

A Silver-Lining in *Alternanthera philoxeroides* Invasion: Exploring Sustainable Alternative Use in the Tropics

ANINDITA CHATTERJEE^{1*}, M. SUDARSHAN² AND ANJANA DEWANJI^{1,3}

¹Agricultural & Ecological Research Unit, Biological Sciences Division, Indian Statistical Institute, 203, B.T. Road, Kolkata 700108, West Bengal, India

²UGC-DAE Consortium for Scientific Research, Kolkata Centre, Kolkata 700098, West Bengal, India

Emails: anindita.chatterjee.ac@gmail.com; ² sude@alpha.inc.res.in; ³ anjdew@gmail.com

* Corresponding author

ABSTRACT

Tropical freshwater ecosystems; an indispensable means of sustenance, food and livelihood for millions of poor people of the developing world; are prone to massive biodiversity declines due to huge pressures of over-exploitation and invasive species. Without mitigation of the problem of biological invasion of the tropics, half the world's population will be soon facing serious food shortages. In an attempt to bridge the gap between successful management of an invasive plant, and a sustainable source of supplementary food for the marginalized population, this pilot study investigated the potential utilization of the widely prevalent invasive *Alternanthera philoxeroides* (Alligatorweed) as a leafy vegetable. Questionnaire-based field-surveys revealed a much higher section of rural populace utilized Alligatorweed as food/fodder as compared to the urban/semi-urban populace. ED-XRF analysis of young 'edible' shoots of Alligatorweed revealed it to have good concentration of essential elements like potassium, calcium, iron, zinc and manganese. However, significant positive correlations of manganese ($p < 0.01$) between Alligatorweed and its soil-substratum indicated its metal hyper-accumulative potential. Hence, Alligatorweed should be used for human-consumption only when it is harvested from non-polluted eco-regions.

This study explores a positive utility of the invasive Alligatorweed and in turn indicates its possible managerial approach. In a country where a large populace is mal-nourished, consumption of Alligatorweed as supplementary-vegetable can not only help in controlling its invasion into our pristine aquatic/wetland ecosystems, but also help in generation of cheap and sustainable source of supplementary food for the marginalized section of our country.

Key Words: Alligatorweed, Biological Invasion, Edxrf, Invasive Plant, Management, Supplementary Food, Sustainable

INTRODUCTION

Biological invasion of our native ecosystems by non-indigenous alien invasive species is one of the most pertinent problems of the present era ([McNeely 2001](#); [Vilà et al. 2010](#)). Invasive species may lead to ecosystem degradation and impairment of ecosystem services in non-native regions ([Pysek and Richardson 2010](#)) and inflict high negative ecological and economic impacts ([Pimentel et al. 2005](#), [Oreska and Aldridge 2011](#)). The problem of biological invasion is especially crucial for the tropical ecosystems of the world since the tropics are one of the richest biodiversity hotspots with about 13%

of all plant diversity in just 0.2% of the total land area of the planet ([Myers 1988](#), [Mittermeier et al. 1998](#)). Freshwater ecosystems, which cover approximately 0.8% of the earth's surface, but support almost 6% of all described species, are especially vulnerable to human activities ([Dudgeon et al. 2006](#)). Freshwater ecosystems are under extreme pressure due to climate change ([Woodward et al. 2010](#)) and are being quantitatively and qualitatively diminished at an alarming rate ([Moyle and Leidy 1992](#)). The situation of tropical freshwater ecosystems, which are an indispensable means of sustenance, food and livelihood for the millions of poor people of the developing world ([Roggeri 1995](#)), is most

critical as they are prone to massive biodiversity declines (Arthington et al. 2014) due to huge pressures of human population growth and over-exploitation (McKee et al. 2003) and biological invasion (Mittermeier et al. 1998, Ricciardi and MacIsaac 2011).

The problems of biological invasion of the aquatic and wetland ecosystems become more profound in the light of the services which these ecosystems perform (Engelhardt and Ritchie 2001). The introduction and establishment of aquatic invasive macrophyte species can dramatically affect native ecosystems (Homans and Smith 2013), profoundly altering their structure and function (Miehls et al. 2009) and even resulting in replacement of native aquatic macrophyte communities (Boylen et al. 1999). Native aquatic macrophytes not only provide livelihood for many marginalised people, but also form an important source of food and medicine for the society in the tropical regions (Ghosh 2005). A large section of the economically poor global populace lives in the tropical and sub-tropical belt, majority of who are dependent on wetland/freshwater ecosystems and native macrophytes for their daily sustenance. Thus, invasive plant induced biotic homogenization (Dar and Reshi 2015) and loss of native biodiversity (Shah and Reshi 2014) have significant socioeconomic and environmental impacts, especially in developing, over-populated tropical countries of Asia (Gopal 2013) and Africa (Juffe-Bignoli et al. 2012) and considerably affecting their food supplies. Therefore, without mitigation of the problem of biological invasion of the tropics, half the world's population will be facing serious food shortages in the coming decades.

The invasion of our inland freshwater ecosystems by non-indigenous macrophytes is a fact that cannot be ignored. Many freshwater species such as *Eichornia crassipes*, *Salvinia molesta*, *Pistia stratiotes*, *Ipomoea carnea*, etc. have become a nuisance for aquatic ecosystems (Raghubanshi et al. 2005). One such plant is *Alternanthera philoxeroides* (Martius) Griseb (Amaranthaceae), commonly known as Alligatorweed, an invasive perennial wetland herb originating from South America (Maddox 1968). Alligatorweed has many attributes of a successful invasive weed such as rapid growth and vegetative propagation (Tao et al. 2009, Wang et al. 2009) as well as broad ecological amplitude (Geng et al. 2007), and is regarded as one of the worst weeds of the world (Chatterjee and Dewanji 2012). This amphibious clonal plant has invaded many ecosystems worldwide (Julien et al. 1995), including riparian zones (Pan et al. 2006) and agricultural lands (Spencer and

