Indian Journal of Weed Science (2025) **57**(3): 262–270
http://dx.doi.org/10.5958/0974-8164.2025.00046.2

RESEARCH ARTICLE

Weed flora dynamics in deep water rice ecosystem of Brahmaputra River ecotone, Assam

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Received: 1 January 2025 | Revised: 16 July 2025 | Accepted: 19 July 2025

ABSTRACT

Majority of the deep-water rice area along the Brahmaputra Valley in Assam represents typical ecotone zone between the hydrophytic and terrestrial ecosystems, and thus the crop-weed competition environment is different from that of terrestrial land. Keeping this in view, a study was undertaken during 2022 and 2023 in the Brahmaputra ecotone of greater Majuli district of Upper Brahmaputra Valley Agro-climatic zone of Assam. The objective was to study the weed flora composition and weed dynamics in deep water rice in the Brahmaputra ecotone in different land situations. The study was conducted by random plotting of one square meter quadrats in the areas along the river in three distinct situations, *viz,* i. Temporary River Island (TRI) of *Dhodang chapori*, ii. Permanent River Island (PRI) and iii. Permanent River edge (PRE) of *Dhodang- Ujjirati*. The climate of the study area is subtropical with a hot-humid summer, heavily showered monsoon and a mild-moderate winter. The soil nutrient content was moderately rich. Sixty weed species were observed during entire cropping period of this study in TRI, out of which 10 species were invariably present from crop growth stage (CGS) 1 to 3. In PRI and PRE, 67 and 49 weed species, respectively, were observed. *Cynodon dactylon* was found to be the most successful weed species and was dominant in the fields from pre- to post monsoon situations and it showed very strong association with *Arundo donax.* In temporary islands, no strong weed-species association was detected. However, in permanent edge ecotone zone, *Cyperus difformis* had strong negative association with *Eleocharis geniculata* and *Cynodon dactylon*, followed by *Alternanthera philoxeroides.* The permanent river islands and temporary islands were dominated by grasses, whereas sedges were dominant in permanent edges. The number of species and weed biomass revealed very strong correlation with Margalef's species richness index, Pielou's evenness index and Shannon and Wiener's diversity index. However, the correlations of all the diversity indices with soil pH, available N, P and K, were found to be weak to very weak. The results of weed flora association study reflected the increasing community relatedness as TRI> PRE > PRI, which might be due to the presence of least disturbance in soil, cropping, and resource availability in permanent islands in comparison to other land situations.

Keywords: Assam, Deep water rice, Brahmaputra, Ecotone, Weed flora, Weed dynamics, Weed diversity indices

INTRODUCTION

Weeds are comparatively fast-growing plants, highly competitive and highly capable of changing floristic composition of a place, and thus, the pattern of biodiversity. Hence, the species appeared, their dominance spectrum, biomass accumulated in definite time frame, association pattern, etc. are always been considered as some of the important parameters in the study of crop weed competition, as well as in floristic analysis, which are rather important in vegetation study of fragile soils or river beds which are very susceptible to erosion and other disturbances caused by water, wind and human activities. The Middle Brahmaputra floodplains of Assam encompass an area of 7294.85 km^2 (Bhuyan *et al*. 2024). Being one of the largest braided rivers in global scenario, the mighty river Brahmaputra possessed nearly 3.60 lakhs hectares of land (as per Socio Economic Survey 2002-03). These river beds, made up of sand-slit deposition, are naturally enriched by annual deposition of humus making suitable for seasonal cultivation of crops. Based on report on National Productivity Council (NPC), several workers (Lahiri-Dutt2014, Momin and Chakraborty 2023) have classified such river beds (vernacular name "*Char*" or "*Chapori*") as (i.) Permanent *Chapori*- that have existed for more than ten years, (ii.) Semi-permanent *Chapories*- those existed from five to ten years and (iii.) Temporary *Chapories*- those existed for less than five years. In some of the *Chapories* suitable for cultivation, farmers used to grow vegetables in dry winter and rice and other

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crops mostly in summer season. Out of different rice cultures practiced in Assam, the deep-water rice is a long duration rice with a crop duration of 5-6 months and was selected for this study, where monsoon floods play a significant role both in growth of rice varieties as well as in changing weed vegetation patterns. The estimated yield reduction due to weed competition in rice varied from 10-80% (Rao and Matsumoto 2017, Rao 2022). The crop yield losses due to weeds depend on several factors such as associated weed flora, weed emergence time, weed density, type of weeds, crops, cropping systems and management practices used (Rao *et al.* 2007, Rao *et al.* 2014). The rice associated weed flora plays several significant roles in ecosystem management, including erosion control.

