1.1 INTRODUCTION

1.1.1 General

Throughout the world there is increasing concern for the cause of environment, its dwindling resources and varied issues of anthropogenic origin. During the last few decades there was a growing interest on biodiversity studies covering the vast array of life forms inhabiting the earth. Biodiversity studies starts with genes and manifests itself as organisms, population, species and communities which give life to ecosystems and biomes of the biosphere.

Alien weed invasion has been identified as one of the biggest threat to biological diversity around the globe. Invasive plants are aggressive colonizers, which have flexible habitat requirement and ability to outcompete native species. These invaders are spreading like a ‘biological wildfire’ ranging out of control. They pose a serious challenge to the sustainable management of the natural ecosystems.
1.1.2 Weeds

King (1966) considered a number of definitions of weeds in general and concluded that there are ten characteristics which are commonly stated or implied as - (1) plants growing where they are not wanted, (2) possess competitive and aggressive habits, (3) wild and rank growth, (4) persistent and resistant to control or eradication, (5) large populations with abundant, rank and extensive growths, (6) useless, unwanted, and undesirable, (7) harmful to man, animals, and crops, (8) exhibit spontaneous growth, appearing without being sown or cultivated, (9) of high reproductive capacity and finally, (10) disfiguring the landscape.

1.1.3 Natural powers of weeds

Weed seeds germinate earlier, their seedlings grow faster, they flower earlier, form seeds in profusion and mature ahead of the crop they infest. Nature has bestowed these qualities on weeds so that their seeds are collected along with the produce of the crop at the harvest and get distributed to other places where the produce may be taken. They have the remarkable capacity to germinate under varied conditions. Another characteristic of the weed seeds is dormancy which is an intrinsic physiological power of the seed to resist germination even under favourable conditions, and also the seeds do not lose their viability for years even under adverse conditions (ICAR, 1997).

1.1.4 Invasive and exotic weeds

Invasive weeds are a special group of weeds, which are of recent concern as these weeds are alien to the native environment and affect the survival of the native plants. Plant invasions threaten the existence of endangered species and the integrity of ecosystems (Culliney, 2005). *Eichhornia crassipes*, *Salvinia molesta* and *Pistia stratiotes* are some of the problematic invasive weeds commonly found in India. Alien weeds are plants introduced to an ecosystem to which they are not indigenous and where they utilize the privileges of the naturally growing plants, thus reducing the components useful to the native plants. Thus, the growth of the native plant is restricted,
yields are usually reduced and at times the native plants may be outnumbered and the alien weeds may start on an invasive rampage.

Cronk and Fuller (1995) considered an ‘invasive plant’ as an alien plant spreading naturally (without the direct assistance of people) in natural or semi-natural habitats, which produce a significant change in terms of composition, structure or ecosystem process.

1.1.5 Aquatic weeds
The term aquatic weeds refers to a large variety of aquatic plants, ranging from large filamentous algae to emergent reeds and cattails, which interfere with one or the other use of the water resources in a water body (river, lake, reservoir, fish pond or paddy field). An aquatic weed is an unscrupulous growth of a plant that influences adverse physical demand or biological effects on a water body with its resultant economic and aesthetic losses (Gupta, 1979).

The aquatic macrophytes commonly found in water bodies include:

- Free floating plants whose entire body except the roots is above water.
  Eg. *Eichhornia crassipes, Pistia stratiotes, Alternanthera philoxerides, Salvinia molesta*

- Submerged plants, whose entire body remains submerged in the water.
  Eg. *Elodea canadensis, Hydrilla verticillata*

- Emergents where plants rooted in soil but emerging to significant heights above water.
  Eg. *Typha latifolia, Phragmites communis*
1.1.6 Detrimental effects of aquatic weeds

Aquatic weeds affects primary aquatic productivity, pose problems to fisheries, inland water transport and provide congenial breeding grounds for mosquitoes, pests and other vectors of contagious diseases causing health hazards and disturb the fragile oxygen balance of water bodies through decay. They also interfere with agricultural operations when they invade the paddy field causing higher evapotranspiration and increase the fertiliser consumption considerably. These weeds prevent normal gaseous exchange between the water and atmosphere.

Aquatic weeds also pose significant threat to wetlands and related agricultural systems. Wetlands are generally rich in nutrients, have shallow water and normally support extensive growth of a large variety of macrophytes. These macrophytes provide shelter, food, nesting and breeding sites (or material) for most of the waterfowls, fishes and also other aquatic biota. Hence they cannot be always considered as weeds. It is only when some plant species start growing in such large proportions that they reduce or eliminate the growth of other desirable plants affecting other biota and their normal utilisation of the wetland, they become weeds. In most cases, such weed species are not the normal component of the wetland and often introduced from other areas.

Weed menace is one of the persistent environmental problems faced globally. Even the most developed nations like USA and UK spend huge sum of resources not to eradicate but just to keep the spread of weed’s under control. Rest of the nations throughout the world also continue with their efforts to control the weeds, especially the aquatic and wetland weeds, as they became major environmental nuisance for the water resources (Abbasi et al., 1988).

1.1.7 Invasive plant impacts

All exotic species have wide niche breadth compared to most of the native species, indicating their ecological flexibility. These exotic weeds invade different habitats successfully, as they possess unique adaptive attributes such as their prolific growth
rates, high seed out-put, multiple modes of propagation including clonal and asexual propagules (by vegetative fragments, tubers, ramets and rhizomes) and high vegetative and physiological flexibility that imparts intense competitiveness and environmental fitness.

1.1.8 Ecological impacts
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 ecosystem resilience, loss of potentially productive land, loss of grazing and livestock production, poisoning of man and his livestock, choking of navigational and irrigation canals and reduction of available water in water bodies. 

Ecological processes may change after invading species have established and spread. These changes may be minimal and the plant invader may simply increase species richness. In contrast, where ecological processes are sufficiently disrupted, native species can be displaced, increasing plant community vulnerability to further invasion and regeneration of the invasive plant. When perturbation of ecosystems 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.

1.1.9 Economic impacts
Economic impacts of invasive plants on natural ecosystems have received limited attention. The difficulty in quantifying the economic value of goods and services provided by the ecosystems, i.e. ecological economics, further constraint assessment of economic impacts of invasive plants.
The economic impacts are both direct and indirect. Direct impacts reflect the effect of the invader and indirect impact implies general effects that are caused by the presence of the invader, which could affect public health. In 2001, Food and Agricultural organization (FAO) identified six types of economic impacts of invasion: (i) on production, (ii) on price and market effects (iii) on trade (iv) on food security and nutrition (v) on human health and environment, ecological and economic cost associated (vi) financial costs impacts (Sharma et al., 2005)

Aquatic weeds cost millions of dollars as lost revenues and control costs. The direct and indirect cost in human suffering in less affluent nations and subsistence communities is immeasurable in monetary terms. In USA as a whole, about $100 million is spent annually for the control of non-indigenous aquatic weed species. About $20 million is spent every year in the Florida; USA, to control *E. crassipes*, *P. stratiotes*, and *H. verticillata* (Abbasi et al., 1988; Charudattan, 2001).

1.1.10 Integrated invasive weed management

Integrated weed management is the application of technologies in a mutually supportive manner and these technologies are integrated and implemented with a consideration of economic, ecological and sociological consequences. Integrated weed management employs the planned, sequential use of multiple tactics (chemical, biological, cultural and mechanical control measures) to improve ecosystem function (energy flow and nutrient cycling) and maintain exotic plant damage below economic levels and emphasizes managing natural ecosystem functions to meet objectives rather than emphasizing a particular weed or control method. Sustainable integrated invasive plant management strategies require assessing plant impacts, understanding and managing the processes influencing invasion, knowledge of invasive plant biology and ecology and are based on ecological principles. Invasive plant management programme must be compatible with and integrated into overall natural resource management objectives and plans.
Chapter I  Ecology and distribution studies of Limnocharis flava

The magnitude and complexity of exotic weeds, combined with the costs for their control, necessitate the use of integrated weed management. Education, prevention, detection, monitoring and assessment and weed control methods are the key components of integrated management strategies. Preventing invader introduction by restricting movement of propagules from infested areas can minimise invader dispersal into new habitats. Early detection followed by swift, intensive and aggressive implementation of effective control measures are essential to eliminate the invader, or at least to prevent seed production. Developing effective integrated alien weed management programmes require a thorough understanding of the biology and ecology of the invasive plant and invaded community.