Coulson 1976). Although the first reports of its presence in India were by Maheshwari (1964, 1965) with the plant commonly inhabiting lakes and ponds in the wetter parts of eastern India (Cook 1996), recent review of Indian literature shows that Alligatorweed has spread across climatologically diverse regions of India (Chatterjee and Dewanji 2010). Once established, *A. philoxeroides* is extremely hard to control and eradication is very expensive (Sainty et al. 1998, Jia et al. 2009). In tropical regions, Alligatorweed can thrive throughout the year, and often competes with and replaces many socio-economically valuable native macrophytes (Chatterjee and Dewanji 2014). Interestingly, some reports about the utilization of this plant as food and/or fodder are also present from India (Panda and Misra 2011, Sen et al. 2011, Swapna et al. 2011). Therefore, along with measures to manage and control the spread of invasion, research into alternative use of invasive plants, leading to their sustainable management, is of fundamental importance in the present times. Based on this ideology, in this pilot study, we focus on bringing to the fore-front the potential nutritional utility value of the widely prevalent invasive Alligatorweed and explore a probable option for its sustainable management especially suited for the tropical eco-regions.

MATERIALS AND METHODS

This study consists of two parts: first, a review of existing Indian literature and field surveys to document the status of indigenous ethnic/local knowledge on alligatorweed, and second, an estimation of the concentration of some essential and trace elements in the edible parts (tender apical shoots) of alligatorweed.

Review of Literature and Field Surveys

The first phase involved a comprehensive literature scanning, to review the present status of documented information about the different usage of Alligatorweed amongst the tribal and ethnic populace of India. Questionnaire-based field surveys were conducted to understand the present status of awareness regarding Alligatorweed and actual local usages (if any) in the study region. The field survey study area was based in the Greater Kolkata metropolitan region, West Bengal, India, comprising both urban/semi-urban and rural populations. It has a tropical monsoon climate with an annual mean temperature of 26.8°C and annual rainfall

1582 mm, maximum rainfall occurring during June–September. The study region included parts of 4 major districts of West Bengal, namely North 24 Parganas, South 24 Parganas, Howrah and Hooghly. The surveys were conducted during 2010 – 2012.

Elemental Analysis of Edible Parts of Alligatorweed

Sampling Sites:

Two local public ponds with Alligatorweed infestation, located in Baranagar (north Greater Kolkata region), were selected from which samples of Alligatorweed and soil-sediment were collected. Pond–1 was a non-polluted (mesotrophic) pond while Pond–2 was polluted (eutrophic). Both the ponds were approximately 0.5 hectare in area and about 3-3.5 m deep at their deepest region. Pond –1, a pristine aquatic body located within the premises of the Indian Statistical Institute, served as a site for recreation and aesthetic beauty for the neighbouring residents. Pond –2 was located within a densely populated area, adjacent to a couple of small-scale industries dealing with paints, rubber and machinery repairs. Due to its proximity to the industries, it was in a state of high eutrophic condition and was not used by the local public. The geographical location of the two ponds, sizes, major associated flora, and their pollution gradation based on water quality, are presented in Table 1. For each pond, three sites, situated approximately equidistant from one another, were chosen for sampling, based on availability of Alligatorweed and ease of sampling.

Sample Collection

Healthy, young tender apical shoot portions of Alligatorweed (each shoot with 5-6 nodes) were harvested at each

sampling site for each season. At each site, soil-substratum (from approximately 5 cm depth) was also collected from directly below the Alligatorweed. Plant and soil samples, thus collected, were transferred into transparent polyethylene bags and transported into the laboratory for further processing and analysis. Sample collections were done throughout the year in 2011 and were sub-divided into 3 sampling seasons, viz. summer (March–June), monsoon (July–October) and winter (November– February).

Sample Preparation:

The Energy-Dispersive–X-Ray-Fluorescence (*EDXRF*) spectrometry was used for analysis of the elemental concentrations of the samples as it has the capacity to quantify the concentration of a multitude of elements of the given pellets of the samples at a single run.

The tender shoot portions were cut at its 5th node and the young portions (containing 4 nodes) including stem and leaves, were designated as ‘edible portions’ of Alligatorweed for our experimental purpose. The plant materials were lightly washed and macroscopic foreign materials (detritus,dust) wereremoved from the samples by sterilized stainless steel forceps. After oven-drying at 60°C for 72 hours, about 150 mg of the samples were powdered and homogenized using a teflon mortar and pestle and made into pellets (1 mm thick and 10 mm diameter) using a tabletop pelletizer (pressure: 100–110 kg cm⁻² for 5 min).

The soil samples were air-dried for 3-4 days, and then oven-dried at 60°C for another 48hours. about 100 mg of the samples were powdered and homogenized using teflon mortar and pestle and made into pellets (1 mm thick and 10 mm diameter) using a tabletop pelletizer (pressure: 120-130 kg cm⁻² for 7-8 min). Three pellets per sample (for both plants and soil-sediment

Table 1. Descriptives of the ponds selected for the study:

Pond	Coordinates	Major Associated Flora	pH	Conductivity μS cm ⁻¹	Turbidity NTU	DO mg L ⁻¹	TP mg L ⁻¹	COD mg L ⁻¹	Pollution Level
1	22°38'47.21"N; 88°22'37.08"E	<i>Vallisneria spiralis</i> ; <i>Nymphaea pubescens</i>	6.5–7.5	< 1000	< 10	> 6.0	< 5	< 5	Low
2	22°39'34.41"N; 88°22'45.88"E	<i>Eichhornia crassipes</i> ; <i>Ipomoea aquatica</i> ; <i>Lemna aequinoctialis</i>	<6.5	> 1000	> 25	< 3.5	> 5	> 50	High

Abbreviations: DO = Dissolved Oxygen, TP = Total Phosphorus, COD = Chemical Oxygen Demand

samples) were made for each sampling site and each sampling season. Thus, for each pond, 27 pairs of plant and soil samples were analysed.

