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Eco-distribution Mapping of Invasive Weed *Limnocharis flava* (L.) Buchenau Using Geographical Information System: Implications for Containment and Integrated Weed Management for Ecosystem Conservation

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ABSTRACT: Exotic weed invasion has been identified as one of the serious environmental problem impacting the structure, composition and function of biological diversity. They are aggressive colonizers, which have flexible habitat requirement and ability to outcompete native species. The present paper describes the distribution and autecology of an exotic weed *Limnocharis flava* (L.) Buchenau (an emergent aquatic weed of '*Limnocharitaceae*') in Kumarakom *Grama Panchayat*, one of the well known tourist spot of South India famous for its vast stretches of paddy fields, wetlands and backwaters. The mapping of *L. flava* in the entire study area has been done using Geographical Information System (Arc-info 8.3 version). The growth and distribution pattern of *L. flava* were studied quantitatively. Data on distribution, abundance, biomass, ecological associations and root zone nutrient quality of water and sediment samples were collected from different sampling points of Kumarakom. The study reflected that nutrients, water depth and land use patterns were the major factors responsible for the growth and proliferation of this exotic weed. The strategies for controlling *L. flava* invasion are discussed in detail. If early steps are not taken to eradicate this weed, it will become a problematic weed in the same way as other noxious aquatic weeds like *Salvinia molesta* D. Mitch and *Eichhornia crassipes* (C. Martius) Solms-Laub.

KEY WORDS: ***Limnocharis flava*** **(L.) Buchenau, Exotic weed, Invasion, Biological diversity, Sustainable management.**

INTRODUCTION

Invasions of alien plant species (plants that have escaped their native range due to unintentional or intentional human involvement, or without help of people) (Pysek et al., 2004) into various habitats are considered a global threat to biodiversity and ecosystem functioning (Mack et al., 2000; Pimentel et al., 2001; Gurevitch and Padilla, 2004), and have attracted considerable attention. Although most alien species are not successful in colonizing new areas, some manage to reproduce and persist in these habitats at high population densities (invasive species) (Bjerknes et al., 2007). Historically human activities have caused the accidental or planned dispersal of many species beyond their original distribution ranges and this process is presently at its highest expression (Zalba et al., 2007). However, only a small percentage of species introduced into a new area are able to establish self-sustaining populations, and only a small number of them become invasive (Williamson, 1996). Nevertheless, the probability of invasion success increases significantly according to three main factors: previous selection of species ecologically suited to the new location, propagule pressure and the degree of ''human assistance'' the species receives during the immediate post-introduction phase, when it is especially susceptible to environmental and demographic stochasticity (Zalba et al., 2007).

Ecological impact of invasive weeds both aquatic and terrestrial (including parasitic), includes interference with cultivation of crops, loss of biodiversity (native plant species are displaced) and

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ecosystem resilience, loss of potentially productive land, loss of grazing and livestock production, poisoning of humans and livestock, choking of navigational and irrigation canals and reduction of available water in water bodies (Abhilash, 2003). Ecological process may change after invading species have established and spread. These changes may be minimal and the plant invader may simply increases species richness. In contrast, where ecological processes are sufficiently disrupted, native species can be displaced, increasing plant vulnerability to further invasion and regeneration of the invasive plant (Zimadahl, 1999). When perturbation of ecosystem exceeds ecological thresholds, ecosystem change can be so profound that controlling the invader may not restore the ecosystem to a desired condition (Hobbs and Humphries, 1995). Ecosystem process, including hydrological cycles, erosion and stream sedimentation, energy flow and nutrient cycling, native plant regeneration, and fire regimes can be altered by alien plant invasions. Invasive plant also pose a threat to species designated as threatened or endangered by reducing the quality of natural areas established to protect habitats critical to the survival of these desirable species (Williamson, 1996).

Timely mapping and frequent monitoring of invasive plant distributions are central to natural resource management and habitat preservation (Anderson et al., 1993; NISC, 2001). Weed mapping is an integral component of all weed management activities. Environmental mangers are looking for better and cost effective means of delineating weed distribution and densities. The varied advantage of geographical Information System (GIS) in effectively harnessing the weed distribution and weed growth modeling have been successfully utilized in many parts of the world. The unique capability of GIS software to provide a wide range of attributes, in easily and more frequent manner, has made this technology as an inevitable tool in the sustainable management and utilization of natural resources (Crossman and Kochergen, 2002).

The magnitude and complexity of exotic weeds, combined with the costs for their control necessitate the use of integrated weed management. Integrated weed management evolved from the concepts of integrated pest management and is defined as the application of technologies in a mutually supportive manner, and selected, integrated, and implemented with consideration of economic, ecological, and sociological consequences (Duke et al., 2002). Detection, mapping, monitoring and assessment, prevention, education and weed control methods are the key components of integrated management strategies. Also, developing effective integrated alien weed management programs requires a thorough understanding of the biology and ecology of the invasive plant and invaded community. The present study has been undertaken to evaluate the ecology and distribution pattern of a recent invader *Limnocharis flava* (L.) Buchenau. *L. flava* is a native of tropical and subtropical America. It is an emergent aquatic weed in the *Limnocharitaceae* family, which has invaded in the flood plains of Kuttanad wetland system and other low lying areas of Kerala, South India. The major objectives of this research were to (1) Described and map the invasion of *L. flava* (L.) Buchenau. in Kumarakom *Grama Panchayat* (*Grama Panchayt* means a locally defined administrative unit having a couple of Village) of Kuttanad wetland system. (2) Analyze the habitat ecology and associations of *L. flava*. Containment and eradication strategies can then be implemented, where appropriate, by targeting known areas of incursion.

