

Spring weed communities of rice agrocoenoses in central Nepal

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Abstract – Rice field weed communities occurring in central Nepal are presented in this study. The research was focussed on the classification of segetal plant communities occurring in paddy fields, which had been poorly investigated from a geobotanical standpoint. In all, 108 phytosociological relevés were sampled, using the Braun-Blanquet method. The analyses classified the vegetation into 9 communities, including 7 associations and one subassociation. Four new plant associations and one new subassociation were proposed: *Elatinetum triandro-ambiguae*, *Mazo pumili-Lindernietum ciliatae*, *Mazo pumili-Lindernietum ciliatae caesulietosum axillaris*, *Rotaletum rotundifoliae* and *Ammanietum pygmae*. Due to species composition and habitat preferences all phytocoenoses were included into the *Oryzetea sativae* class and the *Ludwigion hysopifolio-octovalvis* alliance. As in other rice field phytocoenoses, the main discrimination factors for the plots are depth of water, soil trophic and species richness. The altitudinal distribution also has a significant influence and separates the *Rotaletum rotundifoliae* and *Elatinetum triandro-ambiguae* associations. The study shows that anthropogenic rice fields can harbour relatively rich rush and water vegetation. More than 80 species were noted in the vegetation plots. Several of them are considered to be extremely rare and have been recorded on the world Red List.

Key words: anthropogenic habitats, *Oryzetea sativae*, rice fields, segetal communities

Introduction

Rice production in Nepal plays the most important role in the agricultural economy and in food supply for the society. A half of the total crop area is devoted to rice cultivation, giving ca 60% of total grain production. However, this figure has dropped considerably in the last decade (Gumma et al. 2011). Rice paddy fields are located from lowlands (e.g. Tarai) to ca. 3,000 m in the western Himalayas (Jumla valley), which is the highest elevation of rice cultivation in the world (Paudel 2011). More than 70% of the rice-growing area in Nepal is under rainfed conditions. Rice is usually grown only once a year, in the wet season; monsoon rain is the single source of water supply for rice cultivation. More than 60% of the rice production comes from lowland Tarai from the plain valleys of Gandaki, Narayani, Karnali. Rainfed paddies in hills intermountain basins supply mainly local societies and are less effective. Although Nepal is the world's second richest country in water resources, more

than 18% of the fields are irrigated and some southern areas are threatened by draught (CBS 2007). Rice is the most economically important food crop in Nepal. Its production employs two-thirds of the national labour and supplies more than 40% of calories for the people and is crucial for national food security (Gumma et al. 2011).

In most parts of Nepal, rice is grown on small family-based subsistence farms with an average size varying from less than 0.1 to 1.0 ha. This fragmentation of holdings promotes extensification of rice production and persistence of many weed species in rice segetal agroecosystems.

Weeds are considered one of the major problems in rice production in Asia, including Nepal (Papademetriou et al. 2000, Bhatt et al. 2009). Losses due to weeds have been estimated at 12% of the crop yields (Manandhar et al. 2007). Considerable progress in weed control has been achieved with various measures such as ensuring the purity of rice seed, the proper selection of cultivar and seeding rate, the proper planting method, good land preparation and

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water management, hand weeding and chemical weed control, as well as crop rotation (De Datta 1981), used together in a system of integrated weed management. The frequency and abundance of weeds varies with different methods of cultivation. In Nepal, there are several types of rice cultivation, such as upland, dry-seeded, deepwater, transplanted, and wet-seeded or pre-germinated direct-seeded rice. In transplanted or deepwater plantings the weeds are limited by unsuitable conditions for establishment of plants. Direct seeded rice crops are the most weed-infested with yearly yield losses of up to 75% (Manandhar et al. 2007).

Rice fields are still recognized globally as well as in southern Asia as important refuges for many wetland and water species. Many of them are highlighted by the IUCN as important in terms of biodiversity conservation and red-listed. Among others, *Lindernia ciliata*, *Ammannia multiflora*, *Ludwigia perennis*, *Aeschynomene indica*, *Cyperus michelianus*, *Geissaspis cristata*, *Limnophila erecta*, *Marsilea minuta*, *Hydrocera trifolia* and *Monochoria vaginalis* can be mentioned (IUCN 2013). The increasing food demand will lead inevitably to intensification of rice production and then impoverishment and degradation of rice field phytocoenoses. Perhaps this is the last chance to document and classify the vegetation types of rice paddies in south Asia.

As to maintain the withdrawing segetal weeds and to stop the impoverishment of agrocoenoses, many conservation actions and research works have been implemented in recent years (e.g. van Elsen et al. 2006). Recent studies were focused mainly on the effect of cultivation methods on the floristic composition and richness of weed communities (Kent et al. 2001, Hyvönen and Salonen 2002, Chauhan 2013). Many studies have recorded basic floristic and vegetation data for rice crops, often focussing on their conservation value or ecological services (Barrett and Seaman 1980, Camenisch and Cook 1996, Turki and Sheded 2002, Bambaradeniya et al. 2004). Specific biological features which are supposed to be responsible for weed decline have received less attention (e.g. Gibson et al. 2006). Phytosociological studies of rice field communities have been carried out for several years mainly in the countries of southern Europe (Bolòs and Masclans 1955, Piccoli and Gerdol 1981, Carretero 1989, Parras and Lorca 1993, Garcia and Benzal 2009), Japan (Miyawaki 1960), the Korean Peninsula (Kolbek et al. 1996, Kolbek and Jarolimek 2013, Shimoda and Song 2014), Tajikistan (Nowak et al. 2013) and Thailand (Nowak et al. 2015a). To date, no detailed research into the plant communities of these specific ecosystems has been conducted in other important regions of rice cultivation, for example, in Indonesia, India, Madagascar or central Asian countries. Thus the main aim of the presented research is to reveal the diversity of weed associations in rice crops in Central Nepal and their syntaxonomical classification within the *Oryzetea sativae* class.