1.1.11 *Limnocharis flava*

*Limnocharis flava* (L), an emergent invasive aquatic weed of quiet shallow waters, ditches, pools and flood plains of Kerala, seems to have been introduced for unknown reason and was first reported in Allapuzha and then from Kollam district of Kerala (Kammathy and Subramanyan, 1967; Bahadur and Raizada, 1968). The plant has established well now and is found widespread in abandoned paddy fields and flood plains of Kuttanad, Vembanad lake covering Kollam, Alappuzha and Pathanamthitta districts and in the low lying abandoned paddy fields, lakes, ponds of Ernakulam and Trichur districts in more or less stagnant fresh water and rooted in mud, amidst *Colocassia, Monochoria* and other floating aquatics (Plate I and II). It has been reported that this plant has became a noxious weed in the rice fields of Ceylon, Indonesia and Malaysia and the paddy cultivation is completely abandoned due to its serious infestation. 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 infested the rice fields. However, an extensive search in the available literature revealed that no studies have been taken up in Kuttanad to study the ecology, habitat analysis and distribution mapping of this alien weed. In the present study an attempt has
been made to evaluate some autecological aspects of this aquatic, emergent, invasive weed in Kuttanad wetland ecosystem.

1.1.12 *Limnocharis flava* - a brief Literature Review

*Limnocharis flava* (L) Buchenau is commonly called ‘yellow bur-head’, is a monocot weed in the Limnocharitaceae family. It is an emergent aquatic plant that has invaded the flood plains of Kuttanad and other low-lying areas of Kerala. 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 plant 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 to Thailand around 1909 (Bruhl and Sen, 1927). In 1925, Sen reported it from Southern Myanmar. 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 became 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. Holm-Nielson and Haynes (1992) in their monograph on Limnocharitaceae in the “Flora of Neotropica” has reported that *Limnocharis flava* is a neotropic weed, distributed in the northern Argentina and eastern Brazil. Cook (1990) identified three genera of Limnocharitaceae, such as *Hydrocleys*, *Butomopsis* and *Limnocharis*. He also mentioned the taxonomy of each genera and their respective species. It was in 1961, Ramachandran of Botanical Survey of India, first collected this plant from Alapuzha, Kerala. This species may be mistaken for *Limnophyton obtusifolium* (L.) Miq. at first sight, but can easily be distinguished from the latter by its yellow petals, stout pedicels and flowers and outer sterile stamens (Kammathy and Subramanyan, 1967). In February 1967, Kammathy and Subramanyam, Botanical Survey of India, Calcutta, again collected this plant from Allappuzha district
(Ambalapuzha). Subsequently, in 1967, Ravi, Kollam, collected this species and forwarded it to the Forest Research Institute and College, Dehra Dun for identification. The specimen was thus identified as *Limnocharis flava* (L.) Buchenau. In addition the specimens from Myanmar available in the Dehra Dun Herbarium (DD) were also examined. Again, in 1974, Rao and Das collected and observed *Limnocharis flava*, from a number of sites along the fringes of canal banks and paddy fields in Trichur and its vicinity. Nayar (1985) depicted the key works to the taxonomy of *Limnocharis flava*. According to him the family in India is represented by two genera: *Limnocharis* and *Tenagocharis*.

**Limnocharis flava: Origin, Distribution and Taxonomy**

The family Limnocharitaceae is represented by 3 genera *Hydrocleys* (=*Ostentia*), *Butomopsis* (=*Tenagocharis*) and *Limnocharis*. According to Holm-Nielsen and Haynes (1992), the family 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.

**Geographic distribution**

*Native range:* America: North Western Mexico, Nicaragua, Costa Rica, Panama, Cuba, Haiti, Dominican Republic, Windward Islands, Colombia, Venezuela, Ecuador, West Indies, Peru and Brazil.

*Known introduced range:* Southeast Asia (Malaysia, Indonesia, Thailand, South Myanmar, Srilanka, India and Vietnam) and Australia (Waterhouse, 2003). In a recent report the plant is referred as “Silent killer” the most dangerous wetland weed due to its deadly pace of regeneration. It has been reported that one third of paddy fields in Alapuzha, Thrissur and Ernakulam districts are already under the grip of this killer weed (Thomas, 2005).
Plate I Habitat and habit of *Limnocharis flava*

Plate II *Limnocharis flava* - a closer view

Plate III Flowers of *Limnocharis flava*

Plate IV Ramet formation in *Limnocharis flava*
**Limnocharitaceae**

Annual or perennial with latex in specialised tubes. Juvenile leaves linear; adult leaves differentiated into petiole and blade, the blades lanceolate to ovate or cordate with parallel nerves. Inflorescence umbel-like, auxiliary clusters or flower solitary, flowers bisexual, actinomorphic, sepals 3, green, persistent, with latex tubes. Petals 3, white or yellow, delicate not persistent. Stamens 6-9 or numerous. Carpels superior, 3 to numerous, free, in 1 or rarely 2 whorls, fruit is a head of follicles or thin-walled nutlets; seeds numerous, scattered over the inner surface of carpel wall or solitary; embryos curved or folded.

**Key to the genera of Limnocharitaceae**

Leaf blades obtuse or cordate at base, usually floating; petioles with transverse septate ---------------------------------------------------------------

*Hydrocleys.*

Leaf blades lanceolate to oblanceolate, the apex tipped by a hard, blunt mucro; petals white; stamens about 9, staminodia absent. ----------

*Butomopsis.*

Leaf blades ovate to suborbiculate, the apex rounded or emarginated; petals yellow; stamens more than 9 surrounded by staminidia-------------------------

*Limnocharis*

**Limnocharis**

Plants emerged, stems short, rhizomatous, stolons occasional, erect. Leaves basal, emerged, long petiolate; petiole triangular, aseptate, often with aerenchyma; blade lanceolate to oval, the apex acute to round, the base acute to cordate. Inflorescence of one to many flowers, terminating and elongate, aseptate scape, occasionally
proliferating, the scapes ten in number; peduncles shorter than the length of petioles; bracts separate, delicate throughout; shorter than pedicel subtended. Flowers long-pedicelate, the pedicels somewhat dilated, often winged, often inflated, erect to spreading in flower, recurved in fruit, trigonous; sepals green, broadly ovate, obtuse, appressed; petals yellow, fugacious, ovate to sub orbicular, longer than the sepals, erect to slightly spreading above the sepals; stamens many, the outer ones often sterile, the filaments linear, flattened, the anthers linear, carpels 15-20, laterally compressed, verticillate, scarcely coherent at base, the style absent, the stigma extrose. Fruits laterally compressed, semicircular, scarcely coherent, membranous, dorsally furrowed, dehiscent internally; seeds numerous transversely multicostate.

**Key to the species of Limnocharis**

Peduncles mostly as long or longer than petioles, inflated, blades oval to ovate, the base round to cordate-------------------*L. flava.*

Peduncles mostly shorter than petioles, only slightly inflated, if at all; blades narrowly elliptic to lanceolate, the base attenuate to rounded

----------*L. laforestii.*

**Limnocharis flava** (L.) Buchenau.

**Common names**
The following are the names by which *L.flava* is commonly known globally.

Description

*Limnocharis flava* (L.) Buchenau, is commonly called ‘Yellow bur head’. Name from the Greek word ‘Limno’ means marsh or pond and ‘charis’ means grace. A perennial, erect, glabrous, scapigerous, lactiferous, herb with a short stout rhizome ca. 3 cm long, ca. 3 cm diameter and numerous fibrous roots. Aerial stems (peduncles) 1-4, axillary, erect, flattened at the base, triangular up to 120 cm tall, bearing at the apex a cluster of flowers or a vegetative plant (ramet) or both. Leaves erect, pale green, arising in clusters, rising above the water, sheathing, curvi nerved, often exceeding the aerial stems in length; petiole thick, up to 90 cm long, more or less triangular, with numerous lacunae, sheaths gradually narrowed upwards; leaf blades papery, light green, very variable, rounded to ovate or broad elliptic, 6-20 cm long and almost equally broad, apex generally apiculate with a small hydathode at the tip, base cuneate to repand cordate, margin undulate, main nerves 4-6 pairs and a marginal one, sub parallel and converging towards apices, secondary nerves numerous, parallel, nearly perpendicular to the midrib, reticulations dense and very fine.

