ASSESSMENT OF WATER QUALITY AND BIOMASS PRODUCTIVITY OF THE TROPICAL FLOATING MEADOWS OF KEIBUL LAMJAO NATIONAL PARK, MANIPUR

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CERTIFICATE

This is to certify that the thesis of **Ms. Chongpi Tuboi** entitled "**Assessment of water quality and biomass productivity of the tropical floating meadows of Keibul Lamjao National Park, Manipur**" is an original piece of work submitted to the Saurashtra University, Rajkot (Gujarat), for the award of the degree of **Doctor of Philosophy in Wildlife Science.**

Ms. Chongpi Tuboi has put in more than six terms of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted for any other university or institution.

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EXECUTIVE SUMMARY

Wetlands represent the aquatic edge of many terrestrial plants and animals; they also represent the terrestrial edge of many aquatic plants and animals. They are fast becoming a focus for research, management, and restoration activities because of high biodiversity, productivity and for their well-documented ecosystem service values. Wetlands with floating meadows largely occur in temperate and tropical freshwater wetlands throughout the world. In India, they occur in floodplains of Northeast India, particularly in Loktak Lake of Manipur valley. The Keibul Lamjao National Park (KLNP) located in the southern part of the Loktak Lake, with its characteristic floating meadows is the only natural habitat of the Manipur's brow antlered deer *Rucervus eldii eldii* locally called the Sangai which is perhaps the most threatened deer species in India. These meadows, locally called *phumdis*, are a heterogeneous mass of soil, vegetation and organic matter in various stages of decomposition which occur in different thickness ranging from a few centimeters to about 2.5 m. With the construction of Ithai Barrage on Imphal River, the floating meadows, which used to settle during the lean season and get replenished with soil and nourishment, are now continuously floating, resulting in their thinning and thereby threatening the existence of Sangai. The floating meadows also provide a biological sink for the key nutrients and govern the water and nutrient dynamics of this Lake ecosystem. The need to study the ecology of the floating meadows and the role it plays is therefore immensely important for the conservation of the endangered Sangai. The major objectives of the proposed study were to; (a) examine the ecological conditions of the KLNP in terms of water quality and nutrient status (b) derive the species richness and plant community composition of the Park and, (c) to quantify the pattern of biomass production by the floating meadows and its utilization by Sangai and Hog deer. With these objectives, the following research questions were formulated and addressed through this research (a) does the water quality of KLNP vary across seasons? (b) is there any variation in the plant community structure of the floating meadows of the Park in different seasons? (c) is there any relationship between environmental factors such as rainfall, temperature, humidity and management practices of cutting and burning and the plant biomass production? and (d) what percentage of biomass is available to and used by wild ungulates for their sustenance?

The water quality and nutrient status of the Loktak Lake and KLNP were examined during 2008-10. Surface water and soil sediment samples were collected monthly from eleven sites covering the Loktak Lake as well as the National Park and analyzed using standard laboratory protocols. There was no significant variations in the water quality parameters between the two study years (t-test, $p>0.05$). Across the seasons (summer, winter and monsoon), there was significant variation in the water quality parameters in terms of electrical conductivity, turbidity, total solids, total dissolved solids, hardness, calcium, magnesium, sodium, potassium, transparency and temperature (ANOVA, $p<0.05$). Variations were also observed in water quality parameters between Lake and the National Park in terms of electrical conductivity, total solids, total dissolved solids, hardness, calcium, magnesium, sodium, potassium, total phosphorus and chemical oxygen demand (t-test, $p<0.05$), however no significant variation (ANOVA, $p<0.05$) in terms of pH, dissolved oxygen, turbidity, total nitrogen, biological oxygen demand, transparency and chlorophyll was observed. Across the seasons, the nutrient contents of the soil varied significantly in terms of total nitrogen, phosphorus, calcium, magnesium, sodium and potassium (ANOVA, $p<0.05$) but organic carbon did not vary. Significant difference in the nutrient content of the Lake and the National Park was also not observed (t-test, $p>0.05$). According to Carlson's Trophic State Index, the water quality was hypereutrophic for the Loktak Lake as well as the National Park (TSI >70) suggesting National Park status of the southern part of the Lake has little impact on the water quality.

IIRS LISS IV and CARTOSAT data were used to derive the extent of meadows in the Keibul Lamjao National Park. For the classification of meadow types, 800 ground truth points for the Park area were used. Among the 11 different classes of habitat identified in and around the Park, the thick meadows occupied the largest area with 14.42 km^2 followed by water with floating vegetation (8.56 km^2). The open water with floating vegetation is confined to the north, north eastern and the peripheral region in the western part of the Park. Small portion of hard ground grassland of 0.58 km^2 in Thangbirel located in the western part of the Park and the three hillocks with scrub of 0.46 km^2 in the Park play an important role for the survival of Sangai especially during monsoon and early winter when water level is high in the Park. There was no agricultural encroachment inside the boundary of the Park, however fish ponds of 3.72 km^2 area at the periphery of the Parks especially in the eastern parts are seems to be encroachment in the National Park.

To derive the thickness of the meadows and the rate of decline in thickness over the years, the thickness of the meadows was measured (N = 1659) at different areas of the Park after dividing it into north and south zones based on administrative blocks as demarcated by the Forest Department. In each zone transects of 500 m were laid and the meadows' thickness was measured at every 50 m intervals. A total of 138 transect in both north and south zones were laid. To observe the change in meadow thickness during the study period, all available data on the thickness of meadows (2005-10) was transformed to the log values and regressed against years to derive the annual rate of change.

The mean thickness of the meadow was 107.97 ±4.03 cm, while it was 105.13 ±5.29 cm and 111.36 ±6.24 cm in north and south zones respectively. The overall thickness of meadows was found to be decreasing at a rate of 9% $annum^{-1}$ in the Park. It was 6% $annum^{-1}$ and 12% $annum^{-1}$ in northern and southern zones respectively. Around 8.64 km^2 area of the Park had meadows thickness greater than 120 cm, 7.32 km^2 had thickness between 60-120 cm and 6.33 km^2 areas had thickness of less than 60 cm. Allowing major portion of the meadows to settle during lean seasons by reducing water level, through a consultative process with Loktak Development Authority and other stakeholders could help reduce further thinning of meadows. Trampling and grazing on meadows, resource extraction from meadows and burning are likely to augment thinning process.

The structure and composition of the vegetation of KLNP was examined to study the vegetation types, habitat specificity and communities using quadrat method. On transects of 500 m length, quadrats of 0.5 m x 0.5 m were laid at every 50 m interval. A total of 625 plots were laid in summer and 311 plots in winter. During the study 185 plant species were recorded from the Park. Poaceae was the dominant family followed by Cyperaceae and Asteraceae. Ninety species were recorded in the floating meadows and open water, 19 species in terrestrial habitat and 76 species were common to both terrestrial and floating habitats. To examine the plant community structure data were analyzed for both summer and winter separately using

TWINSPAN and PC-ORD version 4.20. Nine plant communities were recorded in summer and eight in winter. Two communities, *Persicaria perfoliata – Leersia hexandra - Capillipedium* spp and *Zizania latifolia - Leersia hexandra - Capillipedium* spp were common in both summer and winter. Overall Shannon diversity index (H') for the meadows in summer and winter was 1.335 and 1.06 respectively. Overall Simpson diversity index (D) for the meadows was 0.6344 and 0.5105 for summer and winter seasons, respectively. The species richness (S) for summer and winter was 6.8 and 6.5, respectively. The evenness (E) of the species was 0.713 and 0.583 for summer and winter, respectively.

Annual production of vegetation is an important indicator of various ecosystem processes in wetland. During the study the extent of above-ground biomass production of the floating meadows of the Park was estimated by the harvest method. The biomass production was determined by summation of peak live weights of individual species. Sixteen enclosures of 10 m x 10 m were constructed on different meadow types in different areas of the Park. Vegetation from 1 m x 1 m plots from these enclosures was clipped every month for two years to quantify the above ground biomass production. To study the effect of management practices in the Park, one enclosure each in the different areas of the Park was subjected to cutting and burning treatment. Since, the cutting and burning treatments in the Park is done in the month of January-February, the vegetation of the enclosures were cut and burned to aboveground level once during the month of January for the two study years.

In the enclosures 41 plant species belonging to 18 families were recorded, out of which 27 species were on thick meadows, 33 species were on thin meadows and six species were on hard ground. The mean annual biomass productivity of thick, thin and hard ground was 1542.65 ±125.73 g m^{-2}, 1159.96 ±70.11 g m^{-2} and 583.81 ±89.02 g m^{-2} respectively. The overall annual biomass productivity was 3545.99 ±198.2 g m^{-2} (N=24 months, N=41 species). The maximum productivity was observed in the month of August and minimum in the month of February. The annuals contributed more to biomass (60.57%) productivity than the perennials (39.43%) (ANOVA, F=595, df=22, p>0.05).

Among the annuals *Zizania latifolia* contributed maximum to the overall biomass. Among the perennials *Phragmites karka* contributed maximum biomass followed by *Arundo donax*. The productivity was highest in monsoon (4510.73 ±476.51 g m^{-2}), followed by winter (3406.27 ±390.61 g m^{-2}) and summer (3229.21 ±673.4 g m^{-2}). However, no significant difference was found in the annual biomass across the seasons (Kruskal Wallis test, $\chi^2 = 3.345$, $df = 2$, $p>0.05$). *Zizania latifolia* contributed maximum biomass among all the species in summer and monsoon whereas *Arundo donax* contributed maximum biomass among all species in winter.

There was significant difference in the quantity of annual biomass produced by the annual grasses, annual herbs, perennial grasses and perennial herbs ($\chi^2 = 37.498$, $df = 3$, $p<0.05$). Significant difference in the productivity of the annual grasses ($\chi^2 = 8.636$, $df = 11$, $p>0.05$), annual herbs ($\chi^2 = 8.997$, $df = 11$, $p>0.05$), perennial grasses ($\chi^2 = 1.421$, $df = 11$, $p>0.05$) and perennial herbs ($\chi^2 = 4.785$, $df = 11$, $p>0.05$) in different months was not observed.

The productivity varied significantly across meadow types (Kruskal Wallis test, $\chi^2 = 3.956$, $df = 2$, $p<0.05$). The thick meadows of Thangbirel contributed maximum to the annual biomass (26.4%) followed by the thin meadows of Sagram (18.7%) and the least was contributed by the hard- ground of Thangbirel (8.2%). Biomass productivity was significantly correlated with mean annual rainfall ($R^2 = 0.659$, ANOVA $p<0.05$). Linear mixed model was applied to test the influence of environmental variables, rainfall, temperature, humidity, water level, season, meadows thickness and type on biomass productivity. As per the best model, rainfall and temperature best explains the pattern of annual biomass production. There was significant variation in the quantity of above ground biomass produced across the enclosures given different treatments (Kruskal Wallis test, $\chi^2 = 23.358$, $df = 2$, $p< 0.05$). Highest productivity was observed in the enclosure subjected to the burnt treatment followed by cutting treatment.

Standing crop biomass are most often measured to set stocking rates or assess an ecosystem's capability to support grazing animals. The term "forage availability" describes biomass as an amount available to be used for grazing animals. The forage available to the wild ungulates in KLNP was assessed using the harvest method. The actual forage available for use was derived by subtracting the biomass extracted by the local people and taking into account only the percentage plant part utilized by the ungulates. Percentage plant part utilized was derived by comparing the quantity utilized from each stalk of feeding sign observed in the field and measuring the part eaten from the whole stalk collected from the undisturbed control plots. Subsequently, the consumable dry matter was derived by calculating the dry matter consumption of individual Sangai and Hog deer from microhistological analysis. Stocking density was calculated from the actual consumable dry matter and the forage demand of individual Sangai and Hog deer. The stocking density of the Park was calculated across the seasons and meadow types based on the consumable forage available to Sangai and Hog deer.

Out of the 41 plant species recorded from the enclosures, only 20 species contributed to the forage availability accounting for 77.9% of the mean annual biomass. The mean annual biomass of the 41 species was 3545.99 ±198.2 g m^{-2} and of 20 forage species was 2764.26 ±39.93 g m^{-2}. Of the forgeable biomass, 13.3% is extracted by the local people. The mean biomass available to the wild ungulates after extraction was 1765.825 ±222.17 g m^{-2} of which only 26.32% was actually consumed by the wild ungulates. More than 85% of the foraging biomass was contributed by *Z. latifolia*, *A. donax*, *Setaria* spp., *Capillipedium* spp., *P. karka*, *L. hexandra* and *S. spontaneum*. *Zizania latifolia* contributed maximum percentage to the foraging biomass (35.4%) followed by *Arundo donax* (12.5%). The highest percentage plant part utilized was *Zizania latifolia* with 45.8% being utilized by the wild ungulates followed by *Oenanthe javanica* (40.6%) and the least was *Scirpus lacustris* with only 6.3% being utilized by the wild ungulates. The highest biomass utilized was also *Zizania latifolia* (3297.77 g m^{-2}) followed by *Arundo donax* (1163.32 g m^{-2}) and the least utilized was *Alternanthera philoxeroides* (0.59 g m^{-2}).

Since ungulates consumed 2.5% of their body weight daily, the annual forage demand for individual species of Sangai at 110 kg body weight and Hog deer at 50 kg body weight was 1003.75 kg $year^{-1}$ and 456.25 kg $year^{-1}$ respectively. The stoking density for Sangai during 2008-09 was 0.136 ±0.03 individual ha^{-1} and Hog deer was 0.265 ±0.05 individual ha^{-1}. The stocking density for Sangai during 2009-10 was 0.130 ±0.02 individual $ha^{-1}$and Hog deer was 0.254 ±0.04 individual ha^{-1}. The overall stocking density for the two study years for Sangai was 0.133 ±0.02 individual ha^{-}

^{1}and Hog deer was 0.260 ±0.03 individual ha^{-1}. Across the meadow types for the two study years, stocking density for Sangai was highest in the thick meadows with 0.197 ±0.1 individual ha^{-1} followed by thin meadows with 0.163 ±0.02 individual ha^{-1} and hard-ground with 0.039 ±0.01 individual ha^{-1}.

Based on the study, it is evident that deterioration of water quality due to eutrophication, heavy soil sediment nutrient, influx of pollutant through Nambul and Nambol rivers combined with and degradation of catchment area and inflow of silt every year in monsoon are the salient problems affecting the integrity of the Loktak Lake and the KLNP. Apart from these, encroachments into the Lake, excessive proliferation and thinning of meadows and increase in its horizontal dimensional growth decreasing the open water area of the Lake are the other problems. These problems need to be addressed immediately for the long term survival of Sangai and for maintaining the integrity of the Lake ecosystem. The flushing mechanism of the Lake needs to be restored especially during monsoon. The construction of the Ithai barrage has played a significant role in the present status of the Lake ecosystem, as the barrage blocks both of the outlet channels, Ungamel and Khordak. Since the Park remains flooded during monsoon to early winter making some of the areas inaccessible to the ungulates, therefore maintaining the water level through consultative process is imperative for the survival of Sangai.

The change in meadows thickness due to the change in hydrology and meadows proliferation is of great concern for the survival of Sangai. To maintain the integrity of the floating meadows it is important to allow major portion of the floating meadows to settle during lean seasons by reducing water level of the Lake and minimize burning, walking, trampling, resource extraction and grazing on the meadows.

Availability of the forage does not seem to be a limiting factor for the Sangai, however availability of the thick phumdi is crucial for the long term survival of Sangai. Therefore, it is important to maintain the integrity of the meadows thickness for long term conservation of Sangai. Fire as a part of management practice and also by the local people is resulting in loss of base material for the formation of meadows. Hence, cutting of the grasses and leaving it as such is recommended so as to maintain the thickness of the meadows.

The dominant grass species which contributes maximum to the forage diet of the wild ungulates in the Park are being extracted by the local people. Extraction of these economically important plants is done almost all year round which is degrading the habitat and is a threat for the survival of Sangai. In view of these, the restriction on extraction of biomass from the Park needs to be imposed in strict sense. Simultaneously, development of sustainable livelihood options for the local people will greatly reduce the anthropogenic pressure on the Park. A balance needs to be maintained whereby the anthropogenic pressure and hydrological regime do not disturb the habitat of the wildlife and the Park integrity is maintained.

Encroachment in the periphery of the Park by the local people especially for fish farming needs to be checked through a consultative process with local communities and by monitoring the land use change in the peripheral areas. Awareness campaigns amongst local people involved in resource extraction and fishing should be organized to educate them, to minimize extraction and to reduce the number of *athaphum* for fishing and minimize its impact on the Lake.

CHAPTER 1
GENERAL INTRODUCTION

SUMMARY

Floating meadows occur naturally in many parts of the world. It typically consist of a 40-60 cm deep floating organic mat supporting plant growth, the upper portion of which is comprised of densely intertwined live, dead and decaying roots with some litter collection on the surface. Below the active root zone a layer of low-density decomposed peat and decaying plant detritus develops, the depth of which is usually dictated by the rooting depth of the plants. Beneath the peat layer a zone of relatively clear free-water exists, that varies in depth (0 – 2 m) depending on the water level of the wetland. The floating meadows of the Loktak Lake and Keibul Lamjao National Park, Manipur is the only remaining natural habitat for the Eld's deer *Rucervus eldii eldii* locally known as Sangai which is considered as one of the most endangered species of deer in India. The habitat of Sangai in the Park is deteriorating primarily because of the change in water regime due to construction of Ithai barrage. The meadows, which used to settle during lean season and get replenished with soil and nourishment, are now continuously floating resulting in their thinning and making the meadows defunct in supporting the weight of the deer. In light of the above, the present study was conducted to gain a better understanding of the ecology of the floating meadows of the Loktak Lake and the Kebul Lamjao National Park and its implication for the conservation of Sangai. The following objectives were set forth (a) to examine the ecological condition of the Keibul Lamjao National Park in terms of water quality and nutrient status. (b) to derive the species richness and plant community composition of the Park and (c) to quantify the seasonal pattern of biomass production and forage availability to wild ungulates. The thesis specifically looks into following research questions (a) does the water quality of Keibul Lamjao National Park vary across seasons? (b) is there any variation in the plant community structure of the floating meadows of the Park in different seasons? (c) is there any relationship between environmental factors such as rainfall, temperature, humidity and management practices of cutting and burning and the plant biomass production? and

(d) what percentage of biomass is available to and used by wild ungulates for their sustenance?

1.1. INTRODUCTION

Extinction of species worldwide due to anthropogenic pressure is occurring at an extraordinary rate (Pimm et al., 2001; Morrison & Kimble, 2007). More than 52% of mammalian species in the IUCN Red List are showing a declining trend in population especially in South Asia where habitat loss has resulted in the population decline of the land mammals (Schipper et al., 2008; Hoffmann et al., 2010). These trends indicate that the overall conservation status of mammals is likely to deteriorate further and success in their conservation will depend on identifying vulnerable species and understanding environmental factors that support their persistence, particularly in human-dominated landscapes such as South Asia (Karanth et al., 2010). Relative to surrounding areas, wetland habitats often support high levels of biodiversity and a disproportionate number of listed species (Rubec et al., 1988; Mitch & Gosselink, 1993; Merritt, 1994; Boylan & Maclean, 1997; Peck, 2000). They also perform essential hydrological and biogeochemical functions (Rubec et al., 1988; Mitch & Gosselink, 1993; Walbridge, 1993; Nolan & Jeffries, 1996). The progressive loss and conversion of wetlands worldwide has become a key conservation issue and has intensified the need for reliable information on the status and distribution of wetland resources.

Wetland ecosystems are transitional between terrestrial upland and open-water aquatic environments. They are defined as "areas where a water table is at, near, or just above the surface and where soils are saturated for a sufficient length of time such that excess water and resulting low soil oxygen levels are principal determinants of vegetation and soil development" (Banner & MacKenzie, 2000). Their most common diagnostic features are hydric soils and an abundance of obligate hydrophytes in the vegetation community. Examples include fens, bogs and swamps to semi-aquatic marshes and shallow open water. Excluded from this definition are deep water and flowing aquatic ecosystems as well as "transitional wetlands" (i.e., those not saturated long enough to be considered true wetland ecosystems), such as shrubcarrs, riparian low benches, and graminoid wet meadows.

Wetlands are dynamic ecosystems, changing both seasonally and with succession, and often clusters of various types are linked together to form a *wetland complex*. The frequency, duration and depth of flooding are the most important determinants of wetland type, and the water regime in turn influences wetland soils, nutrients, and pH. All of these factors, in combination with the surrounding geology, topography and climate determine associated plant and animal communities (MacKenzie & Banner, 2001). According to the classification given by Cowardin et al., (1979) and Schot (1999), wetlands can be classified into five different types *viz*. a) Marine - Open ocean, continental shelf, including beaches, rocky shores, lagoons, and shallow coral reefs like the high-energy, rocky, marine shoreline; b) Estuarine - Deepwater tidal habitats with a range of fresh-brackish-marine water chemistry and daily tidal cycles like mangroves; c) Riverine - Freshwater, perennial streams comprised of the deepwater habitat contained within a channel; d) Lacustrine - This system includes inland water bodies that are situated in topographic depressions, lack emergent trees and shrubs, have less than 30% vegetation cover like the reed beds grow in fresh, shallow water on the margin of lake; and e) Palustrine - All non-tidal wetlands that are substantially covered with emergent vegetation -trees, shrubs, moss, etc like the Cattails on the margin of a marsh. Among the wetland types, floating meadows are unique with widespread vegetation formation on water (Pallis, 1916; Junk, 1970; Van Duzer, 2002). Much information on the early accounts of floating meadows is provided by Van Duzer (2004), who has collated an extraordinary global bibliography containing references to floating islands in folklore, culture and science from classical times onwards (Machmer et al., 2004).

1.2. Floating Meadows

The terminology used in naming floating wetland systems, both natural and artificial, is extremely varied. Virtually all of the major natural floating wetland ecotypes around the world have been given a different name, typically of local origin. Swarzenski et al (1991) used the term 'floating marsh' to refer to wetlands "in which the floating mats of vegetation are thick enough to support a person's weight", which results from *Sphagnum*-dominated 'floating bogs' as in northern Europe and America (Lewis et al, 1928, in Alberta; French & Moore, 1986, on Llyn Mire in Wales), sub-arctic 'floating mat fens' in

Interior Alaska (Racine & Walters, 1994), in relation to a tropical swamp in Uganda (Eggeling, 1935), or the 'floating papyrus and Miscanthidium swamps' of Lake Victoria (Kansiime et al., 2007), or 'floating raft vegetation' on Australian billabongs (Hill et al., 1987) and 'floating sedge mats' on a Tasmanian lake (Tyler, 1976). Natural floating islands are relatively rare and typically form when masses of terrestrial peat are torn off by storms, or when the buoyant peat uplifts from the floor of basins following inundation (Van Duzer, 2004).

Sasser et al. (1991) define a natural floating marsh community as: "*a marsh of vascular vegetation having a significant mat of live and dead roots, peat land detritus that floats over a layer of free water. The marsh mat is compact and thick enough to support the weight of a person and, because it floats, is only rarely, if ever, inundated.*"

Floating marshes may comprise small, mobile floating islands, or extensive, stationary vegetated mats covering hundreds of hectares of water surface (Ellery et al., 1990; Mallison et al., 2001). The floating mat varies in thickness from about 40 to 60 cm, the upper 25-35 cm, termed the "mat zone", consisting of a layer of densely intertwined live, dead and decaying roots with some litter collection on the surface (Sasser et al., 1991; Swarzenski et al., 1991; Sasser et al., 1995). The structure, composition and thickness of the floating mat can be affected by the growth habit and productivity of the dominant plant species. The vegetation type plays a role in determining the structural characteristics and composition of natural floating wetlands (Azza et al., 2000). The ultimate thickness of a mat tends to be related to the maximum rooting depth of the vegetation, as the roots play an important role in binding the organic material together (Sasser et al., 1995). Although not particularly common around the world, natural floating wetlands tend to have fascinated people through the ages, so that Van Duzer (2004) has been able to collate a global bibliography of more than 1800 citations and articles in 20 languages stretching back over three centuries on floating wetland islands.

As summarised by several authors (*e.g.* Sasser et al., 1991; Swarzenski et al., 1991; Mitsch & Gosselink, 2000; Van Duzer, 2004), floating marsh ecosystems also occur in the Danube Delta (dominated by *Phragmites australis*); along the lower reaches of the

Sud in Africa (dominated by papyrus); South America (lakes of the varzea or “flooded forest” within the Central Amazon, and high elevation lakes in Peru); North Dakota and Arkansas in the USA; Tasmania, Australia; Germany; The Netherlands; and England.

Natural or artificial floating meadows or rafts of vegetation have been used by people for various purposes. Floating-bed agriculture similar to hydroponics has been practiced in several parts of the world since pre-history, and today occurs in Bangladesh, India, Burma and Cambodia. In Bangladesh, a *dhap* is a floating platform comprising heaps of decomposing water hyacinth used to grow vegetables and seedlings; *dhap* agriculture is practiced mainly in common-property wetlands known as khas (Islam & Atkins, 2007). The ‘floating’ gardens or *chinampas* used by the Aztecs were first described by the Spanish explorer Acosta in 1590 (Van Duzer, 2004).The buoyant *embalsados* of the Paraná delta in Argentina are well-used by local hunters (Pratolongo et al., 2007) and it is likely that floating wetlands throughout the world have been used by local people as a source of waterfowl, fish and other foods. Floating islands of papyrus (*Cyperus papyrus*) in Lake Kyoga, Uganda, are inhabited by local people whose livelihoods depend on the lake (Kansiime et. al., 2007).

In India, this floating meadow occurs in the Loktak Lake, Manipur. The floating *phumdi* of Loktak Lake (Manipur) supports small populations of hut-dwellers and are also exploited by the wider lakeside communities. No less than 132 plant species associated with the meadows are utilized for food, cattle fodder, fuel, thatching and hut construction, fencing, human and veterinary medicines, handicraft materials or for cultural purposes (Shyamjai, 2002). Special fishing and fish harvesting systems (*phum* fishing and *athaphum* fishing) are associated with meadows and account for 39% of the fish yield from the Lake system (Trisal & Manihar, 2004). People of Manipur, are socially, economically, culturally and ecologically linked with the Loktak Lake. The Lake is the source of water for domestic uses, generation of hydro-electric power, irrigation, habitat for several plants used as food, fishing ground for local people, fodder, fuel, medicines, biodiversity, recreation, etc. Hence, this Lake has been referred to as the ‘lifeline of Manipur’ (Trisal & Manihar, 2002, 2004).

1.3. REVIEW OF LITERATURE

"Information about the ecology of wetlands has been made available during the past 25 years as ecologist, government regulators and policy makers endeavor to define and delineate wetlands and to characterize their hydrology and geomorphic positions in the landscape. The natural services that wetlands provides services like water purification, groundwater recharge, waste processing, storm buffers, consumptive and non-consumptive natural resources and wildlife habitat are among the most commonly cited examples of how conservation and restoration of wetland ecosystems can be beneficial" (Daily, 1997).

1.3.1. Wetland water quality and nutrient status

The purification potential of wetland plants and soil has been recognized for centuries. As early as 1932, the study of water quality in African lakes found that water passing through a wetland before entering the lake was of higher quality than in lakes without wetlands (Beadle, 1932). Scientific research began in 1953 with the work of Kathe Seidel on the ability of aquatic macrophytes to remove pollutants from water (Seidel, 1953). Water quality can be affected when watersheds are modified by alterations in vegetation, sediment transport, fertilizer use, industrialization, urbanization, or conversion of native forests and grasslands to agriculture (Turner & Rabalais, 1991; Vitousek et al., 1997; Carpenter et al., 1998). These changes in water quality due to excess intake of nutrients lead to eutrophication of the water body. Cultural eutrophication (due to anthropogenic pressures), one of the primary factors causing impairment of surface waters (USEPA, 1998), results from point and nonpoint sources of nutrient pollution. While wetlands play a role in reducing pollutant levels of inflowing water, they also require protection as water resources. The effects of the nutrient-rich water, combined with coastal development and channeling to supply water to communities can have adverse impact on the wetland as in the Everglades (Florida), where significant increase in soil and water column phosphorus levels in naturally oligotrophic areas has been observed (Davis & Ogden, 1994).

Consequences of cultural eutrophication have been observed at both community and ecosystem-level scales. Changes in wetland vegetation composition resulting from cultural eutrophication of these systems have been demonstrated in bogs (Kadlec & Bevis, 1990), fens (Pauli et al., 2002), meadows (Finlayson et al., 1986), marshes (Bedford et al., 1999) and cypress domes (Ewel, 1976).

The chemical limnology of aquatic habitats is known to vary both spatially (Malmer et al., 1992; Pienitz et al., 1997), and temporally due to seasonal and short term climatic events (Jassby, 1998; Stoddard et al., 1998). Also, the intra system cycling of nutrients in wetlands depend on the availability of nutrient and the degree to which processes such as primary productivity and decomposition are controlled by the wetland environment (Mitsch & Gosselink, 2000). Nutrient budget study in the seasonal wetland of the Okavango delta has showed that turnover rates of the floodplain water and biological activities influence the nutrient concentration dynamics in the floodplain water body (Krah et al., 2006).

Wetland plants remove nutrients through uptake and accumulation in tissues, but they also act as a nutrient pump by moving compounds from the sediment and into the water column. The ability of vegetation to improve water quality through the uptake of nutrients, metals, and other contaminants is well documented (Gersberg et al., 1986; Reddy et al., 1989; Peverly et al., 1995; Rai et al., 1995; Tanner et al., 1995). The primary nutrients limiting productivity in wetlands, nitrogen and phosphorus (Vitousek & Howarth, 1991; Bridgham et al., 1996) are usually responsible for changes in ecosystem functions and structure that occur when wetland assimilative capacity is exceeded (Carpenter et al., 1998). Different types of aquatic habitat like bog, fen, marsh, river and lake have been shown to differ in many aspects of chemical limnology (Malmer et al., 1992; Naiman et al., 1994; Bridgham et al., 1996).

Studies also indicate that wetland systems are effective at removal of nutrients and pollutants by physical, chemical and biological processes (Jackson & Pardue, 2000; Kassenga et al., 2003). Scientists have estimated that wetlands may remove between 70% and 90% of entering nitrogen (Gilliam, 1994). Riparian forests can reduce nitrogen concentrations in runoff and floodwater by up to 90% and phosphate concentrations by 50% (Gilliam, 1994). The estimated mean retention of phosphorus by wetlands is 45% (Johnston, 1991). Wetlands with high soil concentrations of aluminum may remove up to 80% of total phosphorus (Peterjohn & Correll, 1984; Richardson, 1985; Walbridge & Struthers, 1993; Gale et al., 1994).

1.3.2. Wetland vegetation composition and plant community structure

Plants are excellent indicators of wetland condition for many reasons including their relatively high levels of species richness, rapid growth rates, and direct response to environmental change (Mitsch & Gosselink, 2000). Individual species show different tolerance to a wide array of stressors. Thus plant communities change in response to hydrologic alterations (Gosselink & Turner, 1978; van der Valk, 1981; Spence, 1982; Squires & van der Valk, 1992), nutrient enrichment (Kadlec & Bevis, 1990; Templer et al., 1998; Craft & Richardson, 1998), sediment loading and turbidity (e.g., van der Valk, 1986; Sager et al., 1998; Wardrop & Brooks, 1998), metals and other pollutants. Because they represent a diverse assemblage of species with different adaptations, ecological tolerances, and life history strategies, the composition of the plant community can reflect the biological integrity of the wetland.

Much research has been done on the links between hydrology and plant community dynamics (Mitsch & Gosselink, 2000). Factors related to the hydrologic regime that affect wetland plants include water depth (Spence, 1982; Grace & Wetzel, 1982), water chemistry (Ewel, 1984; Pip, 1984; Rey Benayas et al., 1990; Rey Benayas & Scheiner, 1993) and flow rates (Westlake, 1967; Lugo et al., 1988; Nilsson, 1987; Carr et al., 1997). As hydrology changes, other environmental conditions change as well. Thus, hydrology influences community composition and productivity by influencing the availability of nutrients (Neill, 1990), soil characteristics (Barko & Smart, 1983), and the deposition of sediments (Barko & Smart, 1979). Water quality (Grootjans et al., 1998) and nutrient enrichment also has a strong bearing on community structure as slower growing native species are replaced by faster growing species that take advantage of high nutrient levels to increase growth (Davis, 1991; Chambers et al. 1999, Galatowitsch et al., 1999). Anthropogenic disturbances to wetlands often leading to eutrophication are manifested in a dramatic and widespread change in plant species composition over time (Jensen, et al., 1987, 1995). Studies have shown that during the eutrophication process, large-scale shifts in plant species composition occur in response to the addition of the limiting nutrient (Davis, 1991). In wetlands where surface water is present, duckweed (*Lemna* sp.) often increases in density and coverage in response to increased nutrients (Portielje & Roijackers, 1995, Janse, 1998; Vaithiyanathan & Richardson, 1999). Another species that may invade in response to increased nutrients is *Phragmites* (Chambers et al., 1999; Galatowitsch et al., 1999).

1.3.3. Wetland productivity

Physical and chemical characteristics such as climate, topography, geology, hydrology, and inputs of nutrients and sediments determine the rate of plant growth and primary productivity of wetlands (Weller, 1981; Crance, 1988; Brinson, 1993; Mitsch & Gosselink, 1993). In studies conducted in wet meadows and fens of Western Europe, shifts have occurred from low-productivity species-rich communities to highly productive and species-poorer communities due to nutrient enrichment (Kooijman, 1993; Alard et al., 1994; Fojt & Harding, 1995; Rich & Woodruff, 1996; Bollens, 2000).

Seasonal changes in water levels are accompanied by changes in the composition (Gopal, 1986) and biomass of plant species (Vijayan, 1989; Zutshi & Gopal, 1990). In a study conducted in the monsoonal wetlands of Gangetic flood plains, the biomass production changed seasonally in response to changing water level and temperature (van der Valk et al., 1993). The productivity increase is also the result of increased availabilities of the potentially growth-limiting nutrients: nitrogen (N), phosphorus (P), and potassium (K) (Bridgham et al., 1996, Verhoeven et al., 1996, Olde Venterink et al., 2001). A decline in plant species richness (Vermeer, 1986; Shaver et al., 2001; Gustafson & Wang, 2002) and increased in nutrient uptake and biomass production (Aerts & Berendse, 1988; Hayati & Proctor, 1991; Verhoeven &Schmitz, 1991; Bridgham et al., 1996; Shaver et al., 1998, 2001) is often seen with progressive nutrient enrichment as aggressive species such as *Typha* spp., *Phalaris arundinacea* and *Phragmites australis* invade and dominate (Chambers et al., 1999; Galatowitsch et al., 1999; Svengsouk & Mitsch, 2001; Green & Galatowitsch, 2002; Woo & Zedler, 2002).

In wetlands, grazing often leads to the disappearance of tall and leafy grasses (Singh, 1985). In a study conducted by Dagar (1987) in Ujjain, some plant species occurred only in un-grazed pasture while some were found only in grazed pasture. The plant biomass was smaller in grazed grassland as compared to the un-grazed area.

From the review, it is clear that significant scientific work has been carried out globally on the importance of wetlands as a control against pollution, its economic and aesthetic value and importance as a habitat for wildlife. But very little work has been done on the floating meadows particularly, the Loktak Lake in the state of Manipur, India which gained national and international importance only after being declared as a Ramsar site in 1990. This study was designed to create a better understanding of the ecology of Loktak Lake and Keibul Lamjao National Park as a whole and its implication for the conservation of the endangered Sangai.

1.3.4 Justification

The brow-antlered deer or the Eld's deer is found in its natural habitat in Keibul Lamjao National Park located in the South Eastern part of the Loktak Lake. Locally it is called as Sangai. This beautiful deer was hunted down to barely 14 individuals. Sangai was believed to be extinct in 1951. In 1953 a few survivors in a small pocket in the Southern fringe of the Loktak Lake was rediscovered. Since then, the State Government has taken several positive measures for the protection of this rare and endangered species. Consequently, in 1954 the Government of Manipur declared about 52 km^2 area of the southern part of the Loktak Lake closed to Keibul village as a Wildlife Sanctuary. During 1959 the total area was however reduced to about 27 km^2 which subsequently increased to about 40 km^2 in 1965. With a view to ensure protection to the species, the Keibul Lamjao was declared as protected in 1965, a Reserved Forest in 1974 and finally a National Park in 1977 under the Wild Life (Protection) Act, 1972. Sangai is now identified with Keibul Lamjao National Park. Subsequent conservation measures together with declaration of the area as National Park in 1977 have yielded satisfactory results. The deer population is now showing an increasing trend. Singh (1992) has reported that the prolific growth of meadows has seriously impacted the ecological processes and functions of Loktak Lake and has deteriorated the Sangai habitat. A close spatial analysis of vegetation cover of the Park over a period of time from 1991-98 with the help of vegetation cover maps of 1991, 1993, 1995 and 1998 and overlaid maps of vegetation cover of 1991 and 1998 clearly point out that these meadows in Northern and Eastern sides are changing (Kumar et al., 2002). The change in vegetation composition of the meadows has been attributed to change in water regime of the Loktak Lake including the Keibul Lamjao National Park (Singh, 2002; Kumar et al., 2002; Singsit, 2003). The floating meadows or the *phumdi*, which used to settle during the lean season and get replenished with soil and nourishment, are now continuously floating with the construction of Ithai Barrage (1983) on Imphal River, resulting in their thinning and thereby threatening the survival of Sangai.

Besides, currently, the Loktak Lake is experiencing tremendous changes due to natural processes and anthropogenic activities leading to reduced carrying capacity of the Lake, enhanced siltation, and changed in the ecological character of the Lake which will adversely affect the livelihoods of the local people and also its biodiversity value (Singh & Khundrakpam, 2009). Field studies have shown that the construction of the Ithai Barrage, overexploitation of Lake resources, and human encroachment for settlement, aquaculture and pollution are the main factors affecting the integrity of the Lake. Inflow of pesticides and pollutants used in the agricultural fields around the Lake, municipal wastes brought by Nambul River that runs through Imphal, soil nutrients from the denuded catchments area and domestic sewage from settlements in and around the Lake are responsible for deterioration of water quality (Trisal & Manihar, 2004). It is believed that the composition of plant species of the Park is changing due to increased anthropogenic pressure such as change in water depth, increased nutrient levels and biomass extraction (Singh, 1985).

In the light of the above discussions, the present study was conducted to evaluate the ecological conditions of the Loktak Lake by measuring key properties of water, soil and the plant community. It is necessary to investigate key nutrients to obtain a better understanding of the function of Loktak Lake and the National Park so as to evaluate their response to different management practices. The need to study the ecology of the floating meadows and the role it plays is immensely important for the conservation of the endangered Sangai. The information gathered through this study will enhance our understanding of nutrient retention in this system for effective management of threatened freshwater wetland ecosystems. The study will also focus attention on the Lake in order to develop better approaches for the critical system and also long term survival of the wildlife in the Park.

In wetlands, annual production is an important indicator of various ecosystem processes. Changes in community structure and ecosystem processes compromise wetland ecological integrity by altering energy flow, nutrient cycling, and niche/habitat characteristics which in turn affect wetland fauna assemblages (USEPA, 2000). Both biotic and abiotic factors can influence production of aboveground biomass (Bhattacharjee, 2009). In recent years the relationship between species richness and plant productivity has received quite a lot of attention (Grime, 1973, 1979; Al-Mufti et al., 1977; Grace, 1999). During environmental stress of moderate strength and interspecific competition at intermediate site productivity, more species persist in the community (Al-Mufti et al., 1977; Grime, 1979; Rosenzweig & Abramsky, 1993; Abrams, 1995). Productivity is dependent on both hydrology and nutrient conditions (Brown, 1981). Seasonal changes in water levels are accompanied by changes in the composition (Gopal, 1986) and biomass of plant species (Vijayan, 1989; Zutshi & Gopal, 1990). Anthropogenic activities, such as grazing may affect plant community. In the Keibul Lamjao National Parl, the areas with heavy presence of domestic livestock have low grass cover dominated by *Leersia hexandra*, *Capillipedium* spp etc. Although clipping does not simulate grazing precisely, an appreciation of grazing responses can be obtained by clipping treatments. Therefore, different frequencies at different heights will reveal the change in the herbage and subterranean biomass of species mostly of grasses. Such investigations have been dealt with great variety of conditions and methods and sought to evaluate the influence of grazing by clipping (Caughenour et al., 1984; Edroma, 1985). Thus, this study also addresses the theoretical aspects of plant community structure and above ground biomass production *vis a vis* nutrient status and management interventions.

1.4 Objectives

Keeping in view the above background, the following objectives were set forth for the present study:

1. To examine the ecological condition of the Keibul Lamjao National Park in terms of water quality and nutrient status.
2. To derive the species richness and plant community composition of the Park.
3. To quantify the seasonal pattern of biomass production and forage availability to wild ungulates.

1.5 Key questions

1. Does the water quality of Keibul Lamjao National Park vary across seasons?
2. Is t here any variation in the plant community structure of the floating meadows of the Park in different seasons?
3. Is there any relationship between environmental factors such as rainfall, temperature, humidity and management practices of cutting and burning and the plant biomass production?
4. What percentage of biomass is available to and used by wild ungulates for their sustenance?

1.6 Organization of thesis

This thesis is organized into seven chapters. Chapter 1 deals with the general introduction, background, justification, objectives, key research questions and significance of the study and review of current literature, Chapter 2 describes the intensive study area, Chapter 3 deals with the water quality and nutrient status of Loktak Lake and the National Park, Chapter 4 describes the pattern of floating meadow's thickness, vegetation composition and plant community structure, Chapter 5 deals with the aboveground biomass productivity of the National Park, Chapter 6 describes the foraging biomass, its availability to Sangai and sympatric Hog deer and their utilization and Chapter 7 synthesizes the findings of this research and provides conservation implications of this study.

CHAPTER 2
STUDY AREA

SUMMARY

The last remaining population of *R. e. eldii* inhabits floating mats of dense vegetation in the southern fringes of the Loktak Lake which is protected as Keibul Lamjao National Park. The Keibul Lamjao National Park is an area of low laying swamps, located in the Southeastern part of Loktak Lake between longitude 93˚48E to 93˚52E and 24˚26´N to 24˚32´N latitude. It is situated near Moirang in Bishnupur district, about 40 km south of Imphal. The Park is demarcated from the Lake by a discontinuous hill range (Thanga Hills). The total area of the Park is 40 km². Of this, 26 km² is covered by a thick and almost contiguous mat of floating meadows, locally called *phumdis*, and the remaining 14 km² consists of open water, drylands, uplands and sporadic hillocks (Singh, 1992). The Park is a low lying lacustrine swamp with a thick floating mass of vegetation and soil, the meadows. The soil in and around the Park is alluvial, underlined by argillaceous rock of the Disang series from the Cretaceous to Eocene period. The soil is generally ferruginous clay to clayey loam. The geological formation of the area is of a sedimentary type. The soil in the meadows is slightly acidic, with the pH value ranging from 5.2 to 6.0 approximately (Singh, 1991). The eastern part, which constitutes one-third of the Park, consists entirely of marshy land, and in the western part, there are three hillocks *viz.* Pabot Chingjao, Pabot Chinglukok and Toya.