EDXRF measurement

The elemental analysis of lichen samples was carried out using a Jordan Valley Ex-3600 Energy dispersive X-ray fluorescence EDXRF spectrometer, which consists of an oil-cooled Rh anode X-ray tube (maximum voltage 50 kV, current 1 mA). The measurements were carried out in vacuum using different filters (between the source and sample) for optimum detection of elements. For example, for Na, Si and Al, no filter was used, and a voltage of 8 kV and current of 85 mA were used. A 0.05-mm-thick Ti filter was used in front of the source for K, Ca, V, Cr, Mn, Fe, Co, Ni, Cu and Zn, with an applied voltage of 20 kV and a current 400 mA. For higher Z elements such as Pb, Bi, Ag and As, an Fe filter of 0.05 mm thickness was used at a voltage of 35 kV and 500 mA current. All measurements were carried out for 1200 s. The X-rays were detected using a liquid-nitrogen-cooled 12.5 mm² Si (Li) semiconductor detector (resolution 150 eV at 5.9 KeV). The X-ray fluorescence spectra were quantitatively analyzed by the software ExWIN integrated with the system. Standard reference materials (SRM) from National Institute of Standards and Technology (NIST) – Apple leaf, SRM 1515, bovine liver, SRM 1577b, coal fly ash, SRM 1633b, and estuarine sediment, SRM 1646a – were used for quantification of the elements and checking the reliability of the data obtained by the system ([Majumdar et al. 2009](#)).

RESULTS AND DISCUSSIONS

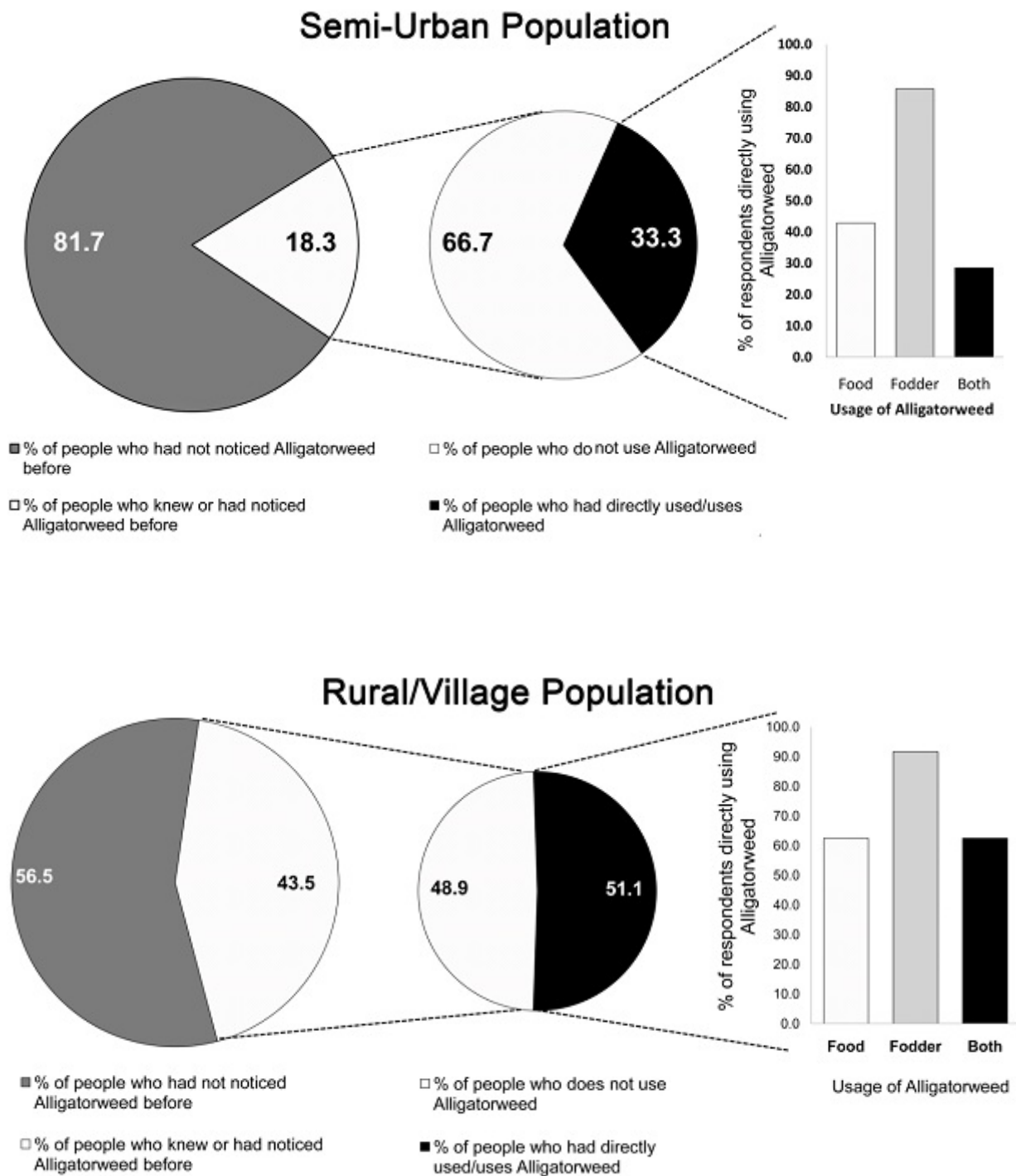
Public Awareness and Utilization of Alligatorweed

The review covered the literature published over the past 51 years, starting from the first published report of Alligatorweed from India in 1964 by J. K Maheswari, until the end of 2014. A total of 73 scientific papers, reporting either directly or indirectly about the presence of Alligatorweed in India, were obtained. The analysis of these reports revealed that a majority of them reported either the presence of this plant from different parts of the country, or studied some aspect of its weediness or invasiveness. Only 24.7 % of the papers (18 out of 73) explicitly stated some positive utilities of this invasive amphibious macrophyte. Out of this, 14 papers stated

about its ethno-botanical usage as food/fodder, while 7 papers mentioned Alligatorweed's medicinal properties. Interestingly, the majority of the papers mentioning the positive usage of Alligatorweed were from the North-East India (9 papers) and the eastern states of Bengal, Bihar and Odisha (7 papers). Thus, usage of Alligatorweed as 'vegetables' was quite popular amongst ethnic Indian people ([Sen et al. 2011](#)), especially from the hilly states of north-eastern India. Reports on the medicinal usage of Alligatorweed by tribal peoples ([Swapna et al. 2011](#)) were also found. Alligatorweed was also reported to be good for pregnant and lactating mothers ([Sarma and Saikia 2010](#), [Panda and Misra 2011](#)).