Material and methods

Study area

Nepal is located in southern Asia between 80°03' and 88°11'E, and 26°21' and 30°26'N, situated at altitudes between 78 m and 8,848 m (Sagarmatha Peak; Fig. 1). It

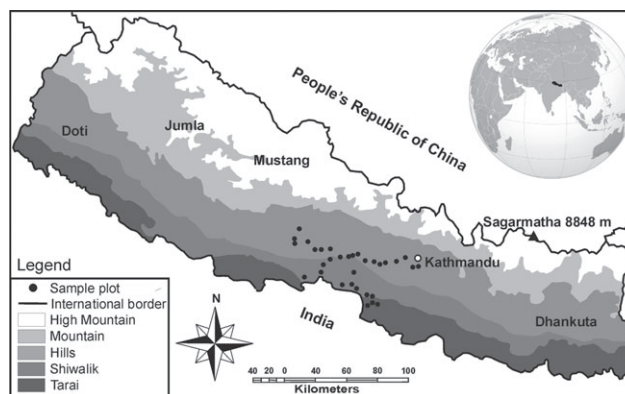


Fig. 1. The study area in Central Nepal with main cities and biogeographical zones.

shares its northern border with China and from the east, south and west it is surrounded by India. The country covers 147,181 km² with a population of ca 29 million. The country is divided into five main ecological zones: Himalayas, High Hills, Mid Hills, Siwalik and lowland Terai. The area of the country is drained by three main tributaries of the Ganges: the Kosi, Gandaki and Karnali Rivers. Because of the extreme variations in altitude, topography and physical condition, the agro-climatic conditions, the cultivation methods and types are very diverse in Nepal. On account of the climate there is a considerable variability of rice landraces found throughout the country, adapted to specific environments. Thus, Nepal is considered a world biodiversity centre for *Oryza sativa* (Asian rice) diversity (van Dusen et al. 2007). It is estimated that in Nepal about 2000 different landraces of cultivated rice are in use and 4 taxa of wild rice still occurs (*O. nivara*, *O. ruffipogon*, *O. officinalis* and *O. granulata*; Gupta et al. 1996). The rice paddy fields are categorized according to the source of irrigation: seasonal streams (kholapani), rivers of snow-melt-water (gadkule) or waterlogged marshes (sim; Bajracharya et al. 2006).

Nepal has tremendously varied climate conditions, from tropical in the south to temperate in the north with alpine and arctic conditions in the highest elevations of the Himalayan range. The country area is divided into 6 climatic zones: tropical (up to 1,000 m a.s.l.), subtropical (1,000–2,000), temperate (2,000–3,000), subalpine (3,000–4,000), alpine (4,000–5,000) and nival (above 5,000 m a.s.l.). Generally five major seasons are distinguished: spring, summer, monsoon, autumn and winter. In the north, summers are cool and winters severe, while in the south summers are tropical and winters are mild. In the Terai, summer temperatures often exceed 37 °C, while winter temperatures range from 7 to 23 °C. In hilly central Nepal and valleys, summers are temperate while winter temperatures can plummet under zero. In Kathmandu the summer temperatures range between 19 and 35 °C and in winter between 2 and 12 °C. The average annual rainfall is 1,600 mm, but it varies by ecoclimatic zones, such as 5,500 mm in the windward slopes of Annapurna Himal to below 300 mm in the rain shadows of Mustang.

According to biogeographical division of Takhtajan (1986) Nepal belongs to the Sino-Japanese region (Eastern Himalayan province), Irano-Turanian region (Tibetan Prov-

ince, Western Himalayan Province), Sudano-Zambezian region (Sindian Province) and Indian region (Bengal and Indochinese provinces). Central Nepal lies generally in the Bengal province.

The flora of Nepal counts more than 6,000 flowering plant species with ca. 250 endemics (Press et al. 2000). This number is still being amended upwards (Ferille and Lachard 2013, Nobis et al. 2014a, b). Around 218 vascular plants were reported as weeds of rice paddy fields (Moody 1989, Bhatt et al. 2009).

Data and analyses

During the study, in May 2013, 108 vegetation relevés were collected in rice fields in central Nepal (Fig. 1). The sampling sites were located mainly in the valleys of the rivers: Trisuli, Kali Gandaki, Rapti, Madi, Marsyangdi, Anahi Khola and Tinau. The size of each vegetation relevé varied from 3 (some plots of water and mud communities) to 25

m², depending on plant density, homogeneity of vegetation cover and the size of homogenous spatial units. In each relevé, all vascular plant species were recorded according to the cover-abundance scale of Braun-Blanquet (1964). The 7-degree scale was used (r, +, 1, 2, 3, 4, 5).

All the relevés were stored in the JUICE program (Tichý 2002). A TWINSpan analysis (Hill 1979) and detrended correspondence analyses (DCA) were performed using the floristic data set (presence-absence data, no down-weighting of rare species) to check the manual floristic-sociological classification and to illuminate the relationships between the groups. For the ordination, CANOCO for Windows 4.5 was used (ter Braak and Šmilauer 2002). The relevés data showed a clear unimodal response, with total inertia of ca. 5.

Vegetation classification follows the sorted table approach of Braun-Blanquet (1964). In the analytic tables (Tab. 1, On-line Suppl. Tabs. 1, 2), species constancies are

Tab. 1. Associations of the Potametea class in rice fields of central Nepal during the study, in May 2013. LS – *Lemno-Spirodeletum polyrrhizae*; Nm – *Najadetum minoris*; CLd – Community of *Limnobium dubium*; No – number. The cover-abundance scale of Braun-Blanquet (1964) was used: r = 1 or 5 individuals; + = few individuals (< 20) with cover < 5%; 1 = many individuals (20–100) with cover < 5%; 2 = 5%–25% cover; 3 = 25%–50% cover; 4 = 50%–75% cover; 5 = 75%–100% cover.