The habitat consists of woodlands on the hillocks, grasslands in the floating meadows and elevated strips of land. The Pabot and Toya hills, which are located in the northern and southern parts of this zone, are extremely important as shelters and resting places. Sagram, Keibul and Chingmei are the main villages on the border of the western zone. The eastern zone extends from Nongmaikhong village to the end of the Khordak channel in the east and to Pabot and Toya in the west. It is mainly covered by meadows intermixed with a thick growth of plant species such as *Saccharum* spp., *Zizania* spp. and *Phragmites* spp. The northern zone extends from Keibul hill to Chingthi hill in the northern side and from Komlakhong village to Laphupat Tera in the eastern side. This is an area of open water. It is relatively deep and covered with thin meadows.

2.1. INTRODUCTION

The Eld’s deer once distributed across much of Southeast Asia is essentially restricted to the Irrawaddy and lower Mekong valleys. Isolated small populations occur in the western part of the Irrawady basin in Manipur and in the Hainan Island, southern China (McShea et al., 2001). Eld’s deer is believed to have originated in the Southeast Asian mainland (Fig. 2.1 Irrawady-Salween-Chao Phraya-Mekong Basin) and reached Hainan during the end of Pleistocene and early Holocene (18,000-8,500 years BP) when the sea level went down below 85 m from the present mean sea level (Ginsburg et al., 1982; Bhumpakphan et al., 2004). Although the primary forest type of most Eld’s deer habitat is dry dipterocarp forest (McShea et al., 2005), the fringe populations of this species occupy wetter ecosystems. Hainan’s population is found in the tropical moist island in shrub forest (Zeng et al., 2005). Isolated populations of *R. e. siamensis*, both in southern Laos (Round, 1998) and in Ang Trapeang Thmor Reservoir (ATT), in northwestern Cambodia inhabit marshy areas in conditions similar to those described by Lekagul & McNeely (1977) in relation to extirpated deer in Thailand. The last remaining population of *R. e. eldii* inhabits floating mats of dense vegetation in the southern fringes of the Loktak Lake which is protected as Keibul Lamjao National Park (KLNP).

The *R. e. eldii* or the Sangai once found in the Manipur valley was declared extinct by the Government of Manipur in 1951. As early as 1891, the Sangai was protected by the order of the royal family of the Meitei clan, and any person who was proved to have killed a Sangai was imposed a fine or heavy punishment, which could even result in the chopping off of the hands. The Manipur State Durbar accepted the Draft Game Rules for Manipur State in 1916, but it was Captain Harvey, the president of the then Manipur State Durbar, who promulgated in 1931 the first Game Rules of Manipur, under which the deer was fully protected. In the past, the name “Sangai” was given locally when people use to hunt with a permit issued under the Manipur Durbar Act. It is derived from “sa”, meaning “animal” in the local language, and “ngai”, meaning “wait” the animal that waited and ran from hunters (Shamungou, 1997). The animal used to run for few seconds, look behind repeatedly by turning its head and run again.

In 1953, the Sangai was rediscovered by E.P. Gee, the then Honorary Secretary, Eastern Region, Indian Board for Wildlife. A total of 6 heads of Sangai were counted in 1959. Due to the persistent efforts of E.P. Gee, the Sangai was declared a protected animal, and its habitat, Keibul Lamjao, was declared a protected sanctuary in 1954, covering an area of about 52 km^2. In 1959 the total area was reduced to about 27 km^2 and subsequently increased to about 40 km^2, in 1965. The sanctuary was officially gazetted in 1966, and in 1967 KLNP came into being under the Wildlife (Protection) Act, 1972. To ensure protection for the animal, Keibul Lamjao was declared protected in 1965, a reserved forest in 1974 and finally a national Park in 1977 (Singh, 1992). The Park received national and international attention when Loktak Lake was declared a site of the Ramsar Convention on 23 March 1990. This faunal significance led the state government of Manipur to declare the Sangai the state animal in 1989 (Trisal & Manihar, 2004).

2.2. The Loktak Lake

The Loktak Lake is the largest natural freshwater Lake in northeastern India, covering 61% of the total extent identified as wetlands in Manipur (Trisal & Manihar, 2004). It is situated 38 km South of Imphal city, the capital of Manipur state. It lies between 93˚46´E and 93˚55´E longitude and 24˚25´N and 24˚42´N latitude. The Lake covers an area of 287 km^2 at the elevation of 768.5 m above mean sea level as per satellite imagery of February 1999 (Singh et al., 2010). The Lake is oval in shape with its long axis running north to south. It has no definite shoreline and its extent and depth varies with season from 0.5 to 4.58 m, with an average depth of 2.7 m. During the dry season, when the rafts sink, deer find shelter at the Lakeshore (Singh, 1992). There are 54 villages along the periphery, including five townships and 12 islands of which four are inhabited. The catchment area includes five important rivers *viz.* Imphal, Iril, Thoubal, Sekmai and Khuga because their water enters the Lake (only occasionally in the past) due to Ithai Barrage through Khordak Channel.

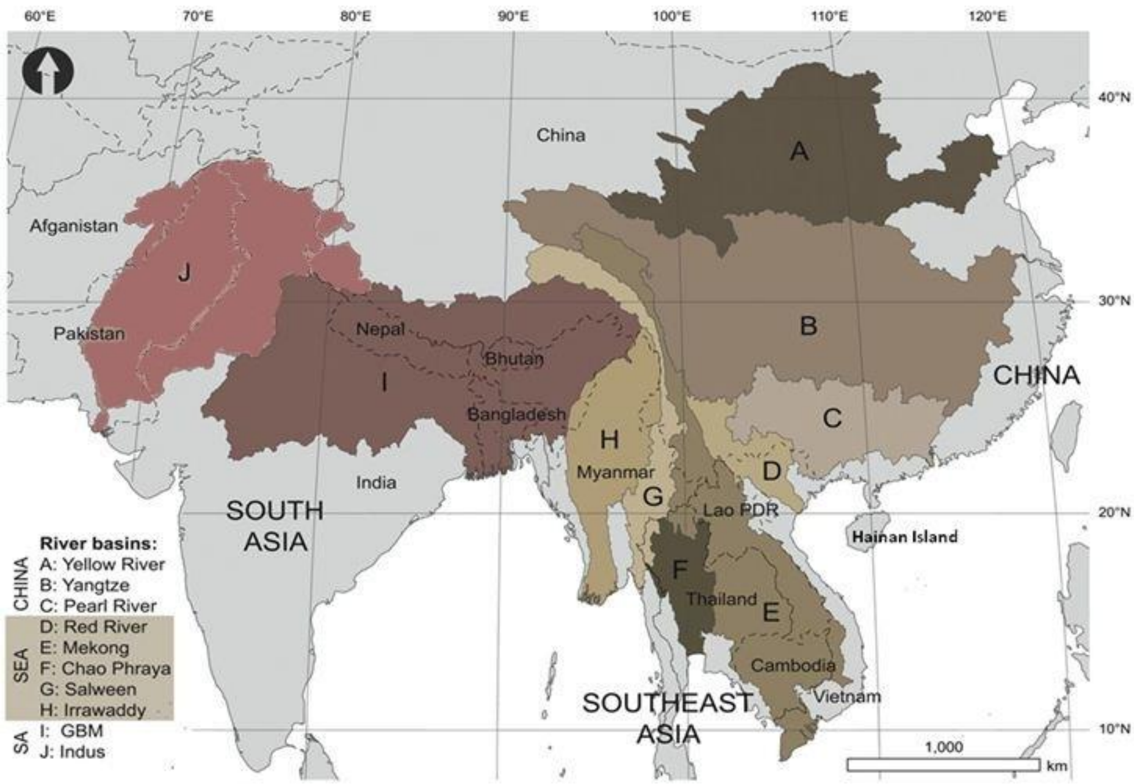

Figure 2.1. Major river basins of South and Southeast Asia (source – USGS, 2001)

The Lake can be broadly divided into northern, central and southern zones. The three zones are characteristically different in terms of biodiversity and pressure of human activities. The southern zone of the Lake includes KLNP, Ungamel, Kumbipat and 14 hills of varying sizes and elevation appearing as islands. The most prominent among the hills are Sendra, Ithing and Thanga. These islands cover 17.2 km^2 of the surface area of the Lake (Singh & Shyamananda, 1994).

The Lake with its numerous floating mats covers a variety of habitats, which sustains rich biological diversity and is of great cultural importance to the people of Manipur. It also plays an important role in providing ecological and economic security to a large population living in and around the Lake and depending upon its resources for sustenance. The Loktak Lake is also called the "Floating Lake" due to the *phumdis* (a Manipuri word meaning floating mats of soil and vegetation) on it. These are heterogeneous masses of soil vegetation in organic matter which occur in all sizes and range in thickness from a few centimetres to about 2.5 m. They float on the Lake with about one-fifth of their thickness above water and the rest below the surface.

The Lake comprises several smaller Lakes or *pats*. Until 1983 the area used to experience great changes in the water level annually, and so the several Lakes that were separated during the low water phase (65 km^2 extent at 765 m above msl) merged into one Lake only at the time of high flooding (495 km^2 at 780 m above msl). The Lake is under stress mainly due to anthropogenic pressures. Deforestation and shifting cultivation in the catchment area have promoted soil erosion, resulting in increased siltation of the Lake. The problem has been aggravated further due to the prolific growth of the floating meadows. Besides nutrients from the catchment area, pesticides used in the agricultural fields and domestic sewage from Imphal city are carried by the Nambul River, which finally discharges these into the Lake. In addition to the above threats, encroachments through construction of fishponds, roads and settlements have gradually led to a degradation of the Lake ecosystem (Trisal & Manihar, 2004).

The basic problems of the Lake can be traced to loss of vegetal cover in the catchments area and construction of the Ithai Barrage in the southern part of the Lake. The permanent flooding of the Lake, with relatively small changes in the water level, caused by the withdrawal of water for hydel power generation and irrigation, has been attributed to the construction of a multi-purpose project, in 1983. This has brought about drastic changes in the hydrological regime and converted a natural wetland with a fluctuating water level into a reservoir with a more or less constant water level (Trisal & Manihar, 2004).

2.3. The Keibul Lamjao National Park (KNLP)

The KLNP is an area of low laying swamps, located in the southeastern part of Loktak Lake between longitude 93˚48E to 93˚52E and 24˚26´N to 24˚32´N latitude. It is situated near Moirang in Bishnupur district, about 40 km south of Imphal (Figure 2.2). The Park is demarcated from the Lake by a discontinuous hill range (Thanga Hills). The eastern part, which constitutes one-third of the Park, consists entirely of marshy land, and in the western part, there are three hillocks *viz.* Pabot Chingjao, Pabot Chinglukok and Toya (Singh, 1991).

The habitat consists of woodlands on the hillocks, grasslands in the floating meadows and elevated strips of land. Based on the thickness of the meadows, the Park is classified into three zones, namely the western zone, eastern zone and northern zone. The western zone forms the main habitat of the Sangai, and the meadows in it are 3 m or more thick. The eastern zone is mainly covered by thin meadows intermixed with dense vegetation whereas the northern zone comprises open water of moderate depth covered with thin meadows. Between two stretches of meadows is an elevated portion, called Thangbirelyangbi that gets exposed during the lean season and is an important place for the breeding of the Sangai.

The Pabot and Toya hills, which are located in the northern and southern parts of this zone, are extremely important as shelters and resting places. Sagram, Keibul and Chingmei are the main villages on the border of the western zone. The eastern zone extends from Nongmaikhong village to the end of the Khordak channel in the east and to Pabot and Toya in the west. It is mainly covered by meadows intermixed with a thick growth of plant species such as *Saccharum* spp., *Zizania* spp. and *Phragmites* spp. The northern zone extends from Keibul hill to Chingthi hill in the northern side and from Komlakhong village to Laphupat Tera in the eastern side. This is an area of open water. It is relatively deep and covered with thin meadows (Trisal & Manihar, 2004).

The total area of the Park is 40 km^2. Of this, 26 km^2 is covered by a thick and almost contiguous mat of meadows, and the remaining 14 km^2 consists of open water, drylands, uplands and sporadic hillocks (Singh, 1992). The Park is a low lying lacustrine swamp with a thick floating mass of vegetation and soil, the floating meadows. The soil in and around the Park is alluvial, underlined by argillaceous rock of the Disang series from the Cretaceous to Eocene period. The soil is generally ferruginous clay to clayey loam. The geological formation of the area is of a sedimentary type. The soil in the meadows is slightly acidic, with the pH value ranging from 5.2 to 6.0 approximately (Singh, 1991).

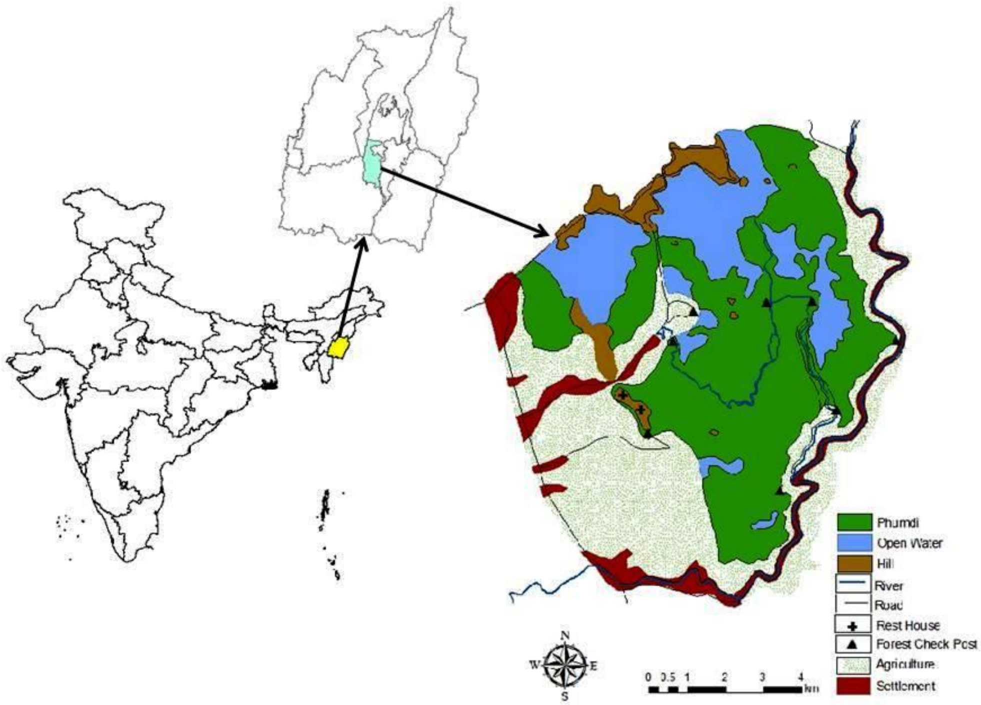

Figure 2.2. Map showing the location of the National Park.

2.3.1. Climate

The Park is characterized by low temperatures and heavy dew at night from November to February. Frost occurs in winter early in the morning and during the night, being common in December and January. The temperature ranges from a maximum of 34.4°C to a minimum of 1.7°C (Singh, 1992). The annual rainfall varies between 1000 and 3500 mm, and the average rainfall is ~1500 mm. The area is most humid in August when the relative humidity is as high as 81%. The relative humidity is least in March, 49% (Singh, 1992).

The Park experiences a moderate climate throughout the year. Summers prevail from March till May, and the monsoons formally arrive in June and drench the state with heavy showers up to September. The months of October and November are, more or less, dry. Winter extends from December to February, when the temperature usually drops down to 0°C. The southwest monsoon chiefly determines the weather and rainfall throughout the state. The state has a tropical to temperate climate, depending upon the elevation (Singh, 1992; Shamungou, 1997).

During the study metrological data was collected during the study period (2006 -2008). It classified the seasons of the study area into three distinct seasons *viz.* Summer (March – May), Monsoon (June – October) and Winter (November – February) (Figure 2.3). The parameters used in the Analysis were Rainfall, Relative Humidity and Temperature. The Dendrogram was developed using Average Between Groups.

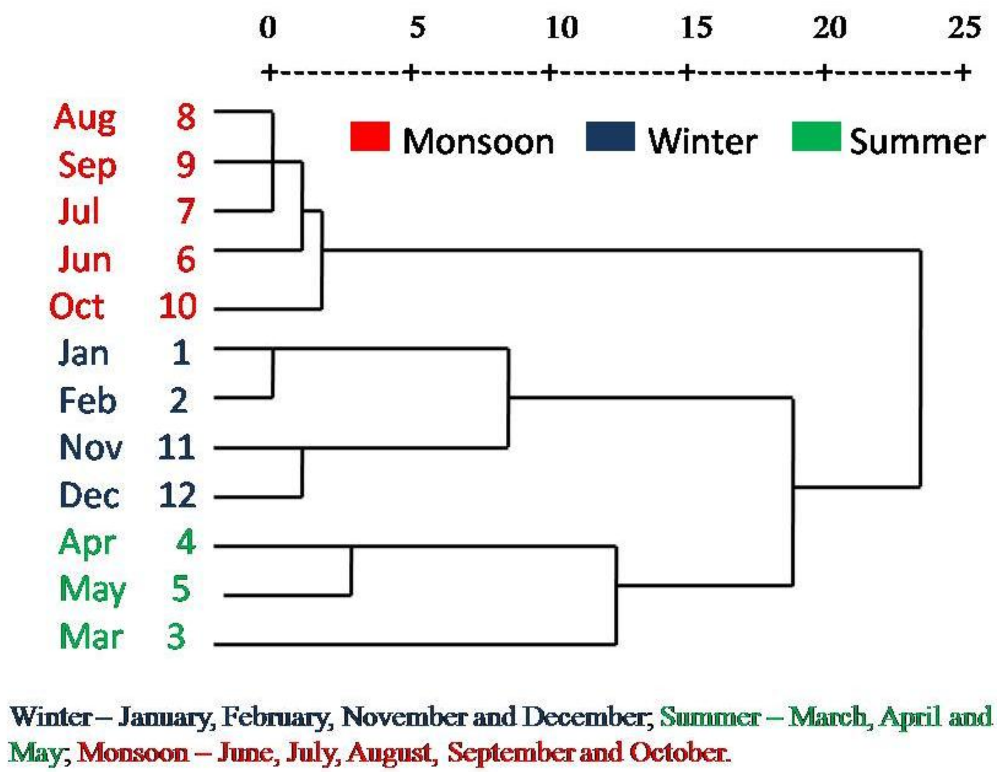

Figure 2.3. Hierarchical classification of seasons of the National Park.

2.3.2. Floral diversity

More than 100 species of grasses and sedges have been recorded on the floating meadows, of which *Zizania latifolia, Phragmites karka, Saccharum munja, Narenga porphyrocoma*, *Leersia hexandra*, *Carex* spp., *Oryza perennis* and *Capillipedium* spp. constitute the major food items of the Sangai (Shamungou, 1985). The dominant plant species are *Pinus kesiya*, *Bombax malabricum*, *Bauhinia variegata*, *Ficus glomerata*, *Phyllanthus emblica*, *Lantana camara*, *Xanthium* spp., *Chrysopogon* spp., etc. in the hills (Singh, 1992).

2.3.3. Faunal diversity

The KLNP fauna includes 22 species of mammal, 81 species of bird and 25 species of reptile (Singh, 1991). Some important mammalian species that dwell in the Park along with the Sangai are the Hog deer (*Axis porcinus*), wild boar (*Sus scrofa*), large Indian civet (*Viverra zibetha*), small Indian civet (*Viverricula indica*), jungle cat (*Felis chaus*) and otter (*Lutra lutra*). The Park is also a unique wintering ground for various migratory waterfowl, the spot-bill duck (*Anas poecilorhyncha*), gadwall (*A. strepera*), shoveller (*A. clypeata*) and common teal (*A. crecca*), and the permanent home for many resident birds (Shamungou, 1997). The Loktak Lake is also the breeding ground of a number of riverine fishes such as the mrigal (*Cirrhinus mrigala*), reba (*Cirrhinus reba*), parmoun barmsky (*Crossocheilus burmanicus*), flying barb (*Esomus danricus*), swamp barb (*Puntius chola*) and orange-fin labeo (*Labeo calbasu*) and continues to be a vital fisheries resource. It also supports a significant population of reptiles such as the viper (*Vipera russellii*), krait (*Bungarus caeruleus*), cobra (*Ophiophagus hannah*) and python (*Python molurus*) (Singh, 1992).

2.3.4. Drainage system

Manipur River Basin drains 30% of the entire state area including Manipur Valley. The hill areas of Manipur constituting catchments of Loktak Lake and associated wetlands fall within Manipur River Basin covering an area of 6,872 km^2. This geographical area is inhabited by 76% of the entire state population.

The drainage system of the Manipur river valley comprises two major rivers system, the Chindwin -Irrawady System and the Barak Drainage System along with various wetlands in the central valley (Figure 2.4). The first group consisting of Iril, Imphal, Thoubal, Khuga, and Chakpi does not feed the Lake directly but does so through the Khordak and Ungamel channels. The second group consists of Nambol, Nambul, and Thongjaorok which flow directly into the Lake. The discharging capacity of the Lake is restricted by an eight - metre high rocky barrier called Sugnu hump, which reduces the river velocity and reverses water currents during the monsoon. This backflow feeds water to the Loktak Lake through the Khurdoak, Khordak, and Ungamlen channels. During the lean season, water drains out of the Lake. Thus, Loktak acts as a temporary reservoir. A channel connects Loktak Lake to Keibul Lamjao National Park to the southeast. Both lakes are drained by Manipur River along their eastern flanks.

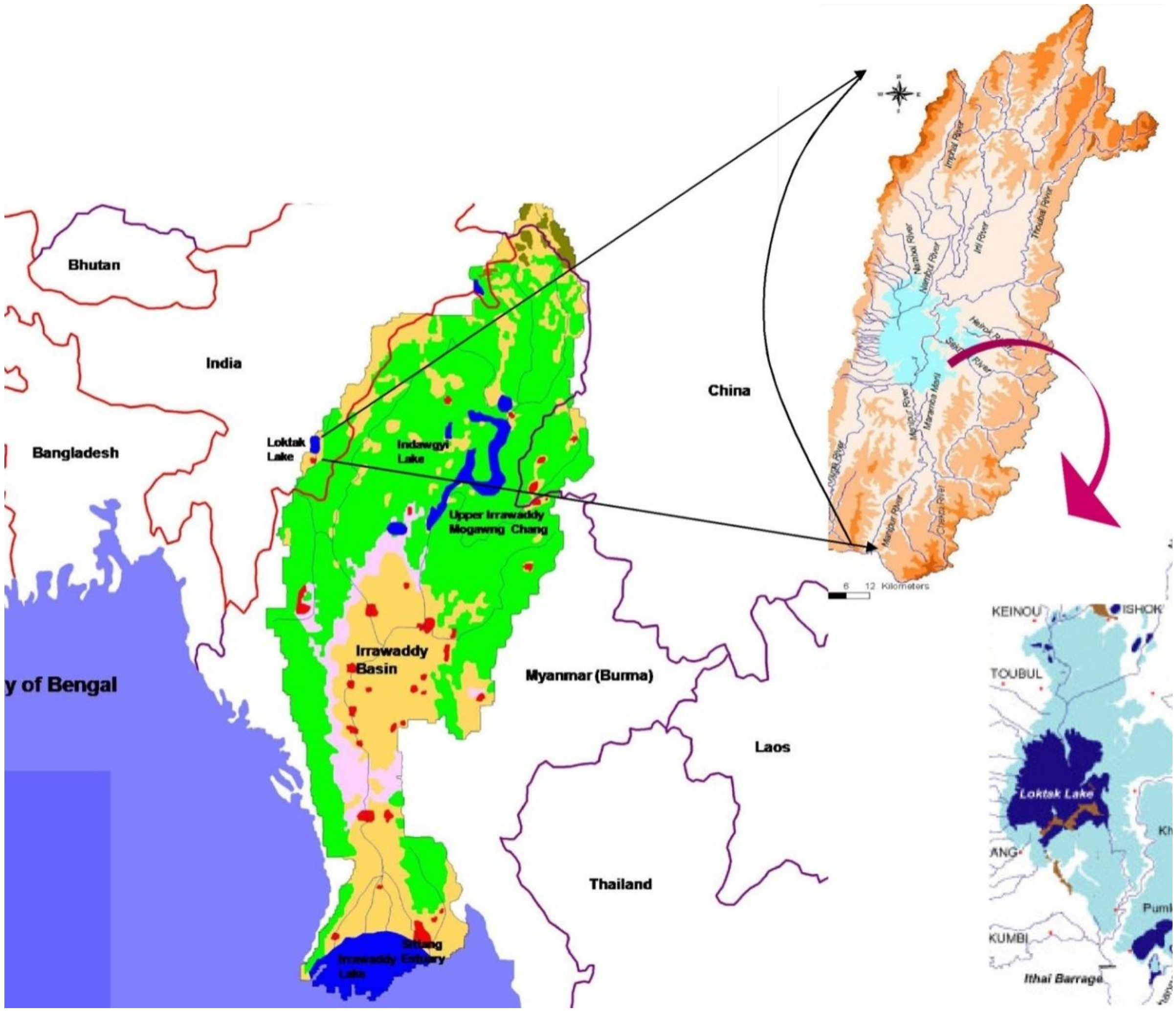

Figure 2.4. Major river basins of Manipur. (source – LDA http://www.loktaklake.org/lwc.html#)

Plate 1. A view of the Loktak Lake and the National Park

CHAPTER 3
WATER QUALITY AND NUTRIENT STATUS

SUMMARY

The water quality and nutrient status of the Loktak Lake and Keibul Lamjao National Park was examined during 2008-10 using standard methods. No significant difference in the water quality parameters was observed between the two sampling years (t-test, $p>0.05$). The water quality in terms of key parameters varied significantly across the sampling sites (ANOVA, $p<0.05$). Across the seasons (summer, winter and monsoon), there was significant variation in the water quality parameters in terms of electrical conductivity, turbidity, total solids, total dissolved solids, hardness, calcium, magnesium, sodium, potassium, transparency and temperature (ANOVA, $p<0.05$) but there was no significant variation in terms of pH, dissolved oxygen, total nitrogen, total phosphorus, biological oxygen demand, chemical oxygen demand and chlorophyll. There was significant variation in the water quality parameters in terms of electrical conductivity, total solids, total dissolved solids, hardness, calcium, magnesium, sodium, potassium, total phosphorus and chemical oxygen demand (t-test, $p<0.05$) between the Lake and the National Park. However, no significant variation (ANOVA, $p<0.05$) in terms of pH, dissolved oxygen, turbidity, total nitrogen, biological oxygen demand, transparency and chlorophyll was observed.

There was significant difference in the soil sediment nutrient status across the sampling sites in terms of total nitrogen, sodium, calcium, magnesium, organic carbon and loss on ignition (ANOVA, $p<0.05$) but did not significantly vary in terms of phosphorus and potassium. Across the season (pre-monsoon, monsoon and post-monsoon), the nutrient status varied significantly in terms of total nitrogen, phosphorus, potassium, sodium, calcium, magnesium and loss on ignition (ANOVA, $p<0.05$) but did not vary significantly in terms of organic carbon. There was no significant difference (t-test, $p>0.05$) in the nutrient status of the Lake and the National Park and between the two year sampling period (t-test, $p>0.05$). According to Carlson's Trophic State Index, the overall water quality was hypereutrophic for both the Lake and the National Park (TSI>70).

3.1. INTRODUCTION

Freshwater bodies are of immense importance as they provide portable water and fodder for the animal, generating employment by boosting tourism and fisheries, recreation and also ensure stability of the microclimate of the area and ground water recharge (Srivastava et al., 2003; Parray et al., 2009). Accurate and reliable information on the water resource system is vital for strategic management of the water resources (Gupta & Deshpande, 2004). The water bodies across the globe are under constant anthropogenic pressure resulting in its quality being affected when watersheds are modified by alterations in vegetation, sediment transport, fertilizer use, industrialization, urbanization, or conversion of native forests and grasslands to agriculture (Turner & Rabalais, 1991; Vitousek et al., 1997; Carpenter et al. 1998). The constant discharge of agricultural waste and untreated sewage into water bodies adversely affect the plant and animal life by enriching the organic content, leading to eutrophication and deterioration of the quality of water (Sukumaran, 2002). In India, inland water bodies have attracted the attention of various workers leading to the studies on water quality and distribution of phytoplankton from time to time (Zafar, 1967; Munawar, 1974).

Nutrients are the basic requirements of plants for their growth along with water and sunlight. Aquatic plants and algae respond to even small changes in the amount of nutrients present in the water. Hence it is necessary to estimate the concentrations of nutrients in the lake water and inflows to the lake. The identification of the watershed areas and land use activities that contribute to these nutrients in the lake water is essential. The two most important nutrients contributing to anthropogenic or cultural eutrophication are nitrogen and phosphorous (Carpenter et al., 1998). Both these nutrients are present in sufficient concentrations in fresh waters to maintain a healthy ecosystem, but anthropogenic activities may alter their concentrations contributing to algal blooms. Phosphorous and nitrogen enter the lake as inorganic ions but also as inorganic polymers, organic compounds, living micro organisms and detritus. Only a few of these forms are readily available for plant and algal growth. A nutrient-poor lake may have only about 1mg/l of phosphorous or 50 mg/l of nitrogen, while the most fertile lake may have up to a milligram of phosphorous or 20-30 mg/l of nitrogen.

Water quality monitoring is of the highest priorities in environmental protection policy (Simeonov et al., 2002). The main objective is to control and minimize the incidence of pollutant oriented problems, and to provide water of appropriate quality to serve various environmental purposes. The quality of water is identified in terms of its physical, chemical and biological parameters (Sargaonkar & Deshpande, 2003). Furthermore, due to temporal and spatial variations in water qualities, monitoring programs that involve a large number of physicochemical parameters and frequent water samplings at various sites are mandatory to produce reliable estimated topographies of surface water qualities (Dixon & Chiswell, 1996). A water quality standard defines the water quality goals of a water body, or a portion thereof, by designating the use or uses to be made of the water and by setting criteria necessary to protect the uses.

Sediment is the most common pollutant in our waterways. Various pollutants may be adsorbed to the sediments accumulated in the bottom of rivers or lakes (Lijklema et al., 1993). Although anthropogenic pressure contributes to a wide range of water quality problems, soil erosion and sedimentation is a global issue that tends to be primarily associated with anthropogenic activities like agriculture and deforestation in the catchment areas. Soil nutrients and chemical pollutants become attached to and are transported by sediment particles as a result of soil erosion or careless waste disposal and other similar incidents (Sastry, et al., 2001). Sediment entering rivers, lakes and streams can cause severe water quality degradation of our waterways that we depend on for our drinking water, fish and wildlife habitat, recreation (Pria & Parivarthan, 1998). Excess sediment can also cause flooding, severe stream bank erosion and undesirable physical and chemical changes to our lakes and ponds. It increases the cost of treating drinking water and it can affect the odor and taste.

Wetlands provide a sink for, or transform, nutrients, organic compounds, metals, and components of organic matter by acting as filters of sediments and organic matter. They can effectively remove pollutants from wastewaters and runoff and improve water quality (Phillips et al., 1993). A wetland may be a permanent sink for these substances if the compounds become buried in the substrate or are released into the atmosphere; or a wetland may retain them only during the growing season or under flooded conditions.

The ecological functions of wetlands include their role in hydrological (Bedford, 1996) and biogeochemical processes (Gorham, 1991) as well as provision of wildlife habitat (Golet, 1978). Nutrients can be re-introduced into a wetland from the sediment, or by microbial transformation, potentially resulting in a long recovery period even after pollutant sources have been reduced. In open wetland systems, nutrients may also be rapidly transported downstream, uncoupling the effects of nutrient inputs from the nutrient source, and further complicating nutrient source control (Mitsch & Gosselink, 2000; Wetzel, 2001). The hydro period of wetland systems significantly affects nutrient transformations, availability, transport, and loss of gaseous forms to the atmosphere (Mitsch & Gosselink, 2000). Recognizing relationships between nutrient input and wetland response is the first step in mitigating the effects of cultural eutrophication. When relationships are established, nutrient criteria can be developed to manage nutrient pollution and protect wetlands from eutrophication. The primary and secondary productivity and species composition of aquatic habitats are influenced by available nutrients and other aspects of chemical limnology (Wetzel, 1983; Mitsch & Gosselink, 1986). Wetlands may retain sediment in the peat or as substrate permanently (Johnston 1991). Sediment deposition is variable across individual wetlands and wetland types, as deposition depends upon the rate and type of water flow (channelized or sheet flow), particulate size, and vegetated area of the wetland (Hemond & Benoit, 1988; Crance, 1988; Aust et al. 1991; Johnston, 1991; USEPA, 1993).

3.1.1. Loktak Lake

Currently, Loktak Lake is experiencing tremendous changes due to natural processes and anthropogenic activities leading to reduced carrying capacity of the Lake ecosystem. A large population of 0.28 million people generates 72.23 million tonnes of solid waste and 31,207 m^3 of sewage. Nambol also contributes 4.9 million tonnes of solid waste and 2,121 m^3 of sewage annually (Trisal & Manihar, 2004). The water quality, in general, falls within class C to E as per the CPCB's designated best use criteria. The Lake water is not fit for direct drinking without treatment but can be used for irrigation and ecological purposes (LDA, 2011). High intensity of fertilizer usage in the agricultural fields contributes significantly to water quality deterioration. All the wastes directly or indirectly find its way into the Loktak Lake. Rapid growth of population in the hills has led to expansion in area under shifting cultivation. Insignificant increase in the net cultivated area accompanied by high rates of population growth has led to tremendous increase in intensity of fertilizer usage in the valley region. Rapid urbanization has led to severe stresses on the civic amenities especially safe drinking water and sanitation. Lack of adequate sewerage and solid waste management systems in the urban areas are the primary factors implicated for dumping of high amounts of wastes in the water bodies leading to water quality deterioration (LDA, 2011). Due to the discharge of sullage water in to the lake, the excessive water hyacinth and algal growth in the water body leads to eutrophication.

It is with this background that the present study was undertaken to assess the water quality and soil sediment nutrient status of the Loktak Lake and Keibul Lamjao National Park (KLNP), Manipur. The main objective of this study was to examine variation in chemical limnology of surface waters among survey sites as well as nutrient status in the soil sediment. Within constraints imposed by accessibility, water samples were assumed to represent the complete spatial area of the site and range of aquatic habitats.

3.2. METHODOLOGY

The present study was conducted during December 2008 to November 2010. On the basis of physical and chemical factors including the nutrient status of sediment the water quality of the Loktak Lake and KLNP was evaluated. The impact of pollution has been explained on the basis of the variations in the composition of Lake water and trophic status of the Lake.

3.2.1. Sampling Sites

Based on data that had been previously obtained, by the Loktak Development Authority (LDA), the sampling sites were selected to allocate the entry points and outlet points and the Park itself as efficiently as possible to meet this objective. Eleven sampling sites were selected out of which six inlet points were from the Loktak Lake (S1, S2, S3, S8, S9 and S10) and two were outlet points (S6 and S7) and three points were inside the Park (S4, S5 and S11) (Figure 3.1).

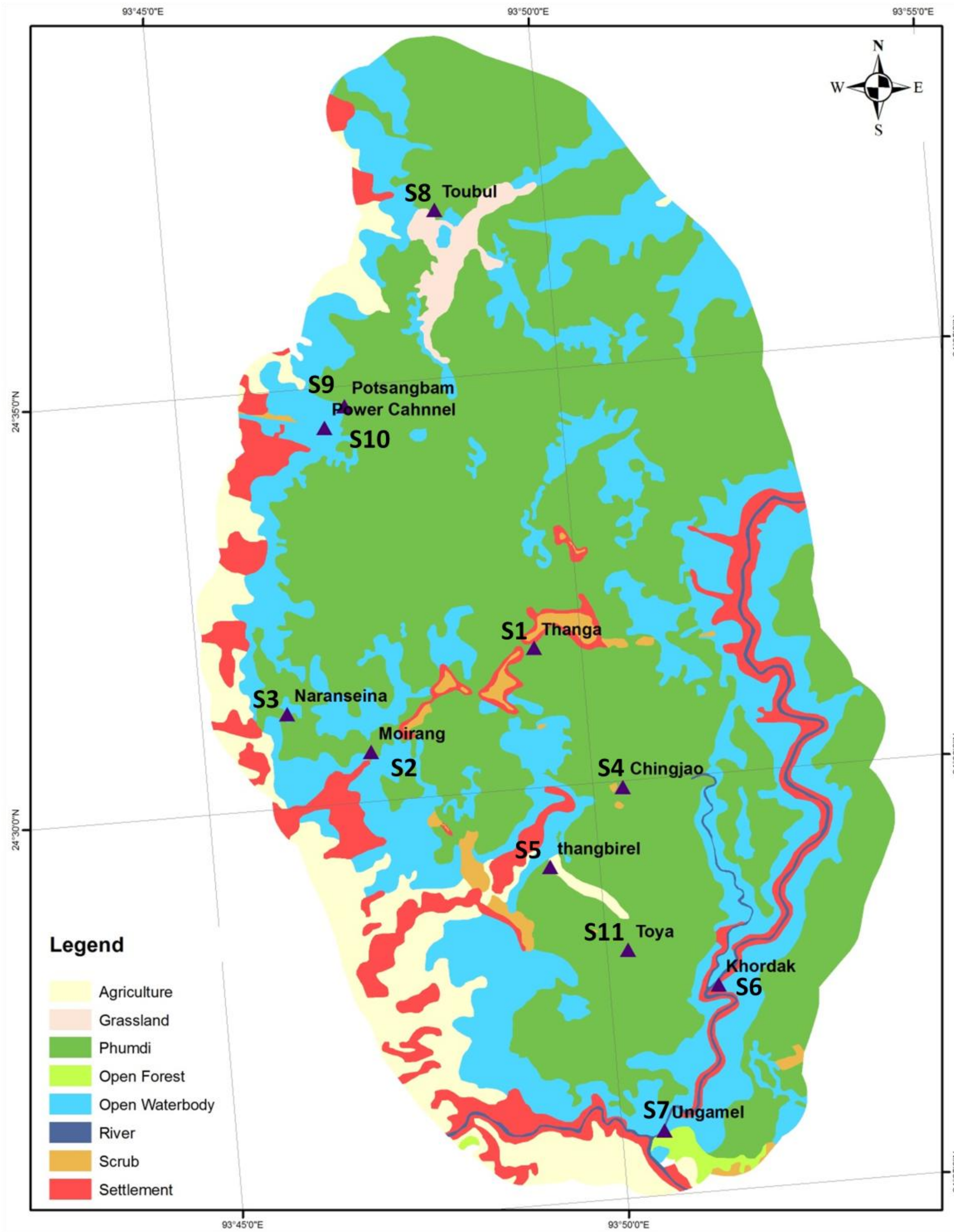

Figure 3.1. Map showing the sampling locations at Loktak Lake and the National Park.

3.2.2. Water Sampling

Water samples and soil samples were collected from the surface of the eleven selected sites every month for two years from December 2008 to November 2010. Grab samples were collected using polyethylene bottles. In a similar way the second sample was collected from the mid-depth from the sampling sites. Water transparency (cm) was measured using Sechhi disc; electrical conductivity, dissolved oxygen and total dissolved solids were measured on the spot using ELICO Water Sampling Kit and pH and temperature were measured using PH-035 (ATC) pH meter. These samples were preserved (APHA, 1998) and later analyzed at the Wildlife Institute of India (WII), Dehra Dun for Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), total nitrogen (TKN), total phosphorus (TP), Heavy metals (iron- Fe, nickel-Ni, cadmium-Cd, chromium-Cr, lead-Pb, copper-Cu, and zinc-Zn), calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K).

3.2.3. Soil sediment sampling

Composite soil sediment samples (15 cm deep) were collected from the eleven selected sites during pre monsoon, post monsoon and monsoon using an Auger. The collected samples were air dried and brought to the WII laboratory for analysis. After the air drying, dried plant materials, stones and other unwanted objects were removed and the samples were grounded using mortar and pestle to break up the soil particles. The soil/sediments were then passed through 2 mm stainless steel sieve. After sieving of soil/sediments, the samples were labeled and stored at room temperature for further analysis. The sieved and dried samples were digested in Microwave Digester prior to further chemical analysis. 0.1 g of the sample was digested with 5 ml of HNO_3 and 2 ml of HCl. The digested sample was filtered and diluted to 50 ml with distilled water.

3.2.4. Laboratory analysis

For physico-chemical analysis of water and soil sediment analysis, the samples were subjected to different chemical treatments depending on the parameter analyzed following Jackson, 1962; Dean, 1974; APHA, 1998; Chaturvedi & Sankar, 2006. Table 3.1 summarizes the parameters examined and the methods used.

Table 3.1. Summary of water and soil parameters analyzed and methods and instruments used.

Sl.No	Parameters	Method/Instrument
1.	Transparency (cm)	Secchi Disk
2.	Water Temperature (°C)	Digital pH Meter ATC PH-035
3.	pH	
4.	Electrical Conductivity (µmho/cm)	ELICO Water Testing Kit
5.	Total Dissolved Solids (mg/l.)	
6.	Dissolved Oxygen (mg/l.)	
7.	Total Suspended Solid (mg/l.)	Filtration Method
8.	Chemical Oxygen Demand (mg/l.)	Open Reflux Method
9.	Biochemical Oxygen Demand (mg/l.)	BOD_3
10.	Total Phosphorus (mg/l.)	Vanadomolybdo-phosphoric Acid Spectrophotometric Method
11.	Sodium and Potassium	Flame Photometric Method
12.	Total Nitrogen (mg/l.)	Kjeldahl Method
13.	Heavy Metals (Ca, Mg, Fe, Ni, Cd, Cr, Pb, Cu, and Zn)	Atomic Absorption Spectrophotometric Method
14.	Organo-chlorine Pesticides	Gas Chromatographic Method
15.	Chlorophyll a	Spectrophotometric Method
16	Organic Carbon	Walkley and Black Method
17	Loss-on-ignition	Furnance Method

3.3. DATA ANALYSIS

Seasonal comparison was done using one- way ANOVA and post-hoc (Tukey's test) for between and within group comparison. Independent t-Test was used for annual comparison between the two year sampling periods (2008-09 and 2009-10) and the Lake and the National Park. For the data analysis, program SPSS v16 (SPSS, 2007) was used.