Based on this prior knowledge, we initiated field surveys in our study region to document the present public awareness and usage of Alligatorweed in Gangetic West Bengal. The survey was conducted in both semi-urban and rural/village areas and aimed to ask two main questions: (1) What was the average public awareness regarding this invasive plant amongst the population sampled; (2) In what different ways (*if at all*) was Alligatorweed used by the local populace. Figures 1 and 2 present the results of the field surveys conducted in the semi-urban and rural localities respectively. Out of the 115 persons who responded to the survey questions, a large section (81.7%) of the population was unaware about this invasive plant or had not noticed it before, in spite of its presence in many ponds/pools of the urban/semi-urban areas. Again, of the 21 individuals (18.3% of respondents) who could identify the plant, only 7 persons (33.3 %) stated to have personally used Alligatorweed. While 6 persons (85.7% of people who were direct users of Alligatorweed) used it for animal fodder, only 3 individuals (42.9%) had tasted it as a leafy-vegetable, amongst whom 2 persons (28.6%) also used it as animal feed (Figure 1). On the contrary, out of the 108 respondents from rural/village areas of Greater Kolkata, 47 individuals (43.5%) mentioned having noticed it before in ponds and wetland regions, amongst whom 24 persons (51.1%) stated to have used Alligatorweed on a personal level (Figure 2). Interestingly, of people able to identify Alligatorweed, 22 persons (91.7%) claimed to use it as animal fodder, while 15 persons (62.5%) also utilized Alligatorweed as supplementary vegetable.

Thus, Alligatorweed usage amongst the urban-semi-urban population of Kolkata and its vicinities was found to be quite meagre. Interestingly, the rural population was more aware about this plant and its usage than the urban population (Figures 1 and 2). Our study revealed



; total

Figure 2: General public awareness about Alligatorweed and their usages in rural/village localities. Values are reported as percentages (%); total number of respondents = 108.

that a considerable portion of rural population of Bengal was harvesting Alligatorweed from local pond/wetland ecosystems for utilization as food and fodder. During the literature review, apart from the different ethno-botanical

and ethno-medicinal usage of Alligatorweed, some reports of metal hyper-accumulative potential of this invasive plant was also found (Reddy 2008). Based on these results, the need to assess the concentrations of

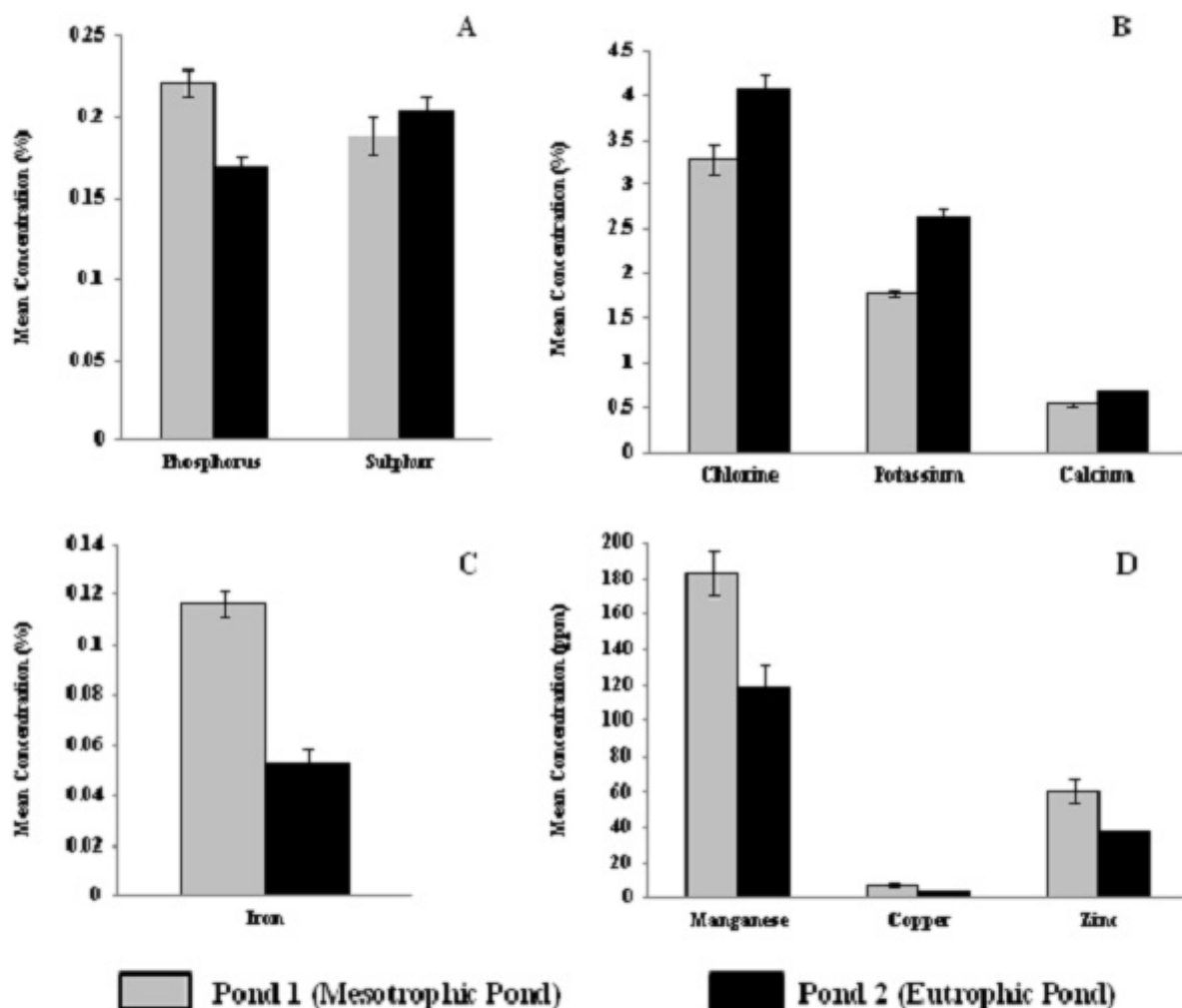


Figure 1: Mean concentrations of elements in the edible portions of Alligatorweed's edible (young shoots & leaves) part for the two study ponds. All values are expressed as % or ppm, per gm dry weight of plant.

soil-substratum of the plant, was felt; thereby, laying the logic for the assessment of elemental concentrations in Alligatorweed and its soil habitat.