METHODS

Study Area

Kumarakom, one of the famous tourist destinies of Kerala, is situated on the southern coast of India, about 16 km west of Kottaym city (Fig. 1). The Kumarakom *Grama Panchayat* is located between 9° 37′ North latitude and 76° 25′ East Longitude. Out of the total 51.67 sq.km. area, about 24.13 sq.km. is the Vemband Lake, one of the largest Ramsar site of South India. The Grama Panchayt is bordered in the North by Kavanar River and Aymanam *Grama Panchayat*, the Kottayam-Alappuzha water Canal on the South, the Thiruvarppu *Grama Panchayat* on the East and the West by the Vembanad Lake, which separates Kumarakom from Allappuzha District. The area falls within the distributary system of the Meenachil River, especially within the realms of Poonkassery watershed, Edavattom East, Edavattom West and Methran Kayal watershed. This region consists of vast stretches of cultivating paddy fields, non-cultivating (wasted) paddy fields, water bodies in between these fields and coconut fields. The paddy fields are below the water level and the water has to be pumped out for paddy cultivation. These fields remain water logged for about 8 months a year. There is dense human inhabitation in the naturally elevated land as well as reclaimed land in this area.

The study area experienced a well balanced tropical climate varies little from season to season. The temperature normally ranges between 27 – 32 ℃.

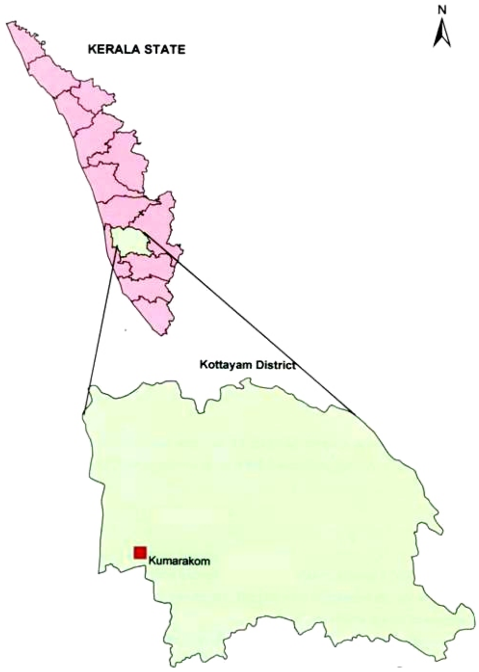

Fig. 1. Study area (Kumarakom) in Kottayam District.

Average annual rainfall is 1100 mm and it is quite high when compared to other Indian states. The area enjoys four types of climate such as winter, summer, south west monsoon and north east monsoon. The winter season sets in during the month of December and continues till the end of February. During this season comparatively there is less rainfall. Winter is followed by summer season. It starts in February and continues till May. Temperature is very high during this period. Occasional rain with lightning is a characteristic feature of this season. The south west monsoon begins either in the end of May or in the beginning of June and fade out by September and the north east monsoon commences in October.

Weed mapping

Base map of the study area was prepared in the cadastral scale of 1:5000 using the Village cadastral map of the *Grama Panchayat*. The plot wise information on land use was obtained from Basic Tax Register (BTR) of Revenue Department. The plot wise information on land use were encoded, interpreted and transferred to the base map for identifying the survey number of the plot and plot wise land use /land cover pattern. The ground truth survey was done with the help of Global Positioning System (GPS). The mapping of the weed *Limnocharis flava* (L.) Buchenau in the entire *Grama Panchayat* was conducted using a quadrate of size 1m x 1m laid at random manner and mapped it into the base map prepared from the Cadastral maps in the scale of 1:5000. The distribution mapping was confirmed by using GPS and also by comparing the survey plot number and other land marks shown in the base maps. The generated data were transferred to the GIS (Arc-Info 8.3 Version) environment, different thematic maps were prepared like distribution of the weed, roads, ponds, paddy fields, water spreads, marshy areas, cultivable wasteland etc and they were chosen and overlayed for the preparation of final distribution map (Fig. 2).

Habitat analysis

Plant samples were collected from different quadrate sites for biomass evaluation. The collected samples were chopped and recorded the fresh weight. The samples were oven dried at 105℃ for 24 hours until their dry weight become constant. Dry weight changes per weed calculated from the total dry weight per meter square divided by the total number of weeds. The population changes were studied by measuring the number of weeds, weeds height, and weed dry weight. The associated species were identified and recorded the level of association (high, medium and low). The