Inflorescence umbellate, 2-15 flowered, supported by an involucre of bracts, sometimes with 1 or 2 leaves between the flowers; bracts roundish to broad-elliptic, tips often emarginate. Flowers pedicelled, dull yellow, actinomorphic, hermaphrodite, 2-4 cm in diameter, pedicels- 2 long, 3-gonous, 3-winged above, enlarging upwards and much elongated in fruit; perianth 2-seriate; sepals 3, persistent, imbricate, green obtuse, 1.5-2 x 1-1.5 cm, enlarging and enclosing the fruit. Petals 3, thin, caducous, imbricate, pale yellow with darker base, broad-ovate to orbicular, apex rounded, 2-3 x 1-2 cm; stamens numerous, surrounded by a whorl of staminoides, filaments flattened, free, anthers basifixed, 2-celled, dehiscing longitudinally; carpels 15-20, verticillate, laterally compressed, free, densely set, seemingly forming one superior ovary, ovules many, placentation superficial, styles wanting, stigmas sessile. Fruit composed of fruitlets as many as carpels; fruitlets scarcely cohering, semi-circular, membranous, opening along
the ventral (adaxial) side, dorsal wall thick. Seeds numerous, very small, horseshoe shaped, closely crowded together; testa brown, spongy; endosperm 0.

Ecology

*Limnocharis flava* is an emergent aquatic weed inhabits shallow swamps, ditches, pools and wet rice fields, occurring in more or less stagnant fresh water, most abundant below 700 m, but found up to 1,300 m in Kerala, it grows in muddy, uncultivated, abandoned paddy fields. Where moisture is present year-round *L. flava* is a perennial herb; in ephemeral water-bodies and sites with pronounced dry seasons it is an annual (van Steenis, 1954).

Phenology

The flowers open in the morning and close by mid-day, after which the stamens and petals disintegrate into a mucilaginous mass (van Steenis, 1954) (Plate III). There is, however, no record of any pollinating agent either from South America or South East Asia. The plant spread mainly by seeds. Fruiting take place throughout the year and the seeds are produced in great abundance. A single fruit produce about 1,000 seeds and a single plant may produce over 1,000,000 seeds per year (Senartana, 1940). The seeds themselves are hardly buoyant, but the fruitlets are for some days. The ripe carpels open on the inner (adaxial) side and the opening widens due to curving of the outer (abaxial) wall, which is thicker, thereby permitting, the fruitlets to escape. The fruitlets 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 frequenting the fields or by man and his impediments, or with cereals from an infested field transported to an uninfected area.

While seed production is so prolific, the plant has also a vegetative method of multiplying. Often, at the centre of the umbels a vegetative plant is developed and after the fruits are 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, the aerial stem
roots, and the new individual start an independent life. Often, as the seeds mature, the fruiting peduncles falls on water, the seeds ripen and sink (as they cannot float) to the bottom, but the peduncles as soon as it rests on water, produces another plant in a short time (ramet), which again produces flowers, seeds and shoots, and so on (Plate IV).

**Uses**

*L. flava* is valued as an ornamental plant in some countries and cultivated in botanical gardens or private homes. A known introduction of the species for ornamental use has been documented in the USA, Singapore, Sri Lanka and Indonesia (Corlett, 1988; van Steenis, 1954; Senartana, 1940). Ochse *et al.*, (1931) included the *L. flava* as an aquatic leaf vegetable in the ‘Vegetables of Dutch East Indies’. National Academy of Sciences, Washington, (1976) reported that, in Java, young plants of *L. flava* are a common and much esteemed vegetable. It is cultivated in rice fields and marketed as a fresh vegetable. In some South-East Asian countries *L. flava* is used as a source of food. For example, in Java the plant is a much-esteemed vegetable, which is cultivated in rice fields and sold in markets for its young leaves, stems and flower clusters. In Vietnam, *L. flava* occurs naturally in many bodies of water and is used as a vegetable in dishes; it is particularly popular in the Mekong Delta. Known as *keo neo or cu neo*, it is frequently gathered by ethnic Vietnamese (*Kinh*) women and sold in local markets and by boat vegetable vendors. The young leaves and tops of the plant are boiled or cooked in mixed soups. The vegetable contains relatively high levels of Ca, Fe and β-carotene, which are frequently insufficient in the diets of women in low-income countries (Ogle *et al.*, 2001). The leaves of *L. flava* are also collected for household consumption in Bangladesh by women. It is also reported to be used as pig or cattle fodder (in Sumatra), and as green crop manure for paddy fields. The leaves, stems and flower clusters are cooked and eaten as a vegetable (Cook *et al.*, 1974; Ruskin and Shipley, 1976). In Malaysia and Java, it is grown in rice fields (Ruskin and Shipley, 1976). This plant is cultivated in ponds with common carp in Western Java.
An attempt has been made in the present chapter to study the ecology, associations and distribution pattern of the plant *Limnocharis flava* (L.) Buchenau, in Kuttanad wetland ecosystem with the following objectives.

**1.1.13 Objectives of the study**
1. To study the distribution of *Limnocharis flava* in the Kuttanad wetland/agro ecosystem.
2. To analyse the growth rate of *L. flava*.
3. To analyse the habitat ecology and associations of the weed *L. flava*.
4. To prepare the eco-distribution maps of *L. flava* in the Kuttanad wetland ecosystem.

**1.2 REVIEW OF LITERATURE**

Bio-invasion, the spread of non-native (exotic) species, may be the least visible and least predictable of all the major dimensions of ecological decline. It is dangerous, because exotics often create pressures for which there is no local evolutionary precedent, native species simply may not be adapted to live with the invaders. The result is widespread suppression of natives and sometimes extinction. As a threat to global biological diversity, bio-invasion or biological pollution now be considered as a major factor behind its decline.

Early detection of new weeds can facilitate timely intervention to minimise their impacts. investigations of probable source and entry routes, as well as knowledge on the weed biology and ecology are important in delineating the extent of a new invader (Masters and Sheley, 2001). Weed ecology is concerned with growth characteristics and adaptations that enable the weeds to survive the changes in the environment and it dictates the distribution, prevalence, competing ability, behaviour and survival of the weeds (Charudattan, 2001). Unfortunately, our current knowledge of the ecology of exotic weeds is limited. While some knowledge of the exotic weeds can be obtained from the countries to which they are native, weeds often change their behaviour under the environmental conditions of their new home. A complete understanding of the life
Plate I Habitat and habit of Limnocharis flava

Plate II Limnocharis flava - a closer view

Plate III Flowers of Limnocharis flava

Plate IV Ramet formation in Limnocharis flava
cycle of any weed would be ideal along with information on the influence of environmental factors.

Campbell and Grice, (2000) reported that an understanding of exotic weed biology would be of help to answer various questions about the weed management, including: How long do individual plants live? How long does it take young plants to become reproductive? How long will it take for the seed bank to be depleted once adult plants are removed from a site? How and how far is the seed dispersed? What is the frequency and scale of seedling recruitment? And what is the distribution pattern? A better understanding of the ecology will help to improve control methods.

