., linear in outline); (2) emergent broadleaf plants (*e-b*), which were emergent plants with leaves about as broad as they were long, including ferns; (3) floating-leaf plants (*fl*), whose leaves float on the water surface but whose roots were anchored in the substrate; (4) submerged plants (*s*), which spend their entire life cycle (except during flowering) beneath the surface of the water; and (5) levee plants (*l*), which prefer upland conditions and therefore appear mainly on levees and were not common inside paddies.

To assess weed diversity of each plant community, species richness (the number of species present in a quadrat) and Simpson (1949) diversity index (D') were used. Correlation analysis was conducted for species richness and Simpson's diversity index with all the other managemental and environmental parameters using all the quadrat data in each month.

Detrended correspondence analysis (DCA; Hill and Gauch, 1980) was performed to investigate the relationships between weed communities and abiotic or anthropogenic factors, some of which were discrete variables with only two categories (e.g., yes or no for the use of herbicides). After omitting rare species that had been