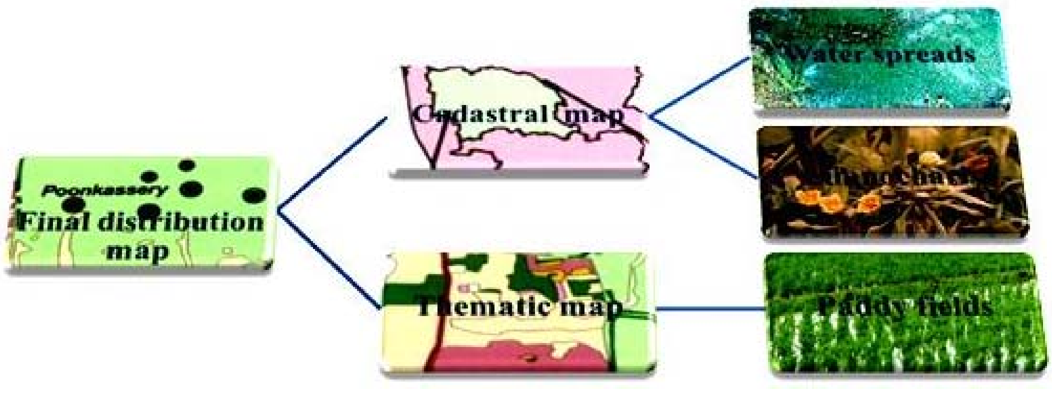

Fig. 2. Graphic representation of various steps involved in the distribution mapping of *L. flava*.

weed growth rate was calculated from the difference in biomass (dry weight) measured in successive sampling. The relative growth rate (RGR), the change in biomass relative to initial biomass (Still, 1996) was computed for different species as follows;

RGR = (In Wf / In Wi) / t
Where ″Wi″ is the initial biomass and ″Wf″ is the biomass after "t" days (60 days).

Water depth of each quadrate site was measured using marked PVC pipes. Water samples being collected from the quadrate sites, according to American Public Health Association (APHA, 2000). Soil samples were collected from rooting depth (up to 30 cm) of *L. flava* using an auger from the same quadrate sites where water samples collected. The samples were refrigerated to minimize the nutrient loss and transported to the laboratory for posterior analysis. The nitrogen content of soil (Jackson, 1967) and water samples were analyzed as Total Kjeldal Nitrogen (TKN). Phosphate content of soil and water samples was determined by colourimetrically using UV-VIS spectrophotometer (Thermo-variance) and potassium concentration by flame photometer (Systronics-128) (APHA, 2000).

Statistical analysis

The distribution data of *L. flava* were subjected to analysis of Variance (ANOVA) followed by post hoc test 'Duncan's Multiple Range Test (DMRT). The degree of association between nutrients, water depth, weed density and biomass has been evaluated by Pearson coefficient of correlation (Sneedecor and Cochran, 1971). All the statistical analysis were performed by using software package SPSS (14.0) (Illinois, USA) for windows program.

RESULTS AND DISCUSSION

Weed biology and ecology

The family *Limnocharitaceae* is represented by three genera *Hydrocleys*, *Butomopsis* and *Limnocharis*. (Abhilash, 2003). *Limnocharitaceae* originated in the Gondwanaland, prior to the separation of present South America from present Africa. The centre of origin is most likely would have been near the region where the present easternmost South America joined with equatorial Africa (Holm-Nielsen, 1992). The native ranges of *L.flava* include North western Mexico, Nicaragua, Costa Rica, Panama, Cuba, Haiti, Dominican Republic, Windward Islands, Colombia, Venezuela, Ecuador, West Indies, Peru and Brazil (Holm-Nielsen, 1992).

Currently, the plant has become invasive in Kerala and other countries like Malaysia, Indonesia, Thailand, South Myanmar, Srilanka, Vietnam, and Australia (Abhilash, 2004; CRC for Australian weed management, 2003). The plant inhabits shallow swamps, ditches, pools and wet rice fields, occurring in more or less stagnant fresh water. In Kerala, the plant mainly invading in wasted paddy fields, coconut groves and other agricultural fields (Abhilash, 2005). But the day may not be far off when it starts infesting rice fields in Kerala too, as it has done in other countries like Malaysia, Indonesia and Srilanka.

L. flava (*Manja payal*; Malayalam common name) is a perennial, erect, glabrous, lactiferous herb with a short stout rhizome with numerous fiberous roots. Aerial stems (peduncles) are flattened at the base, triangular up to 120 cm tall, bearing at the apex a cluster of flowers or a vegetative plant (ramet). Leaves are pale green, arising in clusters and rising above the water. Inflorescence are umbellate, 2-15 flowered supported by an involucre of bracts. Flowers are pedicelled, yellow, actinomorphic and hermaphrodite. The flowers open in the morning and close by mid day, after that which the stamens and petals disintegrate in to a mucilaginous mass. There is no record of any pollinating agent either from South America or South East Asia. Fruiting take place throughout the year and seeds are produced in abundance. A single plant may produce over 1,000,000 seeds per year (Senartana, 1960). The ripe carpels open on the inner (adaxial) side and the opening widen due to curving of the outer (abaxial) wall, which is thicker, there by permitting the friutlets to escape. The friutlets are carried by water, floating to new localities, dispersing the seeds along the journey. Seeds are also carried with the mud sticking to the feet of birds or by man and his impediments, or with cereals from an infested field transported to an uninfected area (Abhilash, 2003).

While seed production is so prolific, the plant has also vegetative method of multiplying. Often, at the centre of the umbels a vegetative plant is developed and after the fruit is shed, the aerial stem bends and comes to lie in a horizontal position in the mud with the young plant in water. The young plant sends out roots, aerial stem and new individual start an independent life.