1.2.1 Abiotic factors and weed growth rate
In order to understand the influence of chemical constituents of water on the distribution of aquatic plants, Unni, (1972) analysed the water samples of Doodhadhari lake, Raipur, Madhya Pradesh and reported that, the composition of species did not vary much during different months but a change in the bulk of the different species was found. The chemical constituents in water play an important role in the distribution and composition of different species of aquatic plants. An ecological study by Unni (1971) on the macrophytic vegetation of Dhhoodhadhari lake on distribution and seasonal change in aquatic plants were done and the results indicates that the perennial species are not affected by the seasonal changes. The growth rate and organic matter production of a cultivated stand of Trapa bispinosa Roxb. was analysed in 1978 and 1980 during the growing season by Unni (1984). The results indicates that the plant had a relative growth rate (RGR) varied from 0.65 to 0.11 g g\(^{-1}\) d\(^{-1}\).

An understanding of the associated species of a particular weed is also important for evolving effective management tactics. Booth and Swanton (2002) revised the assembly theory applied to weed communities. According to Booth, when a weed species (or group of species) is removed from a community (or its density is reduced), other species
either new or already present can invade those vacated gaps. As a result, a weed problem still exists- only the species are different.

In 2001, Jacobs et al. used transect method for the assessment of the population density of *Aphthona nyriiscutis*, a bio-control insect of a rangeland weed *Euphorbia esula* L. They were also found out the leaf spruge cover and density and the level of association between *Euphorbia esula* and *Aphthona nyriiscutis* using the same technique.

The effect of abiotic factors on the growth of the invasive weed Cord grass, *Spartina densiflora* and the native plant *Spartina martima* at low salt marshes of Siberian peninsula at low salt marshes of Siberian peninsula was studied by Jesus and Figueroa in 2007 revealed that the stressful abiotic environment of lower marshes showed a significant lower distribution of the native plant and showing low relative growth rates. The invasive weed tolerates better than the native one.

Stanley et al. (1986) conducted a study on the ecological life histories of three aquatic plants, *Myriophyllum spicatum*, *Potamogeton crispum* and *Elodea canadensis* and reviewed about their life cycles, productivity and relationship of abiotic factors on its growth and establishment.

### 1.2.2 Distribution mapping

One of the factors that make control of invasives so costly is that infestations are rarely caught in the early stages, when the population numbers are low. In fact, invasions are usually targeted for control when the plants of concern are widespread and fully entranced in the ecosystem. Typically, there is no baseline data from plant surveys, which makes it difficult to quantify community changes as a result of invasion and thus difficult to determine the optimum management approach as well as measure its success.
Traditional approaches for surveying the macrophyte composition of an aquatic vegetation are based on ground measurements, such as the transect, quadrate and zone methods (Mueller-Dumbois and Ellenberg, 1974; Chapman, 1976). These give accurate information on aquatic macrophytes, but are time consuming when used for mapping large areas. Remote sensing can offer a supplementary and time-saving means of achieving a better spatial picture.

Weed mapping is an integral component of all weed management activities. Environmental managers are looking for better and cost effective means of delineating weed distributions, densities and increasingly predictions of weed distributions and weed risk assessment. The varied advantages of GIS in effectively harnessing the weed distribution and weed growth modelling have been successfully utilised 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 utilisation of natural resources (Crossman and Kochergen, 2002).

The distribution of selected exotic weeds viz; Lantana camara, Euphorbium repandum and Opuntia dilleni in Nilgiri Biosphere Reserve was done by Mahagan and Aziz (1999). Four transects of 1km each were laid at different sites of each vegetation type and one transect of one km was laid in each plantation to study the distribution, density and abundance of weeds. Doddamani et al. (1999) conducted a survey in Karnataka State (including the Western Ghats region) for the ecological distribution of Chromolaena odorata. The degree of infestation was low in thick evergreen forest, where sunlight is a limiting factor, indicating the importance of light for establishment of this weed. Chandrashekaran (1999) studied the distribution of Lantana camara in Chinnar Wildlife Sanctuary by quadrate method.

Sankaran et al. (2001) studied the status of Mikania infestation in the Western Ghats and prepared a GIS map for the distribution of Mikania micrantha in Kerala State.
Within each district, sites were chosen at random manner and at each site, the abundance of *Mikania* was assessed by selecting, at random, five 1m x 1m quadrates within each 1ha plot. Cousins *et al.* (2002) prepared the distribution map of Cape weed in the 0.9 ha, produced from 1m x 1m quadrates using Kriging. Crossman *et al.* (2002) used GIS and remote sensing techniques for the weed risk assessment and for the management of Feral Olives in the South Australia.

**1.3 MATERIALS AND METHODS.**

**1.3.1 STUDY AREA**

The study area for the autecological studies of the plant is the Kuttanad wetland ecosystem, part of the Vembanad-Kol wetlands, one of the recently declared Ramsar site in India and the largest in Kerala.

**1.3.1.1 Kuttanad - a brief history**

From the very early days, Kuttanad has been acknowledged as “the rice bowl of Kerala”. In ancient days the term Kuttanad refers to a much larger area than what it denotes at present. Then the region extending from Karunagapally to Alwaye was known as ‘Kuttanad’. In early tamil literature like ‘Venpai’ and ‘tholkappiyam’, Kuttanad is mentioned as the one of the twelve ‘nadus’ where people spoke ‘Kodumthamil’. There are references to Kuttand in great Tamil work ‘Thiruvanmoymozhi’ written in 8th century AD.

Apart from these historical records there are also certain legends connected with Kuttanad. It is said that the Khandavi Vana mentioned in the epic Mahabharata was situated in Kuttanad and the burned forest still lie deep under the fields. Logs of burnt and charred wood are seen in the Karinilams of Vaikom, Thuravoor, Thakazhy, Purakad etc. So it is said that this place was originally known as ‘Chuttanadu’ meaning burnt land which later on become Kuttanad. Many people in Kuttanad often connect the
term with ‘Karumadikuttan’ a stone carved statue of Lord Budha situated at Karumady, and the ‘land of kuttan’ become Kuttanad.

1.3.1.2 Kuttanad - Topography and Geographical area

Kuttanad is highly complex dynamic and unique rice growing agro-climatic track of Kerala lying 0.6 to 2.5m below MSL. It extends between north latitude 9° 8’ to 9° 52’ and east longitudes 76° 19’ to 76° 44’ comprising the area of 54 revenue villages spread over Alappuzha, Kottayam and Pathanamthitta districts. The total geographical area of the region is 1100 km². Kuttanad is bounded by Kaduthuruthy - Vaikom road in the north, Kaduthuruthy – Kottayam -Mavelikkara railway line in the east, Mavelikkara - Haripad - Thottapally road in the south and Thottapally- Alapuzha- Thaneermukkom road in the west.

Most of the areas in Kuttanad are water logged almost throughout the year and subjected to flood during the monsoon period. During the monsoon floods the whole area becomes engulfed under a vast sheet of water as many rivers branch into many water course which are connected to one another. The flood waters move towards the Vembanad lake to be drained to the Arabian sea through Cochin estuary. Vast areas of paddy fields get submerged for one or two weeks resulting in considerable loss. Communication and accessibility of the area become difficult as important roads in the locality get branched or submerged under water. The area includes mainly the wet rice fields and dry garden land like sandy areas unclaimed and reclaimed kayal areas and other water spread, rivers, channels and water ways. The garden land is the land where the human population of Kuttanad is inhabited which is up to 1.0 m above MSL. The network of canals and rivers are extensively used for transportation, recreation and livelihood means.

1.3.1.3 Kuttanad - Geology

According to geologists Kuttanad represents a ‘Recent Sedimentary Formation’. It has been established that Arabian Sea was once extended as far east as the eastern border of
Kuttanad region. With the upheaval of the ‘Warkaly Laterite Formation’, the tract of the recent formation got elevated forming an extensive bay into which discharged the water of rivers. The silt carried by these rivers was deposited at the mouth of the rivers and this gave rise to the present sea coast, converting the shallow bay into an extensive backwater track. The lagoon gradually silted up and gave rise to the shallow wet paddy lands, which now characterise the Kuttanad. So it is a deltaic formation of mainly four rivers, Achankovil, Pamba, Manimala and Meenachil and part of the contribution is from Muvattupuzha river towards the northern part. The deeper portion of the lagoon formed the present ‘Kayal’.