Successive number of relevé	1	2	3	4	5	6	7	8	9	10	11	12			
Day/month	3/5	6/5	6/5	6/5	6/5	7/5	7/5	7/5	7/5	8/5	8/5	8/5			
Water depth (cm)	15	15	20	10	13	10	4	5	15	15	15	10			
Altitude (m)	568	217	217	217	217	205	190	190	205	377	377	377			
Cover of herb layer (%)	70	45	40	70	85	40	55	55	25	65	40	45			
Relevé area (m ²)	25	25	25	25	25	25	25	25	25	3	3	3	No. of occurrence	No. of occurrence	No. of occurrence
pH	6.8	6.8	–	6.8	7.0	6.5	–	7.2	7.1	–	7.5	–			
Number of weeds	10	2	3	4	3	3	6	6	2	4	4	3	rel.	rel.	rel.
Association/Community	LS	LS	LS	Nm	Nm	Nm	Nm	Nm	Nm	CLd	CLd	CLd	1–3	4–9	10–12
Cultivated plant															
<i>Oryza sativa</i>	3	3	4	3	2	3	2	3	3	2	2	2			
Ass. <i>Lemno-Spirodeletum polyrrhizae</i>															
<i>Spirodela polyrrhiza</i>	3	3	2	1	+	.	.	.	.	.	.	+	3	2	1
O. <i>Lemnetalia minoris</i> et Cl. <i>Lemnetea minoris</i>															
<i>Azolla filiculoides</i>	1	.	.	.	.	.	.	.	.	.	.	.	1	–	–
Ass. <i>Najadetum minoris</i>															
<i>Najas minor</i>	.	.	.	4	5	3	3	2	2	+	+	.	–	6	2
Comm. <i>Limnobium dubium</i>															
<i>Limnobium dubium</i>	+	.	.	.	.	.	.	.	.	4	3	3	1	–	3
Accompanying species															
<i>Echinochloa colona</i>	.	.	.	.	.	+	+	+	1	.	.	.	–	4	–
<i>Cyperus difformis</i>	+	.	.	.	.	.	+	.	.	.	+	+	1	1	2
<i>Alternanthera sessilis</i>	1	.	.	.	.	.	+	1	.	.	.	.	1	2	–
<i>Cyperus iria</i>	1	.	.	.	.	.	.	.	.	+	+	.	1	–	2
<i>Centella asiatica</i>	.	.	.	.	.	.	2	3	.	.	.	.	–	2	–
<i>Polygonum barbatum</i>	.	1	2	.	.	.	.	.	.	.	.	.	2	–	–
<i>Elatine triandra</i>	.	.	.	.	.	.	1	+	.	.	.	.	–	2	–
<i>Echinochloa crus-galli</i>	.	.	.	.	.	+	.	+	.	.	.	.	–	2	–

Sporadic species: *Commelina diffusa* 1(+); *Cynodon dactylon* 5(+); *Dopatrium junceum* 10(+); *Elatine ambigua* 4(+); *Fimbristylis miliacea* 4(+); *Lindernia anagallis* 1(+); *Lindernia ciliata* 3(+); *Rotala rotundifolia* 1(1); *Veronica beccabunga* 1(2).

Locality of relevé: 1 – (274548,3; 850244,4); 2, 3, 4, 5 – (273454,5; 842941,6); 6, 7, 9 – (273459,1; 842937,5); 8 – (273522,3; 842954,5); 10, 11, 12 – (274804,5; 845203,8).

given in constancy classes (Dierschke 1994). In the case of fewer than 8 relevés, the absolute number of species occurrences was specified. Some newly presented communities are described as associations according to the International code of phytosociological nomenclature (Weber et al. 2000). The presented communities are arranged into a syntaxonomic overview at the end of the description.

For documentation of basic habitat conditions governing the occurrence of the community, alkalinity was determined with an ELMETRON CP-105 pH meter. Plant names were adopted mainly after the International Plant Names Index (2012). The herbarium collection is hosted in OPUN (Opole University, Opole).

Results

General floristic features

The number of taxa recorded in the relevés totals 82, with 68 taxa exceeding 1% constancy and 47 taxa 5%. Those with the highest constancy are: *Alternanthera sessilis* (83 concurrences), *Cyperus difformis* (65), *Mazus pumilus* (61), *Echinochloa colona* (52), *Centella asiatica* (45), *Cynodon dactylon* (44), *Fimbristyllis miliacea* (44), *Lindernia ciliata* (39), *Cyperus iria* (34), *Lindernia procumbens* (31), *Veronica anagallis-aquatica* (28), *Elatine triandra* (26), *Bacopa procumbens* (25) and *Marsilea minuta* (21). The sampled plots of vegetation are almost exclusively composed of species originating from the *Oryzetea sativae* class (Miyawaki 1960). Only a few species, like *Cynodon dactylon*, *Veronica anagallis-aquatica*, *V. beccabunga*, *Juncus prismatocarpus*, *Ranunculus sceleratus*, *Vicia hirsuta*, *Chenopodium album*, *Paspalum distichum* and *Portulaca oleracea*, often occur outside the hygrophilous vegetation of paddy fields. They occupy mostly drier segetal and ruderal habitats or are typical for rushes. *Cynodon dactylon* has a wider ecological amplitude and was spotted in mud, meadow and rush communities. There is also a distinct group of obligatory water species such as *Spirodela polyrrhiza*, *Limnobium dubium*, *Azolla filiculoides*, *Nymphaea nouchalii* and *Vallisneria spiralis*. But the majority of the taxa found are related to muddy biotopes and have an amphibious character.

Numerical ordination

The detrended correspondence ordination run for the entire data set distinctively separates the water plant communities which are set to the left part of the diagram. Those are the *Limnobium dubium* community, *Najadatum minoris* and *Lemno-Spirodeletum polyrrhizae* (Fig. 2). The gradients of water decrease and plots related to communities occurring on mud are located on the right part of the diagram. The associations of *Elatinetum triandro-ambiguae* and *Rotaletum rotundifoliae* are positioned in the bottom part of the graph. They prefer rainfed paddy terraces with clayey, brown muds as a soil substrate and intermediate period of water inundation. Phytocoenoses concentrated in the central and right parts of the graph are similar in terms of habitat preferences. They occupy muddy soils with higher tro-