The deep-water rice locally called as '*Bao Dhan*' in Assam known for its deep-water cultivation grown in flooded conditions with water more than 50 cm deep for at least a month (Catling *et al.*1992, Rohila *et al.* 2019). In global scenario, deep water rice varieties contribute approximately 10% of the total rice production, even though their yields are low, they support 100 million people who live in areas which get flooded extensively every year during the rainy season, such as in the great river deltas in south and southeast Asia (Sauter 2000). Deep water rice is also known for its high nutritional value. The red colour of rice is conferred by the anthocyanin pigments, and it is known for its high medicinal value (Maibangsa *et al.* 2023). Unlike other rice varieties, deep water rice is characterized by its ability to sustain growth in deep water and survive in flooded environment by exposing leaves above the water surface through elongation of the internodes to maintain respiration and photosynthesis. The Ganges-Brahmaputra-Meghna Basin, Nepal and several minor areas in Assam, account for 58 % of Asia's deepwater rice and 55 % of the world's total deepwater rice (Tandon and Soni 2020). Among the states of India, Assam accounts for the highest percent (20%) of deep water rice cultivation, which is approximately 100,000 hectares of area. Most of the deep water rice area in Assam is located in Dhemaji, Lakhimpur, Sivasagar, Jorhat and Majuli districts of Upper Brahmaputra Valley, Kamrup, Nalbari, Barpeta and Goalpara districts of Lower Brahmaputra valley and Morigaon district of Central Brahmaputra Valley agro-climatic zones of the state.

Majority of area where deep water rice is cultivated along the Brahmaputra Valley in Assam represents typical ecotone zone between the hydrophytic and terrestrial ecosystems. Thus, the crop-weed competition environment in Brahmaputra Valley is different from that of terrestrial land, where weed flora played a significant role in crop productivity under the naturally enriched fertile soil, extremely shallow water table and often treeless windy and sunny environment (Borah *et al.* 2024). It is important to understand the weed flora dynamics for developing better weed management technologies. Hence, this study was undertaken during 2022-2023 in the Brahmaputra ecotone of greater Majuli district of Upper Brahmaputra Valley agro-climatic zone of Assam with an objective to study the weed flora composition and weed dynamics in deep water rice in the Brahmaputra ecotone in different land situations.

MATERIALS AND METHODS

Study site: The study was confined to three distinct ecosystems, which have been classified based on Momin and Chakraborty (2023) as follows:

1) Temporary river islands (TRI), at *Dhodang chapori* (Latitude-26°44′57′′N, Longitude-94°10′ 54′′E) which were islands separated from the river banks by a perennial channel and existed for less than five years.

2) Permanent river island (PRI), at *Sikoli chapori* (Latitude-26°54′34′′ N, Longitude-93°58′14′′E)- The long duration river beds (existed for more than ten year) separated from river banks by three perennial channels and

(3) Permanent river edge (PRE), at *Dhodang Ujjirati*, (Latitude-26°47′26′′N, Longitude-93°59′15′′E)- The river beds situated adjacent to the banks of river Brahmaputra, the age of which was more than ten years.

The study area, being a part of the Upper Brahmaputra Valley Agro-climatic zone of Assam, has experienced subtropical monsoon climate, with a hot and humid summer, heavily showered monsoon and a mild and moderate winter. The atmospheric temperature varied from 6° to 36°C, the average annual rainfall ranges from 202 to 210 centimetres and average annual relative humidity varies from 78 to 80%.

The physico–chemical properties of the soils of PRI, TRI and PRE were evaluated at the Assam Agricultural University (**Table 1**).

Data collection: The observations in deep water rice fields were started since 2022, and farmers were interviewed regarding associated weed problem and management strategies adopted. Weed data was collected for the present analysis both in 2022 and

Table 1. Physico-chemical properties of soils of deep-water rice fields along Brahmaputra River ecotone in 2023

	Soil P^H	Electrical Conductivity (ds/m)	Organic Carbon (%)	Available Nitrogen kg/ha	Available Phosphorus kg/ha	Available Potassium kg/ha	Texture
PRI	5.15	0.1	0.73	273.7	23.94	328.18	Silt loam
TRI	5.5 to 6.8	0.11	0.57	236.38	23.76	188.55	Highly Variable silty to Sandy loam
PRE	4.88	0.1	0.7	290.22	24.52	198.27	Silt loam