1.3.1.4 Kuttanad - Climate

Kuttanad experiences fairly uniform temperature throughout the year ranging from 21° to 36° C. The average annual rainfall recorded as 3000mm. 83% of the rainfall is from the two monsoons. Most of it is got from the first rainy season, the south-west monsoon (June- August). The second rainy season is the north- east monsoon (October- November). The summer months extend from February to May.

1.3.1.5 Major problems of Kuttanad

Rice cultivation is the major agricultural activity followed by coconut and plantain cultivation. Besides this, Kuttanad is the natural habitat and home ground of many economically and ecologically important species of fishes, prawns, clams, frogs, birds and cattle. Kuttanad is heavily polluted due to excessive use of fertilizers, pesticides and other harmful chemicals from upstream catchments. The pollutants get concentrated and water is made into a ‘cesspool’ during the summer months due to stagnation, low water level and less water flow and the situation gets further deteriorated after commissioning of Thaneermukkom salt water barrier in 1975, which prevented the tidal activity in summer months, otherwise the water can flow and gets diluted with tidal seawater. The situation paved way for a series of problems like proliferation of unwanted noxious
exotic weeds, poisonous snakes, less fish and a number of infectious diseases seriously affecting the health and livelihood of the inhabitants of the area.

Invasion by exotic weeds has a serious impact on natural and managed ecosystems. Such invasion by alien species modify the ecosystem structure and function, since they can dominate and replace the native vegetation and cause extinction of certain native species, leading to drastic alteration in the biological diversity of an area. The reasons for the arrival, establishment and spread of native plant must be understood before sustained progress can be made towards controlling the plant and improving natural and managed ecosystems.

*Limnocharis* was selected for the present study due to its nuisance for rice fields of Kuttanad. The ecological methodologies employed for the growth rate analysis, distribution mapping and habitat analysis of the weed *Limnocharis flava* (L) Buchenau are detailed below.

**I) Field Exploration**

After a comprehensive field survey, *L. flava* was found to dominate in abandoned paddy fields, marshy areas and cultivated paddy fields in certain parts of Kuttanad which were selected for detailed studies (Fig. 1.1). The criteria used for selection of study locations were based on the physiography, topography, geology, edaphic conditions (Table1.1). The geographical details about the study locations were collected from SOI toposheets, various maps and literature.

**II) Ecological Observation**

For ecological analysis of density, water depth variation in relation to the growth and associated species, 10 different sites were selected in the Aymanam and Kumarakom area (Table1.1). The ten sites were located in different agro-ecological regions include, north Kuttanad, Kayal lands and lower Kuttanad and the sites selected are Vallyad, Ambalakadavu, Cheepunkal, Kareemadam, Pallikayal, M.M.Block, Poonkasserry,
For growth rate analysis, two sites at Nattakom and Vazapallichira were selected as permanent quadrate sites. Water and soil samples were collected from these permanent sites and the other selected 10 sites where *L.flava* was growing gregariously.

i) Habitat Ecology studies

*a) Relative Growth Rate Analysis (RGR)*

Based on the abundance and proximity of *L. flava* plants, permanent quadrate sites were selected at the lower Kuttanad region for growth rate study. Permanent quadrate sites were selected at Vazhappallychira near Changanacherry and at Nattakom near Pallom (Plate V and VI). Growth rate and population analysis of the plant were carried out following the methods by Unni (1984) and Beadle (1993).

The mean relative growth rate (RGR) was calculated from the formula

\[ RGR = \ln \left( \frac{W_f}{W_i} \right) / t \]

Where: ‘*Wi*’ is the initial biomass (per m\(^2\) or per plant).

‘*Wf*’ is the biomass after ‘*t*’ days

Three plots of size 6m x 6m in the selected sites of Vazhappallychira and Nattakom, and each plot was subdivided into 6 subplots of 1m x 1m. Every week *Limnocharis flava* plants of different subplots were numbered, marked and 2-4 representative plant samples were harvested from each subplot. The harvested plants were transported to the laboratory washed to remove any adherent mud and organic matter. The collected samples were chopped and weighed immediately and the fresh weight of the plant was recorded. Then the samples were dried at 70°C until their weight become constant. The plant biomass per square meter were computed from the mean dry weight of one plant.
multiplied by plant density of each sub plot. Dry weight changes per plant were calculated from the total dry weight per square meter divided by the total number of *L. flava* plants. The plant growth rate was computed by dividing the biomass change by days.

**b) Ecological associations, density and water depth**

The associated species were counted in different stations of Aymanam and Kumarakom where the plants were growing gregariously. Sites were selected based on the distribution, growth, proximity and abundance of *Limnocharis*. The ten different sites includes, Vallyad, Ambalakadavu, Cheepunkal, Kareemadam, Pallikayal, M.M.Block, Poonkasserry, Moolepadam, Edavattam Kizhakku and Methran Kayal. The density of the associated weeds was measured by counting the number of associated species per sq m and delineated into three different classes as follows:

<table>
<thead>
<tr>
<th>Density Level</th>
<th>Range (no. of plants per sq. m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low density</td>
<td>0-5</td>
</tr>
<tr>
<td>Medium density</td>
<td>5-10</td>
</tr>
<tr>
<td>High density</td>
<td>10-15</td>
</tr>
</tbody>
</table>

Dry weight changes, water depth and number of associated species were noted. Water depth of each quadrate was measured using PVC pipes. Pipes were inserted into the water column and the height was measured. Water and soil samples for the analysis of nutrients were also collected from the sites.
Plate V  Permanent Quadrate site at Vazhappallychira

Plate VI  Permanent Quadrate site at Nattakom

Plate VII  Experimental setup for lead absorption studies at green house
Fig. 1.6 Map showing the distribution of Limnocharis flava in Kuttanad wetland ecosystem

Fig. 1.1 Sampling sites selected at different ecological zones of Kuttanad Wetland Ecosystem
Table 1.1  Details of the field sites and parameters of study conducted.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Sampling Location</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Soil type</th>
<th>Locality</th>
<th>Agro-ecological regions</th>
<th>Parameters of study</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pallom</td>
<td>76°30’32.82''</td>
<td>9°21.07''</td>
<td>Lateritic</td>
<td>Nattakom</td>
<td>Lower Kuttanad</td>
<td>Growth rate/density, Soil and water analysis</td>
</tr>
<tr>
<td>2</td>
<td>Vazhapally chira</td>
<td>76°32’1.79''</td>
<td>9°7’41.23''</td>
<td>Lateritic</td>
<td>Changana nacherry</td>
<td>Lower Kuttanad</td>
<td>-do-</td>
</tr>
<tr>
<td>3</td>
<td>Vallyad</td>
<td>76°27’5.63''</td>
<td>9°7’57.21''</td>
<td>Clayey</td>
<td>Aymana m</td>
<td>North Kuttanad</td>
<td>Depth variation, associated species, soil and water analysis</td>
</tr>
<tr>
<td>4</td>
<td>Ambalakadavu</td>
<td>76°30’10.74''</td>
<td>9°4’36.52''</td>
<td>Lateritic</td>
<td>Aymana m</td>
<td>Kayal land</td>
<td>-do-</td>
</tr>
<tr>
<td>5</td>
<td>Cheepunkal</td>
<td>76°25’42.24''</td>
<td>9°38’13.7''</td>
<td>Lateritic</td>
<td>Aymana m</td>
<td>North Kuttanad</td>
<td>-do-</td>
</tr>
<tr>
<td>6</td>
<td>Kareemadam</td>
<td>76°26’34.47''</td>
<td>9°37’9.56''</td>
<td>Clayey</td>
<td>Aymana m</td>
<td>North Kuttanad</td>
<td>-do-</td>
</tr>
<tr>
<td>7</td>
<td>Pallikayal</td>
<td>76°25’11.08''</td>
<td>9°34’9.94''</td>
<td>Clayey</td>
<td>Kumarakom</td>
<td>Kayal land</td>
<td>-do-</td>
</tr>
<tr>
<td>8</td>
<td>M.M. Block</td>
<td>76°26’35.39''</td>
<td>9°34’3.53''</td>
<td>Clayey</td>
<td>Kumarakom</td>
<td>Kayal land</td>
<td>-do-</td>
</tr>
<tr>
<td>9</td>
<td>Poonkassery</td>
<td>76°27’1.96''</td>
<td>9°4’21.86''</td>
<td>Clayey</td>
<td>Kumarakom</td>
<td>Kayal land</td>
<td>-do-</td>
</tr>
<tr>
<td>10</td>
<td>Moolepadam</td>
<td>76°26’31.72''</td>
<td>9°6’20.07''</td>
<td>Clayey</td>
<td>Kumarakom</td>
<td>North Kuttanad</td>
<td>-do-</td>
</tr>
<tr>
<td>11</td>
<td>Edavattam kizhakk</td>
<td>76°27’1.05''</td>
<td>9°34’52.1''</td>
<td>Clayey</td>
<td>Kumarakom</td>
<td>North Kuttanad</td>
<td>-do-</td>
</tr>
<tr>
<td>12</td>
<td>Methran kayal</td>
<td>76°26’8.81''</td>
<td>9°3’18.63''</td>
<td>Clayey</td>
<td>Kumarakom</td>
<td>North Kuttanad</td>
<td>-do-</td>
</tr>
</tbody>
</table>
III) Distribution mapping
The distribution pattern of L. *flava* in the Kuttanad wetland ecosystem during the period 2006-2007 was noted through field survey. The exact geographical co-ordinates of the various patches were recorded using a handheld Global Positioning System (GPS) receiver (Garmin GPS Map 76). The co-ordinates were then put into a spatial database of the area in a GIS platform (Software-ARCGIS 8.3). For this, Survey of India (SOI) topographical maps of scale 1:50,000 (58 C/6, C/9, C/10, C/11, and C/12) were used as the base maps.