Distribution and habitat characteristics of *L. flava* in Kumarakom *Grama Panchayat*

The distribution map of *L. flava* in Kumarkom *Grama panchayat* is presented in figure 3. Weed invasion is categorized in to two classes viz (1-5 number of weed per sq.m) and (6-10 number of weed per sq.m). Weed density was varied form 3-10 per

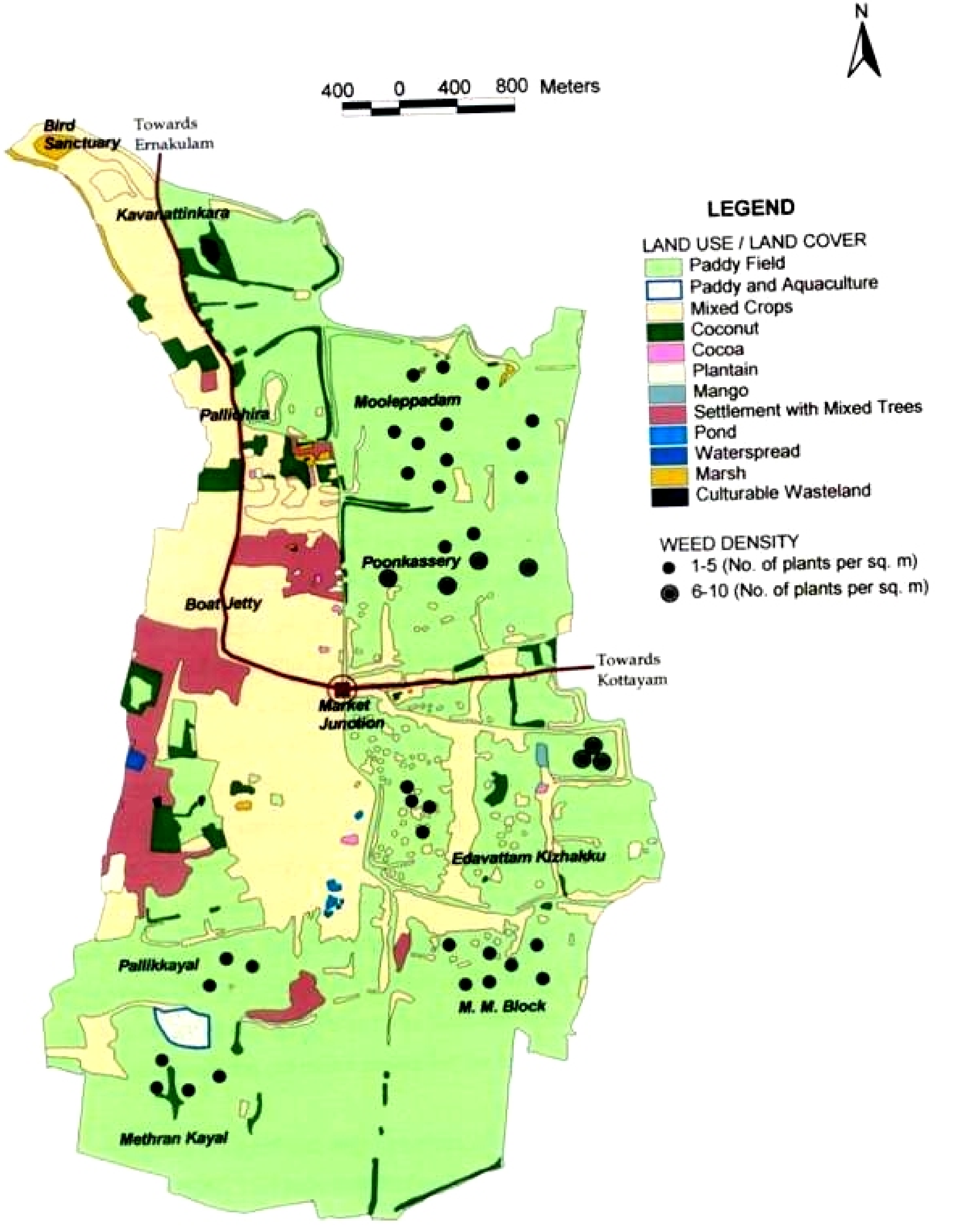

Fig. 3. Map showing distribution of *L. flava* in Kumarakom *Grama Panchayat*.

Table 1. Distribution and habitat characteristic of *Limnocharis flava* (L.) Buchenau. in Kumarakom *Grama Panchayat.*

Location	Weed density (per m^2)	Weed biomass (g/plant) †		Weed height (cm) †		Water depth (cm) †	
		Mean (±SE)	Range	Mean (±SE)	Range	Mean (±SE)	Range
Methran Kayal *(n = 12)*	2.75	48.30 ± 0.113^a	48.10- 48.49	107.18 ± 1. 631^e	103.30 -110.30	104.83 ±1.180^c	103.30 -108.30
Pallikayal *(n = 9)*	4.33	49.26 ± 0.237^b	48.86 – 49.68	102.97 ± 0.926^d	101.30 – 104.50	99.10 ± 0.300^b	98.80-99.70
M.M. Block *(n = 21)*	4.72	50. 80 ± 0.221^c	50.12- 51.60	100.43 ± 0.318^c	99.50 -101.90	93.30 ±0.456a	92.10 - 95.80
Edavattam Kizhakku *(n = 21)*	7.29	51.56 ± 0.155^d	50.99- 52.03	99.27± 0.187b^c	98.30 -99.70	93.36 ± 0.283^a	84.40 - 99.90
Poonkassery *(n = 18)*	8.50	52.91± 0.185^e	52.19- 53.45	96.87 ± 0.198^{ab}	96.30- 97.50	96.68 ± 0.220^{ab}	95.90 -97.40
Mooleppadam *(n= 36)*	5.58	51.35 ± 0.125^{cd}	50.67- 52.34	98.32 ± 0.166^a	97.30- 99.30	98.47 ± 0.178^b	97.00- 99.40