PRI= Permanent River islands; TRI= Temporary River islands; PRE= Permanent River edges

2023 from the selected riverbeds. For collection of data, 1 m x 1 m square quadrats were used. Altogether 10 quadrats were plotted randomly within a radius of 20m from the GPS point recorded in each crop growth stage (CGS) in each land situation. The distribution of CGS were as follows: CGS-I: Before the monsoon flood, in between 30-50 days after sowing (DAS); CGS-II: During the monsoon flood, nearly at 110 to 130 DAS, and CGS-III: After receding the monsoon flood, nearly at 150 to 170 DAS. Collected weeds were immediately sorted out species-wise and their density was recorded by counting. Considering runners as propagating organ, rooted slips of perennial species were considered as separate individuals in the counting process. Basal diameter of each species was recorded nearly at ground level. Collected weeds were oven dried at around 65°C for recording the weed dry weight (biomass). Identification of weed species was authenticated in the "Weed herbarium" of Assam Agriculture University, Jorhat.

Floristic composition: In determining floristic composition of weed flora, following formulae were used as described by Githae *et al.* (2007) and Akwee *et al.* (2010):

(i) Basal area (BA) and relative dominance:

Basal area of species in each quadrat =Average BA x number of Individuals, where: Average BA= $\pi d^2/4$; d= Average basal diameter of the weed; and

Relative Dominance (Rdom)(%)= ΣBA_i x 100 / ΣBA_n

(ii) Density, abundance and relative density:

Density (D) = Number of individuals of each species / Total number of quadrats plotted; and Relative density (RD) (%) = ΣD_i x 100/ΣD_n

(iii) Frequency and relative frequency:

Frequency (F) (%)= Number of quadrats where the species occurred x 100 / Total number of quadrats plotted; and Relative Frequency (RF) (%) = ΣF_i x 100 /ΣF_n

(iv) Importance value index (IVI) and Sum dominance ratio (SDR): The IVI was computed by summing up RD, RF and ground space occupied (Rdom) by each species. The sum dominance ratio (SDR) is the percent values of IVI.

IVI = RD + RF + Rdom and SDR = IVI / 3

Community relationship: For determination of diversity, similarity-dissimilarity, etc. amongst the weed communities of different locations, following formulae were used:

(v) Shannon and Weiner diversity index (H) (Shannon and Weaver 1949):

H = -ΣPi*(LNPi), where: Pi= Proportion of Individuals of the community and

LN= Natural logarithm.

(vi) Pielou's evenness index (I) (Pielou 1977): I = H/ H_{max} where, H= Number derived from Shannon's diversity index, H_{max} = (-) Σ1/S*LN(1/S) and S= Total number of species.

(vii) Species richness index (Dmg) (Margalef 1951): Dmg= (S-1) / LN(N)

Where, S= Number of species; N= Total number of individuals in the community.

(viii) Simpson's Diversity Index (SDI) (Simpson 1949):

SDI = 1 – {Σn*(n-1) / N*(N-1)}

Where, n = Total number of individuals of a particular species and

N = Total number of individuals of all species

Inter specific association: The association between two species and coupling coefficient (AC) was determined by identifying the nearest neighbour to each individual and for that the species with SDR value above 9.0 were selected. By avoiding the highly disturb crop growth period during monsoon flood (CGS-2), the unit-area (quadrat) of CGS-1 and CGS-3 of each location were taken into account. The presence and absence of any two species (A and B) were counted and the number of samples containing both (a), only species A (b), only species B (c) and neither A and B(d) were recorded. AC values were calculated as follows (Gu *et al.* 2017, Ma *et al.* 2022, and Juan *et al.* 2023).

If ad <bc and c < b, then AC = ad-bc/(a+b)(b+d)

If ad <bc and c < b, then AC = ad-bc/(a+c)(c+d)

If ad <bc and a< d, then AC = ad-bc/(a+b)(a+c), and

If ad <bc and a >d, then AC = ad-bc/(b+d)(c+d).

Where, AC values range from -1 to +1. When AC=0.67, a strong positive connection exists; 0.67 > AC > 0 indicates a weak positive connection. AC = 0 indicates no connection, the species are completely independent, and -0.67 < AC < 0 indicates a strong negative connection.

