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COMMUNICATION

Commercially and medicinally significant aquatic macrophytes: potential for improving livelihood security of indigenous communities in northern Bihar, India

Shailendra Raut [1], Nishikant Gupta [2], Mark Everard [3] & Indu Shekhar Singh [4]

[1,4] ICAR-Research Complex for Eastern Region, Research Centre for Makhana, Darbhanga, Bihar 846005, India.
[2] Department of Geography and Environmental Management, University of the West of England, Frenchay Campus, Coldharbour Lane, Bristol BS16 1QY, UK.
[3] University of the West of England, Coldharbour Lane, Bristol BS16 1QY, UK.
[1] shailenmraut10@gmail.com, [2] nish200684@gmail.com (corresponding author), [3] Mark.Everard@uwe.ac.uk,
[4] induciah@rediffmail.com induciah@rediffmail.com

Abstract: The dispersed wetlands in the Darbhanga District of northern Bihar, India, provide a diversity of niches supporting substantial floral and faunal richness. The aquatic macrophytes of a representative range of perennial water bodies were surveyed fortnightly from June to September 2019, supported by a market survey undertaken with local stakeholders. A total of 61 species of vascular macrophytes was recorded, the majority of them Angiosperms (33 species of Dicotyledons from 21 families, and 26 Monocotyledons from 13 families) and two were Pteridophytes. This paper highlights the distribution pattern and potential commercial and medicinal values of aquatic macrophytes found in different wetland systems in northern Bihar. It further stresses their importance for subsistence, medicinal and economic purposes supporting the livelihoods of local people. Current trends and risks contributing to the degradation and loss of this diverse flora and its supporting habitats are considered. We recommend further assessment of the occurrence and values of this botanical resource, and extension of valuation to encompass the diverse additional ecosystem service benefits provided by the region's wetland systems, as a basis for wetland conservation strategies founded on sustainable management and wise use, with particular reference to the potential for enhancing livelihood security of indigenous communities.

Keywords: Aquatic macrophytes, conservation, ecosystem services, livelihoods, nutrition, wetlands.

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Author details: Shailendra Raut and Indu Shekhar Singh are currently working at the Research Centre for Makhana, Darbhanga, Bihar, India as Scientists in the area of wetland ecosystem and cultivation of commercial macrophytes. Nishikant Gupta is a water and climate scientist working to build resilient systems in the fields of livelihoods and ecosystem services. Mark Everard is an Associate Professor at UWE-Bristol, UK working on freshwater ecosystems, livelihoods and ecosystem services.

Author contribution: SR prepared the map of the study area, was involved in the site selection, market survey, and methodology. SR and ISS collected the field data and were involved in the identification of species. NG and ME participated in the methodology selection and evaluation of the commercial macrophytes. All authors participated in preparing the final version of the manuscript.

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INTRODUCTION

Aquatic macrophytes, also known as hydrophytes, are large plants found in the margins or littoral zones, surface or submerged bed of water bodies. They may be emergent, submerged or floating, rooted or unrooted in habit, with associated adaptations to the leaves, stems and/or roots matching the requirements of these aquatic environments (Bornette & Puijalon 2009; Peters & Lodge 2009; Rejmankova 2011). In addition, hydrophytes may serve as secondary, often seasonal habitats for numerous living organisms, with further geomorphological roles such as trapping and accreting sediment or influencing water levels and flows (Holmes & Raven 2014). Hydrophytes also produce oxygen, are significant for primary production (Nag et al. 2019), and play pivotal roles in chemical and energy cycles including important roles in decontamination of polluted water (Pandit 1984). Aquatic macrophytes thereby play key roles in many functions within aquatic ecosystems, generating a diversity of ecosystem services beneficial directly and indirectly to human society (Engelhardt & Ritchie 2001; Cherry 2011). The significance of these various roles must necessarily be included in plans for the management and restoration of wetlands (Kaplan et al. 1998; Larson et al. 2019).

Some of the direct ecosystem services provided by water plants occur through their roles as valuable bioresources with significant associated socioeconomic or subsistence values for indigenous communities. This contribution may be highly locally significant in India, where indigenous communities comprise over 8.2% of the national population (Ministry of Tribal Affairs 2013). Indigenous people traditionally use wetland plants for food, fodder and medicine and for making a range of household and artistic products in various Indian states including Bihar, Odisha, West Bengal, and throughout northeastern India (Maikhuri & Ramakrishnan 1992; Bunting et al. 2010; Jain et al. 2010a; Saha et al. 2014; Gogoi 2016). Important plant species in these regions, including *Azolla* spp., Chinese Water Chestnut *Eleocharis dulcis*, Water Chestnut *Trapa natans*, Makhana *Euryale ferox*, Wild Rice *Zizania* spp., Indian Lotus *Nelumbo nucifera*, Water Spinach *Ipomoea aquatica*, Water Cress *Rorippa nasturtium-aquaticum*, Water Mimosa *Neptunia oleracea*, and Wild Taro *Colocasia esculenta*, have been harvested from wild stock, or cultivated in flooded areas for food, aquaculture, livestock fodder, and religious significance (Hasan & Chakrabarti 2009; Meena & Rout 2016).

This pilot study surveys aquatic macrophytes, and their associated ecological and livelihood benefits from the different wetland ecosystems of northern Bihar. It further investigates commercially important macrophytes and their utilities, and their implications for enhancing livelihood and nutritional security for dependent indigenous communities in northern Bihar. The key objective is to develop initial proposals for sustainable and wise use of this botanical resource and the wetland ecosystems that support it, including recommendations for further research to inform conservation strategies.