*SE: Standard Error
† Means with different letters indicate significant difference at P<0.05 level (ANOVA- DMRT)

Table 2. Root zone soil and water nutrients of *Limnocharis flava* (L.) Buchenau. (±SE)* in Kumarakom *Grama Panchayat.*

Location	Root Zone Soil			Water		
	TKN (mg/g) †	P (mg/g) †	K (mg/g) †	TKN(mg/l) †	P (mg/l) †	K (mg/l) †
Methran Kayal	4.13 ± 0.133^a	1.32 ± 0.109^a	0.97± 0.587^a	1.77 ± 0.189^a	7.16 ± 0.186^a	12.02 ± 0.243^a
(n = 12)	(3.83- 4.43)	(1.17-1.41)	(0.82 – 1.10)	(1.22- 2.03)	(6.74- 7.65)	(11.35 -12.41)
Pallikayal	5.14 ± 0.060 ^{a}	2.48 ± 0.664^a	2.25 ± 0.055^{ab}	2.66 ± 0.136^a	9.69 ± 0.292^b	15.71± 0.254^a
(n = 9)	(5.08-5.27)	(2.27-2.78)	(2.18- 2.36)	(2.45- 2.92)	(9.23- 10.23)	(15.42- 16.22)
M.M. Block	5.36 ± 0.096^a	2.68 ± 0.281^a	2.16 ± 0.038^{ab}	2.63 ± 0.076^a	10.47± 0.236^b	15.84± 0.203^a
(n = 21)	(4.98-5.68)	(2.23-2.95)	(2.00-2.26)	(2.25- 2.85)	(9.25- 11.02)	(14.98- 16.48)
Edavattam Kizhakku	8.56 ± 1.136^b	4.62 ± 2.083^b	4.21± 0.615^c	4.72 ± 0.769^b	14.35± 0.834^{cd}	11.71± 0.203^b
(n = 21)	(5.65 -12.46)	(2.45- 7.47)	(2.39- 6.39)	(2.55-7.45)	(11.17- 17.04)	(6.78- 18.35)
Poonkassery	9.46 ± 1.301^b	4.80 ± 2.517^b	4.64 ± 0.895^c	5.47 ± 0.826^b	15.49 ± 0.946^d	13.09± 2.589^b
(n = 18)	(6.31-12.87)	(2.25-7.58)	(2.41-6.98)	(3.51-7.92)	(13.08 – 18.19)	(11.03- 19.50)
Mooleppadam	6.05 ± 0.180^a	2.59 ± 0.370^a	2.50 ± 0.067^b	2.97 ± 0.124^a	12.84 ± 0.370^c	16.48± 0.207^a
(n= 36)	(5.03-6.63)	(2.08-3.17)	(2.00- 2.90)	(2.19-3.86)	(10.52- 14.23)	(15.03- 17.80)

*SE: Standard Error
† Means with different letters indicate significant difference at P<0.05 level (ANOVA- DMRT)
Results in parenthesis are the range value

sq.m, with an average weed density of 2.75-8.50 (Table 1). The highest weed density (9-10 weeds/ sq.m) was obtained from three sampling points of Edavattam Kizakku and four sampling points of Poonkaserry. The highest weed biomass was recorded from Poonkassery area (53.45 ± 0.450 g) and minimum weed biomass from Methran kayal (48.10 ± 0.255 g), where the weed height (110.3 ± 0.300 cm) and water depth was higher (104. 83 ± 1.180 cm) than other quadrate sites. There was an increases of weed density observed as the water depth decreases from Metran kayal to northen part of the study area.

The analytical results of the root zone soil and water samples collected from different quadrate sites of Kumarakom *Grama Panchayat* is presented in Table 2. In water both phosphorous (7.16 ± 0.186 to 15.49 ± 0.946 mg/l) and potassium concentration (11.71 ± 0.203 to 16.48 ± 0.207 mg/l) was higher than TKN (1.77 ± 0.189 to 5.47 ± 0.826 mg/l). However, soil TKN (4.13 ± 0.133 to 9.46 ± 1.301 mg/kg) was higher than soil phosphorous (1.32 ± 0.109 to 4.80 ± mg/kg) and soil potassium (0.97 ± 0.587 to 4.64 ± 0.895 mg/kg) concentrations. The foregoing results confirm that both soil and water nutrients boosting the growth and multiplication of *L. flava.*