RESULTS AND DISCUSSION

Species composition

TRI- *Dhodang Chapori*: In the temporary river islands of *Dhodang Chapori*, a total of 14 weed species were recorded at CGS-1 of deep-water rice during the study. Poaceae was the largest family with 6 weed species. Malvaceae was the second largest family with two weed species. Other six families had one weed species each. Out of total fourteen weeds recorded at CGS-1, five were dicots and nine monocots including two broad-leaved monocots, six grasses and one sedge. Thirteen weed species were recorded at CGS-2, where too Poaceae was the largest family with all six weeds that were previously observed. It was observed that *Panicum repens*, which was prevalent in CGS-1 could not survive in deep water condition (85-100cm). On the other hand, *Paspalum distichum* appeared later and successfully survived during deep water condition along with other previously occurred grassy species.

Six weeds were recorded at CGS-3, where too Poaceae retained as the largest family with fifteen weed species. Cyperaceae was the second largest family with 6 species and Amaranthaceae and Asteraceae were the third largest families with four species each. Out of total sixty weeds recorded at CGS-3, four were Pteridophytes, twenty-nine were dicots and twenty-seven monocots, including six broad-leaved monocots, fifteen grasses and six sedges.

Sixty weed species were observed during the entire cropping period out of which 10 species were invariably occurred in all the crop growth stages, *viz. Alternanthera philoxeroides, Colocasia esculenta, Cynodon dactylon, Cyperus haspan, Echinochloa colona, Hymenechne amplexicaulis, Ipomoea carnea, Leersia hexandra, Paspalum notatum* and *Sagittaria guayanensis*. Few species, namely *Bombax ceiba, Panicum repens* and *Parthenium hysterophorus* could not survive during flooded situation and hence did not appear during CGS-2, but these weed species reappeared in the CGS-3. The increasing flood water as well as competitive ability of crop might have restricted their growth during CGS-2.

Three weed species, namely *Ageratum houstonianum, Marsilea minuta* and *Paspalum distichum* occurred in CGS-2, and continued till harvest of rice. Unstable ponded water in the sandy-silty riverbeds was the characteristic feature in the study area, even during the monsoon flood. That might encourage the emergence and growth of such weed species, which can withstand short flooding period, especially in sandy situation.

As many as 43 weed species occurred at CGS-3, including, 3 Pteridophyte, 8 grassy species, 5 sedges, 23 broad-leaved dicots (BLWS) and 4 broad-leaved monocots. Probably the propagules of those weeds were disseminated to the site by flood water, which got emerged and established after receding of ponded water at CGS-3.

Site-2: PRI-*Sikoli Chapori*: *Sikoli Chapori* representing permanent river islands, deep water rice fields of which are annually inundated during monsoon flood. Here, twenty-one weed species, belonging to ten families were recorded at CGS-1. Seven weeds were of Poaceae, four were of Asteraceae two each species were of Cyperaceae and Onagraceae. Other six weeds were of Amaranthaceae, Fabaceae, Linderniaceae, Lythraceae, Phyllanthaceae and Verbenaceae, with one species each.

Out of total twenty-one weeds recorded in CGS-1 at PRI, twelve were dicots and nine monocots including seven grasses and two sedges. Sixty-seven weed species were recorded at CGS-3 after receding of monsoon flood. Poaceae again was the largest family with seventeen species. Six species each were of Asteraceae and Cyperaceae family. Three weed species each were of Amaranthaceae and Onagraceae. Apiaceae, Commelinaceae and Phyllanthaceae families were represented by two species each.

Out of total sixty-seven weeds recorded at CGS-3, three were Pteridophytes [*Ceratopteris thalictroides, Equisetum hyemale* and *Marsilea minuta*], thirty-six dicots and twenty-eight monocots including four broad-leaved monocots, six sedges and eighteen grasses (seventeen belonging to Poaceae family and one to Typhaceae).

Out of sixty-nine weed species recorded in the cropping period, *Acmella ciliata, Alternanthera philoxeroides, Arundo donax, Cynodon dactylon,*

Cyperus difformis, Echinochloa colona, Eclipta prostrata, Fimbristylis littoralis, Hymenechne amplexicaulis, Lindernarnia anagalis, Phyla nodiflora, Ludwigia decurrans, L. hyssopifolia, Parthenium hysterophorus, Paspalum conjugatum, P. distichum, P. notatum, Phyllanthus virgatus and *Rotala macrandra* occurred throughout from CGS 1 to CGS-3.

Site-3: PRE-*Dhodang-Ujjirati*: In *Dhodang-Ujjirati,* deep water rice was cultivated in the permanent Chapories adjacent to the mainland of Majuli (PRE). In such a situation, twenty four weed species were recorded during 30-50 DAS. Poaceae family was represented by 7species; Cyperaceae with five species and 12 families, *viz*. Alismataceae, Araceae, Commelinaceae, Amaranthaceae, Asteraceae, Convolvulaceae, Euphorbiaceae, Linderniaceae, Lythraceae, Marsileaceae and Pteridaceae, with one species each.