MATERIALS AND METHODS

The dispersed perennial wetlands of Darbhanga District, in the northern Bihar State, India, were selected for botanical surveys. These wetlands are locally known as ‘Chaur’ (floodplain wetlands/land depressions), ‘Maun’ (ox-bow lakes) and both large and small ponds are known as ‘Pokhari’. Six sampling sites were selected for this pilot survey, taking account of a range of hydrologic conditions, vegetation types, floodplains, and wetland shores found in the surveyed region. Selected sampling stations included two Pokhari (Baghant & Mansar), two Chaur (Sakari & Ladha), and two Maun (Simri & Kusheswar Asthan) (Figure 1). Macrophyte sampling was conducted along transects in each surveyed wetland. Sites were sampled fortnightly from June to September 2019 during the monsoon season, when aquatic macrophytes grow most prolifically under seasonally wet conditions. Identification of macrophytes was carried out with the help of relevant literature (Biswas & Calder 1984; Cook 1996; Ramkrishna & Siddique 2002). The collected macrophytes were also checked by herbaria from the Department of Botany, CM Science College, LNM University, Darbhanga.

The four major markets in Darbhanga City (Bazar Chauki, Donar, Darbhanga tower and Lahariasarai tower) were selected for the market surveys to assess socio-economic implications of aquatic macrophytes extracted from these wetlands (Figure 1). Market surveys consisted of identifying the economic value, quantity and preference of buyers of the products obtained from the surveyed macrophytes.

Semi-structured interviews were conducted with consumers and informants from the sampling area to retrieve the information on the economic importance of different parts of macrophytes. These included fruits (water chestnuts), pops (makhana), flowers (lotus), leaves (taro) and some medicinal plants. The questions

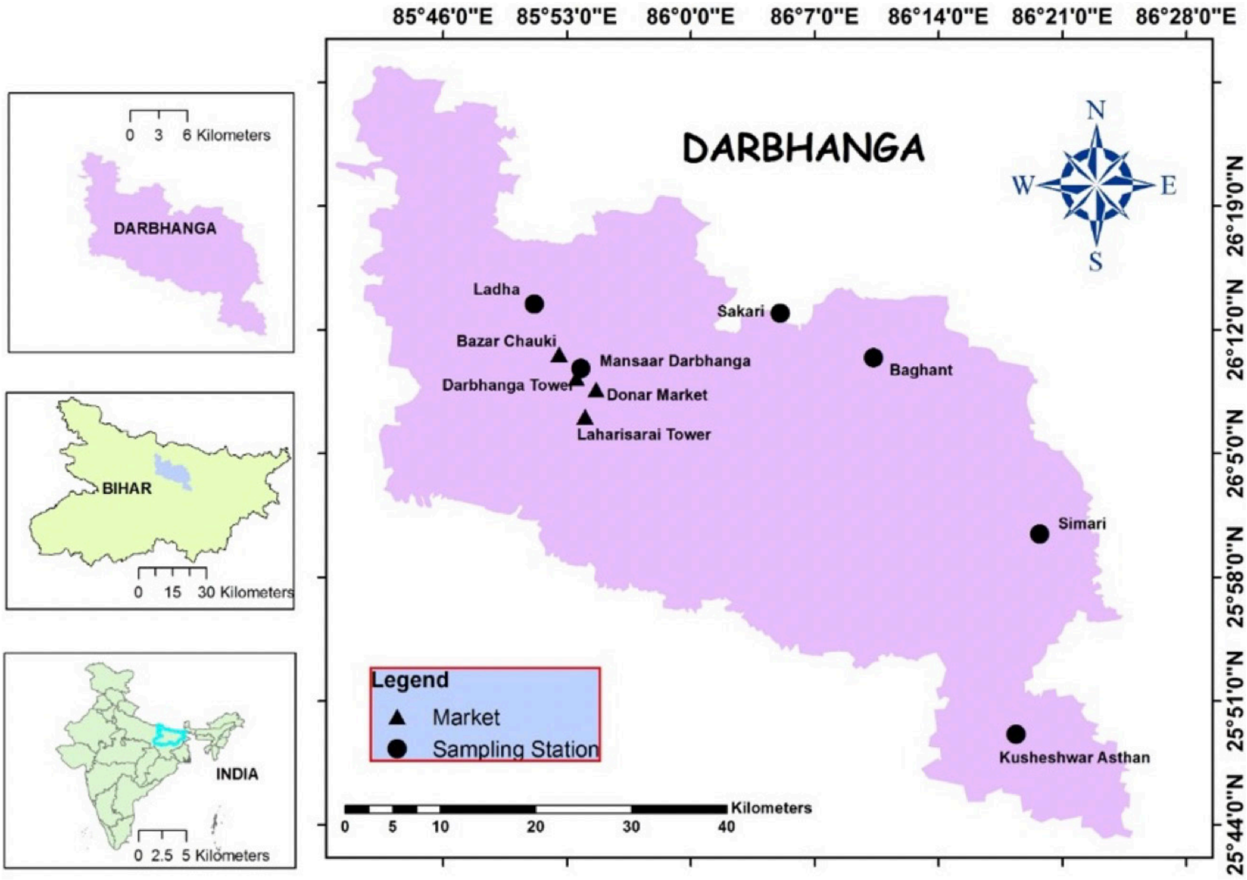

Figure 1. Darbhanga District, Bihar, India showing the sampling stations and the location of the markets

were developed based on the findings of earlier field surveys and interaction with local ethnic groups in the region by the authors (unpublished data). Ethnic group selection was based on the voluntary willingness and the availability of members in the study area during the field survey. Consent was requested and obtained from all the participants to make notes of interviews. Respondents were informed that all responses would be anonymized, so that they felt free to express their views without attribution. Discussions took place primarily in local languages and dialects. Gender sensitivity was considered, including questioning of women by a female member of the research team, though no inhibition was encountered in wider discussions with female or other informants. Conversation flowed freely with no evidence of it being dominated by any individuals. Researchers fluent in local languages translated the responses, taking written notes in English and collating them following the meeting. Additional input was derived from literature searches (as seen in the citations used in this paper).