The Carlson's Trophic State Index (Carlson, 1977) was used to determine the trophic status of the Lake and National Park. Four equations were used: Secchi disk, TSI (SD); chlorophyll pigments, TSI (CHL); total phosphorus, TSI (TP); and total nitrogen, TSI (TN) (Table 3.2).

$TSI (SD) = 60 - 14.41 \ln (SD)$

$TSI (CHL) = 9.81 \ln (CHL) + 30.6$

$TSI (TP) = 14.42 \ln (TP) + 4.15$

$TSI (TN) = 54.45 + 14.43 \ln (TN)$ (7.7)

Table 3.2. Range of Carlson Trophic State Index based on nitrogen, phosphorus, transparency and chlorophyll a.

Carlson's TSI Range	Condition
<30	**Oligotrophy:** Clear water, oxygen throughout the year in the hypolimnion
30-40	Hypolimnia of shallower lakes may become anoxic
40-50	**Mesotrophy:** Water moderately clear; increasing probability of hypolimnetic anoxia during summer
50-60	**Eutrophy:** Anoxic hypolimnia, macrophyte problems possible
60-70	Blue-green algae dominate, algal scums and macrophyte problems
70-80	**Hypereutrophy:** (light limited productivity). Dense algae and macrophytes
>80	Algal scums, few macrophytes

3.4. RESULTS

3.4.1. Water quality

Transparency: The mean transparency of the Lake water was 59.05 ±0.03 cm (N=11). It was 55.87 ±0.04 cm and 62.88 ±0.05 cm for the Lake and the Park respectively (Table 3.3). During summer, the transparency was highest (114.75 ±0.02 cm) while it was least in monsoon (3.59 ±0.02 cm) (Table 3.4). There was no significant difference in transparency between the Lake and Park (t-Test, $p>0.05$; Table 3.5).

Electrical Conductivity (EC): The mean electrical conductivity (EC) for the entire area was 235.18 ±8.3 μ mho cm^{-1} while for the Lake and the Park was 264.87 ±14.12 μ mho cm^{-1} and 199.55 ±5.25 μ mho cm^{-1}, respectively (Table 3.3). During monsoon EC was highest 267.88 ±13.01 μ mho cm^{-1} and was least (204.06 ±17.24 μ mho cm^{-1}) in summer season (Table 3.4). There is significant difference in the EC between the Lake and the Park (t-Test, $p<0.05$; Table 3.5). There was significant difference across the season in EC (ANOVA, $p<0.05$; Table 3.6), between summer - monsoon and monsoon - winter (ANOVA; Post Hoc, Tukey, $p<0.05$) but there was no significant difference between summer and winter (ANOVA; Post Hoc, Tukey, $p>0.05$).

Turbidity: The mean turbidity for the entire area was 72.55 ±5.0 NTU. It was 78.75 ±7.75 NTU for the Lake and 65.11 ±5.83 NTU for the Park (Table 3.3). The highest turbidity was 144.44 ±6.61 NTU in monsoon while least was in winter (16.82 ±5.29 NTU) season (Table 3.4). There was no significant difference between the Lake and Park (t-Test, $p>0.05$; Table 3.5). Across the season, there was significant difference in turbidity (ANOVA, $p<0.05$; Table 3.6), between summer and monsoon and monsoon and winter (ANOVA; Post Hoc, Tukey, $p<0.05$) but there was no significant difference between summer and winter (ANOVA; Post Hoc, Tukey, $p>0.05$).

pH: The mean pH for the entire area was 6.98 ±0.03 and for the Lake and the Park were 7.04 ±0.04 and 6.91 ±0.05, respectively (Table 3.3). Mean pH was recorded highest in summer (7.06 ±0.07) and least (6.90 ±0.05) in winter season (Table 3.4). There was no significant difference between the Lake and Park (t-Test, $p>0.05$; Table 3.5). There was no significant difference across the season in pH (ANOVA, $p>0.05$; Table 3.6).

Dissolved Oxygen (DO): The mean DO for the entire area was 6.67 ±0.10 mg l^{-1}. It was 7.13 ±0.14 mg l^{-1} for the Lake area and 6.13 ±0.15 mg l^{-1} for the Park (Table 3.3). The mean DO was highest in winter (6.98 ±0.19 mg l^{-1}) and least (6.46 ±0.23 mg l^{-1}) in summer season (Table 3.4). There was no significant difference between the Lake and Park (t-Test, $p>0.05$; Table 3.5). There was no significant difference across the season in DO (ANOVA, $p>0.05$; Table 3.6).

Biological Oxygen Demand (BOD): The mean BOD for the entire area was 4.96 ±0.15 mg l^{-1} and was 5.72 ±0.19 mg l^{-1} and 4.05 ±0.17 mg l^{-1} for Lake area and the Park, respectively (Table 3.3). BOD was highest during summer (5.49 ±0.34 mg l^{-1}) and was least (4.72 ±0.22 mg l^{-1}) in monsoon season (Table 3.4). There was no significant difference between the Lake and Park (t-Test, $p>0.05$; Table 3.5). Across the season, there was no significant difference in BOD (ANOVA, $p>0.05$; Table 3.6).

Chemical Oxygen Demand (COD): The mean COD for the entire area was 35.92 ±1.38 mg l^{-1}. It was 43.83 ±2.0 mg l^{-1} for the Lake area and 26.43 ±0.94 mg l^{-1} for the Park (Table 3.3). The value of COD was highest (39.09 ±2.93 mg l^{-1}) in summer and least (34.25 ±1.89 mg l^{-1}) in monsoon season (Table 3.4). There was significant difference in the COD between the Lake and the Park (t-Test, $p<0.05$; Table 3.5). Across the season, there was no significant difference in COD (ANOVA, $p>0.05$; Table 3.6).

Total Solids (TS): The TS for the entire sampling area were 231.11 ±9.98 mg l^{-1}. It was 254.14 ±16.16 mg l^{-1} for Lake and 203.47 ±9.78 mg l^{-1} for the Park area (Table 3.3). It was highest (337.93 ±15.38 mg l^{-1}) in monsoon and least (152.3 ±12.67 mg l^{-1}) in winter season (Table 3.4). There was significant difference in the TS between the Lake and Park (t-Test, $p<0.05$; Table 3.5). Across the season, there was significant difference in TS (ANOVA, $p<0.05$; Table 3.6), between summer and monsoon and monsoon and winter

(ANOVA; Post Hoc, Tukey, $p<0.05$) but there was no significant difference between summer and winter (ANOVA; Post Hoc, Tukey, $p>0.05$).

Total Dissolved solids (TDS): The mean TDS for the entire area was 142.63 ±5.03 mg l^{-1} and for the Lake area and the National Park was 158.1 ±8.59 mg l^{-1} and 124.06 ±3.37 mg l^{-1}, respectively (Table 3.3). TDS was highest during monsoon, (161.79 ±7.931 mg l^{-1}) and least (125.14 ±10.41 mg l^{-1}) during summer season (Table 3.4). There was significant difference in the TDS between the Lake and Park (t-Test, $p<0.05$; Table 3.5). Across the season, there was significant difference in TDS (ANOVA, $p<0.05$; Table 3.6), between summer and monsoon and monsoon and winter (ANOVA; Post Hoc, Tukey, $p<0.05$) but there was no significant difference between summer and winter (ANOVA; Post Hoc, Tukey, $p>0.05$).

Calcium (Ca): The mean Ca for the entire area was 69.53 ±3.33 mg l^{-1} and for the Lake area and the Park it was 79.66 ±5.77 mg l^{-1} and 57.37 ±1.94 mg l^{-1}, respectively (Table 3.3). It was highest (80.08 ±5.33 mg l^{-1}) in monsoon and least (59.12 ±6.9 mg l^{-1}) in summer season (Table 3.4). There was significant difference in the Ca between the Lake and Park (t-Test, $p<0.05$; Table 3.5). Across the season, there was significant difference in Ca (ANOVA, $p<0.05$; Table 3.6), between summer and monsoon and monsoon and winter (ANOVA; Post Hoc, Tukey, $p<0.05$) but there was no significant difference between summer and winter (ANOVA; Post Hoc, Tukey, $p>0.05$).

Magnesium (Mg): The mean Mg for the entire area was 32.79 ±1.44 mg l^{-1}. Mean Mg for the Lake area and the Park were 36.18 ±2.49 mg l^{-1} and 28.71 ±0.97 mg l^{-1}, respectively (Table 3.3). There was significant difference in the Mg between the Lake and Park (t-Test, $p<0.05$; Table 3.5). Across the season, there was significant difference in Mg (ANOVA, $p<0.05$; Table 3.6), between summer and monsoon and monsoon and winter (ANOVA; Post Hoc, Tukey, $p<0.05$) but there was no significant difference between summer and winter (ANOVA; Post Hoc, Tukey, $p>0.05$).

Hardness: The mean hardness of water for the entire area was 121.64 ±4.65 mg l^{-1}. For the Lake mean hardness of water was 134.22 ±7.96 mg l^{-1} and for the Park it was 106.55 ±3.18 mg l^{-1} (Table 3.3). It was highest (139.44 ±7.29 mg l^{-1}) in monsoon and least (104.59 ±9.52 mg l^{-1}) in summer season (Table 3.4). There was significant difference in the hardness and between the Lake and Park (t-Test, $p<0.05$; Table 3.5). Across the season, there was significant difference in hardness (ANOVA, $p<0.05$; Table 3.6), between summer and monsoon and monsoon and winter (ANOVA; Post Hoc, Tukey, $p<0.05$) but there was no significant difference between summer and winter (ANOVA; Post Hoc, Tukey, $p>0.05$).

Sodium (Na): The mean Na for the entire area was 8.90 ±0.28 mg l^{-1}. It was 10.03 ±0.43 mg l^{-1} for the Lake area and 7.54 ±0.28 mg l^{-1} for the Park (Table 3.3). It was highest (10.56 ±0.43 mg l^{-1}) in monsoon and least (7.46 ±0.55 mg l^{-1}) in summer season (Table 3.4). There was significant difference in the Na between the Lake and Park (t-Test, $p<0.05$; Table 3.5). Across the season, there was significant difference in Na (ANOVA, $p<0.05$; Table 3.6), between summer and monsoon and monsoon and winter (ANOVA; Post Hoc, Tukey, $p<0.05$) but there was no significant difference between summer and winter (ANOVA; Post Hoc, Tukey, $p>0.05$).

Potassium (K): The mean K for the entire area was 1.79 ±0.06 mg l^{-1}. For the Lake area and the National Park the mean K was 2.10 ±0.09 mg l^{-1} and 1.42 ±0.08 mg l^{-1} respectively (Table 3.3). The mean K was highest (2.13 ±0.10 mg l^{-1}) during monsoon and least (1.46 ±0.11 mg l^{-1}) in summer season (Table 3.4). There was significant difference in the K concentration between the Lake and Park (t-Test, $p<0.05$; Table 3.5). Across the season, there was significant difference in K (ANOVA, $p<0.05$; Table 3.6), between summer and monsoon and monsoon and winter (ANOVA; Post Hoc, Tukey, $p<0.05$) but there was no significant difference between summer and winter (ANOVA; Post Hoc, Tukey, $p>0.05$).

Total Nitrogen (TKN): The mean TKN for the entire area was 2.68 ±0.06 mg l^{-1}. It was 2.92 ±0.10 mg l^{-1} for the Lake area and 2.39 ±0.08 mg l^{-1} for the Park (Table 3.3). Mean

TKN was highest (2.78 ±0.12 mg l^{-1}) during monsoon, while was least (2.54 ±0.08 mg l^{-1}) in winter season (Table 3.4). There was no significant difference in the TKN between the Lake and Park (t-Test, $p>0.05$; Table 3.5). There was no significant difference in TKN across the season (ANOVA, $p>0.05$; Table 3.6).

Total Phosphorus (TP): The mean TP for the entire area was 0.16 ±0.01 mg l^{-1} and for the Lake area and the National Park it was 0.18 ±0.01 mg l^{-1} and 0.13 ±0.003 mg l^{-1}, respectively (Table 3.3). The mean TP was highest (0.16 ±0.01 mg l^{-1}) in summer and monsoon seasons, while was least (0.15 ±0.01 mg l^{-1}) in winter season (Table 3.4). There was significant difference in the TP between the Lake and Park (t-Test, $p<0.05$; Table 3.5). There was no significant difference in TP across the season (ANOVA, $p>0.05$; Table 3.6).

Chlorophyll a: The mean chlorophyll a for the entire area was 68.18 ±1.22 µg l^{-1}, while for the Lake area and the Park mean chlorophyll a was 69.13 ±1.66 µg l^{-1} and 66.82 ±1.8 µg l^{-1}, respectively (Table 3.3). It was highest (71.81 ±2.75 µg l^{-1}) in summer and least (64.79 ±2.07 µg l^{-1}) in winter season (Table 3.4). There was no significant difference in chlorophyll between the Lake and the Park (t-Test, $p>0.05$; Table 3.5).

Heavy Metals and Organo-chloro Pesticides (OCP): The concentration of heavy metal was analyzed in the Lake water for the two years (December 2008 - November 2010) and pesticides analysis was conducted twice in a year, pre-monsoon (April 2009) and post-monsoon (October 2009) for Organo-chloro Pesticides (OCP). The metal concentration was not significant in the Lake water, though at few locations lead and zinc were found in very low concentration. No pesticide residue was found in the Lake water in all the eleven sampling locations during the study year.

Table 3.3. Overall annual water quality of the Lake and the National Park (ND = No data).

Parameters	2008-09	2009-10	Overall	Lake	Park
Water Level (m)	1.67 ±0.06	1.73 ±0.06	1.7 ±0.04	1.72 ±0.06	1.68 ±0.06
Temperature (°C)	27.9 ±0.36	27.29 ±0.38	27.59 ±0.26	27.73 ±0.37	27.43 ±0.38
Secchi depth (cm)	55.96 ±0.05	62.15 ±0.05	59.05 ±0.03	55.87 ±0.04	62.88 ±0.05
Electrical conductivity (µ mho/ cm)	226.78 ±11.88	243.58 ±11.58	235.18 ±8.3	264.87 ±14.12	199.55 ±5.25
Turbidity (NTU)	70.42 ±6.97	74.69 ±7.19	72.55 ±5	78.75 ±7.75	65.11 ±5.83
pH	6.97 ±0.04	6.99 ±0.04	6.98 ±0.03	7.04 ±0.04	6.91 ±0.05
Dissolved Oxygen (mg/l)	6.7 ±0.15	6.65 ±0.15	6.67 ±0.1	7.13 ±0.14	6.13 ±0.15
Biological Oxygen Demand (mg/l)	ND	4.68 ±0.12	4.96 ±0.15	5.72 ±0.19	4.05 ±0.17
Chemical Oxygen Demand (mg/l)	ND	29.17 ±0.89	35.92 ±1.38	43.83 ±2	26.43 ±0.94
Total solids (mg/l)	223.29 ±14.12	238.93 ±14.11	231.11 ±9.98	254.14 ±16.16	203.47 ±9.78
Total dissolved solids (mg/l)	137.41 ±7.21	147.85 ±7.02	142.63 ±5.03	158.1 ±8.59	124.06 ±3.37
Calcium (mg/l)	66.4 ±4.74	72.66 ±4.69	69.53 ±3.33	79.66 ±5.77	57.37 ±1.94
Magnesium (mg/l)	31.27 ±2.07	34.3 ±2.01	32.79 ±1.44	36.18 ±2.49	28.71 ±0.97
Hardness (mg/l)	116.52 ±6.67	126.77 ±6.47	121.64 ±4.65	134.22 ±7.96	106.55 ±3.18
Sodium (mg/l)	8.51 ±0.39	9.29 ±0.39	8.9 ±0.28	10.03 ±0.43	7.54 ±0.28
Potassium (mg/l)	1.7 ±0.09	1.88 ±0.09	1.79 ±0.06	2.1 ±0.09	1.42 ±0.08
Total Phosphorus (mg/l)	0.159 ±0.01	0.16 ±0.01	0.159 ±0.01	0.182 ±0.01	0.131 ±0
Total Nitrogen (mg/l)	2.62 ±0.09	2.74 ±0.1	2.68 ±0.06	2.92 ±0.1	2.39 ±0.08
Chlorophyll a (µg/l)	ND	71.94 ±1.45	68.18 ±1.22	69.31 ±1.66	66.82 ±1.8

Table 3.4. Seasonal water quality of the Lake and the National Park.

Parameters	Winter	Summer	Monsoon
Water Level (m)	1.74 ±0.06	1.15 ±0.06	2 ±0.07
Temperature (°C)	24.52 ±0.47	29.33 ±0.48	29.01 ±0.27
Secchi depth (cm)	114.75 ±0.02	77.23 ±0.03	3.59 ±0.02
Electrical conductivity (µ mho/cm)	218.39 ±12.89	204.06 ±17.24	267.28 ±13.01
Turbidity (NTU)	16.82 ±5.29	27.06 ±2.09	144.44 ±6.61
pH	6.9 ±0.05	7.06 ±0.07	6.99 ±0.05
Dissolved Oxygen (mg/l)	6.98 ±0.19	6.46 ±0.23	6.56 ±0.14
Biological Oxygen Demand (mg/l)	4.89 ±0.22	5.49 ±0.34	4.72 ±0.22
Chemical Oxygen Demand (mg/l)	35.69 ±2.49	39.09 ±2.93	34.25 ±1.89
Total solids (mg/l)	152.3 ±12.67	158.15 ±12.69	337.93 ±15.38
Total dissolved solids (mg/l)	131.8 ±7.83	125.14 ±10.41	161.79 ±7.93
Calcium (mg/l)	64.14 ±5.17	59.12 ±6.9	80.08 ±5.33
Magnesium (mg/l)	29.93 ±2.28	27.7 ±2.95	38.13 ±2.27
Hardness (mg/l)	112.18 ±7.34	104.59 ±9.52	139.44 ±7.29
Sodium (mg/l)	7.91 ±0.41	7.46 ±0.55	10.56 ±0.43
Potassium (mg/l)	1.61 ±0.1	1.46 ±0.11	2.13 ±0.1
Total Phosphorus (mg/l)	0.148 ±0.01	0.163 ±0.01	0.165 ±0.01
Total Nitrogen (mg/l)	2.54 ±0.08	2.71 ±0.11	2.78 ±0.12
Chlorophyll a (µg/l)	64.79 ±2.07	71.81 ±2.75	69.39 ±1.69

Table 3.5. Results of significance test using independent t-test between the Lake and the National Park.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval	
									Lower	Upper
Water level	Equal variances assumed	5.53	0.02	0.56	262.00	0.58	0.05	0.08	-0.12	0.21
	Equal variances not assumed			0.57	262.00	0.57	0.05	0.08	-0.12	0.21
pH	Equal variances assumed	1.23	0.27	1.98	262.00	0.05	0.12	0.06	0.00	0.24
	Equal variances not assumed			1.97	248.01	0.05	0.12	0.06	0.00	0.25
Temperature	Equal variances assumed	0.43	0.51	0.58	262.00	0.56	0.31	0.53	-0.74	1.35
	Equal variances not assumed			0.58	257.63	0.56	0.31	0.53	-0.73	1.34
Dissolved oxygen	Equal variances assumed	1.41	0.24	4.93	262.00	0	1.00	0.20	0.60	1.39
	Equal variances not assumed			4.94	254.96	0	1.00	0.20	0.60	1.39
Electrical conductivity	Equal variances assumed	48.09	0	4.03	262.00	0	65.31	16.20	33.42	97.20
	Equal variances not assumed			4.34	181.17	0	65.31	15.06	35.59	95.03
Turbidity	Equal variances assumed	2.50	0.12	1.36	262.00	0.18	13.64	10.02	-6.09	33.37
	Equal variances not assumed			1.41	253.29	0.16	13.64	9.70	-5.46	32.74
Total solids	Equal variances assumed	13.36	0	2.56	262.00	0.01	50.67	19.83	11.63	89.71
	Equal variances not assumed			2.68	229.84	0.01	50.67	18.89	13.46	87.88
Total dissolve solids	Equal variances assumed	45.43	0	3.44	262.00	0	34.03	9.90	14.53	53.54
	Equal variances not assumed			3.69	185.12	0	34.03	9.23	15.83	52.24
Hardness	Equal variances assumed	46.93	0	3.01	262.00	0	27.67	9.20	9.56	45.78
	Equal variances not assumed			3.23	186.62	0	27.67	8.58	10.75	44.59
Calcium	Equal variances assumed	55.08	0	3.40	262.00	0	22.30	6.56	9.37	35.22
	Equal variances not assumed			3.66	174.45	0	22.30	6.09	10.28	34.31
Magnesium	Equal variances assumed	48.39	0	2.61	262.00	0.01	7.47	2.87	1.82	13.12

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval	
									Lower	Upper
	Equal variances not assumed			2.80	184.49	0.01	7.47	2.67	2.20	12.74
Sodium	Equal variances assumed	13.74	0	4.66	262.00	0	2.49	0.53	1.44	3.55
	Equal variances not assumed			4.87	237.71	0	2.49	0.51	1.49	3.50
Potassium	Equal variances assumed	12.21	0	5.76	262.00	0	0.68	0.12	0.45	0.91
	Equal variances not assumed			5.88	261.40	0	0.68	0.12	0.45	0.91
Total Kjeldahl Nitrogen	Equal variances assumed	1.09	0.30	4.25	262.00	0	0.54	0.13	0.29	0.78
	Equal variances not assumed			4.36	259.11	0	0.54	0.12	0.29	0.78
Total Phosphorus	Equal variances assumed	86.85	0.00	3.71	255.00	0	0.05	0.01	0.02	0.08
	Equal variances not assumed			4.03	151.58	0	0.05	0.01	0.03	0.08
Secchi Depth	Equal variances assumed	3.25	0.07	-1.05	262.00	0.29	-0.07	0.07	-0.20	0.06
	Equal variances not assumed			-1.05	247.08	0.30	-0.07	0.07	-0.20	0.06
Biological Oxygen Demand	Equal variances assumed	0.11	0.74	6.50	141.00	0	1.68	0.26	1.17	2.19
	Equal variances not assumed			6.62	140.86	0	1.68	0.25	1.18	2.18
Chemical Oxygen Demand	Equal variances assumed	31.48	0	7.38	141.00	0	17.40	2.36	12.74	22.06
	Equal variances not assumed			7.86	108.54	0	17.40	2.21	13.02	21.79
Chlorophyll a	Equal variances assumed	3.67	0.06	1.01	141.00	0.31	2.49	2.45	-2.36	7.34
	Equal variances not assumed			1.01	136.94	0.31	2.49	2.45	-2.36	7.33

Table 3.6. Results of significance test using One-way ANOVA across seasons for water quality parameters of the Lake and the National Park.

Parameters		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	1.03	2	0.51	2.03	0.134
	Within Groups	66.07	261	0.25		
	Total	67.10	263			
Dissolved Oxygen	Between Groups	13.02	2	6.51	2.27	0.106
	Within Groups	749.85	261	2.87		
	Total	762.86	263			
Electrical conductivity	Between Groups	202027.01	2	101013.51	5.76	0.004
	Within Groups	4575411.54	261	17530.31		
	Total	4777438.55	263			
Turbidity	Between Groups	978370.73	2	489185.36	168.82	0
	Within Groups	756283.45	261	2897.64		
	Total	1734654.18	263			
Total solids	Between Groups	2153054.56	2	1076527.28	59.07	0
	Within Groups	4756572.91	261	18224.42		
	Total	6909627.46	263			
Total dissolve solids	Between Groups	70881.10	2	35440.55	5.48	0.005
	Within Groups	1687240.75	261	6464.52		
	Total	1758121.85	263			
Hardness	Between Groups	61913.04	2	30956.52	5.61	0.004
	Within Groups	1439289.74	261	5514.52		
	Total	1501202.78	263			
Calcium	Between Groups	21956.18	2	10978.09	3.82	0.023
	Within Groups	749514.88	261	2871.71		

	Total	771471.06	263			
Magnesium	Between Groups	5562.95	2	2781.48	5.22	0.006
	Within Groups	139082.84	261	532.88		
	Total	144645.80	263			
Sodium	Between Groups	525.71	2	262.85	14.32	0
	Within Groups	4789.89	261	18.35		
	Total	5315.60	263			
Potassium	Between Groups	22.30	2	11.15	11.75	0
	Within Groups	247.72	261	0.95		
	Total	270.01	263			
Total Nitrogen	Between Groups	2.81	2	1.40	1.27	0.28
	Within Groups	288.48	261	1.11		
	Total	291.28	263			
Total Phosphorus	Between Groups	0.02	2	0.01	0.61	0.54
	Within Groups	3.23	254	0.01		
	Total	3.25	256			
Secchi Depth	Between Groups	63.32	2	31.66	638.46	0
	Within Groups	12.94	261	0.05		
	Total	76.26	263			
Biological Oxygen Demand	Between Groups	4.41	2	2.21	0.72	0.49
	Within Groups	428.71	140	3.06		
	Total	433.12	142			
Chemical Oxygen Demand	Between Groups	121.57	2	60.79	0.22	0.80
	Within Groups	38401.08	140	274.29		
	Total	38522.65	142			
Chlorophyll	Between Groups	112.22	2	56.11	0.26	0.77
	Within Groups	30188.62	140	215.63		
	Total	30300.84	142			

Trophic status: Based on nitrogen concentration and transparency, the overall water quality as well as the Lake and the National Park was highly eutrophic whereas based on phosphorus concentration and chlorophyll a, it was hypereutrophic. The overall water quality for the two year sampling period as well as the Lake and the Park was hypereutrophic based on nitrogen, phosphorus, transparency and chlorophyll a (Table 3.7).

Table 3.7. Overall Carlson Trophic State Index for the Lake and the National Park.

Sites	TSI (TKN)	TSI (TP)	TSI (SD)	TSI (Chl)	Overall TSI	Results
Overall	68.7	77.2	67.6	72	71.4	Hypereutrophic
2008-09	68.3	77.2	68.4	ND	71.3	Hypereutrophic
2009-10	69	77.2	66.9	72.5	71.4	Hypereutrophic
Lake	69.9	79.2	68.4	72.2	72.4	Hypereutrophic
Park	67	74.4	66.7	71.8	70	Hypereutrophic

(ND = No Data).

3.4.2. Soil sediment nutrient status

Total Nitrogen (TKN): The mean TKN content of the soil sediment for the entire area was 6.34 ±0.74 mg g^{-1} (N= 11 sites for 6 months). It was 5.85 ±1.0 mg g^{-1} for the Lake area and 6.93 ±1.12 mg g^{-1} for the Park. The mean TKN was highest 10.39 ±1.55 mg g^{-1} during winter and least 4.03 ±0.75 mg g^{-1} during summer (pre-monsoon) season (Table 3.8). There was no significant difference in the TKN between the Lake and Park (t-Test, p>0.05; Table 3.9). Across the season, there was significant difference in the TKN concentration (ANOVA, p<0.05; Table 3.10) between pre-monsoon and monsoon and between pre-monsoon and post-monsoon (ANOVA; Post Hoc Tukey HSD, p<0.05) but there was no significant difference between monsoon and post monsoon (ANOVA; Post Hoc Tukey HSD, p>0.05)

Total Phosphorus (TP): The mean TP for the entire area was 3.88 ±0.26 mg g^{-1} and for the Lake area and the Park were 3.65 ±0.29 mg g^{-1} and 4.14 ±0.45 mg g^{-1} respectively. It was highest 4.79 ±0.52 mg g^{-1} during pre-monsoon and least 2.99 ±0.23 mg g^{-1} during winter (Table 3.8). There was no significant difference in the TP between the Lake and Park (t-Test, $p>0.05$; Table 3.9). There was significant difference in the TP concentration across the season (ANOVA, $p<0.05$; Table 3.10), between pre-monsoon and monsoon and between pre-monsoon and post-monsoon (ANOVA; Post Hoc Tukey HSD, $p<0.05$) but there was no significant difference between monsoon and post monsoon and between pre-monsoon and post-monsoon (ANOVA; Post Hoc Tukey HSD, $p>0.05$)

Sodium (Na): The Na for the entire area was 1.5 ±0.06 mg g^{-1} and for the Lake area and the Park was 1.55 ±0.10 mg g^{-1} and 1.55 ±0.10 mg g^{-1} respectively. It was highest 1.73 ±0.11 mg g^{-1} during post-monsoon and least 1.29 ±0.13 mg g^{-1} during winter season (Table 3.8). There was no significant difference in the Na between the Lake and Park (t-Test, $p>0.05$; Table 3.9). Across the season, there was significant difference in the Na concentration (ANOVA, $p<0.05$; Table 3.10) between pre-monsoon and post-monsoon and between pre-monsoon and monsoon (ANOVA; Post Hoc Tukey HSD, $p<0.05$) but there was no significant difference between monsoon and post monsoon and between pre-monsoon and monsoon (ANOVA; Post Hoc Tukey HSD, $p>0.05$)

Potassium (K): The mean K concentration was 6.34 ±0.31 mg g^{-1} for the entire area. It was 6.34 ±0.46 mg g^{-1} and 6.34 ±0.39 mg g^{-1} for the Lake area and the National Park respectively. During post-monsoon, K was highest 7.72 ±0.47 mg g^{-1} and it was least 4.57 ±0.32 mg g^{-1} during pre-monsoon period (Table 3.8). There was no significant difference in the TKN between the Lake and Park (t-Test, $p>0.05$; Table 3.9). There was significant difference in the K concentration across the season (ANOVA, $p<0.05$; Table 3.10), between pre-monsoon and monsoon and between monsoon and post-monsoon (ANOVA; Post Hoc Tukey HSD, $p<0.05$) but there was no significant difference between pre-monsoon and post-monsoon (ANOVA; Post Hoc Tukey HSD, $p>0.05$)

Calcium (Ca): The mean Ca concentration for the entire area was 13.10 ±0.28 mg g^{-1} and for the Lake area and the Park were 12.93 ±0.38 mg g^{-1} and 13.31 ±0.43 mg g^{-1} respectively. It was highest 14.12 ±0.35 mg g^{-1} during post-monsoon and least 11.53 ±0.57 mg g^{-1} in winter season (Table 3.8). There was no significant difference in the Ca between the Lake and Park (t-Test, $p>0.05$; Table 3.9). There was significant difference in the Ca concentration across the season (ANOVA, $p<0.05$; Table 3.10), between pre-monsoon and monsoon and between pre-monsoon and post-monsoon (ANOVA; Post Hoc Tukey HSD, $p<0.05$) but there was no significant difference between monsoon and post monsoon (ANOVA; Post Hoc Tukey HSD, $p>0.05$).

Magnesium (Mg): The mean Mg concentration was 7.2 ±0.31 mg g^{-1} for the entire area. It was 7.48 ±0.39 mg g^{-1} for the Lake area and 6.87 ±0.49 mg g^{-1} for the Park. The mean percentage of organic carbon was 7.03 ±0.61 mg g^{-1} for the entire area. It was 6.42 ±0.76 mg g^{-1} and 7.76 ±0.98 mg g^{-1} for the Lake area and the Park respectively (Table 3.8). There was no significant difference in the Mg between the Lake and Park (t-Test, $p>0.05$; Table 3.9). There was significant difference in the Mg concentration across the season (ANOVA, $p<0.05$; Table 3.10), between pre-monsoon and monsoon and between pre-monsoon and post-monsoon (ANOVA; Post Hoc Tukey HSD, $p<0.05$) but there was no significant difference between monsoon and post monsoon (ANOVA; Post Hoc Tukey HSD, $p>0.05$).

Organic Carbon (OC): The mean OC concentration for the entire area was 7.03 ±0.61. It was 6.42 ±0.76 and 7.76 ±0.98 for the Lake and the Park respectively. During winter (post-monsoon), OC percentage was highest 8.93 ±1.3 and it was least 5.72 ±0.98 during monsoon (Table 3.8). There was no significant difference in the OC between the Lake and Park (t-Test, $p>0.05$; Table 3.9) and across the seasons (ANOVA, $p>0.05$; Table 3.10).

Loss on Ignition (LOI): The mean percentage LOI was 9.60 ±0.95 for the entire area and it was 9.5 ±1.29 for the Lake area and 9.72 ±1.42 for the Park. It was highest 12.93 ±1.7 during winter and least 7.06 ±1.16 during post monsoon period (Table 3.8). There was no significant difference in the LOI between the Lake and Park (t-Test, $p>0.05$; Table 3.9). There was significant difference in the LOI concentration across the season (ANOVA, $p<0.05$; Table 3.10), between pre-monsoon and post-monsoon (ANOVA; Post Hoc Tukey HSD, $p<0.05$) but there was no significant difference between monsoon and post monsoon and between pre-monsoon and monsoon (ANOVA; Post Hoc Tukey HSD, $p>0.05$)

Heavy Metals: The concentration of heavy metals were analyzed in the soil sediment for the two years sampling period (December 2008 - November 2010). The metal concentration was not significant in the both the Lake and National Park, though at few locations lead and Iron were found in very low concentration.

Table 3.8. Overall annual and seasonal nutrient status of the Lake and the National Park.

Parameters\n	2008-09	2009-10	2008-10	Lake	Park	Pre-monsoon	Monsoon	Post-Monsoon
Nitrogen (mg/g)	6.6 ±1.05	6.09 ±1.07	6.34 ±0.74	5.85 ±1.0	6.93 ±1.12	4.03 ±0.75	4.62 ±1	10.39 ±1.55
Phosphorus (mg/g)	3.79 ±0.34	3.97 ±0.4	3.88 ±0.26	3.65 ±0.29	4.14 ±0.45	4.79 ±0.52	3.85 ±0.48	2.99 ±0.23
Sodium (mg/g)	1.47 ±0.08	1.53 ±0.1	1.5 ±0.06	1.55 ±0.1	1.44 ±0.08	1.48 ±0.05	1.73 ±0.11	1.29 ±0.13
Potassium (mg/g)	6.54 ±0.47	6.14 ±0.4	6.34 ±0.31	6.34 ±0.46	6.34 ±0.39	4.57 ±0.32	7.72 ±0.47	6.73 ±0.55
Calcium (mg/g)	13.04 ±0.41	13.17 ±0.39	13.1 ±0.28	12.93 ±0.38	13.31 ±0.43	13.65 ±0.32	14.12 ±0.35	11.53 ±0.57
Magnesium (mg/g)	7.27 ±0.46	7.14 ±0.41	7.2 ±0.31	7.48 ±0.39	6.87 ±0.49	5.59 ±0.25	6.93 ±0.33	9.08 ±0.64
Organic Carbon (%)	7.07 ±0.89	6.99 ±0.84	7.03 ±0.61	6.42 ±0.76	7.76 ±0.98	6.44 ±0.72	5.72 ±0.98	8.93 ±1.3
Loss-on-ignition (%)	9.57 ±1.34	9.64 ±1.35	9.6 ±0.95	9.5 ±1.29	9.72 ±1.42	8.83 ±1.79	7.06 ±1.16	12.93 ±1.7

Table 3.9. Results of significance test using Independent t-test between the Lake and the National Park for soil sediments

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Nitogen	Equal variances assumed	0.17	0.68	-0.72	64	0.47	-1.08	1.50	-4.08	1.92
	Equal variances not assumed			-0.72	61.49	0.48	-1.08	1.50	-4.09	1.93
Phosphorus	Equal variances assumed	3.77	0.06	-0.94	64	0.35	-0.49	0.52	-1.53	0.55
	Equal variances not assumed			-0.91	50.53	0.37	-0.49	0.54	-1.57	0.59
Sodium	Equal variances assumed	2.49	0.12	0.86	64	0.40	0.11	0.13	-0.14	0.36
	Equal variances not assumed			0.88	63.38	0.38	0.11	0.12	-0.14	0.36
Potassium	Equal variances assumed	1.02	0.32	-0.01	64	1.00	0	0.62	-1.24	1.23
	Equal variances not assumed			-0.01	63.73	0.99	0	0.61	-1.21	1.21
Calcium	Equal variances assumed	0.27	0.60	-0.69	64	0.50	-0.39	0.57	-1.52	0.74
	Equal variances not assumed			-0.68	61.06	0.50	-0.39	0.57	-1.53	0.75
Magnesium	Equal variances assumed	0.63	0.43	0.99	64	0.33	0.61	0.62	-0.62	1.85
	Equal variances not assumed			0.98	58.40	0.33	0.61	0.63	-0.64	1.86
Organic Carbon	Equal variances assumed	2.78	0.10	-1.09	64	0.28	-1.33	1.22	-3.77	1.10
	Equal variances not assumed			-1.08	57.05	0.29	-1.33	1.24	-3.81	1.14
Loss-on-ignition	Equal variances assumed	0.04	0.84	-0.11	64	0.91	-0.22	1.92	-4.05	3.61
	Equal variances not assumed			-0.11	61.83	0.91	-0.22	1.92	-4.05	3.61

Table 3.10. Results of significance test using One-way ANOVA across seasons for soil sediment nutrient status of the Lake and the National Park.

		Sum of Squares	df	Mean Square	F	Sig.
Nitrogen	Between Groups	543.15	2	271.57	9.32	0
	Within Groups	1835.79	63	29.14		
	Total	2378.94	65			
Phosphorus	Between Groups	35.66	2	17.83	4.43	0.02
	Within Groups	253.78	63	4.03		
	Total	289.44	65			
Sodium	Between Groups	2.17	2	1.09	4.61	0.01
	Within Groups	14.85	63	0.24		
	Total	17.03	65			
Potassium	Between Groups	113.98	2	56.99	12.45	0
	Within Groups	288.41	63	4.58		
	Total	402.39	65			
Calcium	Between Groups	84.17	2	42.08	10.40	0
	Within Groups	254.95	63	4.05		
	Total	339.12	65			
Magnesium	Between Groups	136.61	2	68.31	15.97	0
	Within Groups	269.46	63	4.28		
	Total	406.07	65			
Organic Carbon	Between Groups	125.16	2	62.58	2.70	0.075
	Within Groups	1458.53	63	23.15		
	Total	1583.68	65			
Loss-on-ignition	Between Groups	398.63	2	199.32	3.64	0.032
	Within Groups	3449.35	63	54.75		

3.5. DISCUSSIONS

3.5.1. Water quality

Synergistic interrelationships of numerous abiotic factors are known to influence the distribution, growth, reproduction and other activities of aquatic life (Sugunan & Das, 1983). Fluctuation in the physico-chemical characteristics often creates an adverse environment for biological life forms as these characters are interrelated to each other and exert influence on the biological communities and biological production in the water bodies. A change in the physical as well as chemical properties of water often leads to excessive accumulation of the chemicals in the water system resulting in pollution (Saxena, 2007). The physico-chemical characteristics observed in the Loktak Lake with special reference to KLNP have been discussed here in the light of available information in order to arrive at certain conclusions on the structural and functional aspects of the Lake.

Temperature of water depends upon depth besides solar radiation, climate and topography (Surve et al. 2005). It is well known that the main source of heat for lake is the solar radiation. In the present study, the sub surface water temperature of Loktak Lake and the Park ranges from a maximum 31.92°C in summer to a minimum 21.68°C in winter. The water temperature has been found to increase correspondingly with increasing atmosphere temperature (Surve et al., 2005). This phenomenon was also observed in the Loktak Lake. In warmer months, water temperature increases due to increased atmospheric temperature and long day. Water level plays an important role in governing the water quality. Shallow water gets heated up and thus, increases their temperature and consequently affects the biological and chemical reactions of a water body. In the present study, maximum water level was recorded in the power channel at S10 (2.79 m) during monsoon period while minimum water level was recorded at an inlet channel at S9 (0.7 m) during summer season during both year (2008-09 & 2009-10) of study period. This variation was brought about due to its hydrological system (Ithai barrage). Water depth decreased slowly through winter but quite vastly during summer due to evaporation of water and water use at the power channel.

The transparency of water is mainly determined by biological productivity, suspended particles, and colour of water and due to high density of plankton inhabiting the water column (Kadam et al., 2007; Kamath et al., 2006). Earlier studies in India on Hokarsar wetland (J & K) and Kharbav lake (Maharashtra) reported transparency range of 11-55 cm and 57-92 cm respectively (Rather & Pandit, 2001; Lendhe & Yeragi, 2004). Thus, the transparency values of 54 –133.4 cm in the present study falls under the range of the previous studies of different lakes and wetlands in India. The EC was found to increase during monsoon season due to input of ions from surface runoffs thereby increasing concentration of salts. During summer season, the EC values showed a gradual decline, may be due to settling of solids, removal of nutrients by algal bloom during onset of summer and no turbulence.

The pH of water gets drastically changed with exposure to air, biological activity and temperature changes. Webber & Stumm (1963) have concluded that the pH of the raw water sources mostly lies within the range of 6.50 to 8.50. Water bodies can be classified into five categories based on the pH (i) acidobiontic (<5.5), (ii) acidophilous (5.5 to 6.5), (iii) indifferent (6.5 to 7.5), (iv) alkaliphilous (7.5 to 9.00) and (v) alkalibiontic (>9.00) (Venkateswarlu, 1983). When this criterion is applied to the present study, it falls under "indifferent" category in monsoon and winter season and under "alkaliphilous" category in summer season.

Dissolved oxygen (DO) is one of the most important parameter in water quality assessments and reflects the physical and biological process prevailing in the waters. A DO concentration of more than 5 mg l^{-1} favors good growth of flora and fauna in an aquatic ecosystem (Das, 2000; Khatavkar et al., 2004; Veeresha & Hosmani, 2006). The concentration of DO observed during the present study support the biological life in Loktak Lake. Hardness in water depends on a complex mixture of a cation and anion and is predominantly contributed by calcium and magnesium (Yelavarthi, 2002). Sawyer (1960) classified waters based on hardness into three categories (i) soft with hardness from nil to 75.00 mg l^{-1}, (ii) moderately hard with hardness from 76.00 mg l^{-1} to 150.00 mg l^{-1} and (iii) hard with hardness from 151.00 mg l^{-1} to 300.00 mg l^{-1}. If Sawyer's (1960) classification is applied for the Loktak Lake, the Lake water body can be classified as hard at the inlet channel (at S8) and soft to moderately hard at the other locations.