Associated species

An understanding of the associated weed community is also important for delineating the extent of the invading species. Table 3 shows the list of associated species of *L. flava* and its density at the various sampling locations of Kumarakom *Grama panchayat. L. flava* density was low at Methran kayal (2.75) and Pallikayal region (4.33) where the associated species were mostly exotics and their density was high. This may be attributed to the fact that most of the alien species are strict competitors. In most of the cases the associated species was also weed (invasive or local weeds) because common plants could not live in highly disturbed systems, as they can not compete with highly adaptive exotic species. The free floating species like *Eichhornia crassipes* (C. Martius) Solms-Laub.,

Table 3. Associated species of *Limnocharis flava* (L.) Buchenau. in Kumarakom *Grama Panchayat.*

Location	*Eichhornia crasipes* (C. Martius) Solms-Laub	*Salvinia molesta* D. Mitch	*Azolla pinnata*	*Pistia stratiotes* L	*Monochoria vaginalis* (Brum.f.) C. Presli	*Ipomea aquatic* Forssk	Colocasia *esculenta* (L.) Schoof	*Cyperus species*
Methran Kayal	+++	++	+	++	-	-	-	-
Pallikayal	++	++	+	++	-	-	-	-
M.M. Block	+++	-	++	+	-	+	-	+
Edavattam Kizhakku	-	++	+	+	++	+	++	-
Poonkassery	+	+	+	-	++	++	+	+
Mooleppadam	-	+	+	++	++	+	++	+

(+++ High density; ++ Medium density; + Low density)

Table 4. Growth rate of *Limnocharis flava* (±SE) in comparison to two exotic species and two native species from Kumarakom *Grama Panchayat.*

Species	Family	Status	Relative growth rate (RGR)† $gg^{-1}d^{-1}$	Range
Limnocharis flava (L.) Buchenau.	Limnocharitaceae	Exotic	0.7324 ± 0.039^{c}	0.67- 0.81
Eichhornia crasipes (C. Martius) Solms-Laub	Ponteridaceae	Exotic	0.8319 ± 0.012^{d}	0.81-0.85
Salvinia molesta D. Mitch	Salviniaceae	Exotic	0.5594 ± 0.006^{b}	0.55-0.57
Nymphaea nouchali Burm. f.	Nymphaceae	Native	0.0431 ± 0.004^{a}	0.04-0.05
Nymphoides indica (L.) Kuntze	Nymphaceae	Native	0.0468 ± 0.005^{a}	0.04- 0.05

*SE: Standard Error
† Means with different letters indicate significant difference at P<0.05 level (ANOVA- DMRT)

Salvinia molesta D. Mitch, *Pistia stratiotes* L.etc were the common associated species at Methran Kayal and Pallikayal region where water depth was high. As the water depth decreases from south to northern region, associated species was mostly rooted like *Monochoria vaginalis* (Brum. f.) C. Presli., Colocasia *esculenta* (L.) Schoof., *Ipomoea aquatic* Forssk. and *Cyperus species*.

Weed Relative growth rate (RGR)

The relative growth rate (RGR) is an important factor affecting the invasibility of an invader. The high relative growth rate enables them to grow very rapidly and gregariously. The change in growth of *L. flava* and other species was assessed by studying three permanent quadrate sites of Kumarakom *Grama Panchayat* at three consecutive sampling (0th day, 30th day and 60th day harvesting).The relative growth rate (RGR) of *L. flava* was compared with the relative growth rate of two notorious invasive species (*Eichhornia crassipes* (C. Martius) Solms-Laub., and *Salvinia molesta* D. Mitch) and two native species (*Nymphaea nouchali* Burm. f.*, and Nymphoides indica* (L.) Kuntze.) .The RGR of *L .flava* varied from 0.67-0.81 $gg^{-1}d^{-1.}$ The results revealed that *L. flava* is having high mean RGR (0.7324 ± 0.039 $gg^{-1}d^{-1}$) than the exotic species *Salvinia molesta* D. Mitch (0.5594 ± 0.012 $gg^{-1}d^{-1}$) and native species *Nymphaea nouchali* Burm. f. (0.0431 ± 0.004 $gg^{-1}d^{-1}$) and *Nymphoides indica* (L.) Kuntze (0.0468 ± 0.005 $gg^{-1}d^{-1}$) at P<0.05 level (ANOVA). The RGR of different species were; *Eichhornia crassipes* (C. Martius) Solms-Laub > *Limnocharis flava* (L.) Buchenau. > *Salvinia molesta* D. Mitch > *Nymphoides indica* (L.) Kuntze = *Nymphaea nouchali* Burm. f. (Table. 4).

Factors affecting distribution of *L. flava* in Kumarakom *Grama Panhayat*

The statistical analysis revealed that habitat and nutrient factors affecting the successful growth and multiplication of *L. flava* (Table 5). Correlation between weed densities, weed biomass, weed height, nutrients of soil and water samples were evaluated. There is strong correlation between the weed density and weed biomass (P<0.01 level). A high population indicates their easy establishment in that area and ensuring their future growth and multiplication Similarly, water depth is another detrimental factor for the distribution of *L. flava* in Kumarakom *Grama Panchayat* .There was a strong negative correlation between the weed density and water depth (P<0.01). As the water depth increase, the weed density decreases because *L. flava* is a rooted emergent preferring shallow water bodies, lakes, pools, paddy fields and other marshy areas. However, water depth is positively correlated with weed height. The highest weed height was found at Methran kayal; where the wate depth was maximum (104. 83 ± 1.180 cm). Again, the statistical results clear that weed density and biomass are strongly correlated to root zone soil and water nutrients at P<0.01 level and P<0.05 level respectively. During the

Table 5. Pearson correlation coefficients among weed density, weed biomass, weed height, water depth and root zone soil and water nutrients (TKN, P K).