The literature was extensively interrogated (peer-reviewed and non-peer reviewed papers, and grey literature articles) to identify key attributes, chemical composition, ecosystem functions, and medicinal and other uses of aquatic macrophyte species most commonly used and traded in the study region. Google Scholar was used as the preferred search engine using the macrophytes as key terms. It was not possible to fully structure the literature review due to the diversity of plant species and habitats types in northern Bihar, their uses, and their range of associated market and non-market values. Given the breadth of research that had been conducted throughout the region, it was important to analyse available literature for the studied macrophytes. Data and other information obtained through previous extensive field surveys conducted by the authors have been complemented with analysis of available data and a breadth of studies conducted as the empirical basis of this paper.

RESULTS AND DISCUSSION

Aquatic macrophyte surveys of selected wetland ecosystems revealed a total of 61 relevant species of vascular plants. Most of the identified species were Angiosperms, and only two were Pteridophytes. The recorded Angiosperms included 33 species (54% of all species found) of Dicotyledons spread over 21 families and 26 (42% of the survey total) species of Monocotyledons from 13 families (Table 1). Filamentous algae (species were not recorded) and Pteridophytes (two species were recorded) were poorly represented in surveys during the monsoon season, and found to be closely associated with makhana and water chestnut. Figure 2 presents some of the most significant macrophytes extracted for human uses; Table 2 summarizes their chemical and nutritional characteristics derived from literature sources. Table 3 represents the survey prices of commercial important aquatic macrophytes. Based on the observed macrophytes from the study sites and the market surveys, 10 macrophytes were identified as having the highest ecological and commercial importance due to their environmental roles, utilities, market price, availability, and preference by buyers in the markets: Azolla, Makhana, Water chestnut, Taro/elephant ear, Indian lotus, Mandukaparni, Water spinach, Sweet flag, Brahmi, and Bhringraj (see Table 3).

Among the floating species in this survey, the alien invasive water hyacinth *Eichhornia crassipes* was found to be widely distributed and abundant in the stagnant waters of rivers, ditches and other wetland types. The submerged macrophyte *Hydrilla verticillata*, and the floating-leaved macrophyte *Nymphoides cristatum* were both found to be very common in the littoral zone of all examined wetlands. Macrophytes of high commercial value, including Makhana and Water chestnut, were mostly reported from the large ponds (Pokhari) and Chaur/Mauns (wetlands) where they were grown for production purposes, though some were also reported growing naturally in the Mauns. The floating-leaved macrophyte *Nelumbo nucifera* (lotus) was reported from temple pond and wetlands areas of 3–5m depth. Macrophyte species from the families Asteraceae, Cyperaceae, and Poaceae were mostly observed in the marginal portions of the wetlands and adjacent lowland areas. The attributes of the commercial macrophytes in terms of their scientific importance, nutritional quality and quantity, and culture practices possibly contributing to their preferred demand in the markets are summarized in Tables 3 and 4.

Diversity and distribution

The sampled wetlands support a diversity of aquatic macrophytes, which play various ecological roles as primary producers and in the recycling of nutrients (Engelhardt & Ritchie 2001; Bornette & Puijalon 2011). Nutrient recycling from the decomposition of macrophytes at the end of the growing season contributes to requirements for macrophyte growth in the following growing period (Denny 1985). From literature studies, appreciation of the conservation value of this resource appears to be lacking.

Societal benefits supported by aquatic macrophytes

Aquatic macrophytes play significant roles in supporting the needs of indigenous communities, in the forms of food, medicine and tradeable commodities, in addition to diversifying habitat supporting societally important aquatic fauna (Costanza et al. 1997; Petr 2000).

Our study finds that aquatic plants found in the wetlands of northern Bihar are important for the subsistence, medicinal and economic needs of local communities. In addition to wild harvesting, utilization of these wetlands for the culture of important aquatic macrophytes, such as Makhana and Water chestnut, has the potential to enhance the livelihoods of indigenous communities. It is important to acknowledge the extent to which indigenous communities are reliant upon these macrophytes for subsistence as well as other food, aquaculture, livestock fodder, trading and religious significance. Unstructured interviews with community members within this pilot study revealed the dependence of communities, however, with emerging opportunities such as more intensive forms of aquaculture and habitat conversion for agriculture, this low-level and inherently more sustainable dependence is now slowly giving way to habitat exploitation for "quicker benefits".

Given the significant health benefits of these macrophytes for local people and more widely through trade, including their utility in various pharmaceutical industries, it is critical to enhance the capacity of local communities to explore the possibility of growing or harvesting these plants on a sustainable basis as cash crops, further supporting their livelihood options. These values need to be recognized, valued and embedded into the policy environment as a basis for sustainable management and wise use strategies, resisting or better informing current trends towards more intensive forms of aquaculture farms in the region.