Calcium (Ca) and Magnesium (Mg) are often associated in all kinds of waters, but Mg concentration remains generally lower than the Ca (Mishra & Sahoo, 2003). Concentration of Ca is reduced at high pH due to its precipitation as $CaCO_3$. In aquatic environment, Ca serves as one of the macronutrients for most of the organisms whereas Mg is essential for chlorophyll growth. Based on the Ca concentration, Ohle (1938) classified water bodies into: (i) <10.00 mg l^{-1} as poor, (ii) 10.00 mg l^{-1} to 25.00 mg l^{-1} as medium and (iii) >25.00 mg l^{-1} as rich water body. According to the above classification, Loktak Lake falls under the category of medium to rich Ca in water. The sodium (Na) and potassium (K) level were quite variable with Na and K concentration varying from 3.58 mg l^{-1} to 21.31 mg l^{-1} and 0.51 mg l^{-1} to 3.57 mg l^{-1} in winter to monsoon showing a wide range of seasonal fluctuation.

The TKN value (Total Kjeldahl Nitrogen) represents a total nitrogen concentration, which is the sum of organic nitrogen compounds and ammonium nitrogen (TKN = org-N + NH_4-N [mg/l]). At increasing nitrogen concentrations in surface layers, plankton production increases, leading to algal blooms (Trivedy & Goel, 1986). The nitrogen level was highest in summer in both the Lake and the Park supporting the high microbial activity in summer due to high temperature leading to algal blooms and eutrophication. In the inlet channel (S8), the concentration of nitrogen was highest in monsoon probably because the most polluted rivers; Nambol and Nambul drain into the Loktak Lake at this point whereby increasing the nitrogen influx during monsoon.

Eutrophication of water bodies is often correlated with the phosphates in the aquatic environment (Kaushik, 1992). Studies on a global scale have demonstrated the algal biomass in lakes as having a strong correlation with the total phosphorus inputs (Anderson et al., 2002). In the present study, the phosphate content varied from 0.536 mg l^{-1} to 0.103 mg l^{-1}. Lower concentration was recorded in monsoon and winter season, while maximum concentration was recorded in summer in both the Lake and the Park. Similar seasonal variations were observed by Pauli et al. (2002) and Thomas et al. (2006)

while Annalakshmi & Amsath (2012) observed no seasonal variation. Lee et al. (1981) have classified the water bodies on the basis of phosphorus contents into five categories viz Oligotrophic (<0.007 mg l^{-1}), Oligo-mesotrophic (0.008 to 0.011 mg l^{-1}), Mesotrophic (0.012 to 0.027 mg l^{-1}), Meso-eutrophic (0.028 to 0.039 mg l^{-1}) and Eutrophic (>0.040 mg l^{-1}). As per the observed least concentration of P (0.103 mg l^{-1}), Loktak Lake and the National Park falls under the eutrophic category (>0.040 mg l^{-1}).

The intensity of pollution of the water body of the Loktak Lake and the Park was also concluded from Carlson Trophic State Index (TSI) from the concentration of nitrogen (TKN), phosphorus (TP), transparency (SD) and chlorophyll a (Chl). The individual variables of TSI (TKN), TSI (TP), TSI (Chl) and TSI (SD) showed almost all the sampling sites as hypereutrophic. The overall TSI for both the Lake and the National Park was hypereutrophic. The inlet channels at S8 (Toubul) showed the highest pollution level. It is at this site that the most polluted rivers, Nambul and Nambol drain into Loktak Lake. Since sampling was done at the channel where the two rivers meet, pollution level was found to be highest. Also the pollution was high during monsoon at this site due to the high influx of nutrients from these two rivers. The other inlet channels in the Lake, S2 (Moirang river) and S3 (Naranseina) also showed a higher level of pollution compared to the other sites of the Lake followed by the 3 sampling sites inside the Park at S4 (Sagram), S5 (Thangbirel) and S11 (Toya). Among the 3 sampling sites inside the Park, the site at S11 showed the highest pollution level. The S4 and S5 sites are open water bodies whereas the S11 site sampling was done at the narrow boat canal near the thick meadows. Also the S11 site was towards the interior of the Park where the meadows are fixed and more or less form a continuous mass which could explain the higher nutrient concentration as compared to the other two sites where meadows are more dynamic. Another reason why S4 and S5 are less polluted could be that the submerged vegetation like *Ceratophyllum demersum, Hydrilla verticillata, Limnophila* spp that choke the open water body leading to hypereutrophication are being extracted by the local people as fodder. The S10 sampling site at the power channel showed the least pollution status compared to the other sampling sites probably because the meadows are prevented from entering the power channel by a wall made of bamboos where water is being extracted for hydro-electricity. The meadows are clump on the opposite side to were sampling was done where they act as filtering agent, hence the low concentration of nutrients as they are absorbed by the clump of meadows before they enter the channel through the water. The present discussion has been envisaged to elucidate and interpret the variations as well as the interactions of the physico-chemical parameters of water with special reference to the Lake and the National Park. This is especially important from ecological point of view because water chemistry data have been found to better predict the animal resources of an ecosystem.

The basic problems of the Lake and the Park can be traced to loss of vegetal cover in the catchments area and construction of the Ithai Barrage in the southern part of the Lake. The permanent flooding of the Lake, with relatively small changes in the water level, caused by the withdrawal of water for hydel power generation and irrigation, has been attributed to the construction of a multi-purpose project, in 1983. This has brought about drastic changes in the hydrological regime and converted a natural wetland with a fluctuating water level into a reservoir with excess nutrient load and a more or less constant water level (Trisal & Manihar, 2004). Due to the discharge of sullage water into the Lake, the excessive growth of water hyacinth and alga in the water body has resulted in the present hypereutrophication state. At present the Lake water is green in color and has an algal odor.

The natural habitat of Sangai in KLNP is seriously threatened due to change in the habitat ecosystem, mainly caused from permanent flooding of the Lake and Park. This change in hydrology of the Park affects floating meadow’s thickness and has greatly reduced the carrying capacity of the lake ecosystem, enhanced siltation, changed the whole nature of the Lake and adversely affected the livelihoods of the local people dependent on this Lake (Singh & Khundrakpam, 2009). Due to the permanent flooding of the Lake, the meadows which used to settle down during the lean season and get replenished with soil and nutrients are constantly floating resulting in their thinning making it unfit to support the weight of Sangai. Also, without any outlet, all the nutrients entering the Lake remain inside the Lake leading to excessive nutrient load of the Lake. These excess nutrients favor the growth of alga and weeds leading to eutrophication (Thilaga et al., 2005). Eutrophication in its natural process is a very slow plant-growth-promoting process resulting from accumulation of nutrients in lakes or other water bodies but has been greatly accelerated by human activities that increase the rate of nutrient input in a water body (Khan & Ansari, 2005). This is the case in Loktak Lake where nutrient enrichment favoring plant growth has resulted in the proliferation of the meadows so much so that it has become a problem in some areas of the Lake. These newly formed meadows due to proliferation are also thin and cannot support the weight of Sangai. Thus, thinning of the meadows due to permanent flooding of the Lake and excess nutrient load is detrimental for the long term survival of Sangai. Pollution due to anthropogenic activities through the impacts of excessive fertilizer use, untreated wastewater effluents, and detergents significantly increases nutrient loading into lakes, accelerating eutrophication beyond natural levels and generating deleterious changes to the natural ecosystem (Litke, 1999). In the National Park, the main anthropogenic activities affecting the ecosystem are excess resource extraction and sewage discharge. An integrated approach focusing on nutrient loading restrictions and regulated resource extraction is needed for maintaining the resilience of the Loktak Lake and the long term survival of the endangered Sangai.

3.5.2. Soil sediment nutrient status

Plant growth in lakes and wetlands depends upon the nutrients available in the top most layers of soil. An over abundance of nutrients will lead to excessive plant growth, and scarcity of nutrients will lead to plant loss (Scholes et.al, 2007). According to Drenner et al. (1997) while some nutrients such as nitrogen from feces or run-off sink into the lake sediment some is taken in by nitrogen-fixing bacteria. Lake nitrogen concentration depends on the balance of nitrogen inputs into and outputs out of the lake as well as the associated watershed hydrological processes and nitrogen consumption and production by biological processes in the lake (Wetzel, 2001; Mitchell et al., 2003). Phosphorus (P) is an essential element for plant and animal growth but high concentration of Phosphorus (P) in soil sediment combined with surface runoff can cause excessive growth of plants and algae in waters, damaging the aquatic ecosystem due to eutrophication of surface water (Sharpley, 2000).

The importance of organic matter in soil is indisputable. It is both the source of nutrients necessary for plants and the means for effective functioning of nutritive matter (Loveland & Webb, 2003). Amounts of various chemical compounds, their combinations, or other materials differ within a wide range even in the same water body (Hakanson, 1981). Excessive levels of Potassium (K) in soil sediment can result in elevated levels in grass forage crops which may be detrimental to animal health. The K concentration in the soil sediment of the Lake and Park is excessively high which in the long term can affect the nutrient quality of the forage plant species. Calcium (Ca) and magnesium (Mg) deficiencies are found mostly on acidic soils. Sodium (Na) on the other hand is not a plant nutrient but high levels are detrimental to soil tilth and plant growth (Marx et al., 1999). Soil that are high in Na and Mg show more dispersion than soil that are high in Na and Ca (Abbot, 1989; Emersion & Bakker, 1973). They classified soil on the basis of Ca/Mg ratio. A ratio <1 as Ca deficient, 1-4 as low Ca soil, 4-6 as a balanced soil, 6-10 as low Mg and > 10 ratio as Mg deficient soil. According to this classification, the entire study area, the Lake and the Park falls under Ca deficient soil sediment (<1).

The main pollutant was found to be excess nutrient load from sewage carried by the rivers surrounding the Lake that drains into the Lake. This is especially important from ecological point of view because water chemistry data have been found to better predict the animal resources of an ecosystem. Since the natural process of draining the sediment and *meadows* along the Manipur River through Khordak and Ungamel outlet channels has been blocked due to the Ithai barrage, nutrient retention of the two most limiting nutrients for plant growth, nitrogen and phosphorus in the soil sediment of the Park was comparatively higher compared to that of the Lake. Maintaining this outflow of excess nutrient will reduce the nutrient load on the Park as well as the Lake. Also the anthropogenic activities like deforestation and *jhuming* in the catchment area enhancing siltation needs to be checked. During monsoon, large amount of sediment carrying pollutants from the catchment area enters the Lake through the feeder rivers and channels. Since, the outlet has been blocked by the Ithai barrage, these sediments settle down thereby enhancing the nutrient load of the Lake and the Park.

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Plate 2. Collection and analysis of soil and water samples

CHAPTER 4
PLANT SPECIES COMPOSITIONS AND COMMUNITY STRUCTURE

SUMMARY

This chapter deals with the plant species composition of the floating meadows in the Keibul Lamjao National Park *vis a vis* thickness of meadows. To derive the extent of change in floating meadow's thickness over time, the thickness of meadows was measured (N = 1659) in different blocks of the Park during 2005-10. The spatial extent of meadows was derived using Indian Remote Sensing Satellite (IRS-1D), LISS – IV and CARTOSAT data. Subsequently, the Park was divided into north and south zones. In each zone, transects of 500 m were laid and the meadow thickness was measured at every 50 m intervals. A total of 138 transect in both north and south zones were laid. To observe the change in meadows thickness, the data on meadow thickness were converted to logarithmic value and regressed against year to derive the rate of change per annum. The results of the remote sensing data showed that the thick meadows occupied the largest area of 14.42 km^2 among the 11 habitat types identified in the Park and the thin meadows occupied only 3.43 km^2.

The mean thickness of the meadow was 107.97 ±4.03 cm, while it was 105.13 ±5.29 cm and 111.36 ±6.24 cm in north and south zones respectively. The overall thickness was decreasing at the rate of 9% $annum^{-1}$, it was at the rate of 6% and 12% $annum^{-1}$ in the northern zone and southern zone, respectively. Out of the 22.3 km^2 area of the Park where presence of Sangai was observed, 8.64 km^2 had meadows thickness >120 cm, 7.32 km^2 had thickness ranging between 60-120 cm and 6.33 km^2 areas had thickness <60 cm.

The structure and composition of the vegetation on meadows in the Park was examined to study the vegetation types, habitat specificity and communities. A total of 185 plant species were recorded in the Park. Poaceae was the dominant family followed by Cyperaceae and Asteraceae. The percentage distribution of the species was 48.6% in the thick meadows, 41.1% of species in the thin meadows and 10.3% in the terrestrial habitats. Herbs showed the highest percentage distribution (53%) followed by grasses and sedges (17.3% and 16.2% respectively). Nine plant

communities were recorded in summer and eight in winter. Two communities, *Persicaria perfoliata – Leersia hexandra - Capillipedium* spp and *Zizania latifolia - Leersia hexandra - Capillipedium* spp were common to both summer and winter. Overall Shannon diversity indices (*H'*) for the meadows in summer and winter were 1.335 and 1.06 respectively. Overall Simpson diversity indices (*D*) for the meadows was 0.6344 and 0.5105 for summer and winter respectively. The species richness (S) for summer and winter was 6.8 and 6.5 respectively. The evenness (E) of the species was 0.713 and 0.583 for summer and winter respectively.

4.1. INTRODUCTION

The floating meadows of Loktak Lake locally known as '*phumdis*' are a heterogeneous mass of soil, vegetation and organic matter in various stages of decomposition occurring in different thickness ranging from a few centimeters to about 2.5 m. The meadows are often dominated by the reed *Phragmites karka* but other important species include *Eichhornia crassipes*, *Oryza sativa*, *Zizania latifolia*, *Cynodon* spp, *Sagitaria* spp, *Saccharum latifolium*, *Leersia hexandra* and *Carex* spp (Sanjit et al., 2005). People of Manipur are socially, economically, culturally and ecologically linked with the Loktak Lake. The Lake has been the source of water for domestic uses, generation of hydro-electric power, irrigation, and also serves as fishing ground for local people, source of fodder, fuel, medicines, biodiversity, recreation, etc. Hence, this Lake is referred to as the 'lifeline of Manipur'. Floating meadows are also utilized as compost, bio fertilizers and several other products, which can provide economic benefits to the people as well as regenerate the health of Lake ecosystem (LDA, 2011).

Vegetation particularly of the meadows plays a key role in governing the wetland processes and functions of the Loktak Lake. It influences the hydrological regimes, harbours rich biodiversity, supports productive fisheries and provides several economically important plant species to the communities. The meadows in the northern zone, play a critical role in providing a biological sink to the pollutants brought in by Nambol and Nambul rivers and thus are extremely important for maintenance of water quality of the Lake. Similarly maintenance of thickness and overall health of the meadows in the Park is crucial for survival of Sangai and other wildlife species.

The natural habitat of Sangai in the Keibul Lamjao National Park (KLNP) is seriously threatened due to permanent flooding of the Park and its resultant effect on the thickness of the meadows. The meadows are the floating mass of entangled vegetation, formed by the accumulation of organic debris and biomass with soil particles, which has been concentrated in a solid form. The humus of the meadows is black in colour and very spongy with large number of spores. It floats with 1/5 part above water and the remaining 4/5 part under water (Trisal & Manihar, 2002). There is a potential threat to Sangai largely because of deteriorating habitat conditions. The habitat in the Park is deteriorating primarily because of the change in water regime due to construction of Ithai barrage. Prior to commissioning of the Loktak Multi-purpose Project in the year 1983, water in the Lake exhibited large seasonal changes, and correspondingly the meadows floated during flooding and settled down on Lakebed/bottom during dry season. Thus, during the dry period the nutrients and minerals were drawn by the meadows vegetation from the bottom of the Lake. This natural cycle of floating and sinking of the meadows used to be maintained in KLNP. Maintenance of high water level in the Lake throughout the year for Loktak Multi-purpose Project has broken this annual cycle and the meadows float throughout the year and periodic supply of nutrients and minerals during dry season is no more available to the meadows vegetation. Therefore, the growth of vegetation on floating meadows and their thickness is gradually decreasing (Shyamjai, 2002). It is feared that after sometime the floating meadows may not be able to support the weight of the animal. Thus, study of the changing pattern of meadows thickness is very essential to maintain the integrity of the floating ecosystem for the survival of Sangai and other wild animals living on it. In this study, an attempt has been made to examine the extent of floating meadows area and the spatio-temporal change in the thickness and the resultant impacts on the environment.

4.2. PLANT COMMUNITY STRUCTURE

Structure and composition of the vegetation reflects the ecosystem properties and ecological conditions in an area that form the basis for further scientific studies and management (Lindenmayer & Franklin, 1997). Most eco-regions of the world support certain unique and characteristic species, which can be referred to as plant communities (Kent & Coker, 1992). Many plant species serve as indicators of ecological conditions and have been used for site evaluation (Rowe, 1956). Information on these parameters at spatio-temporal scale helps in conservation planning and restoration of degraded ecosystems. A vegetation study includes the investigation of species composition and phyto-sociological interaction of species in communities (Mueller-Dombois & Ellenberg, 1974). The structural property of a community is the quantitative relationship among the species growing around each other. The study of quantitative relationship among the vegetation is called phytosociology and its principal aim is to describe the vegetation, explain or predict its pattern and classify it in a meaningful way (Ilorkar & Khatri, 2003). Phytosociology indicates species diversity which determines the distribution of individuals among the species in a particular habitat.

The community concept is one of the most important principles in ecological thought and ecological practice (Odum, 1971). The fact that diverse organisms usually live together in an orderly manner and not haphazardly as an independent beings emphazies the importance of ecological theory in community concept. Communities may be distinct with defined boundaries but more frequently they co-exist without a distinct and definite boundary between each type of communities. The community concept is important in ecological practices because the behavior of the community as a whole defines the individual organism.

The plant community is composed of synusiae or strata which are regarded as the fundamental units of vegetation. The plant community may be described from two points of view, for diagnosis and classification, and as a working mechanism. It can be understood as a combination of plants dependent on their environment and influence one another as well as modify their own environment (Mueller-Dombois & Ellenberg, 1974). In wetland ecosystems, plants are excellent indicators of wetland condition due to high species richness, rapid growth rates and direct response to environmental changes. Many human-related alterations to the environment cause shifts in plant community composition which can be quantified easily.

Individual species show different tolerance to a wide array of stressors. Thus, as environmental conditions vary, community composition shifts in response. Plant communities have shown to change in response to hydrologic alterations (Gosselink & Turner, 1978; van der Valk, 1981; Spence, 1982; Squires & van der Valk, 1992), nutrient enrichment (Pip, 1984; Kadlec & Bevis, 1990; Templer et al., 1998; Craft & Richardson, 1998), sediment loading and turbidity (e.g., van der Valk, 1981, 1986; Sager et al., 1998; Wardrop & Brooks, 1998), including metals and other pollutants.

Since, the wetland plant community represents a diverse assemblage of species with different adaptations, ecological tolerances, and life history strategies; the community composition thus reflects the biological integrity of the wetland. The wetland hydrology influences community composition (Grootjans et al., 1998) and productivity by influencing the availability of nutrients (Neill, 1990), soil characteristics, and the deposition of sediments (Barko & Smart, 1983). On the other hand, wetland plants act as a nutrient pump by moving compounds from the sediment and into the water column. The ability of wetland vegetation to improve water quality through the uptake of nutrients, metals, and other contaminants is well documented (e.g., Gersberg et al., 1986; Reddy et al., 1989; Peverly et al., 1995; Rai et al., 1995; Tanner et al., 1995).

Ecologists and conservation biologists frequently need to know how a community of organisms is structured. That is, what species compose the community; how abundant is each species; how do the species interact; and are some species increasing in abundance while others are decreasing in abundance over time? Such information is invaluable when biologists develop conservation plans for natural areas or recovery plans for threatened or endangered species. Furthermore, measures of species abundance within a community taken at one point in time provide a baseline against which future measures of species abundance within that community can be compared. Such timelines of community data allow ecologists to measure species changes within communities and to understand succession within a given natural community or the impacts of specific land-management plans.

Among various plant communities, the wetland community supports specialized growth forms and groups adapted to highly seasonal and resource rich environment. The plant community structure of floating meadows in many parts of the world is rarely explored. In India, information on the floating meadows of the Loktak Lake is lacking. This chapter provides information on plant species composition and community structure of floating meadows of the Loktak Lake with special reference to Keibul Lamjao National Park. Data generated through this study will make it possible to compare species or groups of species within a community or to contrast species composition and abundance among communities.

4.3. METHODOLOGY

4.3.1. Floating meadows thickness

The floating meadows of the Park vary in thickness. For this study, following Singh (1991) the meadows with thickness > 120 cm were considered as thick meadows, between 60 cm to 120 cm were medium thick meadows and meadows < 60 cm thickness were considered as the thin meadows.

The habitat map at the landscape level of the Keibul Lamjao National Park was prepared to identify distinct habitat types (Figure 1). Indian Remote Sensing Satellite (IRS-1D), LISS – IV (5.8 m) and CARTOSAT (2.5 m) data were used.

On screen visual interpretation was done for the entire Loktak Lake on LISS IV. The National Park area was interpreted on merge data of LISS IV and CARTOSAT. ERDAS Imagine 2011, ARCINFO 9.3 and MS Excel were used for image processing and data analysis. Digital data was georectified using the Survey of India toposheets. For classification of the meadow thickness, 800 ground truth points from the Park area was used.

The total root mean square error of geo-rectification was estimated at less than half a pixel. The georectified image of the Park was classified into 11 land use classes viz., water with floating vegetation, human settlements, rivers, hills with scrub, agriculture, grassland, fishpond, open water, thick floating meadows, thin floating meadows and tall grass. Based on this classification, area under these classes was calculated.

4.3.2. Spatio-temporal change in the thickness of floating meadows

The Forest Department of Manipur has divided KLNP into 24 blocks – 14 blocks in the northern zone (Block nos. - 2, 3, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21 and 23) and 10 blocks in the southern zone (Block nos. - 1, 4, 5, 6, 7, 8, 9, 10, 22 and 24). Estimation of changes in meadows thickness was carried out in these 24 blocks. In each zone, 500 m long transects were laid and the meadow thickness was measured at every 50 m interval at 10 different locations using bamboo poles, which were marked in centimeters. A total of 138 transects in both north and south zones were laid during the entire study period (14 transects in 2005; 24 transects in 2006; 28 transects in 2007; 20 transects in 2008, 24 transects in 2009 and 28 transects in 2010). For analysis transects were arranged according to the north and south zones, since north zone of the Park is bordered by open water and the south zone of the Park has thick meadows. Temporal change in the meadows thickness was derived by regression analysis of the six years sampling period.

4.3.3. Plant community structure

Extensive floristic surveys were conducted covering different landform units in the Park during 2008 to 2010. Identification of plants in the field was made with the help of published floras, research papers and existing reports for the area. Unidentified plants were collected, preserved following Jain and Rao (1977) and brought to Wildlife Institute of India (WII) Dehra Dun for identification. To study the vegetation structure and composition, quadrat method (Mishra, 1968; Mueller- Dombois, 1974) was used. In each of the 24 blocks, random transect sampling was done seasonally on both thick and thin meadows and hard ground. Each transect was 500m long and at every 50 m interval quadrates of 0.5 m X 0.5 m were laid. Therefore, each transect had 11 such plots. For each quadrat, number of species; total count of each species; and height of individuals of each species were recorded.

Sampling was done seasonally. During winter months (November-January), due to high water level, sampling was restricted. Overall, in winter, 18 transects having 311 plots covering 9 blocks of the Park were laid. However, in summer, 51 transects having 625 plots covering all the 24 blocks of the Park were sampled**.**

4.4. DATA ANALYSIS

4.4.1. Change in meadow thickness

To derive the temporal change in thickness during the study period (2005-10), the data was transformed to the log values and regressed against mean thickness of each year. Linear regression analysis was used in MS Excel to study the change in meadow thickness during the study period.

4.4.2. Plant community structure

The floristic data matrix consisted of 625 plots having 92 species for summer and 311 plots having 51 species for winter. To classify the plant communities present in the study area, the vegetation data was analyzed using two-way indicator species analysis (TWINSPAN) with PC-ORD version 4.20 (McCune & Mefford, 1999). TWINSPAN (Hill, 1979) uses a divisive method of cluster analysis (Gauch & Whittaker, 1981), seeks groups in species data and reports indicator species for those groups. Greig-Smith (1983) suggested that the presence of the species rather than its abundance should be dominant in numerical vegetation classification. Therefore, the analysis employs the presence/absence data and not the cover value of each species. The plots were ordered first by divisive hierarchical clustering, and then the species were clustered based on the classification of samples (Gauch & Whittaker, 1981). An ordered two-way table that expresses succinctly the relationships of the samples and species within the data set was constructed. Major divisions in the data were indicated by a pattern of digits in the margins. The interior of the table contained the abundance class of each species in each sample unit. The communities were segregated and named after dominant species, evident from the clusters. Companion species were mentioned with those species, which had near weightage to the dominant species. The species having higher weightage than other available companion species were ranked second in the community.

Diversity indices

Species diversity was measured using various diversity indices based on species abundance data. It was measured as species richness or evenness or diversity as a whole. *Species richness* was measured using Index of richness (S) given by Margalef (1958), which is the number of species inventoried in a plot. *Species evenness* was measured using evenness index (E) given by Hill (1973). *Diversity of the species* was calculated using the Shannon-Weiner Index (H´) (or simply the Index of diversity or Shannon's index), (Shannon and Weaver, 1963) and the Index of dominance (D'**)** or Simpson's index (Simpson, 1949). Shannon's index has a direct relationship with the species diversity, whereas Index of dominance has an inverse relationship. All diversity indices were calculated using PC-ORD version 4.20 (McCune and Mefford, 1999). The Shannon's index, which takes both species abundance and species richness into account is sensitive to changes in the importance of the rarest classes (Heuserr, 1998) and is the most commonly used index (Kent and Coker, 1992). For any sample it was calculated as:

$$H' = \sum_{i=1}^{s} pi \ln pi$$

Where, *s* equals the number of species and *i p* is the relative cover of *i*th species (Whittaker, 1972; Pielou, 1975).

The Simpson index (*D'*) which measures species dominance (Magurran, 1988), was calculated using the formula:

$$D = \sum \mathrm{P}_\mathrm{i}^2$$

As biodiversity increases, the Simpson index decreases. Therefore, to get a clear picture of species dominance $D' = 1 - D$ was used.

Evenness index (*E=Evenness*), a measure for evenness of spread of species (Magurran, 1988) was calculated using the following formula:

Whereas, the evenness index (*E*) is defined as:

$$E = \frac{H'}{H_{max}} = -- \sum_{i=1}^{s} \frac{pi \ln pi}{\ln s}$$

Where, H_{max} is the natural logarithm of the total number of species.

4.4.3. Frequency, density and abundance

The important quantitative analysis such as density, frequency, and abundance of the plant species were determined as per Curtis and McIntosh (1950). The ratio of abundance to frequency (A/F) for different species was determined for eliciting the distribution pattern. This ratio (A/F) indicates regular (<0.025), random (0.025 to 0.05) and contagious distribution (>0.05) (Curtis and Cotton, 1956).

(a) Density

Density is an expression of the numerical strength of a species where the total numbers of individuals of each species in all the quadrats is divided by the total number of quadrats studied, using the following equation.

$$\text{Density} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

(b) Frequency (%)

Frequency refers to the degree of dispersion of individual species in an area and is usually expressed in terms of percentage occurrence. It was calculated by the equation:

$$\text{Frequency (\%)} = \frac{\text{Number of quadrats in which the species occured}}{\text{Total number of quadrats studied}} \text{ X } 100$$

(c) Abundance

Abundance is the number of individuals of different species in the community per unit area. It was calculated by the equation:

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats in which the species occurred}}$$

4.5. RESULTS

4.5.1. Extent of meadows

Among the 11 different habitat classes identified in and around the Park, the thick floating meadows occupied the largest area (14.42 km²) followed by water with floating vegetation (8.56 km²) and the settlements occupied the least area (0.05 km²). The human settlements inside the Park are encroachments by the local people living around the Park. The fish ponds (3.72 km²) located in the periphery of the Park are also encroachments made by the local people (Figure 4.1; Table 4.1). The open water with floating vegetation is confined to the north, north eastern and the peripheral region in the western part of the Park. This is the area where incidences of fishing, by the local people were high. Athaphum fishing, where large chunks of the floating meadows are cut to from large chunks to make fish ponds inside the water body was found to be a common practice. No agricultural encroachment inside the boundary of the Park was found.

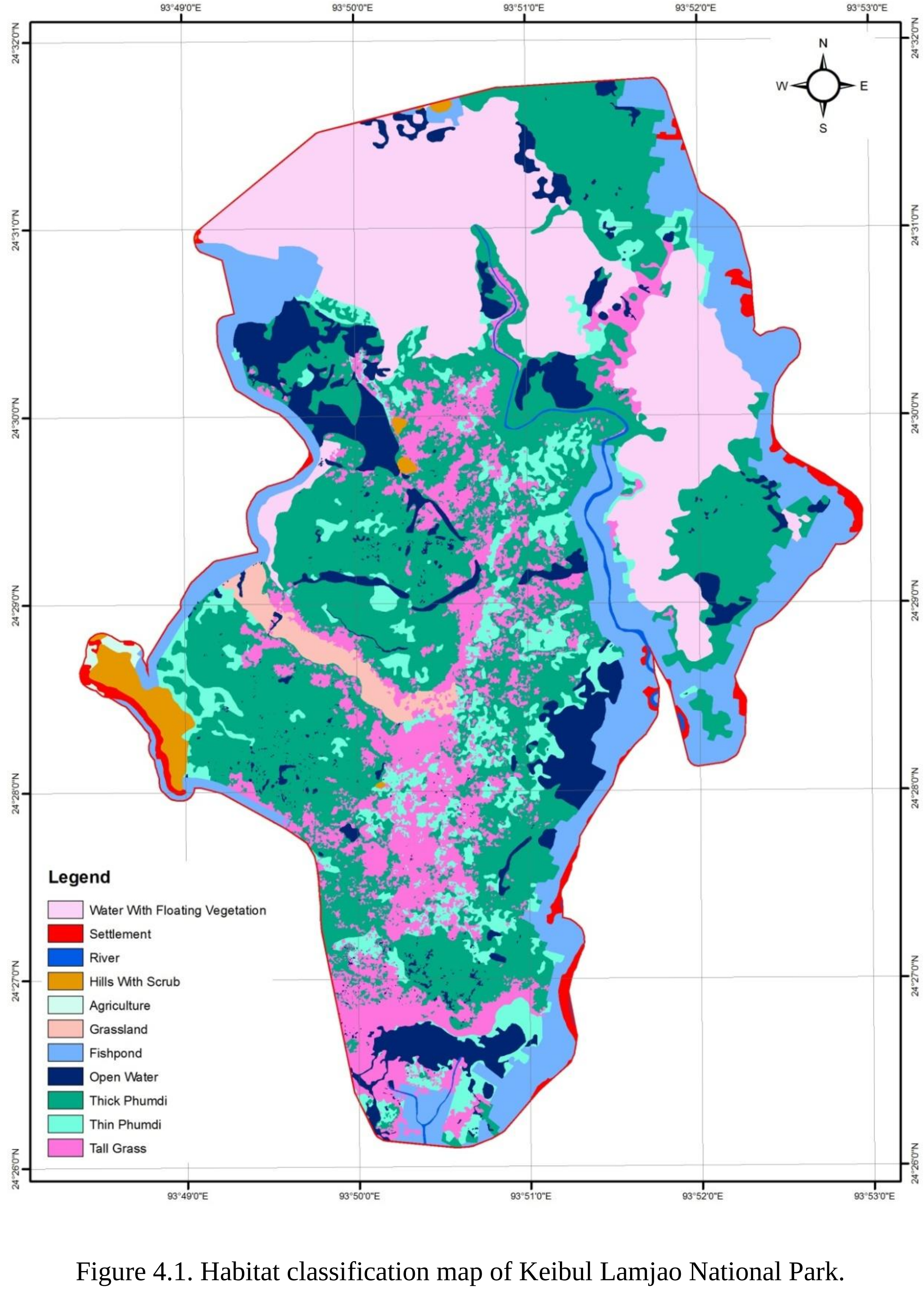


Figure 4.1. Habitat classification map of Keibul Lamjao National Park.

Table 4.1. Habitat types and their extent in the National Park.

Sl. No	Habitat types	Area (km^2)	%
1	Thick floating meadows	14.42	36.06
2	Water with floating vegetation	8.56	21.41
3	Tall grasses on meadows and on land	5.12	12.80
4	Fishpond	3.72	9.30
5	Open water	3.55	8.88
6	Thin floating meadows	3.43	8.58
7	Grassland	0.58	1.45
8	Hills with scrub	0.46	1.15
9	River	0.1	0.25
10	Settlement	0.05	0.13
	Grand Total	39.99	

4.5.2. Spatio-temporal variations in meadow thickness

The mean thickness of the meadow was 107.97 ±4.03 cm, while it was 105.13 ±5.29 cm and 111.36 ±6.24 cm in north and south zones respectively. The mean meadow thickness in different years is summarized in Table 4.2. The mean meadows thickness during the study years show a declining trend with highest thickness 150.60 ±14.71 cm (N =72) in 2005 which gradually declined to 123.20 ±10.96 cm in (660) 2006, 101.80 ±11.1 cm (N =209) in 2007, 96.61 ±10.65 cm (N =109) in 2008, 95.64 ±10.34 cm (N =367) in 2009 and 93.01 ±10.73 cm (N =242) in 2010.

Results of the regression analysis show a strong year wise change in meadow thickness (R^2 = 0.82). The R^2 value indicates that 82% variation in the observed meadow thickness is explained by the equation:

Log_{10} (floating meadows thickness) = -0.092 * Year + 189.4 (Figure 4.2).

The above equation explains that meadow thickness decreases 0.09 times (9%) with every t+1 year (t=year). The regression result indicates significant relation between study year and change in meadows thickness ($F_{1,4}$ = 18.22, $p < 0.05$). Change in meadows thickness year-wise was recorded in both the north and south zones, as summarized in table 4.2. The northern part of the Park showed a strong change in meadows thickness during the entire study period (R^2 = 0.682). The results indicate that 68% of the variation in the observed value of the meadows thickness is explained by the equation:

Log_{10} (floating meadows Thickness) = -0.058 * year + 122.7. (Figure 4.3)

Results of the regression analysis showed significant change in the meadows thickness during the six year study period ($F_{1, 4}$ = 8.59, $p < 0.05$). The equation also indicates, 0.058 (5.8%) times decrease in meadows thickness in the north zone annually *i.e.* in every t+1 year. Meadows thickness in the southern zone of the Park also showed strong year wise change during the study period (R^2 = 0.87) *i.e.* 87% of the observed meadows thickness is explained by the equation:
Log_{10} (floating meadows thickness) = 0.122 * year + 250.9 (Figure 4.4)

The results indicate presence of a strong relation between study year and the change in meadows thickness *i.e.* there is a significant change in meadows thickness each year ($F_{1,4}$ = 25.93, $p <0.05$). The southern zone shows a 0.122 times (12%) decrease in thickness every t+1 year.

Table 4.2. Mean floating meadows thickness in different years 2005-10.

Year	No. of sampling points	Block No.	Thickness (cm)
2005	72	2, 3, 6, 8, 14, 19, 24	150.60 ±14.71
2006	660	2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 17, 18, 19, 20, 21, 22, 23, 24	123.20 ±10.96
2007	209	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 14, 17, 18, 19, 22, 24	101.80 ±11.1
2008	109	5, 6, 7, 9, 12, 13, 18, 20, 24	96.61 ±10.65
2009	367	3, 4, 5, 6, 12, 13, 14, 15, 17, 18, 21, 24	95.64 ±10.34
2010	242	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 14, 17, 19, 23	93.01 ±10.73
Overall			107.97 ±4.03

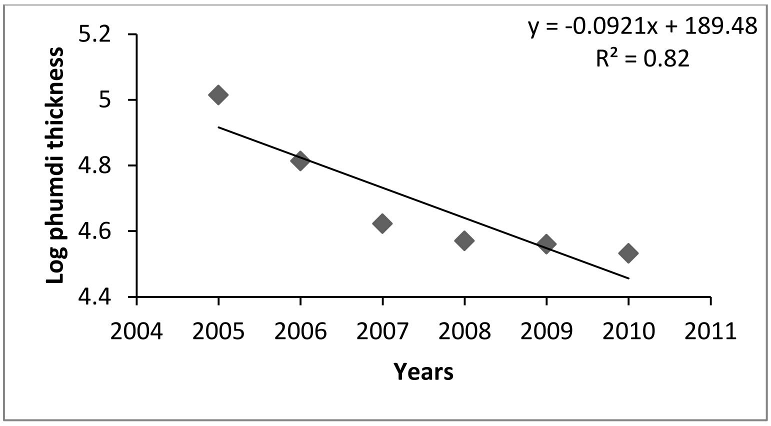


Figure 4.2. Regression graph for overall floating meadows' thickness in the National Park.

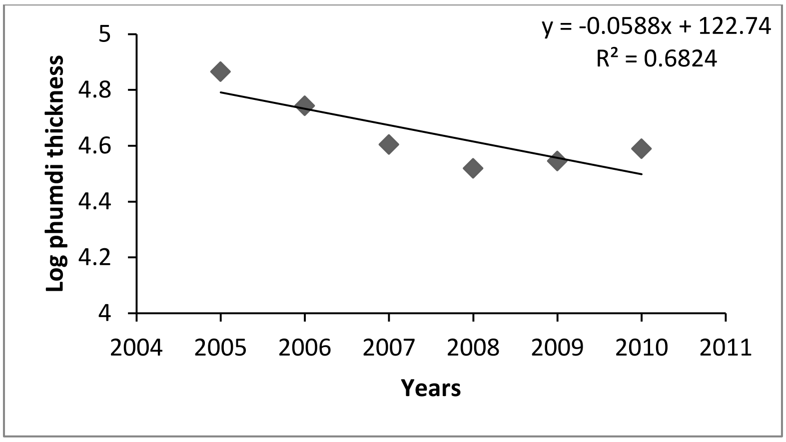


Figure 4.3. Regression graph for floating meadows' thickness in the north zone of the National Park

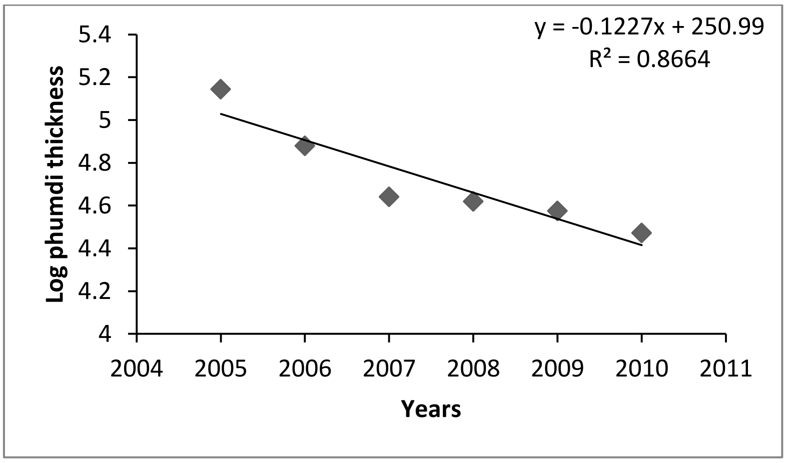


Figure 4.4. Regression graph for floating meadows' thickness in the south zone of the National Park

4.5.3. Area under different types of meadows

The thickness of the meadows varies in the Park. The meadow thickness was divided into three types depending on its ability to support the weight of Sangai. Area covered by each meadow thickness type was calculated from the transect data. Meadows was present in 22.3 km^2 area, of which 8.64 km^2 had > 120 cm thick meadows, 7.32 km^2 had 60-120 cm thick meadows and 6.33 km^2 had < 60 cm thick meadows (Table 4.3).

Table 4.3. Area of different types of floating meadows thickness.

Total Points	Range of thickness (cm)	Mean thickness (cm)	Support for Sangai	% Area	Total Area (km^2)	Thick Area (km^2)
655	>120	163.01	Good	38.76	22.3	8.64
555	60-120	105.58	Fair	32.84	22.3	7.32
480	<60	47.44	poor	28.40	22.3	6.33

4.5.4. Decline in the thickness of the meadows

The thickness of the meadows in the Park as well as the whole of the Loktak Lake is declining due to various factors like change in hydrology due to the construction of Ithai barrage, pollution and anthropogenic pressures. As per the regression analysis given above, the thickness of the meadows was found to be declining at the rate of 9% per annum. Using this value, a 10 years scenario was predicted for the decline in meadows' thickness to determine approximately the time when the thickness will become unsafe for supporting Sangai and Hog deer (Figure 4.5). It is predicted that at the present rate of decline of 9% per year, in 10 years time the thick meadows will reduce to medium thick meadows of 63.48 cm, the medium meadows will reduce to thin meadows 41.11 cm and the thin meadows will reduce to18.47 cm making it unsuitable to support the weight of Sangai or humans (Figure 4.5).

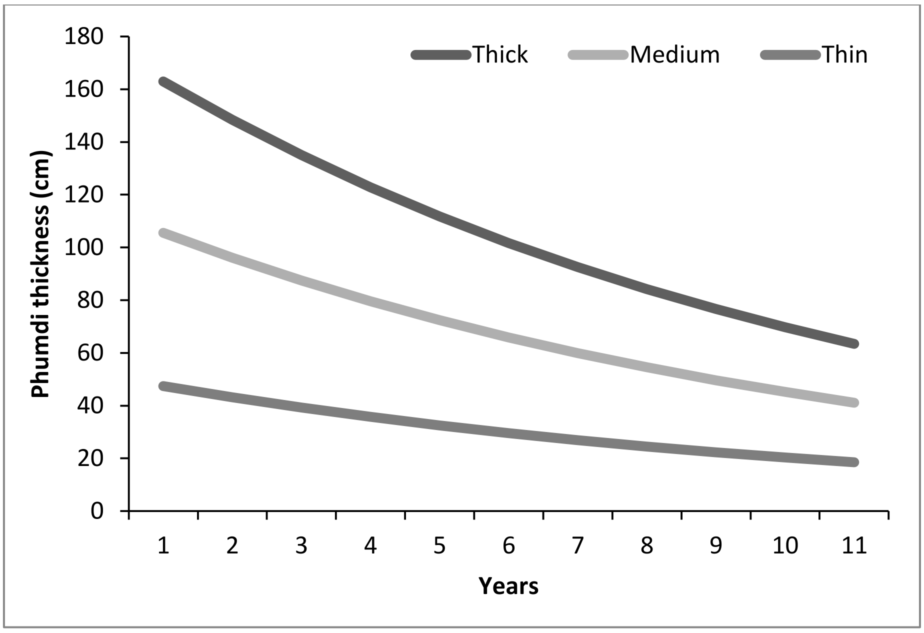


Figure 4.5. Ten years scenario of decline in floating meadows in the National Park

4.5.5. Plant species composition

A total of 185 plant species were recorded from the Keibul Lamjao National Park (Appendix I). Ninety species common to both, the meadows and the open water habitat, comprising 11 grass species, 27 sedges, three ferns and 49 species of herbs belonging to 32 families were recorded. In the terrestrial habitat, a total of 19 species comprising five grasses, four climbers, nine species of herbs and one species of shrub belonging to 11 families were recorded. Seventy six species common to both the floating and the terrestrial habitats, comprising 16 species of grasses, nine climbers, three sedges, two ferns, 40 herbs and six species of shrubs belonging to 30 families were recorded. Overall, poaceae was found to be the dominant family with 33 species followed by Cyperaceae (30 species) and Asteraceae (14 species, Figure 4.6).