Sl No	Sources of correlation	'P' value	Significance level
1	Correlation between weed density and weed biomass	0. 945	P<0.01
2	Correlation between weed density and water depth	-0.636	P<0.01
3	Correlation between weed height and water depth	0.734	P<0.01
4	Correlation between weed biomass and water depth	-0.698	P<0.01
5	Correlation between weed density and root zone soil TKN	0.985	P<0.01
6	Correlation between weed biomass and root zone soil TKN	0.889	P<0.05
7	Correlation between weed density and root zone soil P	0.971	P<0.01
8	Correlation between weed biomass and root zone soil P	0.871	P<0.05
9	Correlation between weed density and root zone soil K	0.987	P<0.01
10	Correlation between weed biomass and root zone soil K	0.886	P<0.05
11	Correlation between weed density and water TKN	0.983	P<0.01
12	Correlation between weed biomass and water TKN	0.875	P<0.05
13	Correlation between weed density and water P	0.982	P<0.01
14	Correlation between weed biomass and water P	0.962	P<0.05
15	Correlation between weed density and water K	0.987	P<0.01
16	Correlation between weed biomass and water K	0.893	P<0.05

present study, *L. flava* was detected mainly from wasted paddy fields, main water canal of the paddy fields, boundary canal of the paddy fields and reclaimed coconut fields having water logged or marshy areas. Very few numbers are noted in paddy fields clearly suggest that land use pattern is also favoring for the invasion and multiplication of *L. flava.* The present study area is mainly having paddy cultivation and these fields are well below (1-3 m) mean sea level (MSL). The entire fields are water logged for more than 8 months a year having an average water depth of 1.5 m. The higher water levels are not supportive for the growth of *L. flava*. During the cultivation time, the farmers would pump out water from the fields, followed by plugging and felid leveling. After this process, they have to leave the field for three to four weeks. During this time, the entire weed seeds previously buried in the fields would germinate. The farmers will again filled the fields with water and leave it as such for one more months. Subsequently, all the germinated weed species will decay and farmers will start the paddy cultivation. In the same way, after the paddy harvesting , farmers will burn out the fields with unwanted residues and this process again check soil seed bank of weed species. Hence *L. flava* is restricted to the paddy fields under regular use and operation. However, in the cases of wasted paddy fields, interferences are minimum and they getting open niches for the luxuriant growth and multiplication. The associated species are another factor check the weed invasion. In our study, it could be clear that *Eichhornia crassipes* (C. Martius) Solms-Laub, *Salvinia molesta* D. Mitch, and *Pistia stratiotes* L. are preventing the rapid multiplication of *L. flava* in some part of the area. However, as the associated species was changing from exotic to local weeds, *L. flava* was growing at maximum density (10 weeds /sq.m). Our study clearly pin point that water depth, nutrients, associated species, habitat and land use pattern are the major factors responsible for the invasion of *L. flava* in Kerala (Fig. 4).

CONCLUSION

The distribution of *L. flava* was studied in Kumarakom *Grama Panchayat* of South India and mapping was done using Geographical Information System (GIS). If allowed to grow unchecked, *L. flava* may become a very invasive environmental weed of paddy fields, streams, wetlands and other shallow water bodies. It has already become a serious weed in the rice fields, irrigation canals and wetlands in the South-East Asia (Waterhouse, 2003). The earliest record of its introduction in the Asia goes back to the year 1866 when it was recorded to have been cultivated as an aquatic ornamental in the Botanic Gardens, Bogor. In 1870, it was for the first time mentioned by Edeling, 'as a newly introduced alien' from the banks of river Tjiliwung near Djakarta (van Steenis, 1954), the same river flows through the Botanic gardens, Bogor. Gradually it became a common weed of rice fields in the environs of Bogor and has now spread almost all over Malaysia and Indonesia. It was introduced in Thailand around 1909 (Burkill, 1935). In November 1925, it was discovered by Sen to be growing in Southern Myanmar (Bruhl and Sen, 1927). Much before this aquatic had got itself established in eastern Asia. During 1898 it was introduced as an ornamental in the Botanic Gardens, Peradeniya, Srilanka (Senartana, 1940). In 1932, however, it was for the first time recorded in a naturalized state in Srilanka and by 1936 it becomes a serious pest in rice fields, so much so that paddy cultivation in some of the fields in Sri Lanka had to be entirely abandoned.