Table 1. List of plant species recorded along with their habits.

	Scientific name	Family	Habits	IUCN status
	Pteridophyta			
1.	*Azolla pinnata* Linn.	Salviniaceae	Floating	Least Concern
2.	*Marsilea minuta* Linn.	Marsileaceae	Emergent	Least Concern
	Dicotyledons			
3.	*Nelumbo nucifera* Gaertu.	Nymphaeaceae	Floating	Data deficient
4.	*Nymphaea nouchali* Burm.	Nymphaeaceae	Floating	Least Concern
5.	*Asterocantha longifolia* Nees	Acanthaceae	Low land	Least Concern
6.	*Boerhaavia diffusa* Linn	Nyctaginaceae	Low land	Not Evaluated
7.	*Alternanthera sessilis* Linn.	Amarenthaceae	Emergent	Least Concern
8.	*Alternanthera philoxeroides* Mart. Griseb.	Amarenthaceae	Emergent	Least Concern
9.	*Ameranthus viridis* Linn.	Amaranthaceae	Low land	Not Evaluated
10.	*Polygonum glabrum* Willd	Polygonaceae	Emergent	Least Concern
11.	*Rumex dentatus* Linn.	Polygonaceae	Low land	Not Evaluated
12.	*Polygonum hydropiper* Linn.	Polygonaceae	Emergent	Least Concern
13.	*Scoparia dulcis* Linn.	Scrophulariaceae	Low land, Emergent	Not Evaluated
14.	*Heliotropium indicum* Linn.	Boraginaceae	Low land	Not Evaluated
15.	*Nymphoides cristatum* Roxb	Menyanthaceae	Floating	Least Concern
16.	*Trapa bispinosa* Roxb.	Lythreaceae	Floating	Not Evaluated
17.	*Eclipta alba* (L.) Hassk	Asteraceae	Low land	Not Evaluated
18.	*Ageratum conyzoides* Linn.	Asteraceae	Low land	Not Evaluated
19.	*Parthenium hysterophorus* Linn.	Asteraceae	Low land	Not Evaluated
20.	*Xanthium strumarium* Linn.	Asteraceae	Low land, Marginal	Not Evaluated
21.	*Vicoa indica* (Willd.) DC.	Asteraceae	Marginal	Not Evaluated
22.	*Malvestrum tricuspidatum* A. Gray	Malvaceae	Low land	Not Evaluated
23.	*Urena spp.*	Malvaceae	Marginal, Submerged	--
24.	*Aeschynomene aspara* Linn.	Papilionaceae	Emergent	Least Concern
	Aeschynomene indica Linn.	Papilionaceae	Emergent	Least Concern
25.	*Desmodium triflorum* (Linn.) DC.	Papilionaceae	Low land	Not Evaluated
26.	*Ipomoea aquatica* Forssk.	Convolvulaceae	Floating, trailing herb	Least Concern
27.	*Convolvulus arvensis* Linn.	Canvolvulaceae	Marginal, low land, trailing herb	Not Evaluated
28.	*Bacopa monnieri* (L.) Pennell	Plantaginaceae	Low land, Creeping herb	Least Concern
29.	*Centella Asiatic* Linn.	Apiaceae	Low land, Creeping herb	Least Concern
30.	*Utricularia stellaris* Linn.	Lentibulariaceae	Submerged	Not Evaluated
31.	*Hyptis suaveolens* (Linn.) Poit.	Lamiaceae	Marginal	Not Evaluated
32	*Ludwigia hyssopifolia* (G. Don) Exell	Onagraceae	Marginal	Least Concern
33.	*Physalis minima* Linn.	Solanaceae	Marginal	Not Evaluated
34.	*Phyllanthus simplex* Retz.	Euphorbiaceae	Marginal, low land	Not Evaluated
35.	*Phyllanthus fraternus* Webster.	Euphorbiaceae	Marginal, low land	Not Evaluated
	Monocotyledons			
36.	*Commelina benghalensis* Linn.	Commelinaceae	Low land	Least Concern
37.	*Commelina nudiflora* Linn.	Commelinaceae	Low land	Not Evaluated
38.	*Lemna gibba* Linn.	Lemnaceae	Floating	Least Concern
39.	*Wolffia arrhiza* Wimm.	Lemnaceae	Floating	Least Concern