Elemental Concentration

The assessment of elemental concentrations in the edible portions of Alligatorweed showed the presence of a number of important elements, including phosphorus, sulphur, chlorine, potassium, calcium and Iron amongst the essential elements; and manganese, copper and zinc amongst the trace elements. Significant differences in the

Alligatorweed are presented in Table 2. The data show that young shoots and leaves of Alligatorweed contain a good concentration of many essential elements, particularly, potassium (3.29%), calcium (0.92%), Iron (0.46%), manganese (305.13 mg kg⁻¹), copper (21.01 mg kg⁻¹) and zinc (137.74 mg kg⁻¹), as evident from their maximum concentrations, based on dry weight of plant materials. The maximum concentrations of potassium and calcium were higher in case of the plants from the mesotrophic pond; while for the other elements, the plants sampled from the polluted eutrophic pond had a higher elemental concentration in their tissues.

Table 2. Range of selected elemental concentrations in the edible portions of Alligatorweed (N=54).

Plant Elements	Eutrophic Pond		Mesotrophic Pond	
	Min.	Max.	Min.	Max.
Potassium, %	1.46	2.21	1.51	3.29
Calcium , %	0.34	0.75	0.51	0.92
Iron, %	0.03	0.46	0.02	0.10
Manganese , mg kg ⁻¹	61.31	305.13	43.53	294.18
Copper , mg kg ⁻¹	1.28	21.01	0.92	6.97
Zinc , mg kg ⁻¹	19.52	137.74	20.71	53.12

Bold figures indicate the higher concentration values for any element across the two ponds

Table 3. Correlation co-efficient of selected elements' concentration between edible portions (young shoots and leaves) of Alligatorweed and its corresponding soil-substratum:

Elements (data pairs)	Symbol	N	Spearman's Rho	
			ρ	Sig (2-tailed)
Potassium	K	54	0.629	< 0.001 **
Calcium	Ca	54	-0.139	0.317
Iron	Fe	54	0.369	0.006 **
Manganese	Mn	54	0.655	< 0.001 **
Copper	Cu	54	-0.098	0.48
Zinc	Zn	54	0.304	0.025 *
Potassium	K	27	-0.189	0.345
Calcium	Ca	27	0.033	0.87
Iron	Fe	27	0.022	0.913
Manganese	Mn	27	0.386	0.047 *
Copper	Cu	27	-0.212	0.289
Zinc	Zn	27	0.042	0.835
Potassium	K	27	-0.048	0.811
Calcium	Ca	27	0.236	0.237
Iron	Fe	27	0.491	0.009 **
Manganese	Mn	27	0.705	< 0.001 **
Copper	Cu	27	-0.181	0.365
Zinc	Zn	27	0.337	0.086

Significant difference: * at 0.05 level; ** at 0.01 level

A reason for this difference in elemental concentrations in plant tissues could be the higher uptake of certain selected elements from the environment by Alligatorweed. Hence, the correlation between the elemental concentration of the plant tissues and their corresponding soil-substratum was analysed pooling the

data for these two ponds (N=54 per pond) and also for each of the two ponds (N=27 per pond) separately. The exploratory data analysis revealed that the elemental concentration data did not always follow the assumptions of normality or homogeneity of variance. Hence, instead of the normal Pearson's product (r) correlation, the non-parametric Spearman's Rho (ρ) correlation test was used for analysis of the data and the results have been presented in Table 3.

When the data from the two habitats were pooled and analysed, significant positive correlations between young shoots and leaves (edible) of Alligatorweed and soil substratum were observed for potassium, iron and manganese (all at $p < 0.01$) and zinc ($\rho = 0.304$ $p < 0.05$). Interestingly, when the pond-wise data were analyzed separately, the results were slightly different. In case of the eutrophic pond (Pond 2), the plant tissue concentrations of both iron ($\rho = 0.491$; $p < 0.05$) and manganese ($\rho = 0.705$; $p < 0.05$) were found to have significant positive correlation with its corresponding soil-substratum; but in case of the mesotrophic pond (Pond 1), the only element which had significant positive correlation between the edible portions of Alligatorweed and soil substratum was manganese ($\rho = 0.386$; $p < 0.05$).

This study, therefore, reports that young shoot parts of Alligatorweed have a good concentration of many essential elements, including potassium, calcium, iron, zinc, copper and manganese. Potassium is an essential element with multiple health benefits. Clinical studies have shown that a high-potassium diet lowers blood pressure in individuals with both raised blood pressure and average population blood pressure, reduces cardiovascular disease mortality and slows the progression of renal diseases ([He and MacGregor 2008](#)). Adequate dietary intake of calcium, a major element needed for building bones and teeth, also helps in the prevention and management of salt-sensitive hypertension and a general good health ([McCarron 1997](#)). Iron, zinc, copper and manganese are required as co-factors of many enzymes and vitamins, and are often required as health supplements ([Gibson et al. 2002](#)). Moreover, iron is an important essential element, extremely important for adolescent girls and pregnant women and deficiency of iron causes severe ill-health, including anaemia ([Nair and Iyengar 2009](#)).