Fourteen weed species were recorded at CGS-2 during the flood. In deep water condition, fourteen weed species were recorded, where Cyperaceae appeared was the most dominant family and Poaceae was the 2nd largest family. One weed species each belonged to five families, *viz*. Alismataceae, Commelinaceae, Linderniaceae, Lythraceae and Onagraceae. Out of total fourteen weeds recorded at CGS-2, three were dicots and eleven were monocots including two broad-leaved monocots, three grasses and six sedges.

Forty-seven weed species, belonging to twenty-four families, have been recorded during 160-180 DAS (CGS-3) in the sandy edges, at the post flood situation. Poaceae(11), Cyperaceae (7) and Asteraceae (4), Alismataceae (1), Amaranthaceae (1), Apiaceae (1) and Onagraceae (1) were the families of weed species that occurred at CGS-3. Other 16 families were represented at this stage with one species each. Three Pteridophytes, twenty-two dicots and twenty-two monocots including four broad-leaved monocots, eleven grasses and seven sedges were recorded at CGS-3.

Out of forty-nine weed species recorded in the cropping period, eleven weed species, *viz*. *Commelina diffusa, Cynodon dactylon, Cyperus difformis, C. haspan, C. iria, C. rotundus, Echinochloa colona, Fimbristylis littoralis, Lindernia anagallis, Ludwigia hyssopifolia, Paspalum distichum* and *Rotala indica* successfully survived in all the three crop growth stages. Twelve species namely, *Ageratum houstonianum, Alternanthera philoxeroides, Ceratopteris thalictroides, Colocasia esculenta, Cyperus rotundus, Eleucine indica, Euphorbia hirta, Hymenachne amplexicaulis, Leersia hexandra, Marsilea minuta, Paspalum notatum* and *Sagittaria guayanensis* could not survive during flooded situation and hence did not appear during CGS-2 but reappeared in the CGS-3, except *Hymenachne amplexicaulis* and *Leersia hexandra*. The increasing flood water as well as competitive ability of crop might have restricted their growth during the CGS-2. Two weed species, namely *Butomopsis latifolia* and *Kyllinga brevifolia* appeared in the CGS-2 and continued upto CGS-3.

Dominance spectrum

The dominance spectrum of weed flora was determined as per the IVI or SDR values. The most dominant weed species with SDR value above four in either of the crop growth stages have been short listed in the **Table 2** showing their relative density and relative frequency. Grasses were rather dominant in island ecosystems rather than permanent edges, in PRE situations, sedges became dominant during and after flood conditions.

This study revealed that *Cynodon dactylon* was the most successful weed with the highest Relative Density (RD) throughout the cropping periods in deep water rice and withstands the flooding period with the relatively highest density in TRI. Non-persistence of flood water for a longer period and adaptability of the weed in short day flooding could be the reason of survival of *Cynodon dactylon* in deep water rice of TRI despite of flooding periods during the monsoon season. *Cynodon dactylon* recorded the highest SDR value in before (53) and post flood situations (16) and second highest (19) during flood situation in the study area. The most dominant weed during flood was *Leersia hexandra*. The cumulative SDR value of grasses was 70.4 , 63.6 and 64.1 in CGS-1, 2 and 3, respectively, followed by the broad-leaved dicots with 20.1, 18.9 and 19.1, respectively.

In PRE ecosystems, *Cyperus difformis* was the most dominant weed in CGS-1, closely followed by *Cynodon dactylon*, while late-emerged *Eleocharis geniculata* dominated the field in later stages. The cumulative SDR of grasses in TRI ecosystems remained above 63 in the entire period of cropping and was as high as 70.4 at CGS-1. Similarly, the SDR of grasses varied from 73.5 at CGS-1 to 58.4 at CGS-3 in the permanent river islands. In both the situations, the cumulative SDR of sedges were rather lower than BLWs. In PRI ecosystems, *Paspalum distichum* and *Cynodon dactylon* were the most dominant weeds in CGS-1, while, *Cynodon dactylon* and *Arundo donax* in CGS-3. The robust grass *Arundo donax* was found as an important constituent

of river ecotone wild vegetation and appeared as facultative weed of deep water rice rather prominently in PRI ecosystems.