	Scientific name	Family	Habits	IUCN status
40.	*Pistia stratiotes* Linn.	Araceae	Floating	Least Concern
41.	*Colocasia esculenta* Linn.	Araceae	Low land	Least Concern
42.	*Sagittaria sagittifolia* Linn.	Alismataceae	Emergent	Least Concern
43.	*Scirpus articulatus* Linn.	Cyperaceae	Low land	Not Evaluated
44.	*Eleocharis dulcis* Burm.	Cyperaceae	Emergent	Not Evaluated
45.	*Fimbristylis tetragona* Br.	Cyperaceae	Low land, Emergent	Least Concern
46.	*Mariscus compactus* Nov. Comb.	Cyperaceae	Low land, Emergent	Least Concern
47.	*Pycreus pumilus,* Turril	Cyperaceae	Low land, Emergent	Least Concern
48.	*Potamogeton crispus* Linn.	Potamogetonaceae	Submerged	Least Concern
49.	*Hydrilla verticillata* (L.F.) Royle	Hydrocharitaceae	Submerged	Least Concern
50.	*Ottelia alismoides* (L.) Pers	Hydrocharitaceae	Submerged	Least Concern
51.	*Monochoria hastata* (L.) Solms.	Pontederiaceae	Emergent	Least Concern
52.	*Eichhornia crassipes* (Mart) solms.	Pontederiaceae	Floating	Not Evaluated
53	*Euryale ferox* Salisb.	Nympheaceae	Floating	Least Concern
54.	*Acorus calamus* Linn.	Acoraceae	Low land	Least Concern
55.	*Bacopa monnieri* Linn.	Plantaginaceae	Low land, Creeping herb	Least Concern
56.	*Chara zeylanica* Willd	Charophyceae	Submerged	Not Evaluated
57.	*Saccharum munja Roxb.*	Poaceae	Marginal	Not Evaluated
58.	*Saccharum spontaneum*	Poaceae	Marginal	Least Concern
59.	*Paspalidium spp.*	Poaceae	Marginal	---
60.	*Brachiaeria romosa* (L.) Stapf.	Poaceae	Marginal	Least Concern
61.	*Cynodon dactylon,* Linn.	Poaceae	Marginal	Not Evaluated

Table 2. Chemical composition of documented macrophytes (Reid 1977; Pullin & Almazan 1983; Becerra et al. 1995; Onwueme & Johnston 2000; Indrayan et al. 2005; Singh et al. 2010; Kumar et al. 2011; Faruk et al. 2012; Adkar et al. 2014).

Species	Carbohydrate	Protein	Crude fat	Crude fiber	Moisture	Ash
Azolla (dry weight basis)	10%	27%	4.6%	11.2%	Not available	15 %
Makhana (popped seeds)	76.90%	9.70%	0.2–0.5%	0.2–0.5%	10-13%	0.4%
Water chestnut (wet basis)	5.63%	1.87%	0.36%	2.13%	81%	1.33%
Taro/elephant ear (wet basis)	13–29 %	1.4–3 %	0.16–0.36	0.6–1.18	63–85 %	0.6–1.3 %
Lotus (seed)	70–72 %	10.6–15.9 %	1.93–2.8 %	2.70%	10.50%	4–4.5 %

Consequences of loss or degradation

Anthropogenic encroachment around the wetlands (such as agriculture and run-off from farming, industrial influent of various types, urbanization and associated sewage emissions) is exacerbated by lack of awareness among local people and regulatory agencies regarding the role of wetlands in the environment, with weak and poorly enforced regulation. Moreover, the presence of *Eichhornia crassipes,* an alien macrophyte in Bihar, threatens local biodiversity due to its high growth rate and tendency to form a dense mat over the water surface (Howard & Harley 1998). These stressors have the potential to reduce the depth of wetlands and negatively impact other desirable water plants such as Water Chestnut, Lotus, and Makhana plants (Jain et al. 2010b). The recent boom of aquaculture industries in northern Bihar has also negatively impacted the diversity of the recorded macrophytes (pers. obs.). Indigenous communities which earlier relied on the cultivation of these crops have moved towards the aquaculture sector due to high profitability in a short period of time, in comparison to Makhana and Water Chestnut culture.

Table 3. Survey prices of commercial important aquatic macrophytes (INR/kg).

Macrophytes	Seed	Leaves/ flowers	Root/ tuber	Pop	Dry/ powder
Makhana	100–150	----	----	400–800	400–1000
Water chestnut	15–40	----	----	----	200–300
Taro/elephant ear	--	10–20	20–40	----	----
Lotus	300–600	10–50*	30–40	-----	-----
Mandukaparni	--	----	-----		80–250
Water spinach	----	10–25	----	----	-----
Sweet flag	----	25–35	25–40	----	100–140
Brahmi	----	-----	------	----	40–150
Bhringraj	----	-----	-----	----	35–150

*per flower

This has led to the Chaur and Maun being converted to aquaculture ponds, denying local communities the traditional uses and values they derived from them.

Declining wetland extent and quality also results in an associated decline in the diverse ecosystem service benefits that the wetlands provide for wider societal wellbeing.

Conservation/wise use implications

The definition of "wise use" of wetlands according to Ramsar Commission is "*...the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development*" (Ramsar Commission 2010). In the context of the diverse wetlands of northern Bihar, the sustainable use of aquatic macrophytes, such as Makhana, Water Chestnut, Taro, and Lotus, can serve as a key focus and indicator of progress with wise and sustainable use. This may, for example, take the form of sustainable levels of harvesting and/or cultivation of local varieties of these plants in areas suitable for their production, safeguarding overall ecological character and the many additional societal benefits that flow from the wetland habitats that support them. Naturally available Taro, Azolla, Water spinach, and other medicinal plants also need critical attention as they are widely used, and relied on by many, for local consumption and medicinal proposes.

Aquatic macrophyte diversity in the study region plays an important role in the supporting aquatic ecosystems, including as a resource for local livelihoods. Therefore, incorporating the wise use of this botanical resource into aquatic management strategies, in which the diverse societal benefits that it provides is explicitly recognized as a key element of sustainable development, can be influential in the sustainable conservation and livelihood needs of local communities associated with the wetland resource. This approach needs to be linked with planning approaches in the adjoining landscape to ensure that associated plans and policies take account of potential adverse impacts on these wetlands.