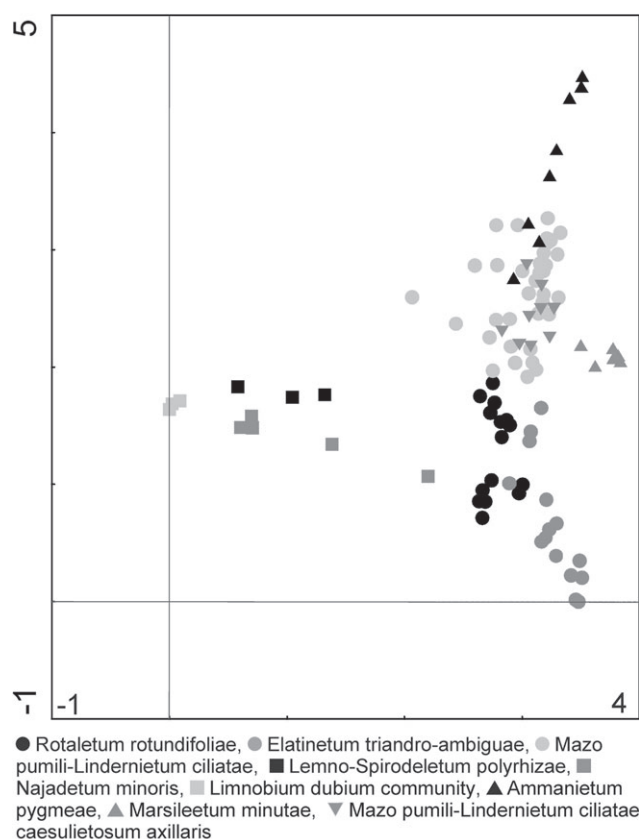


Fig. 2. Detrended correspondence analysis ordination for all samples (N = 108).

phy and are generally composed of higher number of species despite the lower total cover of herb layer (Figs. 2, 3). Only the *Marsileetum minutae* association is rather species poor and occurs in rice stands during the early phenological phase. The *Mazo pumili-Lindernietum ciliatae* association is considerably dispersed, showing the highest variability in floristic structure. Several plots with a greater amount of sand fraction in the soil have been classified as subassociation with frequent occurrence of *Caesulia axillaris* as diagnostic species. The upper section of the figure is occupied by plots related to *Ammanietum pygmeae*. This phytocoenosis is relatively species rich, however with low abundance of weeds. It develops on fertile muddy substrates in irrigated fields located in the warmest areas in the Kali Gandaki River valley. The association has a loose, open structure and was found on sites with low rice stands density. All of the defined plant associations are relatively distinct. Only some small overlaps occur, because of habitat similarities and there are some widely distributed, non-specific species in common (*Alternanthera sessilis*, *Cyperus difformis*, *Cynodon dactylon*, *Echinochloa colona*). This lack of powerful discrimination between some associations in the DCA could be also due to the relatively low number of species per relevé in rice field phytocoenoses and to a low degree of fidelity for some rush or aquatic species. It is widely known, that although species of hygrophilous habitats display certain habitat preferences, different associations can thrive in the same pond (Riis et al. 2000, Hatton-Ellis and Grieve 2003, Gacia et al. 2009).

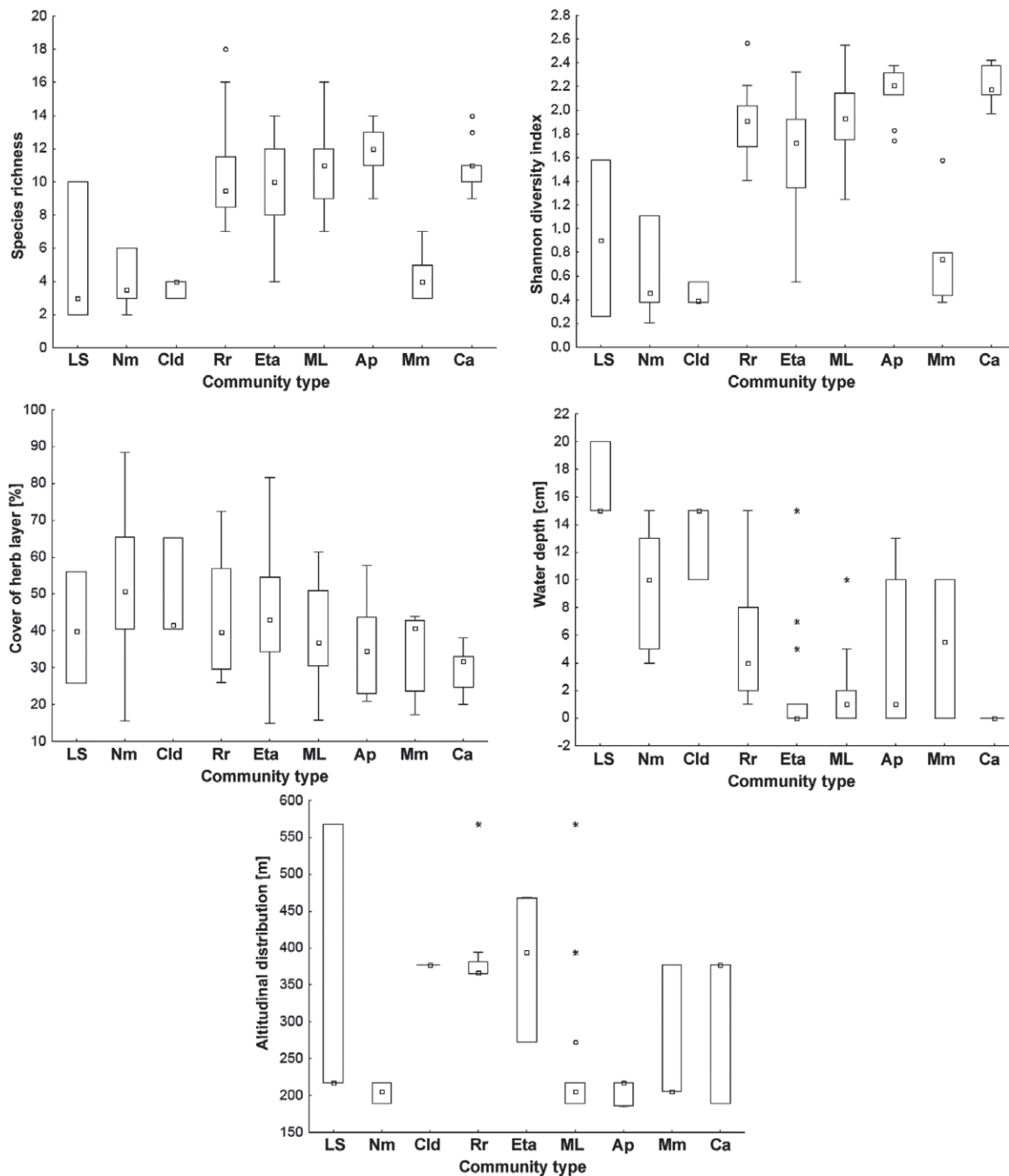


Fig. 3. Species richness, Shannon diversity index, cover of herb layer, water depth and altitudinal distribution of rice field communities in central Nepal. Abbreviations: LS – *Lemno-Spirodeletum polyrrhizae*, Nm – *Najadetum minoris*, Cld – community of *Limnobium dubium*, Rr – *Rotaletum rotundifoliae*, Eta – *Elatinum triandro-ambiguae*, ML – *Mazo pumili-Lindernietum ciliatae*, Ap – *Ammanietum pygmaeae*, Mm – *Marsileetum minutae*, Ca – *Mazo pumili-Lindernietum ciliatae caesulietosum axillarum*. Whiskers present minimum and maximum observations within fences, block indicates first and third quartile, circles the minimum and maximum value. Outliers are shown as asterisks.