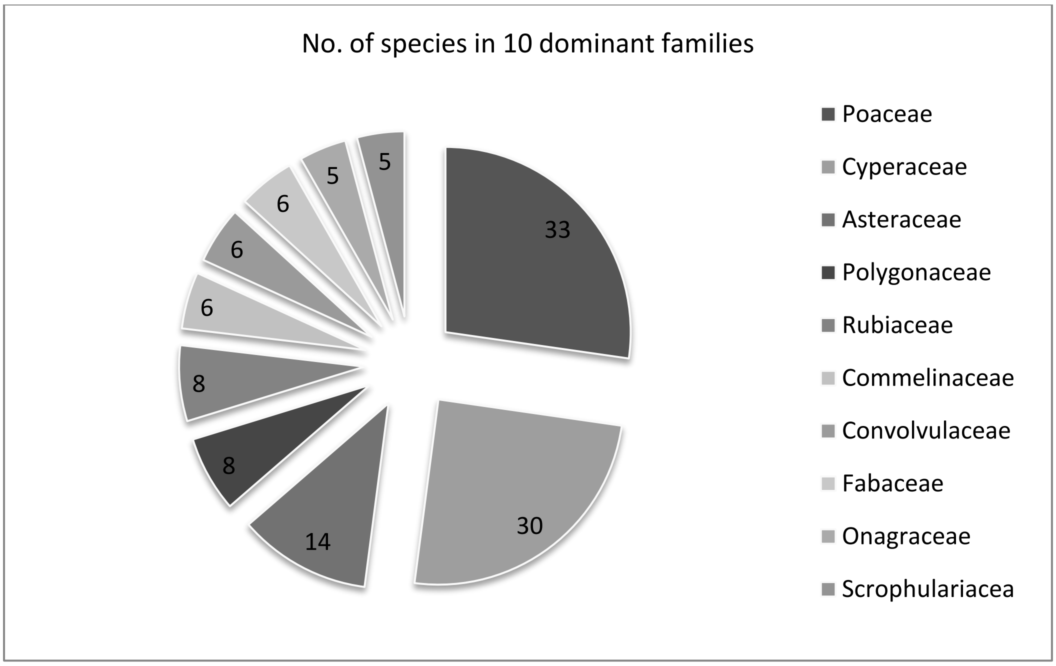


Figure 4.6. Number of species in dominant families found in the National Park.

4.5.6. Habitat specificity

Since the Park has a mosaic of micro habitats (floating meadows, open water, terrestrial and common to both habitats), the type of plants found in specific habitat was also recorded. Of the total species, 48.6% were recorded from the floating meadows or *phumdis* and 10.3% species were recorded from the terrestrial habitat while 41.1% of species were common to both the floating meadows and the terrestrial habitat.

Distribution of the herb was highest in the floating vegetation (54.4%) as well as in the terrestrial habitat (47.4%), followed by sedges in the floating vegetation (30%) and the grasses in the terrestrial habitat (26.3%). Of the plant species common to both the floating vegetation and the terrestrial habitat, herbs showed the highest distribution (52.6%), followed by grasses (21.1%) and climbers (11.8%). Overall herbs showed the highest distribution (53%) followed by grasses (17.3%) and sedges (16.2%) (Table 4.4).

The dominant species found only in the floating vegetation were *Zizania latifolia*, *Hedychium coronarium*, *Impatiens* spp., *Cyperus difformis*, *Cyperus rotundus* and *Polygonum* spp. The dominant species found only in the terrestrial habitat were *Setaria* spp, *Ipomoea nil* and *Cynodon dactylon*. The species common to both the floating meadows and the terrestrial habitat were *Phragmites karka*, *Capillipedium assimile*, *Leersia hexandra*, *Oenanthe javanica* and *Cyanotis barbata*. The common species found floating or submerged in the open water were *Azolla pinnata*, *Ceratophyllum demersum*, *Hydrilla verticillata*, *Salvinia cucullata*, *Salvinia molesta*, *Utricularia* spp., *Nymphoides cristata* and *Pistia stratiotes*. Some of the dominant plant species extracted from the Park area by local people for commercial as well as household purpose are listed in the Table 4.5.

4.5.7. Plant communities

The vegetation data recorded was quantitatively analyzed for density, frequency and abundance using the equations given in the method section. According to the results of the TWINSPAN analysis, the plant community structure of the Park was found to vary across the seasons. Each community was named after dominant or indicator species based on the experience of traditional vegetation classification (Atri, 1995). In summer, 9 plant communities were recorded and in winter 8 plant communities were recorded. Two communities, *Persicaria perfoliata – Leersia hexandra - Capillipedium* spp and *Zizania latifolia - Leersia hexandra - Capillipedium* spp were common to summer and winter seasons.

Table 4.4. Percentage distribution of the different class of plant species in different habitats in the National Park.

Classes	Meadows			Terrestrial			Both			Overall		
	Family	Number	(%)	Family	Number	(%)	Family	Number	(%)	Family	Number	(%)
Herb	28	49	54.44	7	9	47.37	18	40	52.63	37	98	53
Grass	1	11	12.22	1	5	26.32	1	16	21.05	1	32	17.3
Sedges	1	27	30	0	0	0	1	3	3.95	1	30	16.2
Fern	2	3	3.33	0	0	0	2	2	2.63	4	5	2.7
Climber	0	0	0	2	4	21.05	7	9	11.84	9	13	7
Shrub	0	0	0	1	1	5.26	6	6	7.89	7	7	3.8
Total	32	90	100	11	19	100	35	76	100		185	100

Table 4.5. Economically important plant species of the National Park.

Uses	Plant species	Parts used
Vegetable	*Alternanthera philoxeroides, Alternanthera sessilis, Centella asiatica, Oenanthe javanica*	Leaf, stem
	Alpinia allughas, Hedychium coronarium	Stem, young shoot
	Euryale ferox, Nymphaea spp	Seeds
Thatching material	*Imperata cylindrical, Zizania latifolia*	Leaf, stem
Fuel	*Arundo donax, Coix lacryma-jobi, Phragmites karka, Saccharum spontaneum*	Stem
Handicraft	*Cyperus spp, Scirpus lacustris*	Stem
Medicinal purposes	*Centella asiatica, Ageratum conyzoides, Alpinia allughas, Hedychium coronarium Ludwigia adscendens , Oxalis corniculata, Vetiveria zizanioides,*	Leaf, young shoot
Fodder	*Alternanthera philoxeroides, Alternanthera sessilis, Leersia hexandra, Polygonum spp, Zizania latifolia*	Leaf, stem
	Ceratophyllum demersum, Hydrilla verticillata, , Limnophila spp	Whole plant

4.5.7.1. Plant communities in summer

The nine plant communities recorded in summer from the National Park are:

1. *Saccharum spontaneum – Leersia hexandra- Phragmites karka*
2. *Leersia hexandra - Ageretum conizoides - Phragmites karka*
3. *Capillipedium* spp – *Phragmites karka – Leersia hexandra*
4. *Alternanthera philoxeroides – Zizania latifolia – Bracharia* spp
5. *Zizania latifolia - Leersia hexandra - Capillipedium* spp
6. *Persicaria perfoliata – Leersia hexandra - Capillipedium* spp
7. *Hedychium coronarium - Capillipedium* spp - *Phragmites karka*
8. *Pteridium aquilinum - Capillipedium* spp - *Leersia hexandra*
9. *Oryza rufipogon – Hemarthria compressa - Leersia hexandra*

The dendogram showing the division at which the summer communities were classified and the eigen value (λ) at each level of division is represented in the flowchart (Figure 4.7). The first division separates the wet and dry communities at eigen value 0.2363. The second level divides the wet communities into thick and thin floating meadow communities at an eigen value 0.1728. The thick and thin meadow communities are further divided into two groups each with two communities in each group with $\lambda = 0.2739$ and 0.2294 in the thick communities and $\lambda = 0.1415$ and 0.1473 in the thin communities.

SUMMER COMMUNITIES

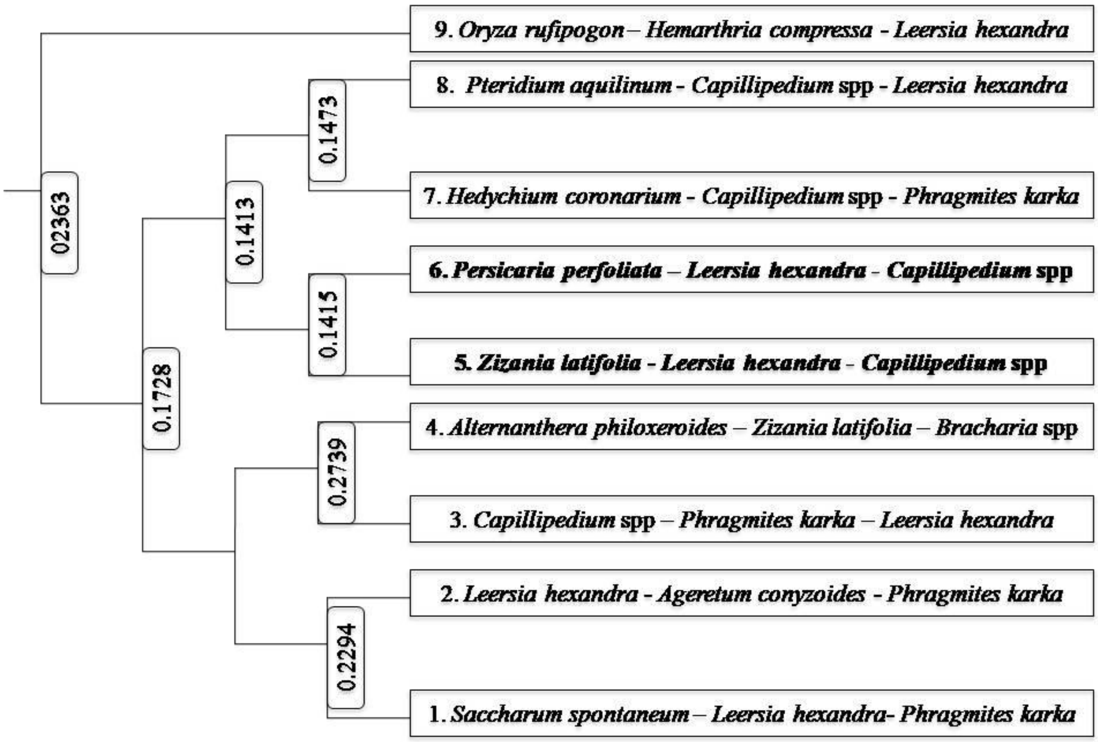


Figure 4.7. Classification of summer communities of the National Park with Eigen values

Community 1. *Saccharum spontaneum – Leersia hexandra- Phragmites karka* community (89 Plots): This community was found in the wet habitat (floating meadows) and 32 species were recorded. The community occupies the least disturbed zone of the Park, indicated by the dominance of taller grasses like *Phragmites karka* (75.28%) and *Saccharrum spontaneum* (43.82%). The other constant species (frequency>50%) were *Leersia hexandra* (94.38%) and *Zizania latifolia* (76.4%). Among the 32 plant species comprising this community, *Leersia hexandra* showed the highest density m^{-2} (33.73) and abundance (71.48) followed by *P. karka* and *Z. latifolia* with density m^{-2} of 8.4 and 7.31 respectively and abundance of 22.33 and 19.15 respectively (Table 4.6a). The A/F ratio indicates that all the dominant species had contagious distribution (A/F =>0.05).

Table 4.6a. Density, frequency and abundance of various species in summer community 1 (*Saccharum spontaneum – Leersia hexandra- Phragmites karka*).

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Leersia hexandra	94.38	33.73	71.48	0.76
Zizania latifolia	76.4	7.31	19.15	0.25
Phragmites karka	75.28	8.4	22.33	0.3
Saccharrum spontaneum	43.82	1.33	6.05	0.14
Oenanthe javanica	29.21	0.76	5.23	0.18
Pteridium aquilinum	15.73	0.5	6.36	0.4
Persicaria perfoliata	12.36	0.18	2.91	0.24
Alternanthera philoxeroides	10.11	0.63	12.44	1.23
Blumea spp	6.74	0.39	11.5	1.71
Capillipedium spp	6.74	0.28	8.17	1.21

Community 2. *Leersia hexandra* - *Ageretum conizoides* - *Phragmites karka* (5 Plots): This community comprised 17 species and occupied the least disturbed area of the Park, indicated by the lack of plant species extracted by the local people and the dominance of tall grasses like *Phragmites karka* (100%) (Table 4.6b). The other constant species were *Ageretum conizoides* (80%), *Leersia hexandra* (80%), *Lycopus uniflorus (60%), Crotolaria* spp (60%) and *Kylinga triceps* (60%). *P. karkas* showed the highest density m^{-2} (21.8) followed by *Ageretum conizoides* (11.8) and *L. hexandra* (6.3). *Oenanthe javanica* (104) was the most abundant species in this community followed by *P. karkas* (43.6) and *A. conizoides* (29.5). The A/F ratio indicates that except for *Kylinga triceps (0.0*3) had random distribution, while rest of the species had contagious distribution (>0.05).

Table 4.6b. Density, frequency and abundance of various species in summer community 2 (*Leersia hexandra - Ageretum conizoides - Phragmites karka).*

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Phragmites karka	100	21.8	43.6	0.44
Ageretum conizoides	80	11.8	29.5	0.37
Leersia hexandra	80	6.3	15.75	0.2
Lycopus uniflorus	60	3.3	11	0.18
Crotolaria spp	60	2.7	9	0.15
Capillipedium spp	60	1.8	6	0.1
Kylinga triceps	60	0.6	2	0.03
Oenanthe javanica	20	10.4	104	5.2
Mosla dianthera	20	1.5	15	0.75
Ludwigia spp	20	1.1	11	0.55

Community 3. *Capillipedium* spp – *Phragmites karka* – *Leersia hexandra* (95 Plots): This community comprised 54 species and occupied the area having anthropogenic disturbances, indicated by *Zizania latifolia* being the most constant species with a frequency of 97.89%. *Z. latifolia* being an invasive fast growing plant can re-grow even from a small rhizome and streamside plant communities by over stopping and suppressing other marginal species (Table 4.6c). The other constant species were *Leersia hexandra* (73.68%), *Capillipedium* spp (51.58%), *Phragmites karka* (53.68%), *Persicaria perfoliata* (54.74%) and *Oenanthe javanica* (51.58%). Among the 54 plant species of this community, *Z. latifolia* showed the highest density m^{-2} (12.96) followed by *L. hexandra* (10.91) and *Capillipedium* spp (7.21). The most abundant species in this community was *L. hexandra* (29.61) followed by *Capillipedium* spp (27.96) and *Z. latifolia (26.4*8). All the dominant plant species of this community had contagious distribution.

Table 4.6c. Density, frequency and abundance of various species in summer community 3(*Capillipedium* spp – *Phragmites karka* – *Leersia hexandra*).

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Zizania latifolia	97.89	12.96	26.48	0.27
Leersia hexandra	73.68	10.91	29.61	0.4
Persicaria perfoliata	54.74	0.87	3.19	0.06
Phragmites karka	53.68	2.93	10.9	0.2
Capillipedium spp	51.58	7.21	27.96	0.54
Oenanthe javanica	51.58	1.18	4.59	0.09
Saccharrum spontaneum	33.68	0.79	4.72	0.14
Mikania macrantha	33.68	0.71	4.19	0.12
Polygonum chinensis	27.37	1.04	7.62	0.28
Blumea spp	14.74	0.14	1.93	0.13

Community 4. *Alternanthera philoxeroides* – *Zizania latifolia* – *Bracharia* spp (13 Plots): This community comprised 26 species occupying the area of the Park towards the margin of the Park where the floating vegetation starts, indicated by the presence and dominance of *Bracharia* spp (92.31%), found only in the outer fringes of the Park (Table 4.6d). The other constant species were *Alternanthera philoxeroides* (69.23%), *Zizania latifolia* (76.92%), *Pteridium aquilinum* (61.54%), *Mikania micrantha* (53.85%) and *Phragmites karka* (53.85%). *Bracharia* spp showed the highest density m^{-2} (26.77) followed by *Z. latifolia* (6.15) and *L. hexandra* (4). The most abundant among the 26 species of this community was *Bracharia* spp (58) followed by *Z. latifolia* (16) and *L. hexandra* (9.45). The A/F ratio indicates that the distribution of all the dominant species was contagious (>0.05).

Table 4.6d. Density, frequency and abundance of various species in summer community 4 (*Alternanthera philoxeroides – Zizania latifolia – Bracharia* spp.)

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Bracharia spp	92.31	26.77	58	0.63
Leersia hexandra	84.62	4	9.45	0.11
Zizania latifolia	76.92	6.15	16	0.21
Alternanthera philoxeroides	69.23	1.15	3.33	0.05
Pteridium aquilinum	61.54	1.08	3.5	0.06
Mikania micrantha	53.85	1.23	4.57	0.08
Phragmites karka	53.85	0.81	3	0.06
Persicaria perfoliata	38.46	0.54	2.8	0.07
Saccharrum spontaneum	30.77	0.42	2.75	0.09
Oenanthe javanica	23.08	0.19	1.67	0.07

Community 5. *Zizania latifolia - Leersia hexandra - Capillipedium* spp (161 Plots): This community comprised 61 species and occupied the more disturbed area of the Park, indicated by the highest frequency of the fast growing invasive species *Zizania latifolia* (91.93%) (Table 4.6e). The other constant species were *Leersia hexandra* (78.88%), *Capillipedium* spp (87.58%), *Pteridium aquilinum* (72.67%), *Crotolaria* spp (70.81%), *Oenanthe javanica* (59.63%), *Phragmites karka* (59.01%) and *Gynura* spp (57.14%). In this community, the species with the highest density m^{-2} was *Capillipedium* spp (18.32) followed by *L. hexandra* (11.16) and *Z. latifolia* (9.9). The most abundant species in this community was also *Capillipedium* spp (41.84) followed by *L. hexandra* (28.31) and *Z. latifolia* (21.55). The A/F ratio indicates that all the species of this community had a contagious distribution (>0.05).

Table 4.6e. Density, frequency and abundance of various species in summer community 5 (*Zizania latifolia - Leersia hexandra - Capillipedium* spp).

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Zizania latifolia	91.93	9.9	21.55	0.23
Capillipedium spp	87.58	18.32	41.84	0.48
Leersia hexandra	78.88	11.16	28.31	0.36
Pteridium aquilinum	72.67	4.04	11.13	0.15
Crotolaria spp	70.81	0.01	0.03	0
Oenanthe javanica	59.63	1.39	4.67	0.08
Phragmites karka	59.01	2	6.79	0.12
Gynura spp	57.14	1.57	5.5	0.1
Hedychium coronarium	43.48	0.79	3.64	0.08
Persicaria perfoliata	37.89	0.7	3.7	0.1

Community 6. *Persicaria perfoliata – Leersia hexandra - Capillipedium* spp (51 Plots): This community comprised 46 species and occupied the thin floating meadows area of the Park, indicated by the dominance of short grasses like *Capillipedium* spp (86.27%) and *Leersia hexandra* (86.27%) and less frequency of tall grasses like *Phragmites karka (15.69%*) and *Saccharrum spontaneum* (15.69%) (Table 4.6f). The other constant species were *Oenanthe javanica* (54.9%) and *Gynura* spp (76.47%). In this community, the species with the highest density m^{-2} was *Capillipedium* spp (14.04) followed by *L. hexandra* (11.1) and *Z. latifolia* (5.5). The most abundant species in this community was *Capillipedium spp* (32.55) followed by *L. hexandra* (25.73) and *Z. latifolia* (22.44). The A/F ratio indicates that all the species of this community had contagious distribution (>0.05).

Table 4.6f. Density, frequency and abundance of various species in summer community 6 (*Persicaria perfoliata – Leersia hexandra - Capillipedium* spp).

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Capillipedium spp	86.27	14.04	32.55	0.38
Leersia hexandra	86.27	11.1	25.73	0.3
Gynura spp	76.47	4.73	12.36	0.16
Oenanthe javanica	54.9	2.57	9.36	0.17
Zizania latifolia	49.02	5.5	22.44	0.46
Kylinga triceps	41.18	2.54	12.33	0.3
Blumea spp	37.25	0.75	4	0.11
Pteridium aquilinum	27.45	2.08	15.14	0.55
Persicaria perfoliata	25.49	0.67	5.23	0.21
Hedychium coronarium	23.53	0.51	4.33	0.18

Community 7. *Hedychium coronarium* - *Capillipedium* spp - *Phragmites karka* (48 Plots): This community comprised 45 species and occupied the highly disturbed area of the Park, indicated by the presence of indicator species *Hedychium coronarium* which was extracted in high quantity from the Park for commercial purpose by the local people. The constant species of this community were *Capillipedium* spp (85.42%) and *Phragmites karka* (85.42%). *Capillipedium* spp (29.92) showed the highest density m^{-2} followed by *P. karka* (10.65) and *L. hexandra* (4.83) (Table 4.6g). *Capillipedium* spp (70.05) also showed the highest abundance followed by *P. karka* (24.93) and *Carex cruciata* (24.85). The A/F ratio indicates that all the species of this community had contagious distribution (>0.05).

Table 4.6g. Density, frequency and abundance of various species in summer community 7 (*Hedychium coronarium* - *Capillipedium* spp - *Phragmites karka*).

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Capillipedium spp	85.42	29.92	70.05	0.82
Phragmites karka	85.42	10.65	24.93	0.29
Leersia hexandra	47.92	4.83	20.17	0.42
Persicaria perfoliata	37.5	0.66	3.5	0.09
Pteridium aquilinum	31.25	1.05	6.73	0.22
Carex cruciata	27.08	3.36	24.85	0.92
Zizania latifolia	25	1.6	12.83	0.51
Polygonum chinensis	25	0.64	5.08	0.2
Oenanthe javanica	22.92	0.59	5.18	0.23
Hedychium coronarium	22.92	0.33	2.91	0.13

Community 8. *Pteridium aquilinum* - *Capillipedium* spp - *Leersia hexandra* (137 Plots): This community comprised 56 species and occupied the highly disturbed area of the Park, indicated by the high frequency of occurrence of *Pteridium aquilinum* (75.91%) (Table 4.6h). It is a highly adaptable plant, which readily colonizes disturbed areas. The other constant species were *Capillipedium* spp (89.05%), *Leersia hexandra* (87.59%), *Phragmites karka* (84.67%) and *Oenanthe javanica* (53.28%). In this community, *Capillipedium* spp (17.61) showed the highest density m^{-2} followed by *L. hexandra* (17.07) and *P. karka* (5.33). *Capillipedium* spp (39.56) also showed the highest abundance followed by *L. hexandra* (38.98) and *P. karka* (12.59). The A/F ratio indicates that all the species of this community had contagious distribution (>0.05).

Table 4.6h. Density, frequency and abundance of various species in summer community 8 (*Pteridium aquilinum* - *Capillipedium* spp - *Leersia hexandra*).

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Capillipedium spp	89.05	17.61	39.56	0.44
Leersia hexandra	87.59	17.07	38.98	0.45
Phragmites karka	84.67	5.33	12.59	0.15
Pteridium aquilinum	75.91	4.61	12.14	0.16
Oenanthe javanica	53.28	1.3	4.86	0.09
Hedychium coronarium	46.72	1.04	4.47	0.1
Zizania latifolia	40.15	2.37	11.82	0.29
Persicaria perfoliata	37.23	0.74	4	0.11
Saccharrum spontaneum	29.2	0.48	3.3	0.11
Gynura spp	16.79	0.35	4.22	0.25

Community 9. *Oryza rufipogon* – *Hemarthria compressa* - *Leersia hexandra* (26 Plots): This community comprised 18 species and occupied the dry hard ground area in the Park. This community separates out in the first division itself. The high frequency of occurrence of species like *Oryza rufipogon* (76.92%), *Hemarthria compressa* (46.15%) and *Setaria* spp (23.08%) are found only in the dry hard ground patch of grassland (Table 4.6i). The other constant species was *Leersia hexandra* (92.31%), which occupied a large part of the area. *L. hexandra* (42.87) showed the highest density m^{-2} followed by *O. rufipogon* (16.5) and *Setaria* spp (14.83). The most abundant species of this community was *Setaria* spp (128.5) followed by *L. hexandra* (92.88) and *Cynodon dactylon* (80.67). The A/F ratio indicates that all the species of this community had contagious distribution (>0.05).

Table 4.6i. Density, frequency and abundance of various species in summer community 9 (*Oryza rufipogon – Hemarthria compressa - Leersia hexandra*).

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Leersia hexandra	92.31	42.87	92.88	1.01
Oryza rufipogon	76.92	16.5	42.9	0.56
Alternanthera philoxeroides	46.15	1.23	5.33	0.12
Hemarthria compressa	46.15	2.4	10.42	0.23
Setaria spp	23.08	14.83	128.5	5.57
Zizania latifolia	15.38	0.25	3.25	0.21
Cynodon dactylon	11.54	4.65	80.67	6.99
Ludwigia spp	11.54	0.08	1.33	0.12
Lemna spp	7.69	0.04	1	0.13
Polygonum chinensis	7.69	0.08	2	0.26

4.5.7.2. Plant communities in winter

Overall eight plant communities were recorded during winter season, which were:

1. *Oryza rufipogon – Setaria* spp - *Leersia hexandra*
2. *Sagitaria sagitifolia - Hemarthria compressa - Leersia hexandra*
3. *Persicaria perfoliata - Leersia hexandra - Capillipedium* spp
4. *Zizania latifolia - Leersia hexandra - Capillipedium* spp
5. *Zizania latifolia - Phragmites karka - Capillipedium* spp
6. *Oenanthe javanica - Capillipedium* spp - *Zizania latifolia*
7. *Alternanthera philoxeroides- Phragmites karka- Zizania latifolia*
8. *Micania micrantha – Nymphea pubesans - Mosla dianthera*

The dendogram showing the division at which the winter communities were classified and the eigen value (λ) at each level of division is represented by the flowchart (Figure 4.7). Unlike the summer classification, the winter classification does not separate the dry and wet communities in the first division. The first division separates out one community at $\lambda = 0.4518$. The next level also classifies one community at $\lambda = 0.4060$. The third division separates out two dry communities at $\lambda = 0.3281$. The wet communities are further divided into four communities at λ =0.1985, 0.1772 and 0.1403 in each level of division respectively (Figure 4.8).

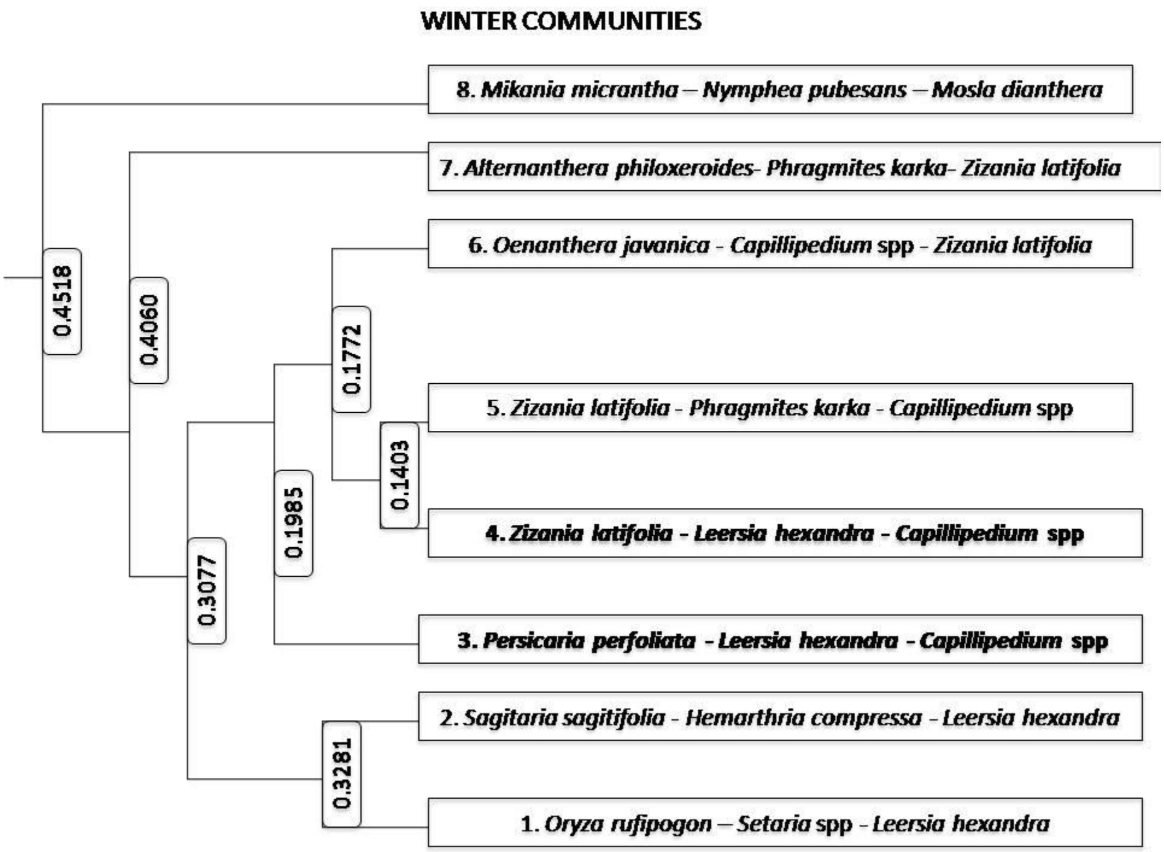


Figure 4.8. Classification of winter communities of the National Park with Eigen values

Community 1. *Oryza rufipogon* – *Setaria* spp - *Leersia hexandra* (12 Plots): This community comprising 9 species was found to occupy the dry hard ground area of the Park,as indicated by high percentage occurrence of species like *Oryza rufipogon* (75%) and *Hemarthria compressa* (66.67%) which were found only in patch of grassland in the Park (Table 4.7a). The other constant species *Leersia hexandra* (100%) also supports the nature of this community as it occupied a large area of this hard ground patch of the Park. *L. hexandra* (64.42) showed the highest density m^{-2} followed by *O. rufipogon* (12.17) and *H. compressa* (7.75). *L. hexandra* (128.83), *O. rufipogon* (32.44) and *H. compressa* (23.25), were also the most abundant species of this community. The A/F ratio indicates that all the species of this community had contagious distribution (>0.05).

Table 4.7a. Density, frequency and abundance of various species in winter community 1 (*Oryza rufipogon* – *Setaria* spp - *Leersia hexandra*).

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Leersia hexandra	100	64.42	128.83	1.29
Oryza rufipogon	75	12.17	32.44	0.43
Hemarthria compressa	66.67	7.75	23.25	0.35
Mosla dianthera	33.33	0.83	5	0.15
Cynodon dactylon	33.33	1.25	7.5	0.23
Polygonum spp	33.33	2.83	17	0.51
Setaria spp	16.67	0.17	2	0.12
Zizania latifolia	16.67	0.17	2	0.12
Oenanthe javanica	8.33	0.08	2	0.24

Community 2. *Sagitaria sagitifolia* - *Hemarthria compressa* - *Leersia hexandra* (9 Plots): In contrast to the summer season which forms only one type of community in the dry hard ground, the winter season forms two communities. This community comprising 10 species also occupied the dry hard ground as indicated by the high frequency of occurrence of *Hemarthria compressa* (66.67%) and *Leersia hexandra* (100%) (Table 4.7b). The other constant species was *Zizania latifolia* (100%). *L. hexandra* (67.67) showed the highest density m^{-2} followed by *H. compressa* (5.67) and *Z. latifolia* (4.17). *L. hexandra* (135.33), *H. compressa* (17) and *O. rufipogon* (12) were the most abundant species of this community. The A/F ratio indicates that all the species of this community had contagious distribution (>0.05).

Table 4.7b. Density, frequency and abundance of various species in winter community 2 (*Sagitaria sagitifolia - Hemarthria compressa - Leersia hexandra*).

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Leersia hexandra	100	67.67	135.33	1.35
Zizania latifolia	100	4.17	8.33	0.08
Hemarthria compressa	66.67	5.67	17	0.25
Pteridium aquilinum	22.22	0.56	5	0.23
Alternanthera pheloxeroides	22.22	0.56	5	0.23
Oryza rufipogon	22.22	1.33	12	0.54
Colocasia antiquorum	11.11	0.33	6	0.54
Ludwigia spp	11.11	0.11	2	0.18
Hedychium coronarium	11.11	0.11	2	0.18
Oenanthe javanica	11.11	0.11	2	0.18

Community 3. *Persicaria perfoliata - Leersia hexandra - Capillipedium* spp (96 Plots): This community comprised 41 species and occupied the floating meadows area of the Park. The constant species of this community were *Leersia hexandra* (89.58%), *Capillipedium* spp (84.38%), *Phragmites karka* (67.71%), *Persicaria perfoliata* (58.33%) and *Oenanthe javanica* (52.08%) (Table 4.7c). In this community, *L. hexandra* (37.73) showed the highest density m^{-2} followed by *Capillipedium* spp (23.94) and *P. karka* (2.99). *L. hexandra* (84.24) also showed the highest abundance followed by *Capillipedium* spp (56.74) and *P. karka* (8.83). The A/F ratio indicates that all the species of this community had contagious distribution (>0.05).

Table 4.7c. Density, frequency and abundance of various species in winter community 3 (*Persicaria perfoliata - Leersia hexandra - Capillipedium* spp).

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Leersia hexandra	89.58	37.73	84.24	0.94
Capillipedium spp	84.38	23.94	56.74	0.67
Phragmites karka	67.71	2.99	8.83	0.13
Persicaria perfoliata	58.33	1.08	3.7	0.06
Oenanthe javanica	53.13	1.2	4.51	0.08
Pteridium aquilinum	38.54	0.85	4.41	0.11
Saccharrum spontaneum	29.17	0.63	4.29	0.15
Eupatorium odoratum	28.13	0.92	6.56	0.23
Hedychium coronarium	27.08	0.32	2.38	0.09
Zizania latifolia	27.08	0.7	5.19	0.19

Community 4. *Zizania latifolia - Leersia hexandra - Capillipedium* spp (92 Plots): This community comprised 34 species and occupied highly disturbed area of the Park. The high percentage of frequency of occurrence of the fast growing species like *Zizania latifolia* (85.87%) and commercially exploited species like *Hedychium coronarium* (52.17%) and *Oenanthe javanica* (66.3%) were indicative of the disturbed nature of the site (Table 4.8d). The other constant species are *Capillipedium* spp (93.70%), *Leersia hexandra* (66.3%) and *Phragmites karka* (56.52%). *Capillipedium* spp (45.47) showed the highest density m^{-2} followed by *L. hexandra* (8.16) and *Z. latifolia* (6.65). *Capillipedium* spp (108.66) also showed the highest abundance followed by *L. hexandra* (24.61) and *Z. latifolia* (15.48). The A/F ratio indicates that all the species of this community have a contagious distribution (>0.05).

Table 4.7d. Density, frequency and abundance of various species in winter community 4 (*Zizania latifolia - Leersia hexandra - Capillipedium* spp).

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Zizania latifolia	85.87	6.65	15.48	0.18
Capillipedium spp	83.7	45.47	108.66	1.3
Leersia hexandra	66.3	8.16	24.61	0.37
Oenanthe javanica	66.3	1.34	4.03	0.06
Phragmites karka	56.52	2.33	8.23	0.15
Hedychium coronarium	52.17	0.85	3.27	0.06
Pteridium aquilinum	39.13	0.83	4.22	0.11
Gynura spp	35.87	0.86	4.82	0.13
Saccharrum spontaneum	30.43	0.54	3.57	0.12
Persicaria perfoliata	27.17	0.33	2.4	0.09

Community 5. *Zizania latifolia - Phragmites karka - Capillipedium* spp (42 Plots): This community comprising 24 species occupied an area of the Park where human disturbance was prevalent. The percentage frequency of the fast growing *Zizania latifolia* (85.71%) and highly adaptable *Pteridium aquilinum* (40.48%) is indicative of the slightly disturbed nature of the area (Table 4.7e). Also, the presence of commercially exploited plant species *Hedychium coronarium* (38.1%) and *Oenanthe javanica* (42.86%) support the fact that this area of the Park is disturbed. The other constant species were *Panicum* spp (92.86%), *Phragmites karka* (90.48%), *Capillipedium* spp (88.1%), *Leersia hexandra* (71.43%) and *Saccharrum spontaneum* (50%). *Capillipedium* spp (71.32) showed the highest density m^{-2} followed by *L. hexandra* (6.68) and *Z. latifolia* (5.75). *Capillipedium* spp (161.92) also showed the highest abundance followed by *L. hexandra* (18.7) and *Z. latifolia* (13.42). The A/F ratio indicates that all the species of this community were contagiously distributed (>0.05). Only *Saccharrum spontaneum* was more or less randomly distributed (A/F ratio = 0.05).

Table 4.7e. Density, frequency and abundance of various species in winter community 5 (*Zizania latifolia - Phragmites karka - Capillipedium* spp).

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Pannicum spp	92.86	4.36	9.38	0.1
Phragmites karka	90.48	4.45	9.84	0.11
Capillipedium spp	88.1	71.32	161.92	1.84
Zizania latifolia	85.71	5.75	13.42	0.16
Leersia hexandra	71.43	6.68	18.7	0.26
Saccharrum spontaneum	50	0.68	2.71	0.05
Oenanthe javanica	42.86	0.57	2.67	0.06
Pteridium aquilinum	40.48	0.51	2.53	0.06
Hedychium coronarium	38.1	0.48	2.5	0.07
Persicaria perfoliata	23.81	0.27	2.3	0.1

Community 6. *Oenanthera javanica - Capillipedium* spp - *Zizania latifolia* (15 Plots): This community comprised 23 species. The plant species of this community indicates that this community occupied a thin floating meadows area of the Park. The high percentage of frequency of *Gynura* spp (60%), *Capillipedium* spp (40%) and *Zizania latifolia* (93.33%) are indicative that this community occupied thin floating meadows as these species tend to dominate and occur more frequently in the thin floating meadows (Table 4.7f). The other constant species was *Oenanthera javanica* (73.33%). In this community, *Gynura* spp (7.5) showed the highest density m^{-2} followed by *Z. latifolia* (6.37) and *Saccharrum spontaneum* (3.17). The A/F ratio indicates that *Oenanthera javanica* (0.03) and *Ludwigia* spp (0.05) were randomly distributed whereas the other dominant species of the community were contagiously distributed.

Table 4.7f. Density, frequency and abundance of various species in winter community 6 (*Oenanthera javanica - Capillipedium* spp - *Zizania latifolia*).

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Zizania latifolia	93.33	6.37	13.64	0.15
Oenanthera javanica	73.33	0.83	2.27	0.03
Gynura spp	60	7.5	25	0.42
Pteridium aquilinum	46.67	1.73	7.43	0.16
Saccharrum spontaneum	46.67	3.17	13.57	0.29
Capillipedium spp	40	2.23	11.17	0.28
Polygonum barbatum	33.33	0.97	5.8	0.17
Ludwigia spp	26.67	0.17	1.25	0.05
Phragmites karka	26.67	0.63	4.75	0.18
Ageratum conyzoides	20	1	10	0.5

Community 7. *Alternanthera philoxeroides- Phragmites karka- Zizania latifolia* (38 Plots): This community comprised 25 species occupying minimal anthropogenic disturbance. The low frequency of occurrence of commercially exploited species is indicative of the minimal disturbance in this area of the Park. The constant species were *Scirpus mucronatus* (78.95%), *Zizania latifolia* (68.42%), *Ludwigia* spp (57.89%) and *Phragmites karka* (55.26%). *S. mucronatus* (14.63) had highest density m^{-2} followed by *Alternanthera philoxeroides* (3.63) and *P. karka* (3.12) (Table 4.7g). The most abundant species of this community was *A. philoxeroides* (39.43) followed by *S. mucronatus* (37.07) and *P. karka* (11.29). The A/F ratio indicates that all the species of this community were contagiously distributed (>0.05).

Table 4.7g. Density, frequency and abundance of various species in winter community 7 (*Alternanthera philoxeroides- Phragmites karka- Zizania latifolia*).

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Scirpus mucronatus	78.95	14.63	37.07	0.47
Zizania latifolia	65.79	3.05	9.28	0.14
Ludwigia spp	57.89	1.26	4.36	0.08
Phragmites karka	55.26	3.12	11.29	0.2
Mikania macrantha	39.47	0.72	3.67	0.09

Community 8. *Mikania micrantha – Nymphea pubesans - Mosla dianthera* (7 Plots): This community comprised 5 species and occupied an area inundated by water, as indicated by the high frequency of occurrence of *Nymphea pubesans* (71.43%) - a free floating species. The other constant species was *Mosla dianthera* (85.71%). *N. pubesans* (8.29) showed the highest density m^{-2} followed by *M. dianthera* (4.29) and *M. micrantha* (0.36). These were also the most abundant species of this community (Table 4.7h). The A/F ratio indicates that all the species of this community were contagiously distributed (>0.05).

Table 4.7h. Density, frequency and abundance of various species in winter community 8 (*Mikania micrantha – Nymphea pubesans - Mosla dianthera*).

Species	Frequency (%)	Density m^{-2}	Abundance	A/F Ratio
Mosla dianthera	85.71	4.29	10	0.12
Nymphea pubesans	71.43	8.29	23.2	0.32
Mikania micrantha	28.57	0.36	2.5	0.09
Gynura spp	14.29	0.07	1	0.07
Polygonum spp	14.29	0.64	9	0.63

4.5.7.3. Diversity Indices

Plant diversity was evaluated using different diversity indices. Shannon diversity index (*H'*) for the meadows in summer and winter were 1.335 and 1.06 respectively. Simpson diversity index (*D*`) for the meadows were 0.6344 and 0.5105 for summer and winter respectively. The species richness (S) for summer and winter was 6.8 and 6.5 respectively. The evenness (E) of the species was 0.713 and 0.583 for summer and winter respectively (Tables 4.8 & 4.9). The species richness ranged from 3.8 to 8.3 in summer whereas in winter it ranged from 2.1 to 7.8. The species evenness in summer ranged from 0.68 to 0.807 whereas in winter it ranged from 0.444 to 0.716. During summer, the Shannon diversity index ranged from 0.873 to 1.593 whereas in winter it ranged from 0.53 to 1.305. The Simpson diversity index in summer ranged from 0.4867 to 0.7226 whereas in winter it ranged from 0.2793 to 0.5465.