The cumulative SDR of grasses was as high as 45.0 followed by that of BLWs (36.7) at CGS-1 in PRE, whereas, that of sedges was 85.1 and 47.9 in CGS-2 and CGS-3, respectively. At PRE, at species level, however, the grassy weeds *Cynodon dactylon* (CGS-1, 2 and 3), *Leersia hexandra* (CGS-2) and *Eleucine indica* (CGS-3) were the most dominant over other associated weed species.

Diversity Indices

The diversity of species in the community of different times in different location has shown two distinct trends between islands and edges. Both in temporary river islands as well as permanent river islands, the Shannon and Wiener Diversity Index has shown an increasing trend corresponding to the crop growth stages. On the other hand, in PRE the diversity index was the highest (2.470) at pre-monsoon period, declined to 1.047 during monsoon flood, and again rose to the extent of 2.297 at post flood period. This finding indicated the role of monsoon flood in controlling weed population rather effectively in the permanent edge situation. Instability of monsoon flood in the islands might be least destructive which was reflected in survival of several weed populations appeared in the field in the pre monsoon period, as well as reappearance of some species at post monsoon period after temporary suppression during flooding period. Simpson's Diversity Index (SDI) has shown similar trend for the weed population of PRI and PRE. However, SDI has shown a slight declination during monsoon and little rise at post monsoon period from 1.0 to 0.85 representing the influence of monsoon flood in controlling the population of certain weed species.

Margalef's index ('Dmg') value indicated the species richness or diversity, considering the total number of individuals observed (Kitikidou *et al*. 2024). In PRI, Dmg varies from 3.387 to 12.976 and in TRI 3.782 to 11.757, whereas, in PRE it varied from 5.119 to 9.711 at CGS-1 and CGS-3, respectively. In all the cases the index was decreased during monsoon flood corresponding to declining

Table 2. Relative density (RD), relative frequency (RF) and sum dominance ratio (SDR) of weed groups and most dominant weed species in deep-water rice at different crop growth stages in different land situations along Brahmaputra River ecotone in 2022 and 2023

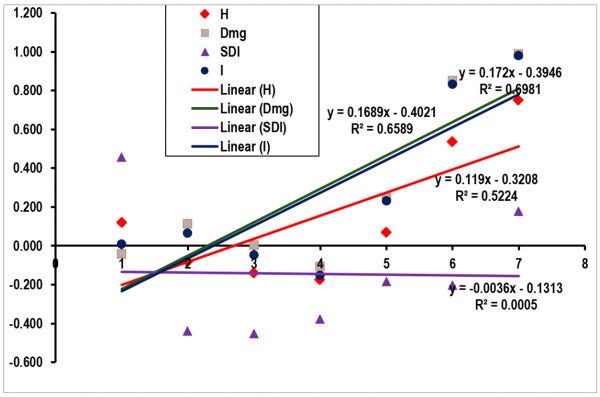
Dominat weed species	CGS-1			CGS-2			CGS-3		
	RD	RF	SDR	RD	RF	SDR	RD	RF	SDR
TRI: *Dhodang chapori*									
Alternanthera philoxeroides (Mart.) Griseb	5.47	12.5	7.46	16.27	13.11	**13.31**	4.23	3.14	3.4
Cynodon dactylon (L.) Pers.	**66.24**	**20.83**	**53.05**	30.45	9.84	**18.9**	24.73	10.47	**16.25**
Eleusine indica (L.) Gaertn.							9.79	5.24	**14.18**
Leersia hexandra Sw.	3.22	4.17	3.37	11.71	14.75	**23.26**	1.49	3.66	2.02
Total BLWs	17.36	45.83	26.65	25.96	37.71	26.51	19.11	43.98	22.69
Total Grasses	79.42	50.00	70.38	63.63	50.83	63.64	66.15	45.55	64.14
Total Sedges	3.22	4.17	2.97	10.41	11.48	9.86	14.74	1047	13.17
PRE: *Dhodang-Ujjirati*									
Cynodon dactylon (L.) Pers.	**22.38**	**8.14**	**13.65**	5.4	5.40	6.17	27.41	12.68	**15.45**
Cyperus difformis L.	16.48	5.81	**14.97**				0.39	1.41	0.6
Cyperus haspan L.	0.51	2.33	0.95	15.37	10.14	**10.89**	1.75	4.23	2.07
Eleocharis geniculata (L.) Roem				71.01	13.04	**58.83**	34.01	4.23	**41.7**
Leersia hexandra Sw.	**8.44**	4.65	**11.32**				1.17	1.41	0.92
Paspalum notatum Flugge	**10.38**	6.98	**11.78**				5.25	2.82	3.38
Total BLWs	31.03	54.66	36.72	2.29	24.64	8.99	14.38	45.12	**20.12**
Total Grasses	49.86	32.56	45.03	3.14	14.49	5.94	46.18	38.06	**31.93**
Total Sedges	19.12	12.79	18.24	94.56	60.86	85.08	39.45	16.92	**47.93**
PRI: *Sikoli chapori*									
Arundo donax L.	8.15	7.94	**12.21**				4.61	0.90	**10.81**
Cynodon dactylon (L.) Pers.	44.83	14.29	**27.36**				38.32	9.91	**25.74**
Eleusine indica (L.) Gaertn.							5.85	2.70	9.26
Paspalum distichum L.	22.19	12.7	**28.5**				0.54	1.80	0.8
Total BLWs	15.64	39.68	19.8				27.14	55.86	31.55
Total Grasses	79.84	46.03	73.52				60.15	35.13	58.36
Total Sedges	4.51	14.28	6.69				12.64	9.01	10.06