Syntaxa of rice fields in central Nepal

1. *Marsileetum minutae* Nowak A., Nowak S., Nobis M. 2015 (On-line Suppl. Tab. 2, rel. 43–48)

Diagnostic species: *Marsilea minuta*

This phytocoenosis has been found at a height of 200–370 m a.s.l. in the valleys of the Rivers Seti and Anahi Khola. Most of the plots of this association were found on wet mud or in shallow water inundation up to 10 cm (mean: approximately 5 cm). The community develops on rather fertile soils with close to neutral pH (7.3). The total herb layer

cover is characterised by intermediate values in relation to other rice field phytocoenoses. The mean cover in research plots was about 40%, ranging from ca. 5% to 50% (Fig. 3). In central Nepal, *Marsileetum minutae* is a community composed of 3–7 species with a clear predominance of the diagnostic species, *Marsilea minuta*. Within the study sites the dwarf water clover clearly dominates, reaching up to 50% cover on plot surfaces. The most frequent accompanying taxa of the association are *Alternanthera sessilis*, *Cyperus difformis* and *Centella asiatica*.

2. *Najadetum minoris* Ubrizsy 1961 (Tab. 1, rel. 4–9)

Diagnostic species: *Najas minor*

This phytocoenosis occurs rarely in shallow waters of irrigated rice paddies in the surrounding of Sauraha village in Rapti River valley. It has been noted at the lowest locations, around 200 m a.s.l. *Najadetum minoris* grows in relatively small patches in whole paddy surface in dens as well as in loose rice stands. It prefers warm, shallow and neutral waters with depths of 5 to 15 cm (mean approx. 10 cm; Fig. 3, Tab. 1). The herb layer of this association is relatively abundant. The mean total cover of vascular plants is approximately 50%, ranging from 15% to almost 90%. However, this is not reflected in species richness, which is one of the lowest, with a mean value of approx. 4 species per plot. Apart from the diagnostic species, the greatest cover and constancy in this phytocoenosis is shared by *Echinochloa colona*, *Centella asiatica* and *Alternanthera sessilis* (Tab. 1).

3. *Elatinetum triandro-ambiguae* ass. nova hoc loco (On-line Suppl. Tab. 2, rel. 1–17)

Nomenclatural type: On-line Suppl. Tab. 2, relevé 1

Diagnostic species: *Elatine ambigua*, *E. triandra*

The *Elatinetum triandro-ambiguae* was defined by the abundant occurrence of the diagnostic species in rainfed paddies of the Kali Gandaki, Marsyangdi, Trisuli and Anahi Khola Rivers near Putalibazar, Aanbu Khaireni, Kurintar, Bharatpur and Siurenitar cities. It was found generally in dried-up or shallowly inundated rice fields with very scarce abundance of cultivated plants. The association was noted on sites with mean water depth value close to 0 cm (Fig. 3) on loamy and clayey soils with pH ca. 7.0. The herb layer develops to moderate values of approximately 15–85% (mean: ca. 45%; Fig. 3; On-line Suppl. Tab. 2). *Elatinetum triandro-ambiguae* is a community of intermediate species richness, with 4 to 14 taxa per plot (mean approx. 10). *Centella asiatica*, *Echinochloa colona* and *Dopatrium junceum* are the most frequent taxa of this association.

4. *Lemno-Spirodeletum polyrrhizae* Koch 1954 (Tab. 1, rel. 1–3)

Diagnostic species: *Spirodela polyrrhiza*

This phytocoenosis occurs with very rare frequency in central Nepal. It was found only in two sites in the Rapti River valley (near Sauraha village) and in the Trisuli River valley (near Goganpani village). It was noted at heights of about 217 and 568 m a.s.l. The association of *Lemno-Spirodeletum polyrrhizae* develops in the study area in relatively deep waters (15–20 cm; Fig. 3) on muddy ground with pH approx. 6.8. It was observed in moderately developed rice stands in early growth phases. The community is characterised by a moderate average herb layer cover. Values of 25 to 65% were noted (mean ca. 40%; Fig. 3). As in other parts of the association range, the plots are characterised by rather low species richness, however in one plot 10 taxa were noted. Apart from the diagnostic plant only *Polygonum barbatum* share was noticeable in research plots.

5. *Mazo pumili-Lindernietum ciliatae* ass. nova hoc loco (On-line Suppl. Tab. 1, rel. 1–39)

Nomenclatural type: On-line Suppl. Tab. 1, relevé 17

Diagnostic species: *Lindernia ciliata*, *Mazus pumilus*

This phytocoenosis appears to be the most frequent in Central Nepal, especially at lower elevations. As well as in the irrigated fields in Kali Gandaki and Rapti River valleys near Sauraha and Bharatpur, it was noted near Jarebagarm Goganpani and Kurintar in Trisuli River valley. This association seems to be most typical for the mid-hills and lowlands of southern Asia within the *Oryzetea sativae* vegetation. The community has been noted mainly at elevations of approx. 200 m with the exception of the Trisuli valley where the plots have altitudes of approx. 400–600 m a.s.l. (On-line Suppl. Tab. 1). Vegetation patches dominated by *Lindernia ciliata* and *Mazus pumilus* develop on paddies with low water depths (0–10, mean 1 cm), on clayey or loamy muds with neutral reaction (pH approx. 7.0). Values of total herb layer cover are moderate in comparison to other rice field associations. The noted mean value was about 35%, ranging from approx. 15% to 65%. The *Mazo pumili-Lindernietum ciliatae* is an association with a relatively high average number of species per plot. Approximately 11 plants were noted in each sample (range: 7 to 16). Besides the diagnostic taxa, the predominant species are *Cyperus difformis*, *Alternanthera sessilis*, *Echinochloa colona*, *Fimbristylis miliacea* and *Lindernia procumbens*.