Green leafy vegetables, which are naturally rich in carotene, ascorbic acid, riboflavin, folic acid and minerals like calcium, iron and phosphorous, occupy an important place among the food crops ([Ghosh 2005](#)). It is true that invasive plants, including Alligatorweed,

competes many native leafy green vegetables, like *Ipomoea aquatic*, *Marsiliaminuta*, *Trapabispinosa* etc.), often replacing a native macrophyte of higher consumption value by its dense floating mats (Chatterjee and Dewanji 2014). Again, once established, the voracious Alligatorweed has the potency to invade the entire aquatic/wetland ecosystem, and is extremely difficult to control (Sainty et al. 1998). But this same power of voracious growth (Tao et al. 2009), high resilience to external disturbances (Dong et al. 2012), tolerance to pollution (Chatterjee and Dewanji 2012) and adaptability under diverse climatic conditions (Chatterjee and Dewanji 2010), can be utilized to extract its potential positive values as a rapidly re-generating source of supplementary leafy vegetables. Such utilization of Alligatorweed as a tasty vegetable supplement are also popular among other south Asian populations, including Sri Lankans (Gunasekera and Bonilla 2001) and Bangladeshis (Biswas and Rahmatullah 2011).

Another important fact indicated by our study is that under both eutrophic and mesotrophic conditions, Alligatorweed showed a high significant positive correlation of manganese between its young apical tissue and the soil-substratum. This might be a cause of concern as it might be a possible indicator of the high metal-accumulative potential of this invasive weed. Reddy (2008) had also cautioned against the usage of this plant for human consumption as he feared that this plant is a probable metal-hyperaccumulator. Similar to our findings of Alligatorweed having a high uptake affinity for manganese from its substratum, Hua et al. (2012) too reported good manganese uptake capacity of Alligatorweed. Therefore, we would like to stress that the utilization of Alligatorweed as supplementary vegetables for human consumptions should only be practiced in those regions which have pristine ecosystems, i.e. those ecosystems which have no or very minimal influx of environmental xenobiotics into them. Probably, this is the precise reason why usage of Alligatorweed as food, medicine and fodder are mainly concentrated to the north-eastern hilly states of India, wherein the level of chemical-intensive agriculture and other influx of pollution are significantly lower as compared with other developed regions of our country. Proper incentivizing and encouraging public or commercial harvest of invasive species represents a significant opportunity to support ecosystem and natural resource management while simultaneously boosting economic development and environmental awareness (Pasko and Goldberg 2014). In nature, there are many

underutilized aquatic greens of promising nutritive value (Boyd 1970), which can nourish the ever increasing human population (Sheela et al. 2004). Low dietary intake of macro and micronutrients is common and under-nutrition and micronutrient deficiencies; including multiple micronutrient deficiencies amongst women (Pathak et al. 2004) of low socio-economic sections (Thankachan et al. 2007); continue to be a major public health problem in India (Narasinga Rao 2010) and other developing tropical countries of the world (Berger and Dillon 2002). Hence, food-based approaches to increase the intake of iron and other multi-nutrients through dietary diversification are important sustainable strategies (Nair and Iyengar 2009) required for solving this problem of public health concern. In such a scenario, probable usage of an invasive macrophyte like Alligatorweed as a good source of essential elements, especially iron, potassium, calcium and manganese, could be an excellent dual-purpose management method of solving firstly, a part of the nutritional requirements of our teeming multitude of marginalized (Bates and Hentges 1976); and secondly, proper managing this invasive macrophyte in a sustainable manner.

ACKNOWLEDGEMENTS

We acknowledge with thanks the Indian Statistical Institute, Kolkata, for funding of the project; and the UGC-DAE Consortium for Scientific Research, Kolkata, for technical collaboration on the elemental analysis of the plant and soil samples. The technical support of Dr. Shidhartha Sankar Ram and Mr. Subhjit Bhar of Trace Element Laboratory, UGC-DAE CSR, Kolkata Centre, during the ED-XRF analysis of plant and soil samples is also highly appreciated.

REFERENCES

- Arthington, A.H.; Godfrey, P.C.; Pearson, R.G.; Karim, F. and Wallace, J. 2015. Biodiversity values of remnant freshwater floodplain lagoons in agricultural catchments: Evidence for fish of the Wet Tropics bioregion, northern Australia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 25(3): 336-352.
- Bates, R.P. and Hentges, J.F.J. 1976. Aquatic Weeds: Eradicate or Cultivate? *Economic Botany* 30(1): 39-50.
- Berger, J. and Dillon, J. C. 2002. Control of iron deficiency in developing countries. *Sante* 12(1): 22-30.