diversity triggered by flood. Pielou's index ('I') is used to measure how evenly the species were distributed in a community. In CGS-1 the Pielou's index of weed flora was as high as 18.651 in PRE ecosystem, which was nearly 52% higher than PRI and 147.8% higher than that of TRI ecosystems. However, Pielou's index was of the trend of TRI>PRI>PRE at CGS-3 (**Table 3**).

The number of species and weed biomass revealed very strong correlation with Margalef's species richness index, Pielou's evenness index and Shannon and Wiener's diversity index. However, the correlations of all the diversity indices with soil pH, available N, P and K, were found to be weak to very weak (**Table 3, Figure 1**).

Inter-specific association

Species interactions are of central importance in the ecology of a species (Sanjerehei and Rundel 2020). In the present study, inter-specific associations amongst neighbouring weeds (tested for dominant weeds only with SDR value above 9.0) revealed a few strong associations with coupling value (AC) 1.0 (both +ve and -ve) and majority of associations were weak to very weak (**Table 4**). A very strong positive AC value was recorded between *Arundo donax* and *Cynodon dactylon*, in the PRI at *Sikoli chapori* followed by *A. donax* x *Paspalum distichum* (0.3) indicating the similarity in the requirements between the species of each pair. In contrary, in the same location, *Eleucine indica* revealed very strong negative association (AC= -1.0) with *Arundo donax* and *Paspalum distichum*. Negative association between species may occur because species have different resource requirements; resources compete and are used exclusively by species, and interference between



H: Shannon and Wiener diversity index; Dmg: Margalef's species richness index; SDI: Simpson's Diversity index and I: Pielou's evenness index

1. Soil pH; 2. Organic Carbon; 3. Available Nitrogen; 4. Available Phosphorus;
5. Available Potassium; 6. Weed biomass; 7. Number of Species

Figure 1. Correlations among different indices of weeds in deep water rice ecosystems of the Brahmaputra River ecotone

Table 3. Different diversity indices in deep water rice weeds in different land situations during 2022 and 2023 and their correlation with the species richness, weed biomass and soil characteristics

	Total number of weed species	Weed biomass	Shannon and wiener diversity index	Margalef's species richness index	Simpson's diversity index	Pielou's evenness index
	(S)	(g/m^2)	(H)	(Dmg)	(SDI)	(I)
PRI CGS-1	21	156.73	1.775	3.387	0.735	12.242
PRI CGS-2	67	399.264	2.531	12.976	0.828	40.332
TRI CGS-1	14	17.917	1.419	3.782	0.997	7.527
TRI CGS-2	13	51.483	2.13	2.383	0.847	10.797
TRI CGS-3	60	335.411	2.898	11.757	0.907	42.47
PRE CGS-1	24	157.457	2.47	5.119	1	18.651
PRE CGS-2	14	214.702	1.047	1.799	0.468	5.553
PRE CGS-3	46	360.294	2.297	9.711	0.807	27.595
Correlation between			H	Dmg	SDI	I
Soil pH			0.121	-0.043	0.457	0.009
Organic Carbon			-0.079	0.113	-0.438	0.064
Available Nitrogen			-0.140	0.004	-0.452	-0.048
Available Phosphorus			-0.174	-0.108	-0.378	-0.153
Available Potassium			0.070	0.249	-0.183	0.232
WEED biomass			0.537	0.851	-0.203	0.832
Number of Species			0.751	0.988	0.177	0.980

PRI= Permanent River islands; TRI= Temporary River islands; PRE= Permanent River edges; CGS- crop growth stages

species produces occasional exclusion (Chesson 2000, Ludwig *et al.* 1988). In the deep water rice of TRI at *Dhodang chapori* no strong weed-species association occurred. Frequent changing of weed flora composition caused mostly for flooding and water current, and under the influence of several biological agents, including human interference might be the reasons behind the unstable coupling behaviour in these temporary islands.