The subassociation *Mazo pumili-Lindernietum ciliatae typicum* is widespread in central Nepal on clayey and loamy soils, inundated for a relatively long period by shallow water. The diagnostic species of the subassociation *typicum* and the nomenclatural type are identical with those of the association.

6. *Mazo pumili-Lindernietum ciliatae caesulietosum axillaris* subass. nova hoc loco (On-line Suppl. Tab. 1, rel. 40–48)

Nomenclatural type: On-line Suppl. Tab. 1, relevé 40

Diagnostic species: *Caesulia axillaris*

This subassociation appears to be typical for hilly landscapes with rainfed paddies on soils with a relatively high amount of the sand fraction. The plots of this syntaxon was found in the Trisuli River valley at a few sites near Chuwabote Gaun. It was also sporadically noted in lowlands near Sauraha in the Rapti River valley. The phytocoenosis of *Mazo pumili-Lindernietum ciliatae* with the contribution of *Caesulia axillaris* develops on wet, sandy muds without inundation (Fig. 3). The soil pH reaction measured near Chuwabote Gaun was 7.8. The herbaceous layer was not abundant in plots, and had a mean value of approximately 30% (range: approx. 20%–40%). However, the phytocoenoses were relatively rich in species, having more than 10 species per plot on average. The most frequent and abundant taxa apart from the diagnostic ones were: *Alternanthera sessilis*, *Bacopa procumbens*, *Cyperus iria*, *Scirpus juncooides*, *Fimbristylis miliacea* and *Echinochloa colona*.

7. *Rotaletum rotundifoliae* ass. nova hoc loco (On-line Suppl. Tab. 2, rel. 18–33)

Nomenclatural type: On-line Suppl. Tab. 2, relevé 20

Diagnostic species: *Rotala rotundifolia*

The association occurs sporadically in Central Nepal in the Trisuli and Seti River valleys (cities of Goganpani, Aambu Khaireni, Dhaptar and Damauli). It prefers higher elevations in mid-hill landscapes at altitudes of 360 to 400 m a.s.l. (Fig. 3). *Rotaletum rotundifoliae* is associated with loamy and clayey muds of pH approx. 6.5. The research plots were sampled in sites of moderate water depth, however some patches were quite deeply inundated. The mean water depth was approx. 4 cm. Between 7 and 18 species were recorded in a single plot (mean approx. 9). The phytocoenoses are characterised by a moderate herb layer cover. The maximum cover of weed species in the phytocoenoses was about 75%. The mean cover of whole herbaceous layer was ca. 45%. (Fig. 3). The diagnostic *Rotala rotundifolia* has relatively high cover in all plots, reaching up to 50% maximum value (mean approx. 25%). Among the most abundant and constant species in the phytocoenosis are *Alternanthera sessilis*, *Centella asiatica*, *Cynodon dactylon*, *Dopatrium junceum* and *Monochoria vaginalis*. Several rush species like *Veronica anagallis-aquatica* were also noted in the sampled plots.

8. *Ammanietum pygmaeae* ass. nova hoc loco (On-line Suppl. Tab. 2, rel. 34–42)

Nomenclatural type: On-line Suppl. Tab. 2, relevé 34

Diagnostic species: *Ammania pygmaea*, *Callitriche palustris* var. *oryzeturum*, *Dichostylis micheliana*

The association is a very distinct from other segetal weed communities noted in rice fields in Central Nepal. It is associated mainly with relatively open, loose rice stands with small amounts of water, often completely dried up. In the research area the *Ammanietum pygmaeae* was noted in the lowest elevation in Chitwan National Park vicinity in the Rapti River valley (near Sauraha, Ratnanagar and Bharatpur) within the altitudinal range between 184 to 217 m a.s.l. (Fig. 3). The association develops on wet and fertile muds in irrigated fields in the bottoms of the river valleys. The soil is neutral or slightly acidic (pH 6.4–7.1). Plots of the association are relatively rich in species, having from 10–14 taxa (mean approx. 12). The total cover of weed species in the phytocoenoses rarely exceeds 60%, and in most cases it varies about 35% (Fig. 3). Typical of the observed plots was the insignificant cover of the diagnostic species – *Ammania pygmaea*, which reaches the average value of approx. 3%. However this species as well as *Dichostylis micheliana* and *Callitriche palustris* var. *oryzeturum* contribute only to this phytocoenosis. Among other species, the highest constancy is found in *Echinochloa colona*, *Fimbristylis miliacea*, *Lindernia procumbens*, *Mazus pumilus* and *Vernonia cinerea*. The last species is typical rather for ruderal wet wastelands and its occurrence is related to high openness of the *Ammanietum pygmaeae*.

9. *Limnobium dubium* community (Tab. 1, rel. 10–12)

Diagnostic species: *Limnobium dubium* (Syn. *Hydrocharis dubia*)

This community was noted in only 3 spots in the Trisulu river valley in the very early stages of rice cultivation. The community was noted at an elevation of ca. 380 m a.s.l. (Fig. 3). The species is typical of various kinds of natural as well as artificial bodies of water in subtropical and tropical southern and south-eastern Asia as well as northern Australia (eFlora 2014). Due to the scarcity of phytosociological data as well as the extreme simplicity of the community, it cannot be defined as an association at present state of research.