Further research and development needs

This pilot survey of aquatic macrophyte occurrence, uses and societal importance highlights the many values that flow to society from the diverse Chaur, Maun, and Pokhari wetlands naturally occurring in north Bihar. Additional surveys can augment this preliminary evidence base concerning plant distribution and socio-economic importance. Societal benefits flowing from the aquatic macrophytes form only a small part of the total ecosystem services benefits generated by these diverse wetlands. Methods such as the RAWES (Rapid Assessment of Wetland Ecosystem Services) approach (Ramsar Convention 2018), adopted in October 2018 by the Ramsar Convention as a globally standard means for assessment of wetland ecosystems on a systemic basis, enable the rapid, semi-quantitative assessment of wetland ecosystem services. Wider ecosystem service assessment can augment the knowledge base, recognizing more of the often-overlooked societal benefits provided by these wetland systems.

This broader knowledge base can in turn inform wise use strategies that reflect the many societal benefits associated with simultaneous use and conservation of wetland systems, as a bulkhead against their conversion for intensive and potentially unsustainable uses such as aquaculture, agricultural and industrial development that yield a narrow subset

Table 4. Key attributes of the ten most commercially important aquatic macrophytes found in this survey.

***Azolla* spp.**

The genus *Azolla* comprises floating freshwater ferns within the family Salviniaceae. These plants have triangular or polygonal fronds, and float on the water surface either as individuals or in mats (Figure 2a). Azolla spreads very quickly in ideal growing conditions, forming dense vegetative masses on areas of still water in Maun and swampy areas. The plant plays an important role in the fixation of atmospheric CO_2 and nitrogen due to its symbiotic relationship with cynobacteria (*Anabaena azollae*) and rhizobium bacteria (Reddy et al. 2002). Simultaneously, it reduces evaporation rates and serves as a water purifier due to its ability to absorb unwanted organic nutrients and trace elements (Sood et al. 2012).

Azolla pinnata var. imbricata is found most commonly in Asian tropical waters, and is very common in most of the water bodies in north Bihar. The size of individual plants ranges from 1–1.5 cm. *Azolla* contains nitrogen hence, can serve as green manure or bio-fertilizer for the paddy fields and aquafarms (Hasan & Chakrabarti 2009). It also contains a substantial quantity of protein, fats and fibers (Table 2), and is also a source of vitamins (A and B12), phosphorus, potash, copper, magnesium and bioactive substances. Widespread use of *Azolla* is mainly due to its low price, and as a very abundant protein source (Reddy & deBusk 1985). Due to its high nutritive value, it is also used as feed for fish and livestock (Sherief & James 1994).

Makhana

Euryale ferox Salisb., locally known as Gorgon or prickly water lily, is also called Makhana. This species belongs to the family Nympheaceae (Zhuang 2011). It has a wide geographic range in north Bihar. It is an annual hydrophyte and its habitat comprises of stagnant perennial water bodies such as ponds, oxbow lakes, swamps and ditches (Figure 2b). The plant is used for edible and medicinal purposes in Ayurveda (Masram et al. 2015). The seed is used for its analgesic and aphrodisiac properties (Masram et al. 2015). It's also taken internally in the treatment of chronic diarrhea, vaginal discharge, kidney weakness, nocturnal emissions, and impotence (Das et al. 2006). Raw Makhana is a good source of carbohydrates, proteins, minerals. The calorific value of raw and popped seeds of Makhana is 362 and 328 K cal/100g respectively (Table 2).

Water chestnut

Trapa natans L. and its infraspecies *Trapa natans var. bispinosa* (Roxb.) Makino. is an aquatic free-floating plant with submerged and floating leaves arranged in a rosette manner (Figure 2c). It belongs to the family Trapacae. The habitat of water chestnut requires sunny conditions and a muddy, nutrient rich, freshwater and soft substrate of ponds, marshes and lakes. Water chestnut is commonly known as Singhara/Singhada in India.

The fruit of water chestnut has nutritional and medicinal values. The approximate composition of the water chestnut kernel is given by Singh et al. 2010 and Adkar et al. 2014 (see Table 2). The immature pulp of the fruit, called milky water chestnut, is eaten raw or cooked. It is also used for preparing tea in Japan, commercial production of wine, and festival food. The fruits have been used as agents of anti-inflammatory, anti-diarrhea, intestinal astringent, antileprotic and urinary discharges (Alfasane et al. 2011; Chandana et al. 2013).

Taro/elephant ear

The common name of *Colocasia esculenta* (L.) Schott. is Taro/elephant ear. It is a lowland aquatic macrophyte belonging to the family Araceae. It is a tropical and subtropical perennial plant with large, heart shape leaves (Figure 2d). The habitat of elephant ear is mostly moisture-rich areas or littoral zone of aquatic marshes, ponds and wetlands in northern Bihar. It has both roots and leaves which are edible (Opara 2001). Members of the genus are also cultivated as ornamental plants. Taro has high importance in ensuring food and livelihood security as it is also a cash crop (Revill et al. 2005; Palapala et al. 2009). Fresh taro is an excellent source of carbohydrate/starch with low amounts of fat and protein (Onwueme & Johnston 2000) (see Table 2). Other nutrients such as minerals, Vitamin C, Thiamin, Riboflavin and Niacin are also present (Temesgen & Ratta 2015). Taro leaves are used as antidiabetic, antihypertensive, immunoprotective, and anticarcenogenic agents (Gupta et al. 2019), possibly due to being an excellent source of carotene, potassium, calcium, phosphorous, iron, riboflavin, thiamine, niacin, Vitamin A, Vitamin C and dietary fibre (Opara 2001). Curry preparation with leaves and stalks are given to women after childbirth to act as a treatment for anemia (Sarmah et al. 2013).