- Biswas, K.R. and Rahmatullah, M. 2011. A survey of non-conventional plants consumed during times of food scarcity in three adjoining villages of Narail and Jessore districts, Bangladesh. *American-Eurasian Journal of Sustainable Agriculture* 5(1): 1-5.
- Boyd, C.E. 1970. Amino acid, protein, and caloric content of vascular aquatic macrophytes. *Ecology* 51(5): 902-906.
- Boylen, C.W.; Eichler, L.W. and Madsen, J.D. 1999. Loss of native aquatic plant species in a community dominated by Eurasian watermilfoil. *Hydrobiologia* 415: 207-211.
- Chatterjee, A. and Dewanji, A. 2010. Global climate change and biotic invasion: A case study of a wetland plant species. pages 270-277. In: Reddy, M.A. and Lakshmi, T.V. (Editors) *Proceedings of 2nd International Conference on Environmental Management*. Jawaharlal Nehru Technological University, Hyderabad, India, B. S. Publications, Hyderabad.
- Chatterjee, A. and Dewanji, A. 2012. Peroxidase as a metric of stress tolerance and invasive potential of alligator weed (*Alternanthera philoxeroides*) growing in aquatic habitats. *Management of Biological Invasions* 3(2): 65-76.
- Chatterjee, A. and Dewanji, A. 2014. Effect of varying *Alternanthera philoxeroides* (Alligator weed) cover on the macrophyte species diversity of pond ecosystems: A quadrat-based study. *Aquatic Invasions* 9(3): 343-355.
- Cook, C.D.K. 1996. *Aquatic and Wetland Plants of India: A Reference Book and Identification Manual for the Vascular Plants Found in Permanent Or Seasonal Fresh Water in the Subcontinent of India South of the Himalayas*. Oxford University Press, Oxford. 394 pages.
- Dar, P.A. and Reshi, Z.A. 2015. Do alien plant invasions cause biotic homogenization of terrestrial ecosystems in the Kashmir Valley, India? *Tropical Ecology* 56(1): 111-123.
- Dong, B.-C.; Alpert, P.; Guo, W. and Yu, F.-H. 2012. Effects of fragmentation on the survival and growth of the invasive, clonal plant *Alternanthera philoxeroides*. *Biological Invasions* 14(6): 1101-1110.
- Dudgeon, D.; Arthington, A.H.; Gessner, M.O.; Kawabata, Z.-I.; Knowler, D. J.; Lévêque, C.; Naiman, R.J.; Prieur-Richard, A.H.; Soto, D.; Stiassny, M.L.J. and Sullivan, C.A. 2006. Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Reviews* 81(2): 163-182.
- Engelhardt, K.A.M. and Ritchie, M.E. 2001. Effects of macrophyte species richness on wetland ecosystem functioning and services. *Nature* 411: 687-689.
- Geng, Y.P.; Pan, X.Y.; Xu, C.Y.; Zhang, W. J.; Li, B.; Chen, J.K.; Lu, B.R. and Song, Z.P. 2007. Phenotypic plasticity rather than locally adapted ecotypes allows the invasive alligator weed to colonize a wide range of habitats. *Biological Invasions* 9: 245-256.
- Ghosh, S.K. 2005. *Illustrated Aquatic and Wetland Plants in Harmony with Mankind*. Standard Literature, Kolkata, India. 25 pages.
- Gibson, R.S.; Heath, A.L. and Ferguson, E.L. 2002. Risk of suboptimal iron and zinc nutrition among adolescent girls in Australia and New Zealand: Causes, consequences, and solutions. *Asia Pacific Journal of Clinical Nutrition* 11(Suppl. 3): S543-S552.
- Gopal, B. 2013. Future of wetlands in tropical and subtropical Asia, especially in the face of climate change. *Aquatic Sciences* 75(1): 39-61.
- Gunasekera, L. and Bonilla, J. 2001. Alligator weed: tasty vegetable in Australian backyards? *Journal of Aquatic Plant Management* 39: 17-20.
- He, F.J. and MacGregor, G.A. 2008. Beneficial effects of potassium on human health. *Physiologia Plantarum* 133(4): 725-735.
- Homans, F. and Smith, D. 2013. Evaluating management options for aquatic invasive species: concepts and methods. *Biological Invasions* 15(1): 7-16.
- Hua, J.; Zhang, C.; Yin, Y.; Chen, R. and Wang, X. 2012. Phytoremediation potential of three aquatic macrophytes in manganese-contaminated water. *Water and Environment Journal* 26(3): 335-342.
- Jia, X.; Pan, X.Y.; Li, B.; Chen, J.K. and Yang, X.Z. 2009. Allometric growth, disturbance regime, and dilemmas of controlling invasive plants: A model analysis. *Biological Invasions* 11: 743-752.
- Juffe-Bignoli, D.; Rhazi, L. and Grillas, P. 2012. The socio-economic value of aquatic plants. Pages 49-53, In: Juffe-Bignoli, D. and Darwall, W.R.T (Editors). *Assessment of the Socio-economic Value of Freshwater Species for the Northern African Region*. IUCN, Gland, Switzerland and Málaga, Spain. iv + 84 pages.
- Julien, M. H.; Skarratt, B. and Maywald, G.F. 1995. Potential geographical distribution of alligator weed and its biological control by *Agasicles hygrophila*. *Journal of Aquatic Plant Management* 33: 55-60.
- Maddox, D.M. 1968. Bionomics of an alligatorweed flea beetle, *Agasicles* sp., in Argentina. *Annals of the Entomological Society of America* 61: 1299-1305.
- Maheshwari, D.K. 1964. *Alternanthera philoxeroides* (Mart.) Griseb. - A new record for India. *Bulletin of Botanical Survey of India* 6(2-4): 313-314.
- Maheshwari, J.K. 1965. Alligator weed in Indian lakes. *Nature* 206: 1270.
- Majumdar, S.; Ram, S. S.; Jana, N. K.; Santra, S.; Chakraborty, A. and Sudarshan, M. 2009. Accumulation of minor and trace elements in lichens in and around Kolkata, India: An application of X-ray fluorescence technique to air pollution monitoring. *X-Ray Spectrometry* 38(6): 469-473.
- McCarron, D.A. 1997. Role of adequate dietary calcium intake in the prevention and management of salt-sensitive hypertension. *The American Journal of Clinical Nutrition* 65(2 Suppl): 712S-716S.
- McKee, J.K.; Sciullia, P.W.; Foocea, C.D. and Waite, T.A. 2003. Forecasting global biodiversity threats associated with human population growth. *Biological Conservation* 115: 161-164.
- McNeely, J. 2001. Invasive species: a costly catastrophe for native biodiversity. *Land Use and Water Resources Research* 1(2): 1-10.
- Miehls, A.L.J.; Mason, D.M.; Frank, K.A.; Krause, A.E.; Peacor, S.D.; Taylor, W.W. 2009. Invasive species impacts on ecosystem structure and function: A comparison of the Bay of Quinte, Canada, and Oneida Lake, USA, before and after zebra