Synopsis of syntaxa

Based on this study, we propose the following classification for the weed communities of rice fields in central Nepal:

Class: *Lemnetea minoris* R. Tx. 1955

O: *Lemnetalia minoris* R. Tx. 1955

All: *Lemnion gibbae* R. Tx. et A. Schwabe 1974 in R. Tx. 1974

1. *Lemno-Spirodeletum polyrrhizae* Koch 1954

Class: *Potametea* Klika in Klika et Novák 1941

O: *Potametalia* Koch 1926

All: *Potamion* Miljan 1933

2. *Najadetum minoris* Ubrizsy 1961

3. *Limnobium dubium* community

Class: *Oryzetea sativae* Miyawaki 1960

O: *Cypero-Echinochloetalia oryzoidis* O. Bolòs & Masclans 1955

All: *Ludwigion hyssopifolio-octovalvis* Nowak A., Nowak S., Nobis M. 2015

4. *Elatinetum triandro-ambiguae* ass. nova

5. *Mazo pumili-Lindernietum ciliatae* ass. nova

6. *Mazo pumili-Lindernietum ciliatae caesulietosum axillaris* subass. nova

7. *Rotaletum rotundifoliae* ass. nova

8. *Ammanietum pygmaeae* ass. nova

9. *Marsileetum minutae* Nowak A., Nowak S., Nobis M. 2015

Discussion

The rather variable landscape of central Nepal, the altitudinal amplitude, climate seasonality, habitat differentiation, various kinds of water supply of the fields, with different methods of rice cultivation, promote the development of several segetal phytocoenoses within paddy fields. Our research reveals a relatively rich weed flora if compared to other studies on Nepal crop agroecosystems which report ca. 40–60 species (e.g. Manandhar et al. 2007, Bhatt et al. 2009, Sapkota et al. 2010). The richness of rice agroecosystems is surely related to the extremely rich species pool

in the whole country. Nepal is known from its extremely rich vascular flora and was indicated as one of the world's biodiversity hotspots (Mittermeier et al. 2006). Despite the ongoing processes of mechanisation and modernisation of agriculture in Nepal including the System of Rice Intensification (Dobermann 2004, Upreti 2010), the rice field plots are still abundant and diverse in weed species. This allows phytosociological studies and brings credible data relating species composition and habitat preferences of weed species communities. Then, the well developed associations could be easily defined and classified in the hierarchical system of the *Oryztea sativae* class (Miyawaki 1960, Nowak et al. 2013). However, the final appearance of the syntaxonomical system of the class for southern and eastern Asia still needs thorough and detailed studies in many regions, e.g. in Burma, India, Sri Lanka, Vietnam and other countries. Our preliminary investigations in Cambodia, southern Thailand, Malaysia, Indonesia and Philippines show, that the beta diversity of rice field phytocoenoses is considerably high and reveals many syntaxa still to be described. This of course could cause changes in the diagnostic value of particular species and need of revision of the system. But even without comprehensive data for the whole SW Asia region, after our studies we can be sure of the extreme richness of rice field vegetation and flora in southern and south-eastern Asia in comparison to phytocoenoses known from southern Europe, Middle Asia and Japan (e.g. Bolòs and Masclans 1955, Miyawaki 1960, Carretero 1989, Nowak et al. 2013).

Obviously the rice phytocoenoses differ substantially in species composition to agrocoenoses known from Mediterranean and temperate climates. Despite several common taxa diagnostic generally on the order level (*Cypero-Echinochloetalia oryzoidis* O. Bolòs & Masclans 1955) like *Cynodon dactylon*, *Cyperus difformis* or *Echinochloa crus-galli*, almost all other species are different. So, even if we compare relatively areas close to Nepal such as Tajikistan, the differences in floristic composition achieve the level of ca. 80%. But there is also considerable distinctiveness between Nepal rice weed flora and tropical rice plant communities of southern Thailand. The latter is characterised by frequent occurrence of *Leptochloa chinensis*, *Ipomea aquatica*, *Echinochloa crus-galii*, *Sphenoclea zeylanica*, *Ludwigia hyssopifolia*, *Eclipta prostrata*, *Ludwigia octovalvis*, *Leersia hexandra*, *Hymenachne acutigluma* and *Aeschynomene indica*. The only common and also frequent species for both areas are *Alternanthera sessilis*, *Fimbristylis miliacea*, *Cyperus difformis* and *Echinochloa colona*. This could suggest that the Nepal rice association should be placed in separate alliance. To decide whether it is reliable to distinguish new alliance closely related to the provisionally proposed *Ludwigion hyssopifolio-octovalvis* further data collection is needed from the whole area of Nepal as well as from India, Sri Lanka, Bangladesh and Burma. At present the only constant and abundant species for the whole data set gathered in central Nepal are *Mazus pumilus*, *Lindernia ciliata* and *Alternanthera sessilis*. But these species have a wide geographical range and also occur in eastern and south-eastern Asia, so they demonstrate considera-

ble weaknesses as diagnostic taxa. That is why we decide to classify the described communities within the provisional alliance of *Ludwigion hyssopifolio-octovalvis* proposed for southern Thailand (Nowak et al. 2015a) even though *Ludwigia octovalvis* and *L. hyssopifolia* were very scarce in our data set from Nepal.

The detrended correspondence analysis ordination run for the entire data set clearly segregates the main syntaxa (Fig. 2). The comparison of habitat requirements and floristic structures of the phytocoenoses found shows that the main dissimilarities in species compositions are due to water depth and trophy of the soil substrate. The left part of the diagram is occupied exclusively by plots of typically aquatic, permanently inundated habitats related to the *Limnobium dubium* community, *Najadetum minoris* and *Lemno-Spirodeletum polyrrhizae*. In the bottom part of the diagram the samples of relatively species poor phytocoenoses of moderately fertile substrates are grouped. Both associations, *Elatinetum triandro-ambiguae* and *Rotaletum rotundifoliae*, were found on brown, loamy and clayey soils of slightly acidic reaction. Conversely, species rich phytocoenoses could be found in the upper part of the diagram. They prefer periodically inundated but sometimes dried-up fields located generally in lowland river valleys on muddy, fertile, close-to-neutral soils. Despite the significant species diversity, these communities, especially *Ammanietum pygmaeae* do not achieve high cover of weeds. This shows the close relation of that type of vegetation to early successional stages of associations belonging to the *Isoëto-Nanojun-cetea* class.

Altitude is a crucial environmental variable influencing the species composition of weed phytocoenoses, particularly in mountainous areas (e.g. Lososová et al. 2004, Cimalová and Lososová 2009, Nowak et al. 2015b). Although we did not explore in detail the variation of weed vegetation explained by altitude, looking at the species composition it is obvious that elevation above sea level, despite the homogenising effects of agricultural practices, is responsible for a considerable degree of the diversity of central Nepal rice phytocoenoses. The higher elevations and hilly colline and montane belts are preferred by the associations of *Rotaletum rotundifoliae* and *Elatinetum triandro-ambiguae*. The apparent differences in climatic conditions between the lowland tropics and montane zone is clearly reflected in species compositions. Several species have found here their ecological optimum, among them *Cyperus pulcherrimus*, *Lindernia antipoda*, *L. anagallis* or *Dopatrium junceum*.