Indian lotus

The Indian lotus, *Nelumbo nucifera* Gaertn., is the national flower of India belonging to the family Nelumbonaceae. The habitat includes shallow and muddy ponds, wetlands and lakes that are exposed to direct sunlight (Figure 2e). The cultivation of lotus can be traced back more than 3,000 years ago for food, medicine, and cultural and religious activities (Shen-Miller 2002; Mandal & Bar 2013).

Lotus rhizomes, stems and leaves are edible (Sridhar & Bhat 2007). Lotus rhizomes comprise 1.7% protein, 0.10% fat, 9.7% carbohydrates, and 1.1% ash (Reid 1977), and stems contain 6, 2.4 and 0.2 mg/100 g of calcium, iron and zinc respectively (Ogle et al. 2001). The seeds of lotus consist of several nutritional properties (see Table 2). Even the petals are used in soups and as a garnish. The rhizome extract has anti-diabetic and anti-inflammatory properties (Mukherjee et al. 1997). The leaves are used effectively for hematemesis, epistaxis and hemoptysis (Ou 1889). The fruits and seeds are used for dermatopathy, halitosis, menorrhagia, and leprosy (Nadkarni 1982).

Mandukaparni

Mandukaparni is a common name for *Centella asiatic* Linn., belonging within the family Apiaceae (Gohil et al. 2010). Mandukaparni grows in moist places and swampy areas of wetlands, particularly at the marginal areas of swamp and earth embankments (Figure 2f) (Khobragade & Khobragade 2016). Mandukaparni contains triterpene acids, flavonoids (Phondke 1992; Jamil et al. 2007), volatiles and fatty oil, alkaloids, glycosides (Chopra et al. 1956), and has also been reported to contain amino acids, minerals (Malhotra et al. 1961), oligosaccharides centellose, carotenoids, Vitamin-B, Vitamin-C (Phondke 1992), and tannins (Kapoor 2005). The species is widely used in Ayurvedic formulations, in Chinese medicine, and in homeopathic medicines. It is used to provide relief from insomnia, epilepsy, skin diseases, fever, high blood pressure, as a memory enhancer, and nervine tonic (Gupta & Sharma 2007). In homeopathic medicine, it is used for skin-related diseases such as itching and swelling, eczema, uterus-related ulceration and inflammation, granular cervicitis, elephantiasis and ascariasis (Singh & Rastogi 1969).

Water spinach

Ipomoea aquatic Forssk., commonly known as water spinach, belongs to the family Convolvulaceae. It is a semi-aquatic plant, with long hollow stems possessing a large number of air passages. Its leaves are elliptic or oval-oblong and cordate. The species is mostly associated with moist soil/mud along the margins of stagnant water bodies such as wetlands, marshes, lakes, ponds, rivers, and canals (Patnaik 1976).

Water spinach is nutritionally rich and found to contain nutrients such as α-tocopherol (Candlish 1983); Vitamin-C, thiamin, riboflavin, niacin, proteins, fats, carbohydrates, fiber, organic acid, ash and minerals (Wills et al. 1984); glycolipids, phospholipids and fatty acids (Rao et al. 1990); and α and β carotenes (Ogle et al. 2001). In Indian traditional medicine, the extract of the leaves is used to alleviate disorders such as jaundice and nervous weakness (Prasad et al. 2008); nosebleed and high blood pressure (Duke & Ayensu 1985); and It also provides relief from eye diseases (Jain & Verma 1981) and constipation (Samuelsson et al. 1992). The plant also possesses anti-nematodal (Mackeen et al. 1997) and antioxidant properties (Prasad et al. 2005).

Sweet flag

Sweet flag or bach is a common name for *Acorus calamus* Linn. It belongs to the family Acoraceae. It is a semi-aquatic, perennial monocotelydonous plant naturally found in wetlands (Tiwari et al. 2012) (Figure 2g). It is mainly used for its oil due to the high occurrence of fatty acids and essential oils including acrenone, isocalamendiol (Balakumbahan et al. 2010), monoterpene hydrocarbon, sequestirine ketones, asarone, and eugenol. Sweet flag has been used for the treatment of fever, asthma, bronchitis, swelling, cough, poor digestive function, epilepsy and insanity (Balakumbahan et al. 2010). Its roots and leaves also exhibit antimicrobial, antioxidant, and insecticidal properties (Asha et al. 2009; Balakumbahan et al. 2010).

Brahmi Brahmi is the common name of *Bacopa monnieri* Linn. Brahmi is a perennial creeping herb belonging to the family Plantaginaceae. It grows in marshy wetlands (Figure 2h). The plant contains Bacoside-A and B, both nootropic major chemical entities (Chatterji et al. 1965; Devendra et al. 2018). It also contains alkaloids such as brahmine, nicotinine, herpestine, triterpenoid, saponins A, B and C, betulinic acid, D-mannitol, stigmastanol, β-sitosterol, stigmasterol and pseudojujubogenin glycoside (Chopra et al. 1956; Bammidi et al. 2011). Brahmi has been used to treat various nervous system-related disorders such as a brain tonic to enhance memory development, learning, motivation, and concentration, and to provide relief to patients with anxiety. It is also used in digestive complains, for skin disorders, and as an antiepileptic, antipyretic, and analgesic agent (Mukherjee & Day 1966; Bammidi et al. 2011), however, its use has some clinical side effects such as mild gastrointestinal upset, nausea and intestinal motility (Aguiar & Borowski 2013).
Bhringraj Bhringraj or *Eclipta alba* Hassk. belongs to the family Asteraceae. Its habitat is along the edges of pools, tanks, ditches, littoral zone of wetlands and rice fields. It contains active coumestans such as wedelolactone and desmethylwedelolactone (Wagner et al. 1986; Jaglan et al. 2013), and furanocoumarins, oleanane and taraxastane glycosides (Singh et al. 2010). The plant is commonly used in hair oil for healthy black and long hair (Roy et al. 2008), and is also popular for enhancing memory and learning abilities (Banji et al. 2007). It is used as a tonic and diuretic in hepatic and spleen enlargement conditions. It is also used in catarrhal jaundice, for skin and gall bladder diseases (Treadway 1998).