IV) Chemical Analysis of Water and Soil

*Sample collection and preservation*

*i) Water samples*
Water samples (2 liters) were collected in cleaned polyethylene containers following the procedure given in APHA (1998) from the permanent quadrate sites as well as from ten different stations of Aymanom and Kumarakom where the plant was abundant. The analyses were done for the chemical characteristics of soil and water in relation to the distribution of *Limnocharis*.

*ii) Soil samples*
Soil samples were collected from rooting depth (up to 20 cm) using an auger from the same site where water samples were collected and kept in polythene bags. The samples were kept in icebox in the field itself to minimise the nutrient loss and transported to the laboratory for posterior analysis.

The samples were first air-dried in a shadow area and subsequently oven dried at 80°C over night and sieve through 5mm mesh. The air-dried samples were oven dried at 105°C for 24 hrs and then powdered and sieved (Jackson, 1967).
Chemical analysis

The collected and processed water and soil samples were analysed for various physical and chemical properties. The nitrogen content of soil and water samples were analyzed following Jackson (1967) and APHA (1998). Phosphate content of soil and water samples was determined colorimetrically using UV-VIS spectrophotometer (Genesys-10UV) and potassium concentration by flame photometer (Systronics-128) (APHA, 1998).

V) Statistical analysis

To test whether there exists any significant difference between growth rate at Vazhappallychira and Nattakom, analysis of variance (ANOVA) was employed (Sneedecor and Cochran, 1971). The degree of association between water depth, nutrients, plant density and biomass was calculated by Pearson coefficient of correlation.

1.4 RESULTS AND DISCUSSION

I) Growth rate analysis

The relative growth rate 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 Limnocharis flava was assessed by studying sample plots in Vazhappallychira and Nattakom (Table 1.2). The results revealed that Limnocharis is having high relative growth rate similar to other exotics, ranging from 0.053 g g⁻¹ d⁻¹ to 0.0625 g g⁻¹ d⁻¹ (Fig.1.2). The growth rate was found quite similar to the relative growth of obnoxious weeds like Salvinia (0.04 - 0.09 g g⁻¹ d⁻¹) (Mitchell and Tur, 1975) and Eichhornia (0.053 g g⁻¹ d⁻¹) (Wotten and Dodd, 1976). Higher growth rate was found at Vazhappallychira (0.0625 g g⁻¹ d⁻¹), compared to Nattakom (0.054 g g⁻¹ d⁻¹). The study revealed that L. flava is a weed having high growth rate. Undoubtedly, this weed is gradually establishing itself everywhere and if early steps are not taken to eradicate this plant, it may become noxious as Salvinia, Typha, Eichhornia etc. The maximum dry
weight per plant was 88.66 g in Vazhappallychira and 42.7g in Nattakom. The percentage moisture content of the weed ranges from 94 – 94.61 (Table1.2).

To test the significance of the difference between the sampling locations for growth rate, the experimental data were statistically analysed using analysis of variance (ANOVA). There is no significant difference exists between two permanent quadrat sites (P<0.05).

II) Associated Plants
An understanding of the associated species of a weed community is also important for delineating the extent of the invading species. In most of the cases the associated species will also be weeds because common plants could not live in a highly disturbed system, as they cannot compete with highly adaptive exotic species. Table 1.3 shows the list of associated species and density at the various sampling locations of Aymanam and Kumarakom Panchayats. In the case of permanent quadrat sites, where the water depth is very less, the associated species are mostly rooted species like Cyperus sp, Colocasia esculenta, Ipomea sp, Monochoria vaginalis etc. However Eichhornia crassipes is also observed at Vazhappallychira. Free floating species like Eichhornia, Salvinia, Pista etc. were the associated species at Aymanam and Kumarakom panchayats where the water level is high.

In Aymanam panchayat, the plant density was 7 plants per square meter at Ambalakadavu, whereas in Cheepunkal and Karremadam there was a decrease in density (4 plants per square meter) and at Vallyad the density was 6 plants per square meter. The average dry weight of Limnocharis at the ten selected sites varied between 47.02- 54.16 g (Table1.4).

The number of L. flava plants per square meter increased from west to east ie. from Vallyad to Methrankayal. The habitat analysis also revealed that increased water level
in the western part (>1m) prevent the rapid growth of the marshy weed *Limnocharis flava*. The associated species were mostly *Salvinia*, *Pistia*, *Eichhornia* and *Azolla*.

It was observed from the distribution pattern of *Limnocharis* in Kumarakam panchayat that as the water depth increases the density of the *Limnocharis* declined (Fig. 1.3). The maximum density of plant was observed in Vazhapallychira, followed by Nattakom, Ambalakadavu and Poonkasserry. In addition to the floating weeds, *Colocasia esculenta* is also growing associated with *Limnocharis* in Moolaepadam region.

The analytical results of the soil and water samples of the above locations revealed that the nutrient concentrations were almost similar to the permanent quadrate sites (Table 1.4) Even though, there is a similarity in nutrient concentration of the soil and water samples of the permanent quadrate sites as well of Aymanam and Kumarakom panchayats, there is a significant variation in weed density. This may be mainly due to the change in land use pattern, weeding operation and other direct human interference. Thus the agriculture activities like ploughing land burning, weeding operations and other activities constraints the growth of *L. flava* in Aymanam and Kumarakom Panchayats, where as in the case of permanent quadrate sites, the land were left untreated as uncultivable or non-profitable. The level of human interference provides open niches for the luxuriant growth of *L. flava* in those locations. The above findings clearly pointed out that land use pattern is the major reason for the establishment of this alien weed in Kuttanad.

There is significant negative correlation between water depth and average number of plants (P<0.01). This indicates that as water depth increases, plant density decreases. Thus the increased level of water in Aymanam and Kumarakom Panchayats prevent the successful establishment of *Limnocharis flava*. Table 1.5 shows the coefficient of correlation between number of plants and nutrients. There is significant positive correlation (P< 0.05) between number of plants and TKN in water (P< 0.05).
Table 1.2  Growth rate analysis and nutrient concentration of *Limnocharis flava* at permanent quadrate sites.