Table 4.8. Summer communities of the National Park and their richness, evenness and diversity indices

Summer Communities	**S**	**E**	***H'***	***D`***
Saccharum spontaneum – Leersia hexandra- Phragmites karka	4.4	0.707	1.007	0.5346
Leersia hexandra - Ageretum conizoides - Phragmites karka	7	0.697	1.362	0.6425
Capillipedium spp – Phragmites karka – Leersia hexandra	6.8	0.718	1.355	0.638
Alternanthera philoxeroides – Zizania latifolia – Bracharia spp	7.5	0.807	1.593	0.7226
Zizania latifolia - Leersia hexandra - Capillipedium spp	8.3	0.752	1.578	0.7093
Persicaria perfoliata – Leersia hexandra - Capillipedium spp	7.5	0.743	1.476	0.6867
Hedychium coronarium - Capillipedium spp - Phragmites karka	6.9	0.68	1.295	0.6098
Pteridium aquilinum - Capillipedium spp - Leersia hexandra	7	0.732	1.401	0.6646
Oryza rufipogon – Hemarthria compressa - Leersia hexandra	3.8	0.687	0.873	0.4867
Overall	6.8	0.713	1.335	0.6344

(S= Richness, E= Evenness, *H'*= Shannon index and *D'*= Simpson Index)

Table 4.9. Winter communities of the National Park and their richness, evenness and diversity indices.

Winter Communities	**S**	**E**	***H'***	***D`***
Oryza rufipogon – Setaria spp - Leersia hexandra	3.8	0.615	0.791	0.4332
Sagitaria sagitifolia - Hemarthria compressa - Leersia hexandra	3.8	0.444	0.575	0.2793
Persicaria perfoliata - Leersia hexandra - Capillipedium spp	6.8	0.594	1.106	0.5465
Zizania latifolia - Leersia hexandra - Capillipedium spp	7	0.571	1.096	0.5105
Zizania latifolia - Phragmites karka - Capillipedium spp	7.8	0.491	1.014	0.4458
Oenanthera javanica - Capillipedium spp - Zizania latifolia	5.7	0.76	1.305	0.6585
Alternanthera philoxeroides- Phragmites karka- Zizania latifolia	5.6	0.624	1.112	0.5406
Micania micrantha – Nymphea pubesans - Mosla dianthera	2.1	0.682	0.53	0.3537
Overall	6.5	0.583	1.06	0.5105

(S= Richness, E= Evenness, *H*= Shannon index and *D'*= Simpson Index)

4.6. DISCUSSIONS

4.6.1. Floating meadows thickness

The natural habitat of Sangai in the Park is seriously threatened due to permanent flooding of the Park and its resultant effect on the meadows' thickness. Results show that the meadows' thickness significantly reduced over the six year period (2005-2010) at the rate of 9% annum^{-1} or at the rate of 0.06 times every t+1 year (t=year).

The meadows in the northern zone of the Park were dynamic due to their close proximity to open water. They tend to float around depending on the direction of the wind. The meadows in the southern zone of the Park were fixed and were changing significantly at the rate of 0.12 times every t+1 year (t=year). The higher rate of change in the southern zone could be due to meadows' proliferation. The meadows in the northern zone being in a state of proliferation are maintaining a somewhat constant thickness whereas the floating meadows in the southern zone are rapidly thinning. The frequent or prolonged presence of water at or near the soil (hydrology) is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface.

Wetlands can be identified by the presence of those plants (hydrophytes) that are adapted to life in the soils that form under flooded or saturated conditions (hydric soils) characteristic of all wetlands (Mitsch & Gosselink, 1993). Thus alteration of wetland hydrology can change the soil chemistry and the plant and animal community. Alteration which reduces or increases the natural amount of water entering a wetland or the period of saturation and inundation can, in time, cause the ecosystem to change to an upland system or, conversely, to a riverine or lacustrine system. This alteration can be natural, such as through the successional process of stream impoundment or anthropogenic pressures. In the case of Keibul Lamjao National Park, the change in hydrology resulting in its effect on floating meadows thickness is man-made, the construction of the Ithai barrage in 1983 for the generation of power. These changes in the hydrology have greatly reduced the carrying capacity of the lake ecosystem, enhanced siltation, changed the nature of the Lake and adversely affected the livelihoods of the local people who depend on this Lake (Singh & Khundrakpam, 2009).

Wetland loss and degradation through hydrologic alteration by humans has occurred historically through actions such as: drainage, dredging, stream channelization, ditching, levees, and deposition of fill material, stream diversion, ground water withdrawal, and impoundment. Apart from affecting the thickness, this change has also resulted in the proliferation of the meadows so much so that it has become a nuisance in some areas of the Loktak Lake. These newly formed meadows due to proliferation are thin and cannot support the weight of Sangai. Mechanical removal of meadows was initiated in January 2010 by LDA. The work was taken up in strategic locations along the shoreline of the Lake. A total of 34.16 lakh cubic meters of floating meadows was removed by this method during 2010 (LDA, 2011). For the successful conservation of Sangai, the meadows thickness needs be to be maintained at least at 1 m or >1 m (Singh, 2002). Out of the 40 km² of the Park, meadows occupies only 26 km² and the rest 14 km² is open water (Hussain et al., 2006). Transects carried out from 2005-2010 covering the entire Park to map the habitat use of Sangai during the study period has revealed that although meadows cover 26 km², signs of habitat use was observed only in 22.3 km² of the Park. Based on these transects, the habitat most suitable for Sangai in terms of meadows thickness was found only 8.64 km². So, even though the area of meadows is increasing due to proliferation, it might not be beneficial to Sangai. The change in meadows thickness due to the change in hydrology and meadows proliferation is of great concern for the survival of Sangai.

4.6.2. Plant community structure

The plant community plays a significant role in the understanding of the structure and functioning of a particular habitat. The biological structure of the community is a result of a rich array of factors relating to both the physical and biological environment. The plant community structure represents a community’s ability to capture and utilize resources (i.e., sunlight, water, and nutrients) from different positions in the canopy and soil profile. Often grazing or human interferences without adequate monitoring, alters community structure and composition. These changes in composition and structure influence forage production, habitat values, and ultimately sustainability of the habitat to support itself (Thomas et al., 1988). It is believed that the plant composition in the Park has changed over the years (Singh, 1985) and the plant species diversity has increased significantly in response to changing environmental conditions (Shyamjai, 2002).

In the present study, 185 plant species belonging to 121 genera and 50 families were recorded. The most dominant families, Poaceae and Cyperaceae indicate the grassland nature of the Park. The dominant grass species *Phragmites karka, Saccharum spontaneum, Zizania latifolia, Leersia hexandra, Capillipedium* spp, and herb species *Alternanthera philoxeroides*, *Oenanthe javanica* and *Hedychium coronarium* contribute maximum to the forage diet of the wild ungulates in the Park, Sangai and Hog deer. The dominance of *Hemarthria compressa*, *Oryza rufipogon*, *Setaria* spp and *Leersia hexandra* in the dry hard ground of the Park indicates the distinct habitat type exhibited by the hard ground compared to the floating meadows (floating meadows). These grass species also contribute maximum to the diet of the wild ungulates which emphasis the importance of these dry patch of hard ground in the Park.

Plant community composition is described by listing dominant species within each structural layer. But some habitats like grasslands lack the structural layers due to the absence of trees and shrubs (Adams et al., 2003). Some communities reflect the dominant species whereas others lack a clear dominant species. In such cases where a particular community lacks a clear dominance, indicator species are the basis of classification. Indicator species are those which are unique more or less to a particular community or due to their abundance give a distinct identity to that community which sets it apart from other communities with the same dominant species or a species which contributes much of the number in a area (Lindenmayer et al., 2000). The nature of plant community at a place is determined by the species that grow and develop in such environment (Bliss, 1962). Difference in the species composition from site to site is mostly due to micro environmental changes (Mishra et al., 1997). In the present study, in almost all the communities, *Leersia hexandra, Phragmites karka, Saccharum spontaneum, Zizania latifolia* and *Capillipedium* spp. were the dominant species, indicated by their abundance and density in each of the summer and winter communities (Table 4.6, a-i and 4.7, a-h). These species are common and seems to be present all year round. In all the communities of both summer and winter, the distribution of the dominant species was mostly contagious indicating that wherever the species occur they occur in small or large groups forming clumps. Contagious distribution indicates micro-topographically peculiar habitat preferences by the dominant species resulting in the patch formations. Dominance of contagious distribution may be due to the fact that the majority of species reproduce vegetatively in addition to their sexual mode of reproduction. Odum (1971) described that in natural conditions contagious distribution is most common type of distribution and is performed due to small but significant variation in environmental conditions, while random distribution is found only in very uniform environment. The uniqueness of some particular species and the percentage frequency of occurrence of the common species is what set them apart into classifying into different communities.

Communities and ecosystems are dynamic in nature. Community structure varies in space (habitat type) and in time and there are directional changes that lead to permanent modifications of the ecosystem (successional changes), and non-directional changes (seasonal) that are temporary fluctuations. Changes in the physical and biological structure of communities as we move across spatial gradients (the landscape) are referred to as zonation (Smith & Smith, 2006). In the floating meadows of KLNP a non-directional change in the community structure was observed with communities differing in summer and winter seasons. Most of the annual species complete their life-cycle within one season but in some cases they extend up to the next season. The perennial species were common in each season. During summer, the total number of species (92) was high compared to winter season (51 species). During summer, just before the onset of monsoon and during early monsoon there was a clear distinction between the wet and dry communities. The wet and dry communities were separated in the first division itself. On the other hand, there was no such clear division during winter season because the whole landscape inside the Park remains flooded (floating meadows areas as well as the dry grassland area in Thangbirel). This flooding greatly reduces accessibility to various areas of the Park. Flooding also led to inaccessibility of some areas of the Park, which were otherwise easily accessible in summer resulting in fewer areas being sampled in winter compared to summer season. However, the plant species in this dry hard ground formed a separate community due to the uniqueness of the plant species present (*Oryza rufipogon*, *Hemarthria compressa* and *Seteria* spp.) which is not found in significant number in other parts of the Park. This is also the reason why species diversity, richness and evenness were more in summer compared to winter season.

On land, plants determine the vertical structure of the community. In this structure, other forms of life are distributed and adapted to live. This vertical distribution has an effect on the amount of light that penetrates to lower layers. The gradient of light affects the vertical distribution of plants and indirectly of animals. Layers or strata, e.g. trees form the canopy, smaller trees form the understory, shrubs, herbs, forest floor, and subterranean layers. Stratification is applicable to underground ecosystems as well as aquatic ecosystems (Odum, 1971). No such vertical structural distribution of the community was observed due to the absence of trees and shrubs and fewer species of tall grasses to influence the community structure of the Park as a whole. There is no obstruction to the amount of light that penetrates the lower strata due to lack of abundant tall grass species.

If the competition is severe, there is low diversity because only those species survive that are able to withstand harsh conditions by suitably adapting themselves. On the other hand, if the competition is weak and the requirements of species do not overlap, the species will not fight for resources and thus more and more species can coexist (Chapman & Reiss, 1999). The competition becomes intense if the resources for the life support system – food, air, water, space, sunlight (in case of plants, especially) are scarce and the requirements of the species overlap. Since the Park remains inundated all throughout the year, there is no shortage of nutrients and moisture. Also due to the Ithai Barrage, very less amount of nutrient that enters the Park flows out, as there is no outlet except during monsoon when the water level is very high at the barrage and the gates are opened for short periods. During other times, the gate remains closed and the water in the Park remains stagnant. The easy availability of nutrients and moisture and lack of abundant tall grasses has resulted in weak competition in the Park. Except in areas where human disturbance is high, fast growing species like *Zizania latifolia* and highly disturbance adaptive *Pteridium aquilinium* tends to overtake the other species.

Increase in dominance of grassland vegetation leads to decrease in their diversity (Singh & Yadava, 1974). Seasonal study of the grassland vegetation reveals that the density as well as the total number of species during summer season shows higher values compared to winter season. In winter season most of the rainy annuals disappear. The plant density decreases due to loss of aerial portion of annuals and disappearance of some parts of perennials also. During winter plant density decreases due to the fact that most of the species have completed their life cycle. In the present study, species diversity was higher in summer compared to winter season as per Shannon and Simpson diversity indices. The evenness (0.713) and diversity (*H'* 1.335) indicates high species diversity, which was mainly due to homogenous distribution of the species. Due to the dominance of few species (*Capillipedium spp, L. hexandra, S. mucronatus, and N. pubesans*) in winter, the diversity (1.06) and evenness (0.583) values were comparatively less. Similar trend was observed in all the communities of summer and winter seasons. This character is attributed to the fact that during summer season species sprouts depending upon the root/ seed stock in the soil and thereby add to the total species resulting in more diversity (Shadangi & Nath, 2005). During winter season the rate of sprouting of root/ seed stock is diminished and species number declines owing to adverse climatic conditions (Shadangi & Nath, 2005). The two communities' common for both summer and winter *viz. Zizania latifolia - Leersia hexandra - Capillipedium* spp and *Persicaria perfoliata - Leersia hexandra - Capillipedium* spp showed similar trends, i.e., they showed more or less homogenous distribution in summer with higher diversity values compared to the winter season. From this results, it can be inferred that season have a great influence on species diversity and distribution. An increase in species diversity was observed during summer season which declined thereafter as winter approached resulting in decreased diversity due to dry environmental conditions, slow growth rate and other climatic factors. Variation in quantitative parameters like, species richness, species evenness and species diversity can be attributed to the environmental and climatic factors.

Vegetation, particularly of the floating meadows plays a key role in governing the wetland structure and function of the Loktak Lake. The vegetation of the floating meadows includes emergent, submerged and floating type life forms. They influence hydrological regimes, harbor rich biodiversity, support productive fisheries and provide several economically important plant species to the communities. The characteristic feature of the Park, the floating mats of vegetation comprise reeds, grasses and terrestrial plants that float on the water surface. These floating mats of vegetation are thick enough (1-2 m) to support the weight of humans. Apart from the moisture loving, submerged and aquatic plants, the presence of terrestrial plants can be attributed to the floating mats of vegetation (Sharma et al., 2002). The rich vegetation of the Park is not only beneficial to the people but also provides food and shelter to the wildlife of the Park. The overexploitation of the Park needs to be checked as most of the extracted resources also play a key role for the survival of the wildlife. This over extraction of the resources is deteriorating the natural habitat of the endangered Sangai and its sympatric species Hog deer. A balance needs to be maintained whereby the extraction does not disturb the habitat of the wildlife and also maintains the integrity of the Park.

Plate 3. Different activities in and around the National Park. (a) Meadows washed away through the Ungamel outlet channel, (b) Proliferating meadows being removed by LDA, and (c) Laying quadrate during transect.

CHAPTER 5
BIOMASS PRODUCTIVITY

SUMMARY

Annual production of vegetation is an important indicator of various ecosystem processes in wetland. In general, relationship of species richness and above-ground biomass is complex and hardly predictable, especially for wetlands. During the present study the extent of above-ground biomass production of the floating meadows of the Park was estimated by the harvest method. The biomass production was determined by summation of peak live weights of individual species. Sixteen enclosures of 10 m x 10 m were constructed in different areas of the Park on different meadow types. Vegetation from 1 m x 1 m plots from these enclosures was clipped every month to quantify the above ground biomass production.

A total of forty-one plant species belonging to 18 families were recorded in the sixteen enclosures out of which 27 species were recorded from thick, 33 species from the thin meadow and only six species were recorded from the hard ground. The mean annual biomass productivity was 3545.991 ±198.2 g m^{-2} (N =24 months, N =41 species). Highest productivity was observed in the month of August and minimum in the month of February. Among the annuals *Zizania latifolia* contributed maximum biomass. Among the perennials *Phragmites karka* contributed maximum biomass followed by *Arundo donax.* The productivity was highest in monsoon, followed by winter and summer. However, no significance difference was found in the annual biomass across the season (Kruskal Wallis test, χ^2 =3.345, *df* =2, *p*>0.05). *Zizania latifolia* contributed maximum biomass among all the species in summer and monsoon whereas *Arundo donax* contributed maximum biomass among all species in winter season. In winter *Saccharum spontaneum* contributed more to the biomass. The productivity of perennial grasses was highest followed by annual grasses and annual herbs. Perennial grasses showed the highest productivity in the month of October and least in December whereas annual grasses had the highest productivity in July and least productive in February. Perennial herbs on the other hand were most productive in August and least in February whereas

annual herbs were most productive in July and were also least productive in March. There was no significant difference in the monthly biomass productivity of the annual grasses (χ^2 =8.636, *df* =11, p>0.05), annual herbs (χ^2 =8.997, *df* =11, p>0.05), perennial grasses (χ^2 =1.421, *df* =11, p>0.05) and perennial herbs (χ^2 =4.785, *df* =11, p>0.05). Productivity varied significantly across meadow types (Kruskal Wallis test, χ^2 =3.956, *df* =2, p<0.05). The thick meadows of Thangbirel showed the highest productivity followed by the thin meadows of Sagram and the least biomass was observed in the hard-ground of Thangbirel. The thick meadows of Thangbirel contributed maximum to the annual biomass with 26.4% followed by the thin meadows of Sagram with 18.7% and the least was contributed by the hard- ground of Thangbirel with 8.2%. Significant variation in the aboveground biomass production was observed in relation to rainfall (ANOVA, p<0.05) though there was no significant difference in the total rainfall in the two year study period (ANOVA, p>0.05). Regression analysis was used to compare the mean annual rainfall and the mean aboveground biomass for the study period to see the effect of rainfall on biomass. Results of the analysis showed a significant relation between rainfall and biomass during 2008-10 (R^2 =0.659, ANOVA p<0.05). There was significant variation in the AGB across the enclosures given the different treatments (Kruskal Wallis test, χ^2 =23.358, *df* =2, p< 0.05). Highest productivity was observed in the enclosure subjected to the burnt treatment (735.99 ±92.8 gm^{-2}, N =24) followed by cutting treatment (650.74 ±86.4 g m^{-2}, N =24).

5.1. INTRODUCTION

Annual production of vegetation is an important indicator of various ecosystem processes in wetland. Both biotic and abiotic factors influence production of aboveground biomass (Bhattacharjee et al., 2009). In recent years the relationship between species richness and plant productivity (Grime, 1973, 1979; Al-Mufti et al., 1977; Grace, 1999) has received a lot of attention. During environmental stress of moderate strength and interspecific competition at intermediate site productivity, more species persist in the community (Al-Mufti et al., 1977; Grime, 1979; Rosenzweig & Abramsky, 1993; Abrams, 1995). Despite global importance of wetlands, estimations of their production and biomass have received little attention (Campbell et al., 2000). Biomass is a plant attribute that is time consuming and difficult to measure or estimate, but easy to interpret. Biomass is regarded as an important indicator of ecological and management processes in the vegetation. Plants that dominate a site, in terms of biomass, are a reflection of the plants that are controlling the nutrient, water, and solar resources on the site. Therefore, biomass is often measured to assess the ecological status of a site (Zobel & Liira, 1997). Measures of standing crop also reflect the amount of energy stored in the vegetation, which can indicate the potential productivity at the site. Therefore, estimates of biomass are used in assessing rangeland condition. Scientists believe that the productivity of an individual species best explain the role of that species in the ecosystem (Bonham, 1989; Cook & Stubbendieck, 1986). Therefore, some measure of production is often used to study the dominance of species in a habitat. Biomass estimation has also been found to strongly influence the hydrologic properties of the habitat including infiltration, runoff, and erosion (Bonham, 1989).

For developing community structure theories, biomass has sometimes been measured e.g. Zobel & Liira (1997) included some wet grasslands into analysis of richness vs biomass relationship. New interest in the subject has risen in the context of biomass use for bioenergy production (Rösch et al., 2009). Net biomass productivity is the difference between gross productivity (production of plant material by photosynthesis) and respiration. So long as the rate of production exceeds that of respiration, the plant will grow. Net productivity represents the amount of organic material produced by a plant. It is closely related to a number of environmental factors like climate, soils, and available nutrients. Net biomass production will be highest where there is an ample supply of moisture to meet the needs of plants (Carmody, 2010). Biomass productivity is also high where soils are rich in nutrients and have a positive soil moisture balance. Biomass is an alternative preferred by some ecologists (Magurran, 2004; Saint-Germain et al., 2007) to study the energy flow in an ecosystem as it is assumed to provide a more direct measure of resource use Kleiber, 1962; Brown et al. 2004). In regions with a dormant season for herbaceous plants in winter, above-ground biomass (that also represents production per year) is in its maximum in the middle of summer, but before abundant flowering. In wetlands different flowering times can be noticed: the sedges usually stop growing and flower in May and June (Leht, 1999) while common reed continues growing up to the

August. The relation between plant species richness and biomass was first discussed by Grime (1973, 1979) and Al-Mufti et al. (1977) when describing general hump-back relationship between species density and community biomass. According to these authors, maximum species richness can be found at medium values of biomass. Later, this relation has been approved (Wheeler & Giller, 1982) or denied (Gough et al., 1994). According to Gough et al. (1994), two types of processes operate in the species richness–productivity relation on wetlands (i) at low levels of productivity, species richness is primarily limited by the ability of the species to survive the abiotic conditions. In this range increase in productivity reflects a decrease in the harshness of the environment (ii) at higher levels of community productivity, the decline in richness is believed to be related in some way to a greater degree of competitive exclusion with increasing productivity. For wetlands this relation was revealed by Wheeler & Giller (1982).

In general, relationship of species richness and above-ground biomass is complex and hardly predictable, especially for wetlands. Water and soil chemistry and nutrient availability to plants are among the important factors controlling the diversity and productivity of wetland vegetation (Brown, et al., 2004). Management of grasslands removes nutrients from soil and biomass production decreases. Without management, however, annual biomass production increases. Clipping increases species richness and shoot density but decrease above-ground biomass, thus creating more favorable conditions for more plant species. Bakker, et al. (2005) demonstrated that cutting reduces the vigor of tall competitive species, allowing smaller species to coexist. On wet meadows the site moisture conditions are greatly responsible for plant ecological traits.

This chapter presents the analysis of above-ground biomass production by the floating meadows of Keibul Lamjao National Park. Understanding of the productivity of the habitat and individual species will help in the management processes of the National Park for the long term survival of survival of Sangai and the unique floating ecosystem.

5.2. METHODOLOGY

Above-ground biomass of the vascular plants was estimated by the harvest method (Milner & Hughes, 1968). The biomass production was determined by summation of peak live weights of individual species. In all cases, biomass samples were air-dried before measuring. Standing biomass measured in its maximum is usually equalized with production.

For this study, 16 enclosures of 10 m x 10 m were constructed in five different areas of the Park on different types of meadows and hard ground which were taken as a representative of the entire Park. Consequently, these enclosures were harvested for two years. Vegetation from 1 m x 1 m plots from these enclosures was clipped every month to quantify the above ground biomass production. Sampling was done once in a month starting from April 2008 to March 2010. All vegetation close to the soil in all the plots was harvested. The harvested plants were sorted by species and placed in labeled paper bags. The bag containing vegetation was weighed using a pan balance and oven dried at 80ºC and again weighed for its dry weight. The difference in the fresh and oven dried weight is the total biomass of each species.

To determine the leaf and stem biomass separately, the leaves of individual species were removed from the whole plant. The leaf and stem were weighed and oven dried separately to determine the biomass. The sum of the leaf and stem biomass was the total biomass of that species for that month.

Effect of management practices in terms of burning and clipping effects on the biomass of the meadows was also studied. Since burning and cutting as a part of management practice is carried out by the Forest Department, Manipur annually (January - February), two enclosures each in the different zones of habitat were subjected to cutting and burning in the month of January each year for the two year study period. In the enclosures given the cutting treatment, all the plant species were cut down to aboveground level whereas in the burning treatment, all the plant species were burnt to aboveground level. A total of 10 enclosures were subjected to cutting and burning from the 16 enclosures constructed across the different areas of the Park.

5.3. DATA ANALYSIS

To determine if the annual productivity varied across the season, habit (annuals & perennials) and different sites, non-parametric Kruskal-Wallis test was performed between the variables, separately for seasons, sites and habit. Mann-Whitney U test was used for the variables that demonstrated significant differences. ANOVA was used to test the significance between two years sampling period. Linear mixed model was applied to test the influence of environmental variables on biomass productivity. The "best" model was chosen as the one yielding the highest explained variance, provided that the residuals did not show systematic errors or deviation from homoscedasticity (Zar, 1998). All the Statistical analyses were performed using SPSS 16.0 (SPSS, 2007).

5.4. RESULTS

5.4.1. Overall biomass production

A total of forty-one plant species (six enclosures which were used as control) belonging to 18 families were recorded in the sixteen enclosures out of which 27 species were recorded on thick, 33 species on thin floating meadows enclosures and only six species were recorded from the hard ground. Out of the forty-one species, 18 species were of grasses, 22 species herbs and one species was shrub. Poaceae was the dominant family with 13 species followed by Cyperaceae with 5 species and Asteraceae with 4 species. Twelve families of the 18 families consist of only one species each.

The mean annual biomass for the two year study period (2008-10) was 3545.991 ±198.2 g m^{-2} (N =24 months, N =41 species). The mean annual biomass for the year 2008-2009 and 2009-2010 was 3822.2 ±316.4 g m^{-2} and 3269.79 ±224.5 g m^{-2} respectively. The mean biomass produced during the year 2008-09 and 2009-10 did not vary significantly (ANOVA, $p>0.05$). The mean annual leaf and stem biomass for the two year study period was 1040.67 ±109.0 g m^{-2} and 2660.11 ±186.4 g m^{-2} respectively (Table 5.1).

Table 5.1. Annual total, leaf, stem and mean above ground biomass production of the meadows of the National Park.

Year		Total Biomass ($g\ m^{-2}$)	Mean Biomass ($g\ m^{-2}$)
	Leaf	10790.96	899.25 ±140.9
	Stem	36880.21	3073.35 ±239.1
2008-09	Total	45866.37	3822.2 ±316.4
	Leaf	14185.11	1182.09 ±161.8
	Stem	26962.41	2246.87 ±238.9
2009-10	Total	39237.42	3269.79 ±224.5
	Leaf	24976.07	1040.67 ±109.0
	Stem	63842.62	2660.11 ±186.4
2008-10	Total	85103.79	3545.99 ±198.2

During 2008-09, *Zizania latifolia* contributed maximum to the annual biomass (7535.2 g m^{-2}, $\bar{x}$ =627.93 ±117.75 g m^{-2}, N =12 months) followed by *Phragmites karka* (3842.8 g m^{-2}, $\bar{x}$ =320.23 ±46.42 g m^{-2} N =12 months) and *Arundo donax* (3373.77 g m^{-2}, $\bar{x}$ =281.15 ±51.25 g m^{-2}, N =12 months). Similarly during 2009-2010 *Zizania latifolia* contributed maximum annual biomass (6859.02 g m^{-2}, $\bar{x}$ =571.58 ±80.55 g m^{-2}, N =12) followed by *Arundo donax* (4483.04 g m^{-2}, $\bar{x}$ =373.59 ±62.41 g m^{-2}, N =12) and *Phragmites karka* (4336.87 g m^{-2}, $\bar{x}$ =361.41 ±39.3 g m^{-2}) (Table 5.2).

During 2008-2009, maximum productivity was observed in the month of August (154.34 ±31.53 g m^{-2}) and minimum in the month of March (62.7 ±19.02 g m^{-2}) whereas during 2009-2010, maximum productivity was observed in the month of September (102.87 ±27.93 g m^{-2}) and minimum in the month of February (55.26 ±17.14 g m^{-2}). Overall highest productivity was observed in the month of August (244.19 ±50.79 g m^{-2}) and minimum in the month of February (115.22 ±34.21 g m^{-2}) (Table 5.3).

Table 5.2. Species-wise contribution to the annual above ground biomass (g m^{-2}) in the National Park.

Species	2008-2009 (N =12)		2009-2010 (N =12)		2008-2010 (N =24)	
	Total	Mean	Total	Mean	Total	Mean
Zizania latifolia	7535.2	627.93 ±117.75	6859.02	571.58 ±80.55	14394.22	599.76 ±90.87
Phragmites karka	3842.8	320.23 ±46.42	4336.87	361.41 ±39.3	8179.67	340.82 ±35.06
Arundo donax	3373.77	281.15 ±51.25	4483.04	373.59 ±62.41	7856.81	327.37 ±48.56
Pteridium aquilinium	3028.41	252.37 ±49.15	3083.03	256.92 ±46.41	6111.44	254.64 ±44.88
Capillipedium spp	2241.72	186.81 ±23.84	3031.95	252.66 ±47.6	5273.67	219.74 ±27.83
Saccharum spontaneum	2682.31	223.53 ±41.94	2524.1	210.34 ±36.67	5206.42	216.93 ±35.92
Hemarthria compressa	1835.39	152.95 ±52.06	2746.05	228.84 ±52.3	4581.44	190.89 ±36.2
Hedydhium coronarium	2870.02	239.17 ±57.33	1504.71	125.39 ±19.05	4374.73	182.28 ±34.1
Leersia hexandra	2690.67	224.22 ±30.57	1673.68	139.47 ±31.92	4364.36	181.85 ±25.15
Impatiens balsamina	3035.07	252.92 ±59.68	598.35	49.86 ±12.24	3633.43	151.39 ±30.46
Osbeckia stellata	1956.39	163.03 ±44.78	797.28	66.44 ±31.33	2753.67	114.74 ±33.38
Cyperus spp	2316.91	193.08 ±34.26	65.74	5.48 ±4.55	2382.65	99.28 ±17.34
Blumea balsamiflora	1158.28	96.52 ±20.36	660.44	55.04 ±13.89	1818.72	75.78 ±14.18
Carex cruciata	668.61	55.72 ±11.8	756.34	63.03 ±21.9	1424.95	59.37 ±14.11
Scirpus lacustris	521.77	43.48 ±11.99	724.82	60.4 ±10.72	1246.58	51.94 ±8.99
Polygonum sp.	612.55	51.05 ±25.98	322.67	26.89 ±10.18	935.22	38.97 ±14
Anotis urophylla	294.45	24.54 ±8.3	571.11	47.59 ±9.74	865.56	36.06 ±7.19
Imperata cylindrica	340.91	28.41 ±7.05	458.02	38.17 ±6.5	798.93	33.29 ±4.55
Erianthus sp.	772.54	64.38 ±24.92	18.9	1.57 ±1.57	791.43	32.98 ±12.3
Spargaium erectum	608.95	50.75 ±24.91	170.83	14.24 ±4.39	779.78	32.49 ±13.23

UK6	424.29	35.36 ±12.81	353.82	29.48 ±10.06	778.11	32.42 ±7.39
Coix lacrymajobi	12.57	1.05 ±0.75	700.56	58.38 ±15.86	713.13	29.71 ±7.83
Panicum spp	358.37	29.86 ±11.81	319.58	26.63 ±5.29	677.95	28.25 ±6.27
Oryza rufipogon	294.5	24.54 ±6.07	340.2	28.35 ±7.68	634.7	26.45 ±4.34
Uk1	79.07	6.59 ±3.05	518.32	43.19 ±8.89	597.4	24.89 ±4.42
Oenanthe javanica	292.87	24.41 ±6.36	295.04	24.59 ±8.06	587.91	24.5 ±5.98
Alternanthera philoxeroides	453.7	37.81 ±35.71	68.9	5.74 ±3.03	522.6	21.78 ±18.63
Ludwigia spp	301.13	25.09 ±5.98	183.07	15.26 ±4.96	484.2	20.18 ±3.7
Persicaria perfoliata	312.4	26.03 ±11.89	131.71	10.98 ±4.05	444.1	18.5 ±6.08
Kylinga triceps	92.15	7.68 ±2.6	321.48	26.79 ±6.5	413.63	17.23 ±3.92
Fuirena umbellata	83.09	6.92 ±2.43	268.96	22.41 ±8.65	352.05	14.67 ±4.81
Alternanthera sessiles	252.73	21.06 ±8.54	37.15	3.1 ±1.5	289.88	12.08 ±4.35
Cyanotis barbata	163.97	13.66 ±4.5	101.13	8.43 ±2.75	265.1	11.05 ±2.47
Setaria sp.	158.24	13.19 ±7.11	29.9	2.49 ±1.98	188.14	7.84 ±3.54
Mikania micrantha	47.03	3.92 ±1.48	80.4	6.7 ±1.75	127.43	5.31 ±1.33
Ageratum sp.	62.59	5.22 ±3.28	49.28	4.11 ±1.4	111.86	4.66 ±1.76
Mosla dianthera	72.2	6.02 ±3.75	1.11	0.09 ±0.09	73.31	3.05 ±1.9
Eriocaulon spp	3.52	0.29 ±0.29	40.04	3.34 ±2.83	43.57	1.82 ±1.41
Colocasia antiquorum	14.26	1.19 ±0.5	6.09	0.51 ±0.51	20.35	0.85 ±0.32
Habenaria spp	0	±	3.72	0.31 ±0.31	3.72	0.16 ±0.16
Rotala rotundifolia	0.98	0.08 ±0.08	0		0.98	0.04 ±0.04
Total	45866.37		39237.42		85103.79	
Mean		3822.2 ±316.4		3269.79 ±224.5		3545.99 ±198.2

(UK = un-identified)

Table 5.3. Monthly above ground biomass productivity (g m^{-2}) of the meadows of the National Park.

	2008-2009 N =12		2009-2010 N =12		2008-2010 N =24	
Months	Total	Mean	Total	Mean	Total	Mean
Mar	2508.19	62.7 ±19.02	2657.34	66.43 ±21.65	5165.54	125.99 ±39.16
Apr	2604.58	65.11 ±21.8	2211.68	55.29 ±21.34	4816.25	117.47 ±41.09
May	4574.87	114.37 ±45.55	3917.77	97.94 ±27	8492.64	207.14 ±69.04
Jun	3560.4	89.01 ±20.09	4006.4	100.16 ±23.45	7566.8	184.56 ±38.82
Jul	4942.32	123.56 ±29.28	4089.7	102.24 ±28.73	9032.02	220.29 ±55.6
Aug	6173.59	154.34 ±31.53	3838.03	95.95 ±25.49	10011.62	244.19 ±50.79
Sep	4065.72	101.64 ±30.51	4114.63	102.87 ±27.93	8180.35	199.52 ±53.36
Oct	3811.6	95.29 ±21.9	3927.45	98.19 ±28.36	7739.04	188.76 ±46.45
Nov	4198.84	104.97 ±21.6	3039.75	75.99 ±20.65	7238.59	176.55 ±35.76
Dec	3904.08	97.6 ±25.79	2691.83	67.3 ±19.68	6595.91	160.88 ±34.4
Jan	3008.52	75.21 ±16.59	2532.41	63.31 ±20.42	5540.92	135.14 ±31.79
Feb	2513.66	62.84 ±18.55	2210.45	55.26 ±17.14	4724.11	115.22 ±34.21
Total	45866.37	3822.2 ±316.4	39237.42	3269.79 ±224.5	85103.79	3545.99 ±198.2

A total of 18 grasses, 22 herbs and only one species of shrub contributed to the total biomass in the six enclosures. Grasses contributed maximum to the annual biomass production (2 years combined 2478.36 ±108.62 g m^{-2}; Year I 2485.13 ±174.72 g m^{-2}; Year II 2471.6 ±461.54 g m^{-2}) followed by herbs (2 years combined 952.89 ±107.88 g m^{-2}; Year I 1174.04 ±177.54 g m^{-2} and Year II 731.74 ±90.85 g m^{-2}) (Table 5.4). Details of the monthly contribution of the individual species are given in Tables 5.5, 5.6, 5.7.

Table 5.4. Contribution of grasses, herbs and shrubs to annual above ground biomass (g m^{-2}) in the National Park.

Habit	2008-09		2009-10		2008-10	
	Total	Mean	Total	Mean	Total	Mean
Grasses	29821.52	2485.13 ±174.72	29659.22	2471.6 ±137.12	59480.73	2478.36 ±108.62
Herbs	14088.46	1174.04 ±177.54	8780.92	731.74 ±90.85	22869.39	952.89 ±107.88
Shrubs	1956.39	NA	797.28	NA	2753.67	NA

Table 5.5. Monthly species-wise contribution to total above ground biomass (g m^{-2}) for 2008-09 in the National Park.

Species	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Zizania latifolia	443.92	736.57	1714.43	520.28	837.75	536.77	947.76	491.47	446.80	414.60	300.29	144.56
Phragmites karka	223.48	361.52	593.84	337.77	407.18	238.77	606.92	345.97	173.63	104.99	137.81	310.93
Arundo donax	511.92	325.42	111.72	160.18	304.04	198.01	0.00	399.07	343.71	48.13	431.80	539.78
Impatiens balsamina	63.94	69.12	234.51	106.66	352.32	275.58	248.42	275.70	288.82	836.46	169.40	114.15
Pteridium aquilinium	39.60	229.75	405.06	476.10	471.76	460.64	347.92	137.65	192.55	129.34	71.09	66.95
Hedydhium coronarium	132.08	80.24	112.30	55.38	105.12	711.77	168.23	317.24	411.67	444.32	244.01	87.65
Leersia hexandra	130.40	95.50	299.42	174.37	325.33	208.44	471.64	255.88	258.02	144.02	197.55	130.12
Saccharum spontaneum	353.47	113.62	114.77	37.88	55.46	120.57	219.09	450.37	313.00	298.20	160.81	445.06
Cyperus spp	145.02	87.66	162.89	180.88	210.68	503.55	158.36	115.90	322.69	233.33	103.60	92.37
Capillipedium spp	124.66	84.09	97.73	157.76	339.71	259.12	227.91	113.78	262.04	268.17	182.63	124.13
Osbeckia stellata	27.05	119.11	195.44	81.73	111.61	556.74	0.00	241.46	173.65	119.58	313.81	16.22
Hemarthria compressa	76.54	114.58	181.59	289.38	497.25	499.70	50.51	29.10	19.57	27.68	26.97	22.51
Blumea balsamiflora	17.63	14.64	17.52	78.79	128.46	47.67	114.69	94.16	236.47	205.36	103.53	99.37
Erianthus sp.	22.62	0.00	31.21	0.00	117.37	195.30	64.68	27.18	269.67	10.72	15.53	18.27
Carex cruciata	17.86	6.22	82.13	89.19	121.03	116.16	78.66	36.18	23.97	43.92	49.18	4.13
Polygonum sp.	1.83	1.33	6.60	17.53	22.80	320.04	31.02	6.84	36.74	29.99	115.23	22.62
Spargaium erectum	0.00	1.05	35.77	249.39	210.78	5.08	64.82	5.18	0.00	22.08	13.39	1.41
Scirpus lacustris	36.34	15.57	0.00	99.62	17.94	103.72	0.00	89.03	0.00	78.84	69.39	11.31
Alternanthera philoxeroides	0.00	0.00	0.97	3.64	2.55	430.37	0.00	15.80	0.00	0.00	0.38	0.00
UK6	18.18	9.09	0.00	0.00	19.49	2.61	36.71	58.80	11.75	35.98	153.20	78.49
Panicum spp	5.94	0.25	31.49	103.43	12.10	13.48	8.15	6.78	126.11	8.77	27.37	14.50
Imperata cylindrica	12.23	0.77	39.16	27.60	11.32	10.23	17.18	37.92	96.03	29.01	29.11	30.37
Persicaria perfoliata	4.45	1.41	7.86	8.31	46.39	150.03	20.42	14.61	11.60	33.46	5.37	8.49

Species	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Ludwigia spp	21.59	25.84	0.00	26.32	68.19	45.35	39.71	1.05	12.22	0.00	21.54	39.33
Oryza rufipogon	10.36	15.24	20.35	19.67	12.36	4.85	3.92	63.54	51.91	56.96	26.56	8.80
Anotis urophylla	17.65	29.13	17.30	99.74	5.76	15.66	9.69	0.00	56.75	35.71	0.00	7.06
Oenanthe javanica	9.62	14.36	18.36	62.46	48.92	33.62	63.22	1.57	7.71	12.37	10.48	10.19
Alternanthera sessiles	5.49	9.67	1.98	31.07	23.80	0.00	12.36	102.94	0.00	47.00	0.00	18.42
Cyanotis barbata	19.72	27.45	6.11	7.90	13.66	6.24	1.35	0.00	7.71	55.12	0.00	18.72
Setaria sp.	3.47	4.88	7.67	16.73	3.41	89.65	0.00	4.75	10.49	13.60	0.00	3.59
Kylinga triceps	0.83	0.79	0.75	1.52	15.72	0.76	27.84	2.32	3.45	18.07	13.64	6.46
Fuirena umbellata	0.00	0.00	0.00	0.00	8.15	5.25	13.01	24.68	0.00	18.76	11.15	2.10
Uk1	2.53	4.04	23.57	0.00	0.00	0.00	0.00	0.00	20.91	27.02	0.00	1.01
Mosla dianthera	0.00	0.00	0.00	24.82	0.00	7.04	0.00	40.34	0.00	0.00	0.00	0.00
Ageratum sp.	0.00	0.00	0.00	0.00	13.96	0.00	0.00	0.00	0.00	37.89	0.00	10.74
Mikania micrantha	7.80	5.19	1.66	14.38	0.00	0.00	0.00	0.00	0.00	12.64	3.70	1.68
Colocasia antiquorum	0.00	0.49	0.74	0.00	0.00	0.88	3.27	0.00	5.68	1.01	0.00	2.18
Coix lacrymajobi	0.00	0.00	0.00	0.00	0.00	0.00	8.26	4.31	0.00	0.00	0.00	0.00
Eriocaulon spp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.52	0.00	0.00	0.00
Rotala rotundifolia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.98	0.00	0.00
Total	2508.19	2604.58	4574.87	3560.40	4942.32	6173.59	4065.72	3811.60	4198.84	3904.08	3008.52	2513.66
Mean	62.7 ± 19.02	65.11 ± 21.8	114.37 ± 45.55	89.01 ± 20.09	123.56 ± 29.28	154.34 ± 31.53	101.64 ± 30.51	95.29 ± 21.9	104.97 ± 21.6	97.6 ± 25.79	75.21 ± 16.59	62.84 ± 18.55

(UK = un-identified)

Table 5.6. Monthly species-wise contribution to total above ground biomass (g m^{-2}) for 2009-10 in the National Park.