of short-term benefits whilst tending to undermine their wider and longer-term societal values.

As India is a signatory of the Ramsar Convention, ensuring wise use of wetlands is an obligation, also safeguarding their contributions to other areas of concern such as their roles in regulating flooding, disaster risk reduction, carbon sequestration, and fish recruitment. It is also an important contributor to protecting tribal and other local community rights for example under India's Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006. This study provides preliminary evidence of the roles that aquatic macrophytes play in supporting the case for conservation and continuing sustainable use of the wetlands of northern Bihar.

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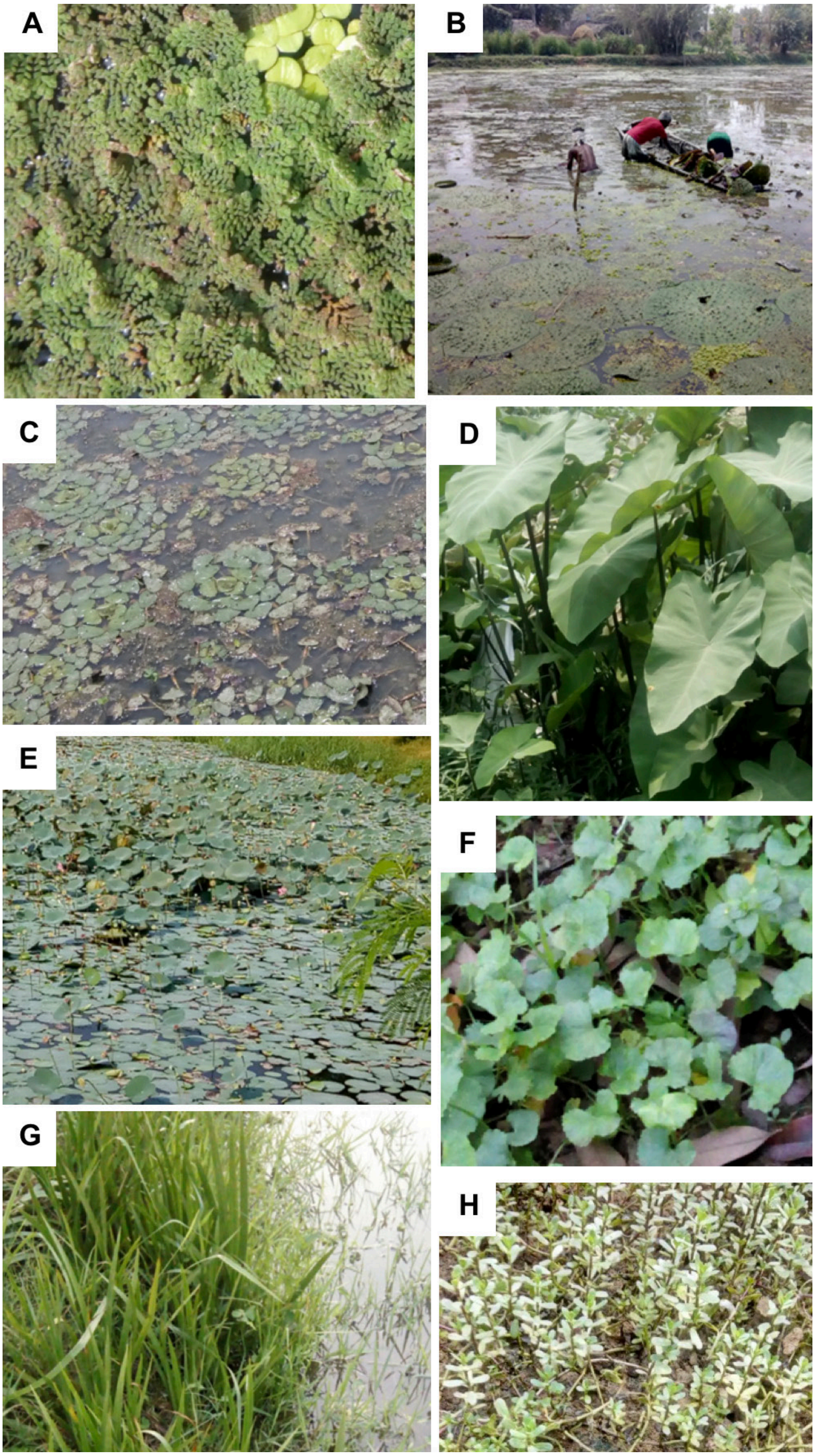

Image 1. Macrophytes from northern Bihar shown are A—Azolla | B—Makhana | C—Water chestnut | D—Taro | E—Lotus | F—Mandukaparni | G—Sweet flag | H—Brahmi. © Shailendra Raut.

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