<table>
<thead>
<tr>
<th>Location</th>
<th>Sampling stations</th>
<th>Plot no.</th>
<th>Dry wt (g)</th>
<th>Moisture content (%)</th>
<th>Growth rate</th>
<th>Nutrients</th>
<th>Water</th>
<th>Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TKN (mg/L)</td>
<td>P (mg/L)</td>
</tr>
<tr>
<td>Vazhappally, China</td>
<td>1</td>
<td>1-6</td>
<td>88.65</td>
<td>94.0</td>
<td>0.0625</td>
<td>6.14±0.08</td>
<td>2.85±0.42</td>
<td>1.90±0.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>7-12</td>
<td>79.17</td>
<td>94.2</td>
<td>0.06</td>
<td>6.13±0.07</td>
<td>2.04±0.59</td>
</tr>
<tr>
<td>Vazhappally, China</td>
<td>3</td>
<td>13-18</td>
<td>79.27</td>
<td>94.2</td>
<td>0.06</td>
<td>6.02±0.07</td>
<td>2.15±0.72</td>
<td>1.13±0.17</td>
</tr>
<tr>
<td>Nattakom</td>
<td>1</td>
<td>1-6</td>
<td>40.57</td>
<td>94.6</td>
<td>0.054</td>
<td>5.98±0.06</td>
<td>1.88±0.63</td>
<td>1.02±0.9</td>
</tr>
<tr>
<td>Nattakom</td>
<td>2</td>
<td>7-12</td>
<td>42.75</td>
<td>94.3</td>
<td>0.054</td>
<td>5.73±0.08</td>
<td>1.75±0.48</td>
<td>0.98±0.04</td>
</tr>
</tbody>
</table>

All values are mean of three samples ± S.D. TKN-Total Kjeldhal Nitrogen, P-Phosphorous, K- Potassium
Chapter-I  Ecology and distribution studies of *Limnocharis flava*

Fig. 1.2 Growth rate of *Limnocharis flava* at the permanent quadrate sites

V1, V2, V3→ Vazhappallychira (Sub plot no. 1- 6, 7- 12, 13- 18 respectively);
N1, N2→Nattakom (Subplot no. 1-6 and 7-12 respectively)
**Fig. 1.3** Number of *L. flava* at various water depth in different locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Water Depth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vazhappallychira</td>
<td>15</td>
</tr>
<tr>
<td>Nattakom</td>
<td>18</td>
</tr>
<tr>
<td>Ambalakadavu</td>
<td>65</td>
</tr>
<tr>
<td>Vallyad</td>
<td>72</td>
</tr>
<tr>
<td>Edavattam Kizhakku</td>
<td>85</td>
</tr>
<tr>
<td>Poonkasserry</td>
<td>89</td>
</tr>
<tr>
<td>Kareemadam</td>
<td>89</td>
</tr>
<tr>
<td>MM Block</td>
<td>93</td>
</tr>
<tr>
<td>Pallikayal</td>
<td>95</td>
</tr>
<tr>
<td>Moolaepadam</td>
<td>96</td>
</tr>
<tr>
<td>Methran Kayal</td>
<td>103</td>
</tr>
<tr>
<td>Cheepunkal</td>
<td>109</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water Depth (cm)</th>
<th>No. of <em>Limnocharis flava</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>18</td>
<td>14</td>
</tr>
<tr>
<td>65</td>
<td>12</td>
</tr>
<tr>
<td>72</td>
<td>10</td>
</tr>
<tr>
<td>85</td>
<td>8</td>
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<tr>
<td>89</td>
<td>6</td>
</tr>
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<td>93</td>
<td>4</td>
</tr>
<tr>
<td>96</td>
<td>2</td>
</tr>
<tr>
<td>103</td>
<td>1</td>
</tr>
<tr>
<td>109</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 1.3  Associated species and their density in various locations

<table>
<thead>
<tr>
<th>Species name</th>
<th>Habit</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Vallyad</td>
</tr>
<tr>
<td><strong>Eichhornia crassipes</strong></td>
<td>Floating</td>
<td>+++</td>
</tr>
<tr>
<td><strong>Salvinia molesta</strong></td>
<td>Floating</td>
<td>+</td>
</tr>
<tr>
<td><strong>Pistia</strong></td>
<td>Floating</td>
<td>+</td>
</tr>
<tr>
<td><strong>Azolla</strong></td>
<td>Floating</td>
<td>+</td>
</tr>
<tr>
<td><strong>Colocasia esculenta</strong></td>
<td>Emergent</td>
<td>++</td>
</tr>
<tr>
<td><strong>Monochoria vaginalis</strong></td>
<td>Emergent</td>
<td>++</td>
</tr>
<tr>
<td><strong>Cypreus sp.</strong></td>
<td>Emergent</td>
<td>++</td>
</tr>
<tr>
<td><strong>Ipomea sp.</strong></td>
<td>Mat forming</td>
<td>++</td>
</tr>
</tbody>
</table>

+++→high density; ++ → Medium density; + → Low density

Chapter-1  Ecology and distribution studies of Limnocharis flava
Table 1.4  Density and Habitat characteristics of *Limnocharis flava* at various locations

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Location</th>
<th>L. flava samples</th>
<th>Water Depth (cm)</th>
<th>No. of associated species</th>
<th>Nutrients</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Density (per m²)</td>
<td>Plant Biomass (g/plant)</td>
<td></td>
<td>Water</td>
<td>Soil</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TKN (mg/l)</td>
<td>P  (mg/l)</td>
<td>K  (mg/l)</td>
</tr>
<tr>
<td>1</td>
<td>Vallyad</td>
<td>6 51.99</td>
<td>72</td>
<td>3</td>
<td>4.92±2.52</td>
<td>1.42±3.85</td>
<td>0.98±0.95</td>
</tr>
<tr>
<td>2</td>
<td>Ambalakadavu</td>
<td>7 54.16</td>
<td>65</td>
<td>3</td>
<td>5.20±1.95</td>
<td>1.73±4.63</td>
<td>1.04±0.79</td>
</tr>
<tr>
<td>3</td>
<td>Cheepunkal</td>
<td>4 47.02</td>
<td>109</td>
<td>3</td>
<td>5.11±0.86</td>
<td>1.92±4.29</td>
<td>1.28±0.51</td>
</tr>
<tr>
<td>4</td>
<td>Kareemadam</td>
<td>5 50.77</td>
<td>89</td>
<td>3</td>
<td>4.89±3.42</td>
<td>2.10±5.21</td>
<td>0.85±0.49</td>
</tr>
<tr>
<td>5</td>
<td>Pallikayal</td>
<td>4 47.85</td>
<td>95</td>
<td>2</td>
<td>4.96±9.35</td>
<td>1.10±3.71</td>
<td>0.99±0.64</td>
</tr>
<tr>
<td>6</td>
<td>M.M. Block</td>
<td>5 49.16</td>
<td>93</td>
<td>4</td>
<td>4.70±6.74</td>
<td>1.32±2.34</td>
<td>1.14±0.39</td>
</tr>
<tr>
<td>7</td>
<td>Poonkasserry</td>
<td>6 53.05</td>
<td>89</td>
<td>3</td>
<td>5.54±3.63</td>
<td>1.83±1.96</td>
<td>0.98±0.52</td>
</tr>
<tr>
<td>8</td>
<td>Moolaepadam</td>
<td>5 49.11</td>
<td>96</td>
<td>3</td>
<td>4.95±1.82</td>
<td>1.95±2.32</td>
<td>1.12±0.57</td>
</tr>
<tr>
<td>9</td>
<td>Edavattam</td>
<td>6 50.10</td>
<td>85</td>
<td>2</td>
<td>5.07±2.17</td>
<td>1.72±0.36</td>
<td>0.98±0.42</td>
</tr>
<tr>
<td>10</td>
<td>Methran Kayal</td>
<td>3 48.95</td>
<td>103</td>
<td>4</td>
<td>5.12±1.54</td>
<td>2.07±1.2</td>
<td>1.07±2.3</td>
</tr>
</tbody>
</table>

All values mean of 3 samples. TKN-Total Kjeldhal Nitrogen, P-Phosphorous, K- Potassium
Table 1.5  Pearson Correlation coefficients between plant density, biomass, water depth and root zone soil and water nutrients (TKN, P, K)