Species	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Zizania latifolia	482.04	808.97	810.37	602.07	897.88	837.55	780.22	627.68	486.35	298.85	46.61	180.43
Arundo donax	673.14	167.65	204.22	207.71	107.73	215.46	502.50	789.54	305.89	310.63	485.79	512.78
Phragmites karka	194.08	154.96	664.02	386.72	341.45	276.33	402.60	436.69	396.91	453.14	392.67	237.31
Pteridium aquilinium	150.15	229.82	378.14	192.84	542.29	435.88	383.52	320.80	274.71	85.93	44.85	44.12
Capillipedium spp	105.31	56.42	143.00	651.92	192.79	265.38	463.93	308.51	169.37	199.99	291.27	184.07
Hemarthria compressa	50.16	50.51	60.11	94.86	418.69	203.49	76.85	174.54	452.52	548.13	416.88	199.33
Saccharum spontaneum	319.84	9.63	240.79	137.18	31.13	112.16	272.89	342.57	235.97	104.73	353.96	363.26
Leersia hexandra	109.62	66.74	256.77	255.26	403.18	166.15	86.54	86.12	50.91	59.14	54.33	78.91
Hedydhium coronarium	70.69	79.90	98.71	62.12	131.50	216.86	264.91	191.14	89.73	108.44	131.26	59.46
Osbeckia stellata	30.79	79.02	39.64	0.16	45.20	354.92	212.91	0.00	12.39	14.84	7.42	0.00
Carex cruciata	77.01	154.03	75.03	229.80	136.27	64.77	4.71	5.45	6.19	3.10	0.00	0.00
Scirpus lacustris	0.00	0.00	92.41	98.25	95.22	96.11	97.00	69.48	41.96	49.34	56.71	28.35
Coix lacrymajobi	23.10	46.20	160.71	171.26	56.02	32.08	8.14	45.02	81.91	52.68	23.45	0.00
Blumea balsamiflora	2.22	3.61	34.30	24.18	127.72	84.47	112.56	128.42	68.97	46.89	20.47	6.64
Impatiens balsamina	40.26	0.00	96.06	84.14	141.72	83.23	15.69	13.02	22.76	23.45	30.76	47.28
Anotis urophylla	18.83	37.66	58.05	70.48	14.29	60.95	107.60	88.82	70.03	35.01	0.00	9.41
Uk1	58.16	116.31	63.89	58.56	51.28	45.79	40.31	28.85	17.40	8.70	0.00	29.08
Imperata cylindrica	44.42	88.85	44.76	72.77	14.89	16.39	17.88	27.68	37.49	31.73	25.97	35.20
UK6	2.40	0.00	21.06	91.46	16.87	43.43	96.34	57.79	1.73	9.27	7.86	5.63
Oryza rufipogon	34.64	3.92	41.14	80.09	49.99	30.10	4.03	0.00	0.00	52.98	0.00	43.32
Polygonum sp.	111.57	0.00	28.80	5.56	6.82	16.89	13.32	3.25	3.37	5.82	77.32	49.97
Kylinga triceps	1.26	0.97	35.19	26.10	56.39	46.41	63.25	47.78	20.32	13.14	7.88	2.80

Panicum spp	27.29	38.21	44.75	53.78	36.07	33.01	40.51	20.26	0.00	0.00	0.00	25.72
Oenanthe javanica	6.53	11.47	92.87	61.83	45.09	24.24	8.09	10.72	16.21	11.49	3.56	2.96
Fuirena umbellata	0.00	0.00	0.83	10.92	28.39	14.19	0.00	48.49	96.98	53.66	10.34	5.17
Ludwigia spp	0.00	0.00	0.00	45.76	21.70	14.01	6.31	24.44	46.36	22.09	1.61	0.80
Spargaium erectum	8.93	4.03	30.24	22.91	20.18	1.00	3.64	6.28	8.08	53.16	9.05	3.35
Persicaria perfoliata	7.53	0.00	51.86	19.25	13.72	7.03	11.02	2.90	0.00	3.56	7.93	6.93
Cyanotis barbata	1.13	0.00	33.45	8.19	20.23	9.62	4.42	4.18	7.54	7.63	2.48	2.26
Mikania micrantha	1.36	0.00	0.00	17.13	0.00	3.14	6.29	9.10	16.24	10.24	9.92	6.99
Alternanthera philoxeroides	0.00	0.00	1.40	33.17	3.16	21.71	3.16	0.00	0.00	2.00	2.87	1.44
Cyperus spp	0.00	0.00	0.00	55.07	7.12	3.56	0.00	0.00	0.00	0.00	0.00	0.00
Ageratum sp.	1.41	2.83	9.18	11.14	14.75	1.76	3.52	2.49	1.47	0.74	0.00	0.00
Eriocaulon spp	0.00	0.00	6.06	33.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alternanthera sessiles	2.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.38	9.21	13.82
Setaria sp.	0.77	0.00	0.00	0.00	0.00	0.00	0.00	5.47	0.00	0.00	0.00	23.67
Erianthus sp.	0.00	0.00	0.00	18.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Colocasia antiquorum	0.00	0.00	0.00	6.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Habenaria spp	0.00	0.00	0.00	3.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mosla dianthera	0.00	0.00	0.00	1.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	2657.3	2211.68	3917.77	4006.40	4089.70	3838.03	4114.63	3927.45	3039.75	2691.83	2532.41	2210.45
Mean	66.43 ± 21.65	55.29 ± 21.34	97.94 ± 27	100.16 ± 23.45	102.24 ± 28.73	95.95 ± 25.49	102.87 ± 27.93	98.19 ± 28.36	75.99 ± 20.65	67.3 ± 19.68	63.31 ± 20.42	55.26 ± 17.14

(UK = un-identified)

Table 5.7. Monthly species-wise contribution to total above ground biomass (g m^{-2}) for 2008-10 in the National Park.

Species	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Zizania latifolia	925.96	1545.54	2524.80	1122.34	1735.62	1374.32	1727.98	1119.16	933.16	713.45	346.90	324.99
Phragmites karka	417.56	516.48	1257.86	724.48	748.62	515.09	1009.52	782.66	570.54	558.13	530.47	548.24
Arundo donax	1185.06	493.07	315.94	367.89	411.77	413.47	502.50	1188.61	649.60	358.76	917.59	1052.56
Pteridium aquilinium	189.75	459.56	783.21	668.93	1014.05	896.51	731.44	458.45	467.27	215.27	115.94	111.08
Capillipedium spp	229.96	140.51	240.73	809.68	532.50	524.50	691.84	422.29	431.42	468.16	473.90	308.19
Saccharum spontaneum	673.31	123.25	355.56	175.06	86.59	232.73	491.99	792.94	548.97	402.93	514.78	808.32
Hemarthria compressa	126.70	165.09	241.70	384.24	915.94	703.19	127.36	203.64	472.09	575.81	443.86	221.84
Hedydhium coronarium	202.77	160.14	211.01	117.50	236.62	928.63	433.14	508.38	501.40	552.77	375.26	147.12
Leersia hexandra	240.02	162.24	556.19	429.63	728.51	374.59	558.18	342.00	308.93	203.17	251.88	209.03
Impatiens balsamina	104.20	69.12	330.57	190.80	494.03	358.81	264.11	288.72	311.58	859.91	200.17	161.42
Osbeckia stellata	57.83	198.13	235.08	81.88	156.80	911.66	212.91	241.46	186.03	134.43	321.24	16.22
Cyperus spp	145.02	87.66	162.89	235.95	217.80	507.10	158.36	115.90	322.69	233.33	103.60	92.37
Blumea balsamiflora	19.85	18.24	51.82	102.97	256.18	132.14	227.25	222.59	305.44	252.25	123.99	106.01
Carex cruciata	94.87	160.25	157.16	318.98	257.30	180.92	83.37	41.62	30.16	47.01	49.18	4.13
Scirpus lacustris	36.34	15.57	92.41	197.87	113.16	199.83	97.00	158.51	41.96	128.18	126.09	39.66
Polygonum sp.	113.40	1.33	35.40	23.09	29.61	336.92	44.33	10.09	40.11	35.81	192.54	72.59
Anotis urophylla	36.48	66.79	75.35	170.21	20.04	76.61	117.29	88.82	126.77	70.72	0.00	16.48
Imperata cylindrica	56.65	89.62	83.92	100.36	26.21	26.61	35.05	65.61	133.52	60.74	55.08	65.56
Erianthus sp.	22.62	0.00	31.21	18.90	117.37	195.30	64.68	27.18	269.67	10.72	15.53	18.27
Spargaium erectum	8.93	5.08	66.01	272.30	230.96	6.07	68.46	11.46	8.08	75.24	22.44	4.76
UK6	20.58	9.09	21.06	91.46	36.36	46.04	133.04	116.59	13.48	45.24	161.06	84.12
Coix lacrymajobi	23.10	46.20	160.71	171.26	56.02	32.08	16.39	49.33	81.91	52.68	23.45	0.00

Panicum spp	33.22	38.45	76.23	157.21	48.18	46.49	48.66	27.04	126.11	8.77	27.37	40.22
Oryza rufipogon	44.99	19.16	61.48	99.76	62.35	34.95	7.95	63.54	51.91	109.94	26.56	52.12
Uk1	60.68	120.35	87.46	58.56	51.28	45.79	40.31	28.85	38.31	35.72	0.00	30.09
Oenanthe javanica	16.15	25.83	111.22	124.29	94.01	57.85	71.31	12.29	23.91	23.86	14.04	13.15
Alternanthera philoxeroides	0.00	0.00	2.37	36.81	5.70	452.08	3.16	15.80	0.00	2.00	3.25	1.44
Ludwigia spp	21.59	25.84	0.00	72.08	89.89	59.35	46.02	25.49	58.58	22.09	23.14	40.13
Persicaria perfoliata	11.97	1.41	59.72	27.56	60.11	157.05	31.44	17.51	11.60	37.02	13.31	15.42
Kylinga triceps	2.10	1.76	35.94	27.61	72.11	47.16	91.10	50.10	23.77	31.21	21.52	9.26
Fuirena umbellata	0.00	0.00	0.83	10.92	36.54	19.44	13.01	73.17	96.98	72.42	21.48	7.27
Alternanthera sessiles	8.24	9.67	1.98	31.07	23.80	0.00	12.36	102.94	0.00	58.38	9.21	32.24
Cyanotis barbata	20.85	27.45	39.55	16.09	33.89	15.87	5.77	4.18	15.25	62.75	2.48	20.98
Setaria sp.	4.23	4.88	7.67	16.73	3.41	89.65	0.00	10.22	10.49	13.60	0.00	27.26
Mikania micrantha	9.15	5.19	1.66	31.51	0.00	3.14	6.29	9.10	16.24	22.87	13.61	8.67
Ageratum sp.	1.41	2.83	9.18	11.14	28.71	1.76	3.52	2.49	1.47	38.62	0.00	10.74
Mosla dianthera	0.00	0.00	0.00	25.93	0.00	7.04	0.00	40.34	0.00	0.00	0.00	0.00
Eriocaulon spp	0.00	0.00	6.06	33.99	0.00	0.00	0.00	0.00	3.52	0.00	0.00	0.00
Colocasia antiquorum	0.00	0.49	0.74	6.09	0.00	0.88	3.27	0.00	5.68	1.01	0.00	2.18
Habenaria spp	0.00	0.00	0.00	3.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rotala rotundifolia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.98	0.00	0.00
Total	5165.54	4816.25	8492.64	7566.80	9032.02	10011.62	8180.35	7739.04	7238.59	6595.91	5540.92	4724.11
Mean	125.99 ± 39.16	117.47 ± 41.09	207.14 ± 69.04	184.56 ± 38.82	220.29 ± 55.6	244.19 ± 50.79	199.52 ± 53.36	188.76 ± 46.45	176.55 ± 35.76	160.88 ± 34.4	135.14 ± 31.79	115.22 ± 34.21

(UK = un-identified)

5.4.2. Percentage contribution of individual species

Zizania latifolia (16.4%) contributed maximum percentage to the biomass production in Year I followed by *Phragmites karka* (8.4%), *Arundo donax* (7.4%), *Impatiens balsamina* (6.6%), *Pteridium aquilinium* (6.6%), *Hedychium coronarium* (6.3%) and *Leersia hexandra* (5.9%). *Zizania latifolia* showed highest productivity in the month of May (37.5%) and least productivity in February (5.8%) (Table 5.8, Figure 5.1).

Table 5.8. Monthly and species wise percentage above ground biomass (g m^{-2}) for 2008-09 in the National Park.

Species	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Total
Zizania latifolia	17.7	28.3	37.5	14.6	17.0	8.7	23.3	12.9	10.6	10.6	10.0	5.8	16.4
Phragmites karka	8.9	13.9	13.0	9.5	8.2	3.9	14.9	9.1	4.1	2.7	4.6	12.4	8.4
Arundo donax	20.4	12.5	2.4	4.5	6.2	3.2	0.0	10.5	8.2	1.2	14.4	21.5	7.4
Impatiens balsamina	2.5	2.7	5.1	3.0	7.1	4.5	6.1	7.2	6.9	21.4	5.6	4.5	6.6
Pteridium aquilinium	1.6	8.8	8.9	13.4	9.5	7.5	8.6	3.6	4.6	3.3	2.4	2.7	6.6
Hedydhium coronarium	5.3	3.1	2.5	1.6	2.1	11.5	4.1	8.3	9.8	11.4	8.1	3.5	6.3
Leersia hexandra	5.2	3.7	6.5	4.9	6.6	3.4	11.6	6.7	6.1	3.7	6.6	5.2	5.9
Saccharum spontaneum	14.1	4.4	2.5	1.1	1.1	2.0	5.4	11.8	7.5	7.6	5.3	17.7	5.8
Cyperus spp	5.8	3.4	3.6	5.1	4.3	8.2	3.9	3.0	7.7	6.0	3.4	3.7	5.1
Capillipedium spp	5.0	3.2	2.1	4.4	6.9	4.2	5.6	3.0	6.2	6.9	6.1	4.9	4.9
Osbeckia stellata	1.1	4.6	4.3	2.3	2.3	9.0	0.0	6.3	4.1	3.1	10.4	0.6	4.3
Hemarthria compressa	3.1	4.4	4.0	8.1	10.1	8.1	1.2	0.8	0.5	0.7	0.9	0.9	4.0
Blumea balsamiflora	0.7	0.6	0.4	2.2	2.6	0.8	2.8	2.5	5.6	5.3	3.4	4.0	2.5
Erianthus sp.	0.9	0.0	0.7	0.0	2.4	3.2	1.6	0.7	6.4	0.3	0.5	0.7	1.7
Carex cruciata	0.7	0.2	1.8	2.5	2.4	1.9	1.9	0.9	0.6	1.1	1.6	0.2	1.5
Polygonum sp.	0.1	0.1	0.1	0.5	0.5	5.2	0.8	0.2	0.9	0.8	3.8	0.9	1.3
Spargaium erectum	0.0	0.0	0.8	7.0	4.3	0.1	1.6	0.1	0.0	0.6	0.4	0.1	1.3
Scirpus lacustris	1.4	0.6	0.0	2.8	0.4	1.7	0.0	2.3	0.0	2.0	2.3	0.4	1.1
Alternanthera philoxeroides	0.0	0.0	0.0	0.1	0.1	7.0	0.0	0.4	0.0	0.0	0.0	0.0	1.0

UK6	0.7	0.3	0.0	0.0	0.4	0.0	0.9	1.5	0.3	0.9	5.1	3.1	0.9
Panicum spp	0.2	0.0	0.7	2.9	0.2	0.2	0.2	0.2	3.0	0.2	0.9	0.6	0.8
Imperata cylindrica	0.5	0.0	0.9	0.8	0.2	0.2	0.4	1.0	2.3	0.7	1.0	1.2	0.7
Persicaria perfoliata	0.2	0.1	0.2	0.2	0.9	2.4	0.5	0.4	0.3	0.9	0.2	0.3	0.7
Ludwigia spp	0.9	1.0	0.0	0.7	1.4	0.7	1.0	0.0	0.3	0.0	0.7	1.6	0.7
Oryza rufipogon	0.4	0.6	0.4	0.6	0.3	0.1	0.1	1.7	1.2	1.5	0.9	0.3	0.6
Anotis urophylla	0.7	1.1	0.4	2.8	0.1	0.3	0.2	0.0	1.4	0.9	0.0	0.3	0.6
Oenanthe javanica	0.4	0.6	0.4	1.8	1.0	0.5	1.6	0.0	0.2	0.3	0.3	0.4	0.6
Alternanthera sessiles	0.2	0.4	0.0	0.9	0.5	0.0	0.3	2.7	0.0	1.2	0.0	0.7	0.6
Cyanotis barbata	0.8	1.1	0.1	0.2	0.3	0.1	0.0	0.0	0.2	1.4	0.0	0.7	0.4
Setaria sp.	0.1	0.2	0.2	0.5	0.1	1.5	0.0	0.1	0.2	0.3	0.0	0.1	0.3
Kylinga triceps	0.0	0.0	0.0	0.0	0.3	0.0	0.7	0.1	0.1	0.5	0.5	0.3	0.2
Fuirena umbellata	0.0	0.0	0.0	0.0	0.2	0.1	0.3	0.6	0.0	0.5	0.4	0.1	0.2
Uk1	0.1	0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.7	0.0	0.0	0.2
Mosla dianthera	0.0	0.0	0.0	0.7	0.0	0.1	0.0	1.1	0.0	0.0	0.0	0.0	0.2
Ageratum sp.	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	1.0	0.0	0.4	0.1
Mikania micrantha	0.3	0.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.1
Colocasia antiquorum	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0
Coix lacrymajobi	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0
Eriocaulon spp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Rotala rotundifolia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

(UK = un-identified)

Table 5.9. Monthly and species wise percentage above ground biomass (g m^{-2}) for 2009-10 in the National Park.

Species	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Total
Zizania latifolia	18.1	36.6	20.7	15.0	22.0	21.8	19.0	16.0	16.0	11.1	1.8	8.2	17.5
Arundo donax	25.3	7.6	5.2	5.2	2.6	5.6	12.2	20.1	10.1	11.5	19.2	23.2	11.4
Phragmites karka	7.3	7.0	16.9	9.7	8.3	7.2	9.8	11.1	13.1	16.8	15.5	10.7	11.1
Pteridium aquilinium	5.7	10.4	9.7	4.8	13.3	11.4	9.3	8.2	9.0	3.2	1.8	2.0	7.9
Capillipedium spp	4.0	2.6	3.7	16.3	4.7	6.9	11.3	7.9	5.6	7.4	11.5	8.3	7.7
Hemarthria compressa	1.9	2.3	1.5	2.4	10.2	5.3	1.9	4.4	14.9	20.4	16.5	9.0	7.0
Saccharum spontaneum	12.0	0.4	6.1	3.4	0.8	2.9	6.6	8.7	7.8	3.9	14.0	16.4	6.4
Leersia hexandra	4.1	3.0	6.6	6.4	9.9	4.3	2.1	2.2	1.7	2.2	2.1	3.6	4.3
Hedychium coronarium	2.7	3.6	2.5	1.6	3.2	5.7	6.4	4.9	3.0	4.0	5.2	2.7	3.8
Osbeckia stellata	1.2	3.6	1.0	0.0	1.1	9.2	5.2	0.0	0.4	0.6	0.3	0.0	2.0
Carex cruciata	2.9	7.0	1.9	5.7	3.3	1.7	0.1	0.1	0.2	0.1	0.0	0.0	1.9
Scirpus lacustris	0.0	0.0	2.4	2.5	2.3	2.5	2.4	1.8	1.4	1.8	2.2	1.3	1.8
Coix lacrymajobi	0.9	2.1	4.1	4.3	1.4	0.8	0.2	1.1	2.7	2.0	0.9	0.0	1.8
Blumea balsamiflora	0.1	0.2	0.9	0.6	3.1	2.2	2.7	3.3	2.3	1.7	0.8	0.3	1.7
Impatiens balsamina	1.5	0.0	2.5	2.1	3.5	2.2	0.4	0.3	0.7	0.9	1.2	2.1	1.5
Anotis urophylla	0.7	1.7	1.5	1.8	0.3	1.6	2.6	2.3	2.3	1.3	0.0	0.4	1.5
Uk1	2.2	5.3	1.6	1.5	1.3	1.2	1.0	0.7	0.6	0.3	0.0	1.3	1.3
Imperata cylindrica	1.7	4.0	1.1	1.8	0.4	0.4	0.4	0.7	1.2	1.2	1.0	1.6	1.2
UK6	0.1	0.0	0.5	2.3	0.4	1.1	2.3	1.5	0.1	0.3	0.3	0.3	0.9
Oryza rufipogon	1.3	0.2	1.0	2.0	1.2	0.8	0.1	0.0	0.0	2.0	0.0	2.0	0.9
Polygonum sp.	4.2	0.0	0.7	0.1	0.2	0.4	0.3	0.1	0.1	0.2	3.1	2.3	0.8
Kylinga triceps	0.0	0.0	0.9	0.7	1.4	1.2	1.5	1.2	0.7	0.5	0.3	0.1	0.8
Panicum spp	1.0	1.7	1.1	1.3	0.9	0.9	1.0	0.5	0.0	0.0	0.0	1.2	0.8
Oenanthe javanica	0.2	0.5	2.4	1.5	1.1	0.6	0.2	0.3	0.5	0.4	0.1	0.1	0.8
Fuirena umbellata	0.0	0.0	0.0	0.3	0.7	0.4	0.0	1.2	3.2	2.0	0.4	0.2	0.7
Ludwigia spp	0.0	0.0	0.0	1.1	0.5	0.4	0.2	0.6	1.5	0.8	0.1	0.0	0.5
Spargaium erectum	0.3	0.2	0.8	0.6	0.5	0.0	0.1	0.2	0.3	2.0	0.4	0.2	0.4
Persicaria perfoliata	0.3	0.0	1.3	0.5	0.3	0.2	0.3	0.1	0.0	0.1	0.3	0.3	0.3
Cyanotis barbata	0.0	0.0	0.9	0.2	0.5	0.3	0.1	0.1	0.2	0.3	0.1	0.1	0.3
Mikania micrantha	0.1	0.0	0.0	0.4	0.0	0.1	0.2	0.2	0.5	0.4	0.4	0.3	0.2

Alternanthera philoxeroides	0.0	0.0	0.0	0.8	0.1	0.6	0.1	0.0	0.0	0.1	0.1	0.1	0.2
Cyperus spp	0.0	0.0	0.0	1.4	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Ageratum sp.	0.1	0.1	0.2	0.3	0.4	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1
Eriocaulon spp	0.0	0.0	0.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Alternanthera sessiles	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.6	0.1
Setaria sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	1.1	0.1
Erianthus sp.	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Colocasia antiquorum	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Habenaria spp	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mosla dianthera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rotala rotundifolia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

(UK = un-identified)

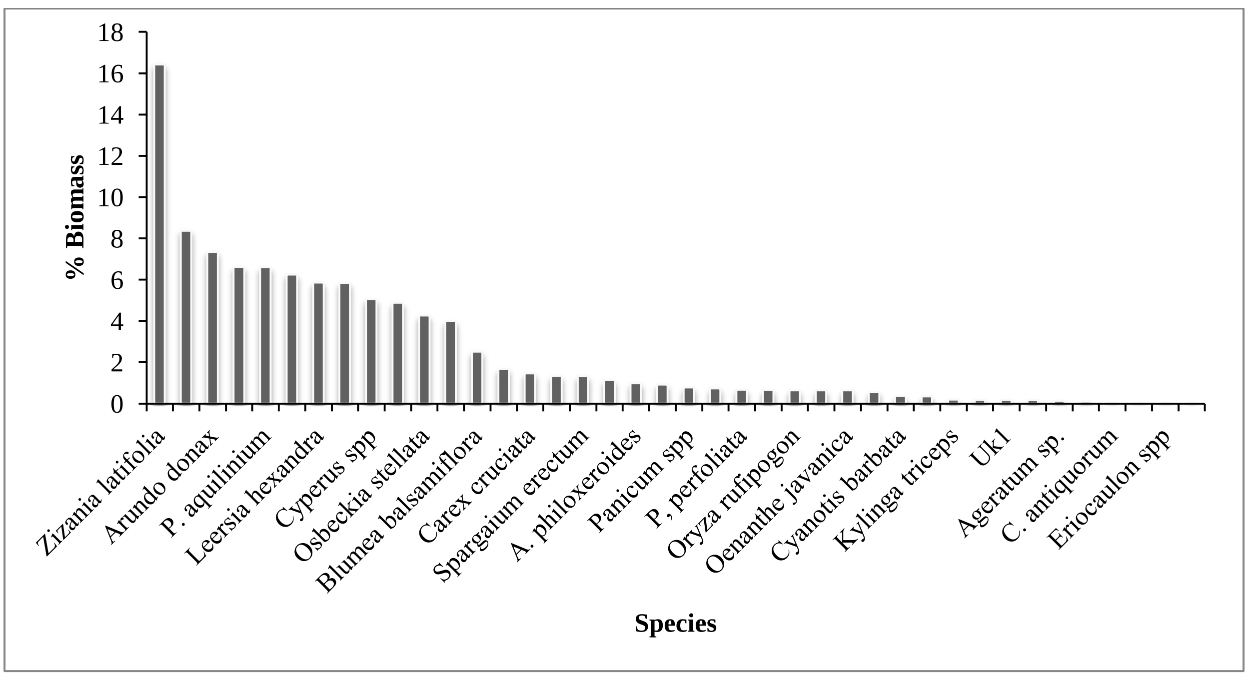


Figure 5.1. Percentage biomass contribution of individual species (2008-09) in the National Park.

Also during Year II, *Zizania latifolia* (17.5%) contributed maximum percentage to the biomass production followed by *Arundo donax* (11.4%), *Phragmites karka* (11.1%), *Pteridium aquilinium* (7.9%), *Capillipedium* spp. (7.4%), *Hemarthria compressa* (7.0%), *Saccharum spontaneum* (6.4%) and *Leersia hexandra* (4.3%). *Zizania latifolia* showed highest productivity in the month of April (36.6%) and least productivity in the month of January (1.8%) (Table 5.9, Figure 5.2).

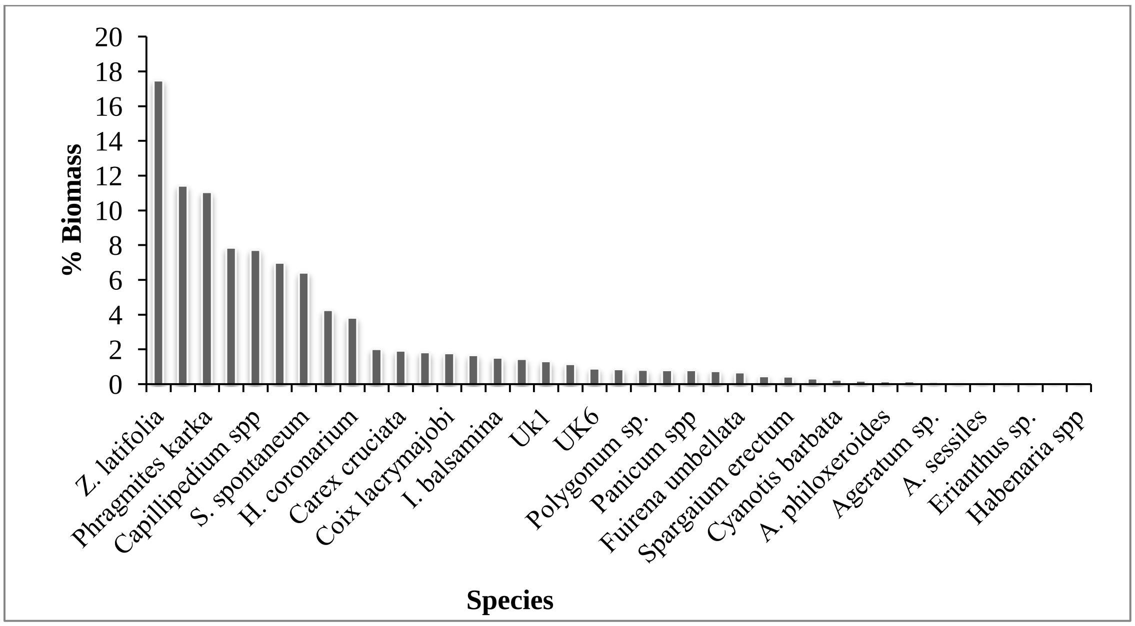


Figure 5.2. Percentage biomass contribution of individual species (2009-10) in the National Park.

5.4.3. Contribution of annuals and perennials to biomass

Out of the forty-one species recorded in the enclosures, 15 species are perennials and 26 species are annuals. The annuals (Year I =63.23%; Year II =57.47%; N= 12) contribute more to biomass productivity than the perennials (Year I =36.77%; Year II =42.53%; N =12). Among the annuals, *Zizania latifolia* contributed maximum biomass (Year I =25.98; Year II =30.42). The other species that contributed more in Year I are *Impatiens balsamina*(10.47%), *Pteridium aquilinium* (10.44%) and *Leersia hexandra* (9.28%) whereas in Year II, the species that contributed more are *Pteridium aquilinium* (13.67%), *Capillipedium* spp. (13.45%) and *Saccharum spontaneum* (11.19%). Among the perennials, *Phragmites karka* (22.78%) contributed maximum biomass in Year I followed by *Arundo donax* (20%), *Hedychium coronarium* (17.02%) and *Osbeckia stellata* (11.6%) whereas in Year II *Arundo donax* (26.86%) followed by *Phragmites karka* (25.99%), *Hemarthria compressa* (16.45%) *Hedychium coronarium* (9.02%) and *Osbeckia stellata* (5.91%) contributed maximum biomass (Table 5.10, Figure 5.3).

Table 5.10. Percentage contribution of annuals and perennials to above ground biomass in the National Park. (A= Annuals, P= Perennials)

Species	Habit	% Biomass (2008-09)	% Biomass (2009-10)	% Biomass (2008-10)
Alternanthera philoxeroides	P	2.69	0.41	1.56
Alternanthera sessiles	P	1.50	0.22	0.86
Arundo donax	P	20.00	26.86	23.41
Carex cruciata	P	3.96	4.53	4.25
Colocasia antiquorum	P	0.08	0.04	0.06
Hedydhium coronarium	P	17.02	9.02	13.04
Hemarthria compressa	P	10.88	16.45	13.65
Imperata cylindrica	P	2.02	2.74	2.38
Lycopus uniflorus	P	0.47	3.11	1.78
Mikania micrantha	P	0.28	0.48	0.38
Osbeckia stellata	P	11.60	4.78	8.21
Phragmites karka	P	22.78	25.99	24.38
Rotala rotundifolia	P	0.01	0.00	0.00
Scirpus lacustris	P	3.09	4.34	3.72
Spargaium erectum	P	3.61	1.02	2.32
Overall		36.77	42.53	39.43
Ageratum sp.	A	0.22	0.22	0.22
Blumea balsamiflora	A	1.46	1.57	1.51
Capillipedium spp	A	7.73	13.45	10.23
Coix lacrymajobi	A	0.04	3.11	1.38
Cyanotis barbata	A	0.57	0.45	0.51
Cyperus spp	A	7.99	0.29	4.62
Erianthus sp.	A	2.66	0.08	1.54
Eriocaulon spp	A	0.01	0.18	0.08
Fuirena umbellata	A	0.29	1.19	0.68
Habenaria spp	A	0.00	0.02	0.01
Impatiens balsamina	A	10.47	2.65	7.05
Kylinga triceps	A	0.32	1.43	0.80

Species	Habit	% Biomass (2008-09)	% Biomass (2009-10)	% Biomass (2008-10)
Leersia hexandra	A	9.28	7.42	8.47
Ludwigia spp	A	1.04	0.81	0.94
Mosla dianthera	A	0.25	0.00	0.14
Oenanthe javanica	A	1.01	1.31	1.14
Oryza rufipogon	A	1.02	1.51	1.23
Panicum spp	A	1.24	1.42	1.32
Persicaria perfoliata	A	1.08	0.58	0.86
Polygonum sp.	A	2.11	1.43	1.81
Pteridium aquilinium	A	10.44	13.67	11.86
Saccharum spontaneum	A	9.25	11.19	10.10
Setaria sp.	A	0.55	0.13	0.36
Zizania latifolia	A	25.98	30.42	27.92
UK 1	A	1.02	2.53	3.53
Uk 6	A	3.99	2.93	1.68
Overall		63.23	57.47	60.57

(UK = un-identified)

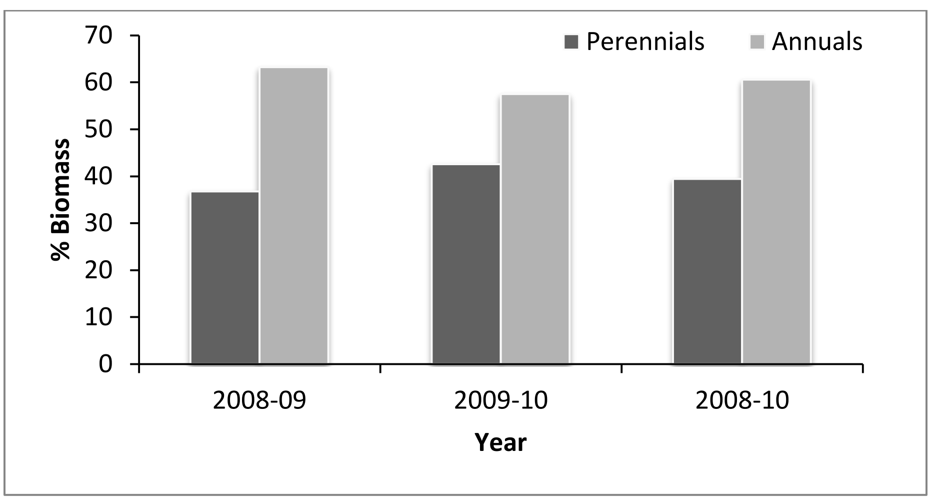


Figure 5.3. Percentage contribution of annuals and perennials to biomass in the National Park.

5.4.4. Seasonal pattern of biomass production

Annual biomass productivity was found to be highest in monsoon (4510.73 ±476.51 g m^{-2}, N =12; 3995.24 ±51.29 g m^{-2}, N =5; 4252.98 ±241.71 g m^{-2}, N =10) followed by winter

(3406.27 ±390.61 g m^{-2}, N=12; 2618.61 ±172.42 g m^{-2}, N =4; 3012.44 ±247.43 g m^{-2}, N =8) and least productivity was in summer (3229.21 ±673.4 g m^{-2}, N =12; 2928.93 ±510.88 g m^{-2}, N =3; 3079.07 ±383.93 g m^{-2}, N =6) during 2008-09, 2009-10 and 2008-10 respectively (Table 5.11). However, no significant difference was found in the annual biomass across the seasons (Kruskal Wallis test, χ^2 =3.345, *df* =2, *p*>0.05).

Table 5.11. Seasonal pattern of above ground biomass production (g m^{-2}) across the two year sampling period (2008-2010) in the National Park.

Year	Summer	Monsoon	Winter
2008-09	3229.21 ±673.4	4510.73 ±476.51	3406.27 ±390.61
2009-10	2928.93 ±510.88	3995.24 ±51.29	2618.61 ±172.42
2008-10	3079.07 ±383.93	4252.98 ±241.71	3012.44 ±247.43

During 2008-09, productivity of *Zizania latifolia* was highest in summer (964.97 ±384.13 g m^{-2}, N=12) and monsoon (666.81 ±94.15 g m^{-2}, N =12) whereas in winter, productivity of *Impatiens balsamina* (352.21 ±165.48 g m^{-2}, N =12) was highest. The other species with high productivity in summer are *Phragmites karka* (392.95 ±108.06 g m^{-2}, N =12) and *Arundo donax* (316.35 ±115.62 g m^{-2}, N =12). In monsoon, species with high productivity are *Phragmites karka* (387.32 ±61.18 g m^{-2}, N =12), *Impatiens balsamina* (251.74 ±40.2 g m^{-2}, N =12) and *Arundo donax* (212.26 ±67.56 g m^{-2}, N =12) whereas in winter species with high productivity are *Arundo donax* (340.85 ±105.49 g m^{-2}, N =12) and *Zizania latifolia* (326.56 ±68.33 g m^{-2}, N =12) (Table 5.12).

Table 5.12. Species-wise above ground biomass (g m^{-2}) of plant species across seasons (2008-09 & 2009-10) in the National Park.

	2008-09 Biomass (g m^{-2}) N = 12			2009-10 Biomass (g m^{-2}) N = 12		
Species	Summer	Monsoon	Winter	Summer	Monsoon	Winter
Zizania latifolia	964.97 ±384.13	666.81 ±94.15	326.56 ±68.33	700.46 ±109.21	749.08 ±58	253.06 ±93.28
Phragmites karka	392.95 ±108.06	387.32 ±61.18	181.84 ±45.25	337.69 ±163.56	368.76 ±27.72	370.01 ±46.33
Arundo donax	316.35 ±115.62	212.26 ±67.56	340.85 ±105.49	348.33 ±162.74	364.59 ±124.99	403.77 ±55.43
Impatiens balsamina	122.52 ±56.01	251.74 ±40.2	352.21 ±165.48	45.44 ±27.85	67.56 ±24.17	31.06 ±5.7
Pteridium aquilinium	224.8 ±105.53	378.81 ±64.77	114.98 ±29.52	252.7 ±66.8	375.06 ±58.26	112.4 ±54.98
Hedydhium coronarium	108.21 ±15.11	271.55 ±118.53	296.91 ±82.41	83.1 ±8.25	173.3 ±35.15	97.22 ±15.18
Leersia hexandra	175.1 ±62.97	287.13 ±52.62	182.43 ±29.09	144.38 ±57.54	199.45 ±59.72	60.82 ±6.26
Saccharum spontaneum	193.95 ±79.76	176.68 ±75.44	304.27 ±58.11	190.09 ±93.07	179.19 ±56.41	264.48 ±60.62
Cyperus spp	131.85 ±22.69	233.87 ±69.17	188 ±55.12	0 ±0	13.15 ±10.56	0 ±0
Capillipedium spp	102.16 ±11.92	219.65 ±39.42	209.24 ±34.42	101.58 ±25.06	376.5 ±81.92	211.17 ±27.42
Osbeckia stellata	113.87 ±48.68	198.31 ±97.66	155.82 ±61.97	49.82 ±14.82	122.64 ±70.05	8.66 ±3.27
Hemarthria compressa	124.24 ±30.71	273.19 ±102.7	24.19 ±1.92	53.59 ±3.26	193.68 ±61.04	404.22 ±73.7
Blumea balsamiflora	16.6 ±0.98	92.75 ±14.12	161.18 ±35.08	13.38 ±10.47	95.47 ±19.52	35.74 ±13.87
Erianthus spp	17.94 ±9.31	80.91 ±34.72	78.54 ±63.73	0 ±0	3.78 ±3.78	0 ±0
Carex cruciata	35.4 ±23.6	88.24 ±15.26	30.3 ±10.28	102.02 ±26.01	88.2 ±42.85	2.32 ±1.48
Polygonum spp.	3.25 ±1.68	79.64 ±60.23	51.15 ±21.55	46.79 ±33.44	9.17 ±2.55	34.12 ±17.94
Spargaium erectum	12.27 ±11.75	107.05 ±51.76	9.22 ±5.23	14.4 ±8.05	10.8 ±4.49	18.41 ±11.65
Scirpus lacustris	17.3 ±10.53	62.06 ±21.99	39.89 ±19.99	30.8 ±30.8	91.21 ±5.46	44.09 ±6.05
Alternanthera philoxeroides	0.32 ±0.32	90.47 ±85.02	0.1 ±0.1	0.47 ±0.47	12.24 ±6.49	1.58 ±0.6
UK6	9.09 ±5.25	23.52 ±11.01	69.85 ±31.02	7.82 ±6.66	61.18 ±14.9	6.12 ±1.64

Panicum spp	12.56 ±9.61	28.79 ±18.7	44.19 ±27.58	36.75 ±5.09	36.73 ±5.44	6.43 ±6.43
Imperata cylindrica	17.39 ±11.38	20.85 ±5.26	46.13 ±16.64	59.34 ±14.75	29.92 ±10.94	32.6 ±2.5
Persicaria perfoliata	4.57 ±1.86	47.95 ±26.33	14.73 ±6.37	19.8 ±16.18	10.78 ±2.8	4.6 ±1.8
Ludwigia spp	15.81 ±8	36.12 ±11.07	18.27 ±8.29	0 ±0	22.44 ±6.63	17.71 ±10.74
Oryza rufipogon	15.32 ±2.88	20.87 ±11.04	36.06 ±11.26	26.56 ±11.48	32.84 ±14.9	24.08 ±14.04
Anotis urophylla	21.36 ±3.89	26.17 ±18.57	24.88 ±13.13	38.18 ±11.32	68.43 ±15.72	28.61 ±15.66
Oenanthe javanica	14.11 ±2.53	41.96 ±11.45	10.19 ±0.96	36.96 ±27.99	29.99 ±10.31	8.55 ±3.21
Alternanthera sessiles	5.71 ±2.22	34.03 ±18.01	16.36 ±11.1	0.92 ±0.92	0 ±0	8.6 ±3.02
Cyanotis barbata	17.76 ±6.24	5.83 ±2.45	20.38 ±12.2	11.53 ±10.96	9.33 ±2.92	4.98 ±1.51
Setaria sp.	5.34 ±1.23	22.91 ±16.92	6.92 ±3.11	0.26 ±0.26	1.09 ±1.09	5.92 ±5.92
Kylinga triceps	0.79 ±0.02	9.63 ±5.32	10.41 ±3.33	12.47 ±11.36	47.99 ±6.27	11.03 ±3.75
Fuirena umbellata	0 ±0	10.22 ±4.19	8 ±4.33	0.28 ±0.28	20.4 ±8.36	41.54 ±21.44
Uk1	10.05 ±6.77	0 ±0	12.23 ±6.89	79.45 ±18.5	44.96 ±5.03	13.79 ±6.21
Mosla dianthera	0 ±0	14.44 ±7.91	0 ±0	0.22 ±0.22	0 ±0	
Ageratum sp.	0 ±0	2.79 ±2.79	12.16 ±8.94	4.47 ±2.39	6.73 ±2.61	0.55 ±0.35
Mikania micrantha	4.88 ±1.78	2.88 ±2.88	4.5 ±2.81	0.45 ±0.45	7.13 ±2.93	10.85 ±1.94
Colocasia antiquorum	0.41 ±0.22	0.83 ±0.63	2.22 ±1.24	0 ±0	1.22 ±1.22	0 ±0
Coix lacrymajobi	0 ±0	2.51 ±1.66	0 ±0	76.67 ±42.55	62.5 ±28.34	39.51 ±17.77
Eriocaulon spp	0 ±0	0 ±0	0.88 ±0.88	2.02 ±2.02	6.8 ±6.8	0 ±0
Rotala rotundifolia	0 ±0	0 ±0	0.24 ±0.24	0 ±0	0 ±0	0 ±0
Habenaria spp	0 ±0	0 ±0	0 ±0	0 ±0	0.74 ±0.74	0 ±0
Overall	236.28 ±79.01	550.09 ±111.66	332.32 ±68.31	236.28 ±79.01	550.09 ±111.66	332.32 ±68.31

(UK = un-identified)

Also during 2009-10, productivity of *Zizania latifolia* was highest in summer (700.46 ±109.21 g m^{-2}, N =12) and monsoon (749.08 ±58 g m^{-2}, N =12) whereas in winter, productivity of *Hemarthria compressa* (404.22 ±73.7 g m^{-2}, N =12) was highest. The other species with high productivity in summer are *Arundo donax* (348.33 ±162.74 g m^{-2}, N =12), *Phragmites karka* (337.69 ±163.56 g m^{-2}, N =12) and *Pteridium aquilinium* (252.7 ±66.8 g m^{-2}, N =12). In monsoon, other species with high productivity are *Capillipedium* spp. (376.5 ±81.92 g m^{-2}, N=12), *Pteridium aquilinium* (375.06 ±58.26 g m^{-2}, N =12) and *Phragmites karka* (368.76 ±27.72 g m^{-2}, N =12) whereas in winter, other species with high productivity are *Arundo donax* (403.77 ±55.43 g m^{-2}, N =12), *Phragmites karka* (370.01 ±46.33 g m^{-2}, N =12) and *Saccharum spontaneum* (264.48 ±60.62 g m^{-2}, N =12) (Table 5.12).