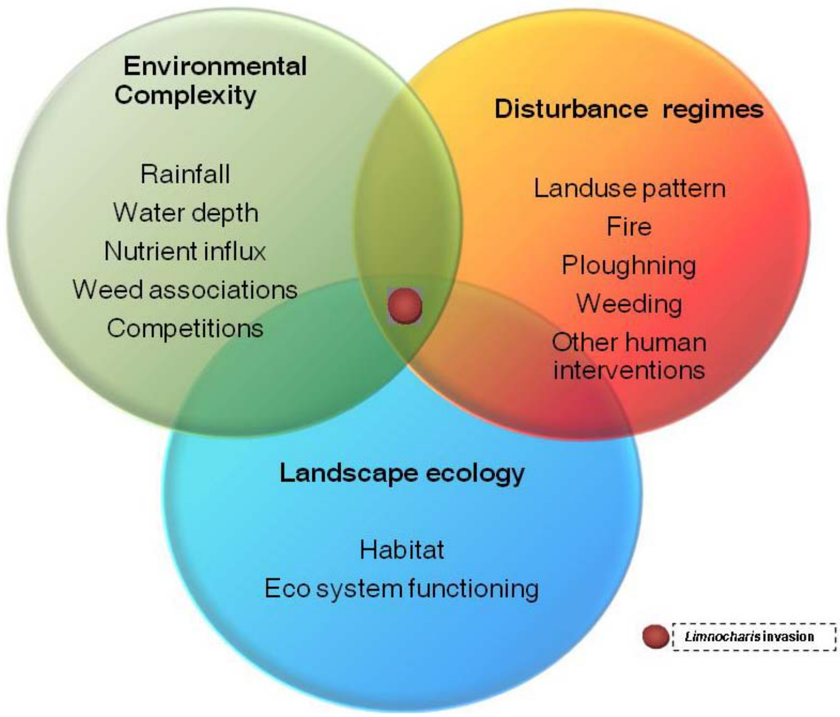

Fig. 4. Intercation of various factors on succesful invasion of *Limnocharis flava* (L.) Buchenau.

It is difficult to know exactly, how this alien species found its way in to India and got naturalized in Kerala. In India, this weed has been first reported from a wetland area in Alappuzha, Kerala, by Ramachandran (1961). In 1967, Bahadur and Raizada reported this species from Kollam and they presumed that the viable seeds might have been introduced accidentally with the imported rice from South East Asian countries like Myanmar, Thailand and Srilanka where this species has already become a pest of rice fields. Nakayama et al., 1999 reported that *L. flava* in Malaysian agricultural rice fields was not killed by the application of 2,4-D and bensulfuron-methyl. In Malaysia this weed first evolved multiple resistances (to two herbicide mode of action) in 1998 and infests rice. Whatever may have been the mode of its introduction, the fact however remains that the plant has now become wild in Kerala. Land use/land cover pattern, water depth, nutrients and associated species are the major factors affecting the *L flava* invasion. Undoubtedly this alien weed is gradually establishing itself everywhere and if early steps are not taken to eradicate this weed, it may become a noxious weed in the same way as *Salvinia* or *Eichhornia*. For developing effective measures for the rapid spread of *L. flava* in Kumarakom and other parts of Kerala, the following strategies are given below:

1. Survey for dominance and growth of *L. flava* under different geographical locations (low land, mid land, high land).
2. Study on the effect of different environmental factors on weed infestation and distribution.
3. Use of geographical Information System to assess pattern of spread of the *L. flava* and for ecosystem modeling.
4. Influence of weed on biodiversity and vector borne disease.
5. Evaluation of control measures under different growing conditions involving eco-physiological approaches.
6. Prioritization of taxonomic survey, identification of biotypes and preparation of distribution maps of *L. flava* in all the affected areas.
7. Identification of bio-control agents and study of the biology of natural enemy and the weed-natural enemy relationships to determine how best they could be used to solve the problem.
8. Evaluation of the effectiveness of the natural enemy/ enemies.

The strategies for controlling *L. flava* should also stress on the following points:

1. Educating people and ensuring people participation for uprooting and burning the weed before flowering and seed shedding.
2. Understanding the most vulnerable stages in the life of the weed by studying its ecology and biology to arrest its spread.
3. Utilization aspects of the weed as leafy vegetable, green manure, in medicines and other applications

should be studied so that the population is controlled through exploitation.

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入侵植物黃花藺枝生態分布：
地理資訊系統在雜草管理及生態系保育上之應用

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摘　　要

外來雜草的入侵對於生物多樣性的結構、組成以及功能所造成的衝擊，已是全世界公認的重大環境議題之一。這些外來物種多半是具有侵略性的殖民者，對於棲地環境的要求具有彈性，並且有能力競爭排除原生物種。本研究就印度南部克拉拉邦庫瑪蘭肯地區 (Kumarakom *Grama Panchayat*) 的黃花藺 (*Limnocharis flava* (L.) Buchenau) 之分布及個體生態學進行探討。庫瑪蘭肯地區是印度南部為人熟知的觀光勝地，向來以其一望無際的稻田及濕地著稱。本研究以地理資訊系統軟體 (Arc-info 8.3 版本) 繪製、量化黃花藺於本地區的分布。此外，並於研究範圍內之採樣點，收集黃花藺之豐富度、生物量、生態相關數值、根部營養鹽、水質及沉積物樣本加以分析研究。結果顯示，營養程度、水深以及土地利用類型為主要造成黃花藺大量繁殖的元兇。本文中也就黃花藺的控制方法加以討論。針對此物種而言，早期的發現與移除最為重要，否則造成的危害，將如人厭槐葉萍 (*Salvinia molesta* D. Mitch) 及布袋蓮 (*Eichhornia crassipes* (C. Martius) Solms-Laub) 所造成的入侵一般難以收拾。

關鍵詞：黃花藺、Buchenau、外來雜草、入侵、生物多樣性、Sustainable management。

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