<table>
<thead>
<tr>
<th>S1 no.</th>
<th>Source of correlation</th>
<th>P value</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Plant density and biomass</td>
<td>0.945</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>2</td>
<td>Plant density and water depth</td>
<td>-0.636</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>3</td>
<td>Plant biomass and water depth</td>
<td>-0.698</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>4</td>
<td>Plant density and root zone soil TKN</td>
<td>0.985</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>5</td>
<td>Plant biomass and root zone soil TKN</td>
<td>0.889</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td>6</td>
<td>Plant density and root zone soil P</td>
<td>0.971</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td>7</td>
<td>Plant biomass and root zone soil P</td>
<td>0.871</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>8</td>
<td>Plant density and root zone soil K</td>
<td>0.987</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td>9</td>
<td>Plant density and water TKN</td>
<td>0.983</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>10</td>
<td>Plant biomass and water TKN</td>
<td>0.875</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td>11</td>
<td>Plant density and water P</td>
<td>0.982</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>12</td>
<td>Plant biomass and water P</td>
<td>0.962</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>13</td>
<td>Plant density and water K</td>
<td>0.987</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>14</td>
<td>Plant biomass and water K</td>
<td>0.893</td>
<td>P&lt;0.05</td>
</tr>
</tbody>
</table>

III) Habitat analysis
Of all the sites studied *Limnocharis* were found larger in size and dominant is in Vazhapallychira, the highly polluted site (Table 1.2 and 1.4). Compared to Nattakom site these plants had two times greater biomass. Nutrients like nitrogen, potassium and phosphorous were found maximum (of 6.0 - 6.14, 2.04 - 2.85 and 1.13 - 1.9 mg/l respectively) in water. Out of 10 sites (Table 1.4) there observed an increase in the number of plants at site 2, 7 and nine where TKN in water was above 5 mg/l and TKN of soil was above 2 mg/g.

The TKN and Phosphorous concentration in water at the permanent quadrate sites were very high (5.73-6.14 mg/L and 1.75-2.85 mg/L respectively), whereas potassium concentration was very low (0.98-1.90 mg/L) (Fig.1.4). However, potassium content in soil (39.78-41.12 mg/L) was higher than phosphorous (5.99-6.43 mg/L) (Fig.1.5). Earlier studies (Chandran and Satheesh, 2006) showed a similar result on the distribution of nutrients in soil and water samples. They also reported that *L. flava* has rich potential in absorbing nutrients like phosphorous and nitrogen. The results of the habitat analysis revealed that both soil and water nutrients are boosting the growth and spread of the plant.

IV) Distribution Mapping
The map showing the distribution pattern of *L. flava* in Kuttanad wetland ecosystem is presented in Fig.1.6. *L. flava* were present in 35 locations in the study area. The plants were seen mainly inhabiting in the muddy uncultivated paddy fields, abandoned water logged paddy fields, fringes of canal banks, and even in between pockets of cultivated paddy fields.
Factors affecting distribution of *L. flava* in Kuttanad.

The statistical analysis revealed that habitat and nutrient factors greatly influenced the growth and rapid multiplication of *L. flava* (Table 1.5) Correlation between plant densities, plant biomass and nutrients in water and soil samples were evaluated. There exists strong correlation between the plant density and plant biomass (P<0.01). A high population indicates their easy establishment in that area and ensuring their future growth and multiplication. Similarly, water depth is another factor which limits the distribution of this plant. There exists strong negative correlation between the weed density and water depth (P<0.01). As the water depth increases, the plant density decreases. *L. flava* is a rooted emergent plant preferring shallow water bodies, lakes, pools paddy fields and other marshy areas. It was clear from the statistical results that plant 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 present study, *L. flava* was found inhabiting the abandoned paddy fields, main water channels of the paddy fields, boundary canal of the paddy fields and reclaimed coconut fields having water logged or marshy areas. Very few numbers were noted in paddy fields, clearly suggesting that land use pattern has also favored the invasion and multiplication of *L. flava*. The Kuttanad region mainly comprises of paddy fields below 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 act as a detrimental factor for the growth of *L. flava*. During the cultivation time, the farmers would pump out water from the fields, followed by plugging and field 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 fill the fields with water and leave it as such for one more month. Subsequently, all the germinated weed species are decayed enabling to start the paddy cultivation. In the same way, after the paddy harvesting, farmers 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 case of uncultivated paddy fields, interferences are minimum and hence the plant obtain open niches for the luxuriant growth and multiplication. The frequency of associated species is another factor that check the weed invasion. It was clear that *Eichhornia crassipes*, *Salvinia molesta*, and *Pistia stratiotes* are preventing the rapid multiplication of *L. flava* in some part of the area. The water depth, nutrients, associated species, habitat and land use pattern are the major factors responsible for the invasion of *L. flava* in Kerala.

![Nutrient concentration in water in the permanent quadrate sites](image)

**Fig. 1.4** Nutrient concentration in water in the permanent quadrate sites

*V1, V2, V3→ Vazhappallychira (Sub plot no. 1- 6, 7-12, 13-18 respectively), N1, N2→Nattakom (Subplot no. 1-6 and 7-12 respectively)*

Chapter-I  Ecology and distribution studies of *Limnocharis flava*
Fig. 1.5 Concentration of soil nutrients in the permanent quadrate sites.

V1, V2, V3 → Vazhappallychira (Sub plot no. 1-6, 7-12, 13-18 respectively),
N1, N2 → Nattakom (Subplot no. 1-6 and 7-12 respectively)
Fig. 1.6 Map showing the distribution of Limnocharis flava in Kuttanad wetland ecosystem

Fig. 1.1 Sampling sites selected at different ecological zones of Kuttanad Wetland Ecosystem
In order to develop the strategies and control measures for the rapid spread of *Limnocharis* in Kerala, the following thrust areas may be focussed in future research.

**Future needs**

i) Survey for dominance and growth of *Limnocharis* under different geographical locations (low land, mid land and highland).

ii) Use of geographical information system to assess pattern of spread of the *Limnocharis* and for ecosystem modelling.

iii) Influence of weed on biodiversity and vector borne diseases.

iv) Evaluation of control measures under different growing conditions involving eco-physiological approaches.

v) Prioritisation of taxonomic survey, identification of biotypes and preparation of distribution maps of *Limnocharis*.

vi) Identification of biocontrol 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;

vii) Evaluation of the effectiveness of the natural enemy/ enemies.

viii) Educating people and ensuring people’s participation for uprooting and burning the weed before flowering and seed shedding.

ix) Understanding the most vulnerable stages in the life of the weed by studying its ecology and biology to arrest its spread.

x) Utilisation aspects of the weed as leafy vegetable, green manure, in medicines and other applications such as a source of manure, bioenergy and its potential in remediating the contaminated water and soil should be studied so that the plant population is controlled through exploitation.
1.5 CONCLUSION

*Limnocharis flava* (L) Buchenau of the family Limnocharitaceae is a recent invader to Kerala. It seems to have been introduced in Kerala sometime around 1960s. However, no one knows how this alien made its way into India and got naturalised in Kerala. Whatever may have been the mode of its introduction, the fact however remains that the plant has now become wild in our state and may become a noxious rice weed in due course of time.

The plant inhabits shallow swamps, ditches, pools and abandoned paddy fields, occurring in more or less stagnant water, rooted in mud amidst *Colocassia, Monochoria* and other floating aquatics. Currently, the plant has become invasive in flood plains of Kuttanad and other countries like Malaysia, Indonesia, Thailand, Vietnam, Australia and Sri Lanka. It has been noted that now the paddy cultivation is completely abandoned due to its serious infestation.

The results of the studies conducted in the present chapter indicated that *Limnocharis* has high growth rate which is quite similar to the growth rate of the other noxious weeds like *Salvinia* and *Eichhornia*. The results of habitat analysis showed significant correlation between the plant growth rate and nutrients in water and soil. The habitat analysis revealed that soil and water nutrients, land use/land cover pattern and water depth are the important factors affecting the successful growth and establishment of this weed. The high relative growth, multiple mode of reproduction, (stolons, ramets, and seeds) ensure the rapid spread of this weed. 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*.