In permanent edge (PRE) ecotone zone, *Cyperus difformis* had strong negative association with *Eleocharis geniculata* and *Cynodon dactylon* with (-)1.0 coupling value followed by *Alternanthera philoxeroides* x *Cynodon dactylon* (AC= -0.618) and rest of the weed pairs had very low coupling values. It is fact that community relatedness reflects the stability of the community structure (Juan *et al.* 2023). When a community is in the early stage of succession, the overall degree of community relatedness is low, and negative association may even occur (Liu *et al.* 2017); however, the overall community relatedness tends to be higher in course of achieving stable co-existence in course of succession of a community. The results of weed flora association study, thus, reflected the increasing community relatedness as TRI> PRE >PRI, which might be due to the presence of least disturbance in soil, cropping, and resource availability in permanent islands in comparison to other land situations.

Table 4. Inter-specific association and coupling coefficient (AC) between dominant weed species of deep-water rice in different land situations along Brahmaputra River ecotone in 2022 and 2023

Species A	Species B	AC
PRI: *Sikoli Chapori*		
Arundo donax	*Eleusine indica*	-1.000
Arundo donax	*Paspalum distichum*	0.333
Arundo donax	*Cynodon dactylon*	1.000
Eleusine indica	*Paspalum distichum*	-1.000
Eleusine indica	*Cynodon dactylon*	0.029
Paspalum distichum	*Cynodon dactylon*	0.057
TRI: *Dhodang Chapori*		
Alternanthera philoxeroides	*Leersia hexandra*	0.242
Alternanthera philoxeroides	*Eleusine indica*	-0.333
Alternanthera philoxeroides	*Eragrostis Unioloides*	0.000
Alternanthera philoxeroides	*Cynodon dactylon*	-0.143
Leersia hexandra	*Eleusine indica*	0.318
Leersia hexandra	*Eragrostis Unioloides*	0.045
Leersia hexandra	*Cynodon dactylon*	0.018
Eleusine indica	*Eragrostis Unioloides*	-0.100
Eleusine indica	*Cynodon dactylon*	-0.500
Eragrostis Unioloides	*Cynodon dactylon*	0.100
PRE: *Dhodang Ujjirati*		
Paspalum notatum	*Alternanthera philoxeroides*	0.354
Paspalum notatum	*Leersia hexandra*	0.016
Paspalum notatum	*Cyperus difformis*	0.300
Paspalum notatum	*Eleocharis geniculata*	-0.125
Paspalum notatum	*Cynodon dactylon*	-0.354
Alternanthera philoxeroides	*Leersia hexandra*	0.213
Alternanthera philoxeroides	*Cyperus difformis*	0.300
Alternanthera philoxeroides	*Eleocharis geniculata*	-0.300
Alternanthera philoxeroides	*Cynodon dactylon*	-0.618
Leersia hexandra	*Cyperus difformis*	0.344
Leersia hexandra	*Eleocharis geniculata*	0.067
Leersia hexandra	*Cynodon dactylon*	-0.213
Cyperus difformis	*Eleocharis geniculata*	-1.000
Cyperus difformis	*Cynodon dactylon*	-1.000
Eleocharis geniculata	*Cynodon dactylon*	0.052

In deep water rice, especially in Brahmaputra River ecotone, farmers are dependent on flood for weed management and growth and yield of the crop as well. Better understanding of weed dynamics and crop weed association at different crop growth stages in different land situations might be the key factor for adoption of effective and eco-friendly agronomic management practices to manage the weeds.

Conclusion

The deepwater rice fields along the Brahmaputra River ecotone possessed some unique-features in crop-weed association during its 5 to 6 months long cropping period, between March to November. Monsoon flood caused mortality of most of the early emerged weeds and certain other weeds carried by water current were added. The number of species and weed biomass revealed very strong correlation with Margalef's species richness index, Pielou's evenness index and Shannon and Wiener's diversity index. However, the correlations of all the diversity indices with soil pH, available N, P and K, were found to be weak to very weak.

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