As regards the geography of the described plant communities, at the present state of research it is hardly possible to show their range limits. There is still a lack of credible data regarding the phytosociology and co-occurrence of rice weeds in southern Asia. Undoubtedly, the *Lemno-Spirodeletum polyrrhizae* Koch 1954 and *Najadetum minoris* Ubrizsy 1961 are plant communities distributed worldwide. Other phytocoenoses noted in the research area have more unique character and presumably occupy subtropical and tropical zones of south-eastern Asia. To state precisely to what extent and how frequently, further detailed studies are needed.

There is still a need to analyze the weed occurrence in rice paddy field not only in context of agriculture (problems with yield losses, weeding effectiveness), but also considering the conservation issues. Looking inside the floristic structure of rice phytocoenoses it is obvious that many weeds originated from former marshlands. After transformation of wetland habitats of river valleys into rice paddies, many species were able to adapt to new environments and regular human impact. The sump pond of rice fields, canals, drainage ditches could harbour many species known formerly exclusively from natural marshlands. Many of them are regarded as rare and listed on the world red list of vascular plants (IUCN 2013). Generally they are assessed as of least concern, but with the demand for permanent monitoring and evaluation against IUCN criteria. In Central Nepal we noted *Lindernia ciliata*, *L. antipoda*, *L. anagallis*, *Ammannia baccifera*, *A. multiflora*, *Dopatrium junceum*, *Lud-*

wigia perennis, *L. hyssopifolia*, *L. octovalvis*, *Caesulia axillaris*, *Elatine ambigua*, *Eleocharis retroflexa*, *Lippia nodiflora*, *Cyperus difformis*, *C. diffusus*, *C. iria*, *C. michelianus*, *C. rotundus*, *Marsilea minuta*, *Monochoria vaginalis*, *Najas minor*, *Nymphaea nouchali* in vegetation plots of rice fields. It seems to be important to find the relation between the rice field flora and natural marshland flora, their history, habitat requirements and adaptation potential. The dispute over the recruitment of the *Isoëto-Nanojuncetea* species and their spread in the northern hemisphere could be effectively supported by the outcomes of thorough analyses of rice field vegetation and species diversity. Then we can precisely ascertain the conservation value of rice paddies for rare and threatened flora, as it was suggested in earlier studies (Barrett and Seaman 1980, Camenisch and Cook 1996, Bambaradeniya et al. 2004).

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On-line Suppl. Tab. 1. Communities of the *Oryzeta sativae* class (part I) during the study, in May 2013. ML – *Mazo pumili-Lindernietum ciliatae caesulitosum axillaris*. The cover-abundance scale of Braun-Blanquet (1964) was used: r = 1 or 5 individuals; + = few individuals (< 20) with cover < 5%; 1 = many individuals (20– 100) with cover < 5%; 2 = 5%–25% cover; 3 = 25%–50% cover; 4 = 50%–75% cover; 5 = 75%–100% cover.

	Successive number of relevé																																																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48							
Day of the month	7	6	3	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7					
Water depth (cm)	0	0	10	0	0	1	0	0	1	1	2	0	1	2	0	1	3	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
Altitude (m)	394	217	568	217	217	217	217	217	217	217	217	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205						
Cover of herb layer (%)	55	60	35	45	60	60	20	55	40	45	30	60	30	45	50	35	70	55	20	30	60	50	55	35	35	30	40	20	40	50	60	70	40	50	30	20	70	30	30	50	20	35	40	60	15	45									
Relevé area (m ²)	3	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25						
pH	6,8	–	–	7,0	7,2	–	7,3	–	–	7,0	–	6,9	7,3	–	7,2	7,2	6,9	–	7,2	6,9	–	–	7,2	6,9	–	–	7,2	6,9	–	–	7,2	6,9	–	–	7,2	6,9	–	–	7,2	6,9	–	–	7,2	6,9	–	–	7,2	6,9	–	–					
Number of weeds	10	9	8	9	11	11	12	13	10	11	12	13	11	11	9	11	8	9	7	9	8	9	8	9	8	9	8	9	10	12	11	11	14	11	10	9	10	12	11	15	16	11	14	11	11	10	13	12	12	12	12				
Association/Community	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML					
Cultivated plant	2	3	3	4	3	3	4	3	4	4	4	3	4	4	4	3	3	4	4	4	4	4	4	3	3	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4				
<i>Oryza sativa</i>																																																							
Ass. <i>Mazo pumili-Lindernietum ciliatae</i>																																																							
<i>Mazus pumilus</i>	1	3	+	2	1	1	1	1	1	1	1	1	1	1	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
<i>Lindernia ciliata</i>																																																							
SubAss. <i>Mazo pumili-Lindernietum ciliatae caesulitosum axillaris</i>																																																							
<i>Caesulia axillaris</i>																																																							
All. <i>Ludwigion hyssopifolio-octovalvis</i>																																																							
<i>Alternanthera sessilis</i>	+	+	1	1	1	+	+	1	1	+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
<i>Fimbristylis miliacea</i>	+	+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
<i>Marsilea minuta</i>																																																							
<i>Sphenoclea zeylanica</i>																																																							
<i>Elatine triandra</i>	1																																																						
<i>Cyperus kyllingia</i>	+	1	1																																																				
<i>Ludwigia perennis</i>																																																							
<i>Alternanthera phioxeroides</i>																																																							
Sporadic species: <i>Calitriche palustris</i> var. <i>oryzetosum</i> 38(+)																																																							
O. <i>Cypero-Echinochloetalia oryzoidis</i> et Cl. <i>Oryzeta sativae</i>																																																							
<i>Cyperus difformis</i>	1	2	1	2	1	1	1	+																																															
<i>Echinochloa colona</i>																																																							
<i>Cyperus iria</i>	1																																																						
<i>Scirpus juncoides</i>	+																																																						
<i>Ammannia baccifera</i>																																																							
<i>Ammannia multiflora</i>																																																							
<i>Monochoria vaginalis</i>																																																							
<i>Synedrella nodiflora</i>	+																																																						
<i>Phyllanthus fraternes</i>																																																							
<i>Leptochloa chinensis</i>																																																							