- mussel invasion. *Ecological Modelling* 220(22): 3182-3193.
- Mittermeier, R.A.; Myers, N.; Thomsen, J.B.; da Fonseca, G.A.B. and Olivieri, S. 1998. Biodiversity hotspots and major tropical wilderness areas: Approaches to setting conservation priorities. *Conservation Biology* 12(3): 516–520.
- Moyle, P.B. and Leidy, R.A. 1992. Loss of Biodiversity in Aquatic Ecosystems: Evidence from Fish Faunas. pages 127-169. In: Fiedler, P. and Jain, S. (Editors) *Conservation Biology*. Springer, Dordrecht. 481 pages.
- Myers, N. 1988. Threatened biotas: 'hotspots' in tropical forests. *Environmentalist* 8(3): 187-208.
- Nair, K.M. and Iyengar, V. 2009. Iron content, bioavailability & factors affecting iron status of Indians. *The Indian Journal of Medical Research* 130(5): 634-645.
- Narasimha Rao, B.S. 2010. Nutrient requirement and safe dietary intake for Indians. *Bulletin of the Nutrition Foundation of India* 31(1): 1-5.
- Oreska, M.P.J. and Aldridge, D.C. 2011. Estimating the financial costs of freshwater invasive species in Great Britain: A standardized approach to invasive species costing. *Biological Invasions* 13: 305–319.
- Pan, X.; Geng, Y.; Zhang, V.; Li, B. and Chen, J. 2006. The influence of abiotic stress and phenotypic plasticity on the distribution of invasive *Alternanthera philoxeroides* along a riparian zone. *Acta Oecologica* 30(3): 333–341.
- Panda, A. and Misra, M.K. 2011. Ethnomedicinal survey of some wetland plants of South Orissa and their conservation. *Indian Journal of Traditional Knowledge* 10(2): 296 – 303.
- Pasko, S. and Goldberg, J. 2014. Review of harvest incentives to control invasive species. *Management of Biological Invasions* 5(3): 263–277.
- Pathak, P.; Kapil, U.; Kapoor, S.K.; Saxena, R.; Kumar, A.; Gupta, N.; Dwivedi, S.N.; Singh, R. and Singh, P. 2004. Prevalence of multiple micronutrient deficiencies amongst pregnant women in a rural area of Haryana. *Indian Journal of Pediatrics* 71(11): 1007-1014.
- Pimentel, D.; Zuniga R. and Morrison, D. 2005. Update on the environmental and economic costs associated with alien invasive species in the United States. *Ecological Economics* 52: 273–288.
- Pysek, P. and Richardson, D.M. 2010. Invasive species, environmental change and management, and health. *Annual Review of Environment and Resources* 35: 25–55.
- Raghubanshi, A.S.; Rai, L.C.; Gaur, J.P. and Singh, J.S. 2005. Invasive alien species and biodiversity in India. *Current Science* 88(4): 539-540.
- Reddy, C.S. 2008. Not all green is good...Ban on consumption of Alligator weed. *Current Science* 95(3): 296-297.
- Ricciardi, A. and MacIsaac, H.J. 2011. Impacts of biological invasions on freshwater ecosystems. pages 211-224. In: Richardson, D.M. (Editor) *Fifty Years of Invasion Ecology: the Legacy of Charles Elton*. Blackwell Publishing, Oxford. 458 pages.
- Roggeri, H. 1995. *Tropical Freshwater Wetlands: A Guide to Current Knowledge and Sustainable Management*. Springer, Dordrecht. 364 pages.
- Sainty, G.; McCorkelle, G. and Julien, M. 1998. Control and spread of Alligator Weed *Alternanthera philoxeroides* (Mart.) Griseb., in Australia: Lessons for other regions. *Wetlands Ecology and Management* 5: 195–201.
- Sarma, S.K. and Saikia, M. 2010. Utilization of wetland resources by the rural people of Nagaon district, Assam. *Indian Journal of Traditional Knowledge* 9(1): 145-151.
- Sen, S.; Chakraborty, R.; De, B. and Devanna, N. 2011. An ethnobotanical survey of medicinal plants used by ethnic people in West and South district of Tripura, India. *Journal of Forestry Research* 22(3): 417–426.
- Shah, M.A. and Reshi, Z.A. 2014. Characterization of alien aquatic flora of Kashmir Himalaya: implications for invasion management. *Tropical Ecology* 55(2): 143-157.
- Sheela, K.; Kamal, G.N.; Vijayalakshmi, D.; Yankanchi, G.M. and Patil, R.B. 2004. Proximate composition of underutilized green leafy vegetables in southern Karnataka. *Journal of Human Ecology* 15(3): 227-229.
- Spencer, N.R. and Coulson, J.R. 1976. The biological control of alligator weed, *Alternanthera philoxeroides*, in the United States of America. *Aquatic Botany* 2: 177-190.
- Swapna, M.M.; Prakashkumar, R.; Anoop, K.P.; Manju, C.N. and Rajith, N.P. 2011. A review on the medicinal and edible aspects of aquatic and wetland plants of India *Journal of Medicinal Plants Research* 5(33): 7163-7176.
- Tao, Y.; Chen, F.; Wan, K.; Li, X. and Li, J. 2009. The structural adaptation of aerial parts of invasive *Alternanthera philoxeroides* to water regime. *Journal of Plant Biology* 52: 403–410.
- Thankachan, P.; Muthayya, S.; Walczyk, T.; Kurpad, A.V. and Hurrell, R.F. 2007. An analysis of the etiology of anemia and iron deficiency in young women of low socioeconomic status in Bangalore, India. *Food and Nutrition Bulletin* 28(3): 328-336.
- Vilà, M.; Basnou, C.; Pysek, P.; Josefsson, M.; Genovesi, P.; Gollasch, S.; Nentwig, W.; Olenin, S.; Roques, A.; Roy, D. and Hulme, P.H. 2010. How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment. *Frontiers in Ecology and the Environment* 8(3): 135–144.
- Wang, N.; Yu, F.H.; Li, P.X.; He, W.M.; Liu, J.; Yu, G.L.; Song, Y.B. and Dong, M. 2009. Clonal integration supports the expansion from terrestrial to aquatic environments of the amphibious stoloniferous herb *Alternanthera philoxeroides*. *Plant Biology* 11: 483–489.
- Woodward, G.; Perkins, D.M. and Brown, L.E. 2010. Climate change and freshwater ecosystems: Impacts across multiple levels of organization. *Philosophical Transactions of the Royal Society of London B Biological Sciences* 365(1549): 2093–2106.

Received 5 November 2016

Accepted 19 June 2017