When all data for all the species was combined (N =24), *Zizania latifolia* was found to be contributing maximum biomass among all the species in summer (832.72 ±188.1 g m^{-2}, N =24) and monsoon (707.94 ±53.9 g m^{-2}, N =24) whereas *Arundo donax* contributed maximum biomass among all species in winter season (372.31 ±56.4 g m^{-2}, N =24).

The other species which contributed more in summer were *Phragmites karka* (365.32 ±88.53 g m^{-2}, N =24) and *Arundo donax* (332.34 ±89.56 g m^{-2}, N =24) whereas in monsoon it was followed by *P. karka* (378.04 ±31.81 g m^{-2}, N =24), *Pteridium aquilinium* (376.94 ±41.07 g m^{-2}, N =24) and *Arundo donax* (332.34 ±89.56 g m^{-2}, N =24).

In winter, *Z. latifolia* (289.81 ±55.3 g m^{-2}, N =24) and *Saccharum spontaneum* (284.37 ±39.59 g m^{-2}, N =24) contributed most to the biomass (Table 5.13).

Table 5.13. Overall (2008-10) species-wise above ground biomass productivity (g m^{-2}) of plant species across seasons in the National Park.

Species	Summer	Monsoon	Winter	Annual
Zizania latifolia	832.72 ±188.14	707.94 ±53.9	289.81 ±55.3	599.76 ±90.87
Phragmites karka	365.32 ±88.53	378.04 ±31.81	275.92 ±46.51	340.82 ±35.06
Arundo donax	332.34 ±89.56	288.42 ±71.63	372.31 ±56.43	327.37 ±48.56
Pteridium aquilinium	238.75 ±56.2	376.94 ±41.07	113.69 ±28.89	254.64 ±44.88
Capillipedium spp	101.87 ±12.41	298.08 ±50.2	210.21 ±20.37	219.74 ±27.83
Saccharum spontaneum	192.01 ±54.82	177.93 ±44.41	284.37 ±39.59	216.93 ±35.92

Hemarthria compressa	88.91 ±20.98	233.44 ±57.85	214.2 ±79.52	190.89 ±36.2
Hedydhium coronarium	95.65 ±9.53	222.43 ±60.54	197.07 ±54.12	182.28 ±34.1
Leersia hexandra	159.74 ±38.76	243.29 ±40.27	121.63 ±26.79	181.85 ±25.15
Impatiens balsamina	83.98 ±32.86	159.65 ±37.83	191.63 ±97.77	151.39 ±30.46
Osbeckia stellata	81.84 ±26.89	160.47 ±58.04	82.24 ±39.98	114.74 ±33.38
Cyperus spp	65.93 ±31.18	123.51 ±49.41	94 ±43.74	99.28 ±17.34
Blumea balsamiflora	14.99 ±4.76	94.11 ±11.37	98.46 ±29.44	75.78 ±14.18
Carex cruciata	68.71 ±21.65	88.22 ±21.44	16.31 ±7.14	59.37 ±14.11
Scirpus lacustris	24.05 ±14.87	76.64 ±11.73	41.99 ±9.7	51.94 ±8.99
Polygonum sp.	25.02 ±17.86	44.4 ±30.75	42.63 ±13.38	38.97 ±14
Anotis urophylla	29.77 ±6.54	47.3 ±13.46	26.75 ±9.49	36.06 ±7.19
Imperata cylindrica	38.36 ±12.55	25.38 ±5.92	39.36 ±8.2	33.29 ±4.55
Erianthus sp.	8.97 ±5.78	42.34 ±20.89	39.27 ±33.02	32.98 ±12.3
Spargaium erectum	13.34 ±6.39	58.92 ±29.28	13.81 ±6.16	32.49 ±13.23
UK6	8.45 ±3.8	42.35 ±10.76	37.99 ±18.76	32.42 ±7.39
Coix lacrymajobi	38.34 ±25.61	32.51 ±16.7	19.75 ±11.11	29.71 ±7.83
Panicum spp	24.65 ±7.27	32.76 ±9.27	25.31 ±14.93	28.25 ±6.27
Oryza rufipogon	20.94 ±5.86	26.85 ±8.97	30.07 ±8.63	26.45 ±4.34
Uk1	44.75 ±17.85	22.48 ±7.86	13.01 ±4.3	24.89 ±4.42
Oenanthe javanica	25.53 ±13.57	35.98 ±7.53	9.37 ±1.58	24.5 ±5.98
Alternanthera philoxeroides	0.39 ±0.26	51.35 ±42.26	0.84 ±0.4	21.78 ±18.63
Ludwigia spp	7.91 ±5.03	29.28 ±6.5	17.99 ±6.28	20.18 ±3.7
Persicaria perfoliata	12.18 ±8.04	29.37 ±13.93	9.67 ±3.61	18.5 ±6.08
Kylinga triceps	6.63 ±5.71	28.81 ±7.48	10.72 ±2.32	17.23 ±3.92
Fuirena umbellata	0.14 ±0.14	15.31 ±4.72	24.77 ±11.95	14.67 ±4.81
Alternanthera sessiles	3.31 ±1.52	17.02 ±10.21	12.48 ±5.52	12.08 ±4.35
Cyanotis barbata	14.64 ±5.81	7.58 ±1.89	12.68 ±6.39	11.05 ±2.47
Setaria sp.	2.8 ±1.27	12 ±8.78	6.42 ±3.1	7.84 ±3.54
Mikania micrantha	2.67 ±1.29	5 ±2.06	7.67 ±1.98	5.31 ±1.33
Ageratum sp.	2.24 ±1.46	4.76 ±1.92	6.35 ±4.69	4.66 ±1.76
Mosla dianthera	0 ±0	7.33 ±4.42	0 ±0	3.05 ±1.9
Eriocaulon spp	1.01 ±1.01	3.4 ±3.4	0.44 ±0.44	1.82 ±1.41
Colocasia antiquorum	0.2 ±0.13	1.02 ±0.65	1.11 ±0.71	0.85 ±0.32
Habenaria spp	0 ±0	0.37 ±0.37	0 ±0	0.16 ±0.16
Rotala rotundifolia	0 ±0	0 ±0	0.12 ±0.12	0.04 ±0.04

(UK = un-identified)

5.4.5. Contribution of annuals and perennials to biomass across seasons

The annuals contribute more to biomass productivity compared to perennials across the season. Among perennials during Year I, highest productivity was in monsoon season (38.77%) followed by summer (35.9%) and least in winter (34.08%) whereas in Year II, highest productivity was in monsoon season (34.65%) followed by winter (33.89%) and least in summer (26.61%). Among the annuals during Year I, highest productivity was in winter (65.92%) followed by summer (64.1%) and least in monsoon (61.23%) whereas in Year II, highest productivity was in summer (73.39%) followed by winter (66.11%) and monsoon (65.35%) (Table 5.14).

Table 5.14. Percentage above ground biomass (g m^{-2}) of annuals and perennials across the season in the National Park. (A= Annuals, P= Perennials)

		2008-09% Biomass			2009-10% Biomass		
Species	Habit	Summer	Monsoon	Winter	Summer	Monsoon	Winter
Alternanthera philoxeroides	P	0.03	5.17	0.01	0.06	0.88	0.18
Alternanthera sessiles	P	0.49	1.95	1.41	0.12	0.00	0.97
Arundo donax	P	27.29	12.14	29.36	4.90	4.94	3.22
Carex cruciata	P	3.05	5.05	2.61	13.03	27.20	23.79
Colocasia antiquorum	P	0.04	0.05	0.19	9.84	4.52	4.45
Hemarthria compressa	P	9.33	15.53	25.58	0.00	0.05	0.00
Imperata cylindrica	P	10.72	15.62	2.08	10.66	12.52	10.95
Hedydhium coronarium	P	1.50	1.19	3.97	5.83	4.88	3.50
Lycopus uniflorus	P	0.87	0.00	1.05	0.00	1.62	2.00
Mikania micrantha	P	0.42	0.16	0.39	0.06	0.52	1.22
Osbeckia stellata	P	9.82	11.34	13.42	6.39	8.86	0.98
Phragmites karka	P	33.89	22.14	15.67	43.32	26.64	41.69
Rotala rotundifolia	P	0.00	0.00	0.02	0.00	0.00	0.00
Scirpus lacustris	P	1.49	3.55	3.44	3.95	6.59	4.97
Spargaium erectum	P	1.06	6.12	0.79	1.85	0.78	2.07
Overall Perennials		35.90	38.77	34.08	26.61	34.65	33.89
Ageratum sp.	A	0.00	0.10	0.54	0.21	0.26	0.03
Blumea balsamiflora	A	0.44	0.85	3.11	16.21	13.96	23.32

Capillipedium spp	A	4.94	7.95	9.32	0.62	3.66	2.06
Coix lacrymajobi	A	0.00	0.09	0.00	4.75	3.38	0.13
Cyanotis barbata	A	0.86	0.21	0.91	0.00	0.05	0.00
Cyperus spp	A	6.37	8.47	8.37	0.54	0.36	0.29
Erianthus sp.	A	0.87	2.93	3.50	0.00	0.50	0.00
Eriocaulon spp	A	0.00	0.00	0.04	0.00	0.14	0.00
Fuirena umbellata	A	0.00	0.37	0.36	0.09	0.26	0.00
Habenaria spp	A	0.00	0.00	0.00	0.01	0.78	2.40
Impatiens balsamina	A	5.92	9.12	15.69	2.49	7.42	23.35
Kylinga triceps	A	0.04	0.35	0.46	2.76	1.15	1.88
Leersia hexandra	A	8.46	10.40	8.12	0.58	1.84	0.64
Ludwigia spp	A	0.76	1.31	0.81	6.72	7.64	3.51
Mosla dianthera	A	0.00	0.52	0.00	0.00	0.01	0.00
Oenanthe javanica	A	0.68	1.52	0.45	1.72	1.15	0.49
Oryza rufipogon	A	0.74	0.76	1.61	1.24	1.26	1.39
Panicum spp	A	0.61	1.04	1.97	1.71	1.41	0.37
Persicaria perfoliata	A	0.22	1.74	0.66	0.92	0.41	0.27
Polygonum sp.	A	0.16	2.88	2.28	2.18	0.35	1.97
Pteridium aquilinium	A	10.86	13.72	5.12	11.76	14.36	6.49
Saccharum spontaneum	A	9.37	6.40	13.55	8.84	6.86	15.28
Setaria sp.	A	0.26	0.83	0.31	0.01	0.04	0.34
Zizania latifolia	A	46.62	24.14	14.54	32.59	28.69	14.62
UK 1	A	1.03	0.95	1.11	3.70	1.72	0.80
UK 6	A	0.80	3.36	7.18	0.36	2.34	0.35
Overall Annuals		64.10	61.23	65.92	73.39	65.35	66.11

(UK = un-identified)

5.4.6. Contribution of grasses, herbs and shrubs to biomass

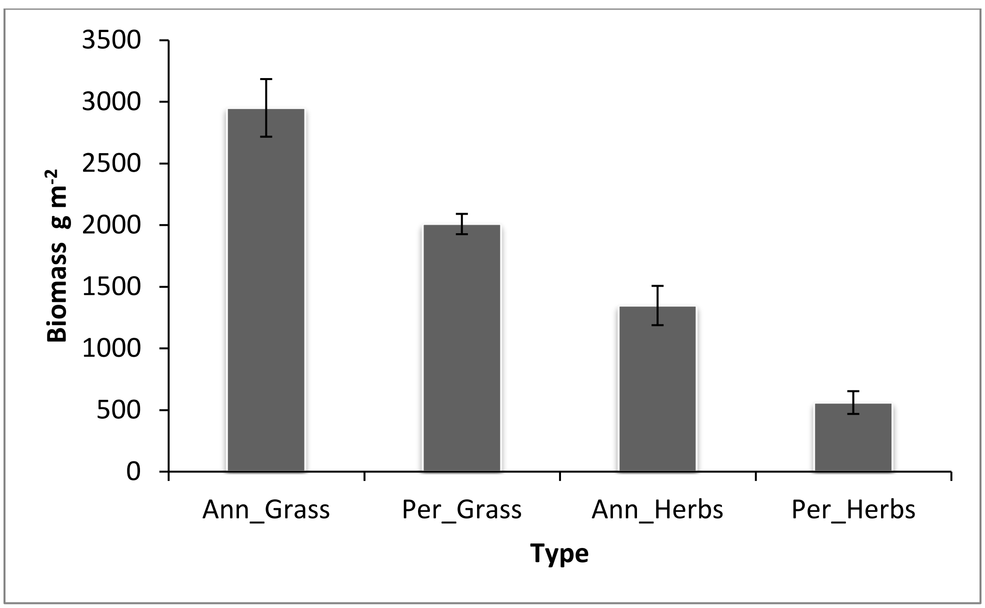
Grasses had highest productivity in summer (Year I =78.15%; Year II =61.17%), followed by monsoon (Year I =62.16%; Year II =60.96%) and winter (Year I =60.41%; Year II =54.33%) whereas herbs had highest productivity in winter (Year I =35.01%; Year II =45.34%) followed by monsoon (Year I =33.44%; Year II =35.97%) and summer (Year I =18.32%; Year II =37.13%) (Table 5.15).

Table 5.15. Percentage above ground biomass (g m^{-2}) of grasses, herbs and shrubs across the season in the National Park.

	% Biomass (2008-09)			% Biomass (2009-10)		
Habit	Summer	Monsoon	Winter	Summer	Monsoon	Winter
Grasses	78.15	62.16	60.41	61.17	60.96	54.33
Herbs	18.32	33.44	35.01	37.13	35.97	45.34
Shrub	3.53	4.4	4.57	1.7	3.07	0.33

5.4.7. Biomass of annual and perennial grasses and herbs

Biomass productivity of annual grasses was highest (2949.36 ±233.79 g m^{-2} $annum^{-1}$, N =12), followed by perennial grasses (2007.37 ±82.34 g m^{-2} $annum^{-1}$, N =12) and annual herbs (1346.35 ±159.35 g m^{-2} $annum^{-1}$, N =12). Perennial herbs had the least annual biomass productivity (559.43 ±92.26 g m^{-2} $annum^{-1}$, N =12) (Figure 5.4).



(Ann – Annuals, Per – Perennials)

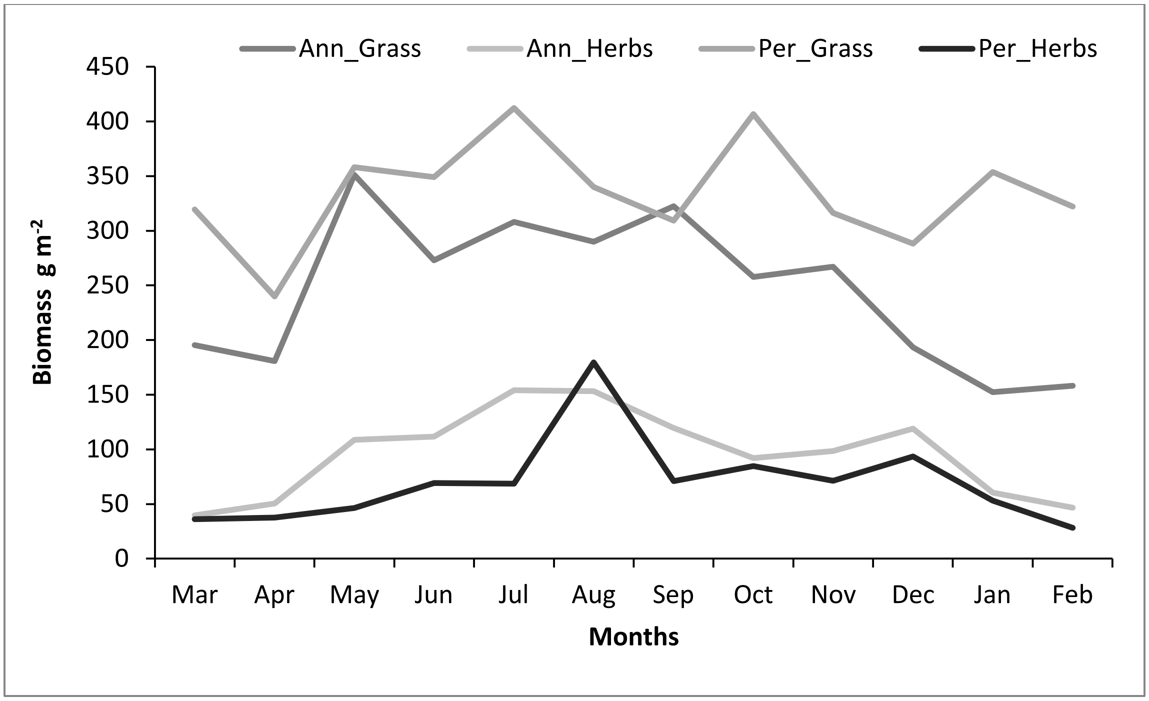
Figure 5.4. Annual biomass productivity (g m^{-2}) of annual and perennial grass and herb species in the National Park.

Perennial grasses showed the highest productivity in the month of July (412.17 ±144.84 g m^{-2}) and least productivity in April (240.01 ±86.69 g m^{-2}) whereas annual grasses had the highest productivity in May (351.19 ±203.24 g m^{-2}) and were least productive in January (152.25 ±55.67 g m^{-2}). Perennial herbs were most productive in August (179.58 ±120.33 g m^{-2}) and least productive in February (28.31 ±17.57 g m^{-2}) whereas annual herbs were most productive in July (154.06 ±75.26 g m^{-2}) and least in March (39.73 ±15.02 g m^{-2}) (Table 5.16, Figure 5.5).

There was no significant difference in the monthly biomass productivity of the annual grasses (χ^2 =8.636, *df* =11, p>0.05), annual herbs (χ^2 =8.997, *df* =11, p>0.05), perennial grasses (χ^2 =1.421, *df* =11, p>0.05) and perennial herbs (χ^2 =4.785, *df* =11, p>0.05). There was significant difference in the annual biomass between the annual grasses, annual herbs, perennial grasses and perennial herbs (χ^2 =37.498, *df* =3, p<0.05).

Table 5.16. Monthly above ground biomass productivity (g m^{-2}) of annual and perennial grasses and herbs species in the National Park. (N= No. of species)

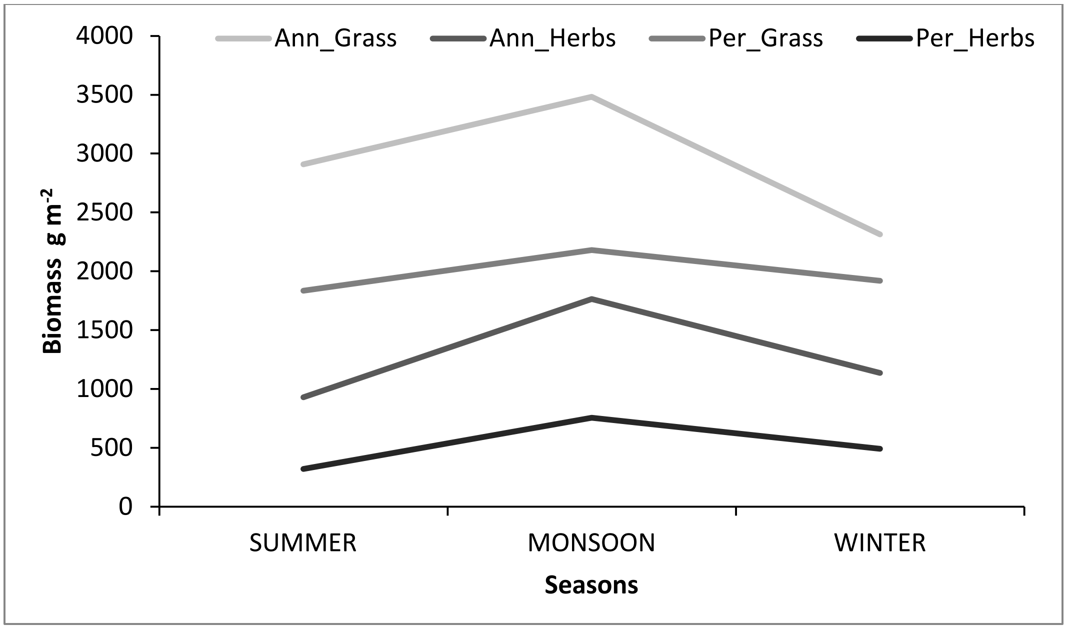
	Annual biomass		Perennial biomass	
Months	Grasses (N=12)	Herbs (N=14)	Grasses (N=6)	Herbs (N=8)
Mar	195.38 ±86.53	39.73 ±15.02	319.53 ±182.18	36.22 ±24.83
Apr	180.8 ±125.21	50.53 ±32.07	240.01 ±86.69	37.61 ±22.74
May	351.19 ±203.24	108.79 ±56.68	358.16 ±183.58	46.4 ±26.5
Jun	272.92 ±101.42	111.59 ±45.79	348.97 ±87.21	69.23 ±31.73
Jul	308.08 ±144.92	154.06 ±75.26	412.17 ±144.84	68.54 ±36.59
Aug	289.86 ±112.16	153.28 ±65.23	339.85 ±101.84	179.58 ±120.33
Sep	322.51 ±145.92	119.68 ±52.29	309.13 ±156.21	70.87 ±52.43
Oct	257.74 ±103.31	91.97 ±36.99	406.78 ±191.94	84.57 ±61.69
Nov	267.17 ±78.31	98.5 ±40.27	346.31 ±114.1	71.21 ±61.62
Dec	193.36 ±65.08	118.82 ±60.58	288.1 ±99.34	93.62 ±66.32
Jan	152.25 ±55.67	60.48 ±21.18	353.71 ±140.36	52.97 ±46.13
Feb	158.11 ±68.08	46.58 ±13.76	322 ±167.48	28.31 ±17.57



(Ann – Annuals, Per – Perennials)

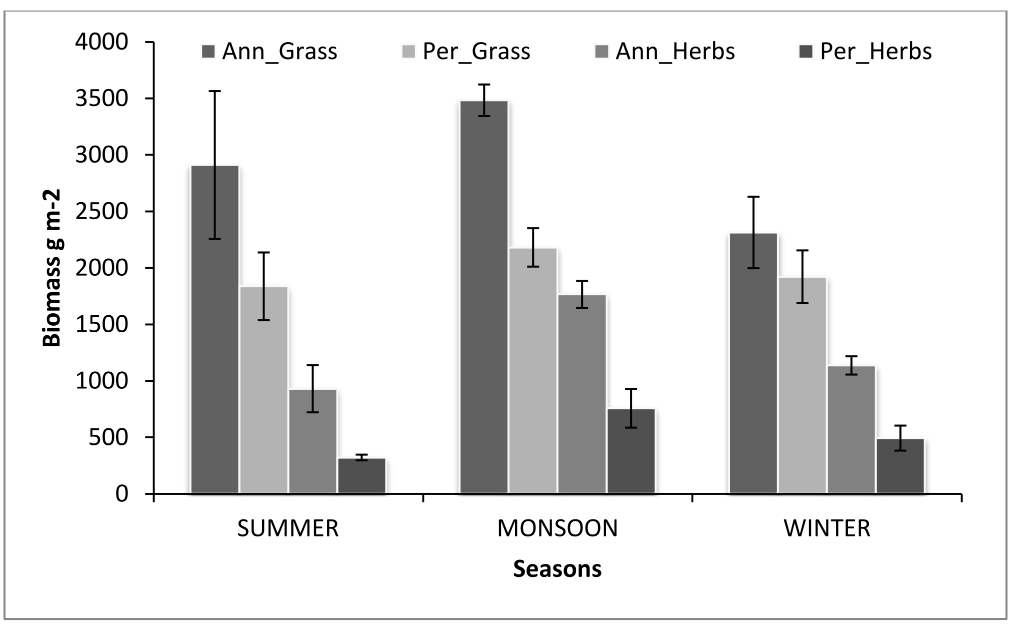
Figure 5.5. Monthly biomass productivity (g m^{-2}) of annual and perennial species of grasses and herbs in the National Park.

Productivity was highest in monsoon in both annual and perennial grasses and herbs (Figure 5.6). Across the seasons, summer, monsoon and winter, annual grasses (2909.47 ±654.33 g m^{-2}, 3482.66 ±139.85 g m^{-2} and 2312.66 ±317.09 g m^{-2} respectively) had the highest productivity and perennial herbs had the least productivity (320.63 ±25.5 g m^{-2}, 756.46 ±171.65 g m^{-2} and 492.23 ±110.76 g m^{-2} respectively). Annual grasses had the least productivity in winter (2312.66 ±317.09 g m^{-2}) whereas perennial grasses had least productivity in summer (1835.41 ±203.69 g m^{-2}). Annual and perennial herbs had the least productivity in summer (928.95 ±300.28 g m^{-2} and 320.63 ±25.5 g m^{-2} respectively) (Figure 5.7).



(Ann – Annuals, Per – Perennials)

Figure 5.6. Seasonal biomass productivity (g m^{-2}) of annuals (grasses & herbs) and perennials (grasses & herbs) in the National Park.



(Ann – Annuals, Per – Perennials)

Figure 5.7. Seasonal biomass productivity (g m^{-2}) of annuals (grass & herbs) and perennials (grass & herbs) in the National Park during 2008-10.

There was no significant difference in the seasonal biomass productivity of the annual grasses (χ^2 =2.547, *df* =2, *p*>0.05), annual herbs (χ^2 =5.313, *df* =2, *p*>0.05), perennial grasses (χ^2 =0.897, *df* =2, *p*>0.05) and perennial herbs (χ^2 =1.692, *df* =2, *p*>0.05).

Among the 14 species of annual grasses, *Zizania latifolia* (599.76 ±90.87 g m^{-2} $annum^{-1}$) had the highest productivity and *Setaria* spp. (7.84 ±3.54 g m^{-2} $annum^{-1}$) had the least productivity. *Pteridium aquilinium* (254.64 ±44.88 g m^{-2} $annum^{-1}$) had the highest productivity and *Habenaria* spp. (0.16 ±0.16 g m^{-2} $annum^{-1}$) had the least productivity among the 14 species of annual herbs. Out of the 4 perennial grass species, the highest productivity was *Phragmites karka* (340.82 ±35.06 g m^{-2} $annum^{-1}$) and the least was *Impereta cylindrica* (33.29 ±4.55 g m^{-2} $annum^{-1}$). *Hedychium coronarium* (182.28 ±34.1 g m^{-2} $annum^{-1}$) had the highest productivity out of the 8 perennial herb species and *Rotala rotundifolia* (0.04 ±0.04 g m^{-2} $annum^{-1}$) had the least productivity (Table 5.17).

Table 5.17. Species wise contribution of annual and perennial grasses and herbs to annual above ground biomass (g m^{-2}) in the National Park during 2008-10.

Species	LC	Habit	Total biomass N=24	Mean biomass N=24
Zizania latifolia	A	G	14394.22	599.76 ±90.87
Capillipedium spp	A	G	5273.67	219.74 ±27.83
Saccharum spontaneum	A	G	5206.42	216.93 ±35.92
Leersia hexandra	A	G	4364.36	181.85 ±25.15
Cyperus spp	A	G	2382.65	99.28 ±17.34
Erianthus sp.	A	G	791.43	32.98 ±12.3
Coix lacrymajobi	A	G	713.13	29.71 ±7.83
Panicum spp	A	G	677.95	28.25 ±6.27
Oryza rufipogon	A	G	634.7	26.45 ±4.34
Kylinga triceps	A	G	413.63	17.23 ±3.92
Fuirena umbellata	A	G	352.05	14.67 ±4.81
Setaria sp.	A	G	188.14	7.84 ±3.54
Overall Annual Grasses				2949.34 ±233.79
Pteridium aquilinium	A	H	6111.44	254.64 ±44.88

Impatiens balsamina	A	H	3633.43	151.39 ±30.46
UK6	A	H	1818.72	75.78 ±14.18
Polygonum sp.	A	H	935.22	38.97 ±14
UK1	A	H	865.56	36.06 ±7.19
Blumea balsamiflora	A	H	778.11	32.42 ±7.39
Oenanthe javanica	A	H	587.91	24.5 ±5.98
Ludwigia spp	A	H	484.2	20.18 ±3.7
Persicaria perfoliata	A	H	444.1	18.5 ±6.08
Cyanotis barbata	A	H	265.1	11.05 ±2.47
Ageratum sp.	A	H	111.86	4.66 ±1.76
Mosla dianthera	A	H	73.31	3.05 ±1.9
Eriocaulon spp	A	H	43.57	1.82 ±1.41
Habenaria spp	A	H	3.72	0.16 ±0.16
Overall Annual Herbs				1346.35 ±159.35
Phragmites karka	P	G	8179.67	340.82 ±35.06
Arundo donax	P	G	7856.81	327.37 ±48.56
Hemarthria compressa	P	G	4581.44	190.89 ±36.2
Carex cruciata	P	G	1424.95	59.37 ±14.11
Scirpus lacustris	P	G	1246.58	51.94 ±8.99
Imperata cylindrica	P	G	798.93	33.29 ±4.55
Overall Perennial Grasses				2007.37 ±82.34
Hedydhium coronarium	P	H	4374.73	182.28 ±34.1
Spargaium erectum	P	H	779.78	32.49 ±13.23
Lycopus uniflorus	P	H	597.4	24.89 ±4.42
Alternanthera philoxeroides	P	H	522.6	21.78 ±18.63
Alternanthera sessiles	P	H	289.88	12.08 ±4.35
Mikania micrantha	P	H	127.43	5.31 ±1.33
Colocasia antiquorum	P	H	20.35	0.85 ±0.32
Rotala rotundifolia	P	H	0.98	0.04 ±0.04
Overall Perennial Herbs				559.43 ±92.26

(A= Annual, P= Perennial, G= Grass, H= Herb, LC= Life cycle, N= No. of months, UK = un-identified)

5.4.8. Pattern of biomass production across meadow types

Based on the thickness of the meadows, water depth of the site and monthly biomass productivity, cluster analysis of the six sites was done. The results showed that the thick meadows of Toya (TOYA) and Thangbirel (THA) are similar whereas the thin meadows of Sagram (SAG) and Khodangkhong (KHO) are similar. The thin meadows of RH2 showed similarity with both the thick and thin meadows. The hard ground (HG) of Thangbirel showed a unique habitat and did not share any similarities with the habitat of the floating meadows (Figure 5.8).

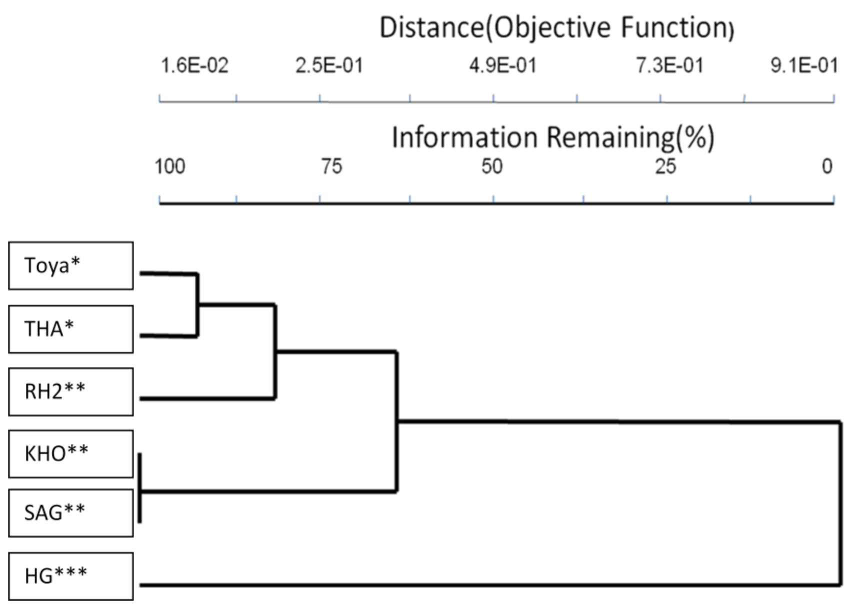


Figure 5.8. Similarity of the enclosures on the different types of meadows in the National Park (THA= Thangbirel, KHO= Khodangkhong, SAG= Sagram, HG= Hard ground) (* thick meadows, ** thin meadows, *** hard ground)

Productivity varied significantly across the sites (Kruskal Wallis test, χ^2 =3.956, *df* =2, $p< 0.05$). The thick meadows of Thangbirel (1886.43 ±130.16 g m^{-2}) showed the highest productivity followed by the thin meadows of Sagram (1340.71 ±136.27 g m^{-2}) and the least biomass was observed in the hard-ground of Thangbirel (583.81 ±89.02 g m^{-2}). The thick meadows of Thangbirel contributed maximum to the annual biomass with 26.4% followed by the thin meadows of Sagram with 18.7% and the least was contributed by the hard- ground of Thangbirel with 8.2% (Table 5.18).

Table 5.18. Spatial pattern of annual above ground biomass production (g m^{-2}) in the National Park during 2008-10.

Sites	Mean annual biomass	% contribution
Thangbirel *	1886.43 ±130.16	26.4
Sagram **	1340.71 ±136.27	18.7
Toya *	1198.88 ±166.37	16.8
RH 2 **	1097.82 ±100.20	15.3
Khodangkhong **	1041.35 ±117.07	14.6
Hard ground ***	583.81 ±89.02	8.2

(* thick meadows, ** thin meadows, *** hard ground)

5.4.9. Pattern of biomass in the treatment enclosures

There was significant variation in the AGB across the enclosures given the different treatments (Kruskal Wallis test, χ^2 =23.358, *df* =2, $p< 0.05$). Highest productivity was observed in the enclosure subjected to the burnt treatment (735.99 ±92.8 g m^{-2}, N =24) followed by cutting treatment (650.74 ±86.4 g m^{-2}, N =24) and the least productivity was observed in the control enclosures (590.00 ±41.8 g m^{-2}, N =24) (Figure 5.9).

Kruskal Wallis test and Mann-Whitney U non-parametric test was used to test the level of difference in the annual productivity of annual grasses, annual herbs, perennial grasses and perennial herbs across the different treatments. There was no significant difference in the annual grasses under the different treatments (Kruskal Wallis test, χ^2 =3.790, *df* =2, $p>0.05$). Among the annual herbs, there was significant difference in the annual biomass productivity across different treatments (Kruskal Wallis test, χ^2 =16.290, *df* =2, $p<0.05$). Within the annual herbs group, the significant difference in productivity was between control and burnt enclosures (Mann-Whitney U test, U =9.00, $p<0.05$) and control and cut treatment (Mann-Whitney U test, U =15.00, $p<0.05$) but there was no significant difference between burnt and cut treatments (Mann-Whitney U test, U =68.00, $p>0.05$). There was significant difference in the annual productivity of the perennial grasses across the different treatments (Kruskal Wallis test, χ^2 =19.893, *df* =2, $p<0.05$). Within the perennial grasses group, the significant difference in productivity was between control and burnt enclosures (Mann-Whitney U test, U =1.00, $p<0.05$) and control and cut treatments (Mann-Whitney U test, U =15.00, $p<0.05$) but there was no significant difference between burnt and cut treatments (Mann-Whitney U test, U =48.00, p>0.05). Significant difference in the annual productivity of the perennial herbs across the different treatments was observed (Kruskal Wallis test, χ^2 =17.952, df =2, p<0.05).Within the perennial herbs group, the significant difference in productivity was between control and cut enclosures (Mann-Whitney U test, U =4.00, p<0.05) and burnt and cut treatment (Mann-Whitney U test, U =14.00, p<0.05) but there was no significant difference between control and burnt treatments (Mann-Whitney U test, U =70.00, p>0.05).

5.4.10 Pattern of biomass in thick and thin meadows

The annual biomass productivity of the thick meadows was 1542.65 ±125.73 g m^{-2}, of the thin meadows was 1159.96 ±70.11 g m^{-2} and of the hard ground was 583.81 ±89.02 g m^{-2}. In the thin meadows' enclosures, out of 38 plant species, 33 plant species contributed to the annual biomass productivity whereas in the thick meadows, only 27 species contributed to the annual biomass productivity. In the hard ground, only 6 species of the 41 species recorded in the permanent enclosures contributed to the annual biomass productivity. No significant difference was found in the biomass productivity of the control enclosures between the thick and thin meadows (ANOVA, F =8.199, df =2, p>0.05) although the thin meadows had higher species richness (N=33) compared to the thick meadows (N =27). In the control enclosures, between the hard ground, thick and thin meadows, there was significant difference in the annual productivity (Kruskal Wallis test, χ^2 =22.281, df =2, p< 0.05). Also there was significant difference in the annual productivity across the meadow types and hard ground in the burnt (Kruskal Wallis test, χ^2 =15.065, df =2, p< 0.05) and cut enclosures (Kruskal Wallis test, χ^2 =17.248, df =2, p< 0.05). Mann-Whitney U test was used to test the significance within the meadow types of the burnt and cut treatments. No significant difference between the thick and thin meadows in both the burnt (Mann-Whitney U test, U =50.00, p>0.05) and cut treatment (Mann-Whitney U test, U =54.00, p>0.05) was observed. Between the thick meadow and the hard ground, there was significant difference in the productivity in both the burnt (Mann-Whitney U test, U =19.00, p<0.05) and cut (Mann-Whitney U test, U =11.00, p<0.05) treatments. Also, between the thin meadow and the hard ground, there was significant difference in the productivity in both the burnt (Mann-Whitney U test, U =13.00, p<0.05) and cut (Mann-Whitney U test, U =11.00, p<0.05) treatments.

The percentage contribution of annuals was highest in the thin meadows (76.2%) followed by the hard ground (77.9%) and the thick meadows (38.2%). The percentage contribution of perennials was highest in the thick meadows (61.8%) followed by the thin meadows (23.8%) and least in the hard ground (22.1%) (Figure 5.10). Among the annual grass, there was no significant difference in the productivity of the control enclosures among the thick and thin meadows and hard ground (Kruskal Wallis test, χ^2 =1.302, *df* =2, p>0.05) but there was significant difference in the burnt (Kruskal Wallis test, χ^2 =6.317, *df* =2, p<0.05) and cut (Kruskal Wallis test, χ^2 =12.434, *df* =2, p<0.05) treatments. There was no significant difference in the productivity of the annual grass between the thick and thin meadows in the burnt (Mann-Whitney U test, U =39.00, p>0.05) and cut (Mann-Whitney U test, U =61.00, p>0.05) treatments. Between the thick meadows and hard ground, there was no significant difference in the productivity of the annual grass in the burnt (Mann-Whitney U test, U =61.00, p>0.05) treatment but there was significant difference in the cut (Mann-Whitney U test, U =22.00, p<0.05) treatment. Between the thin meadows and the hard ground, there was significant difference in the annual grass productivity in the burnt (Mann-Whitney U test, U =32.00, p<0.05) and cut (Mann-Whitney U test, U =18.00, p<0.05) treatments. Among the annual herbs, between the thick and thin meadows, there was significant difference in the productivity in the control (Mann-Whitney U test, U =37.00, p<0.05) and burnt (Mann-Whitney U test, U =17.00, p<0.05) treatments but there was no significant difference in the cut (Mann-Whitney U test, U =72.00, p>0.05) treatment. Among the perennial grass, between the thick and thin meadows, there was significant difference in the productivity in the control (Mann-Whitney U test, U =2.00, p<0.05) and burnt (Mann-Whitney U test, U =30.00, p<0.05) treatments but there was no significant difference in the cut (Mann-Whitney U test, U =71.00, p>0.05) treatment.

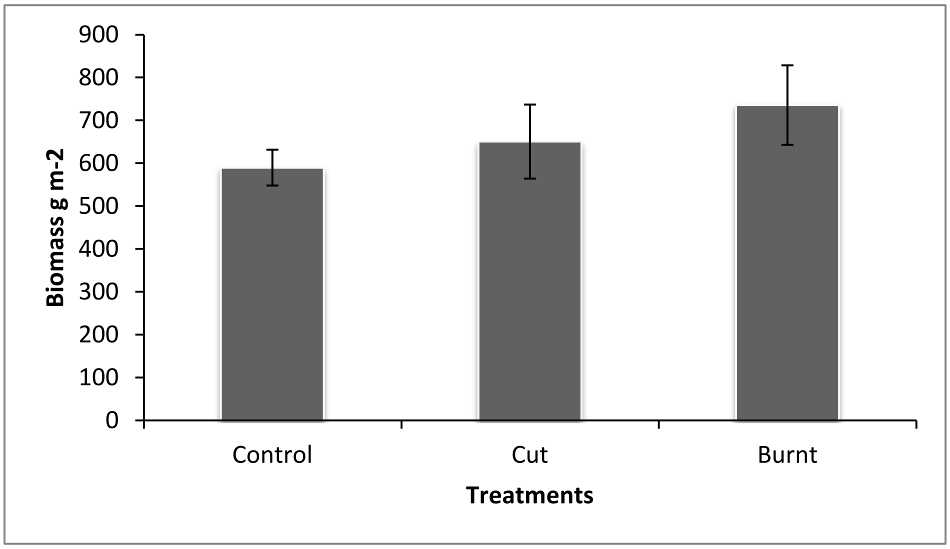


Figure 5.9. Comparison of annual biomass (g m^{-2}) across the treatments in the National Park.

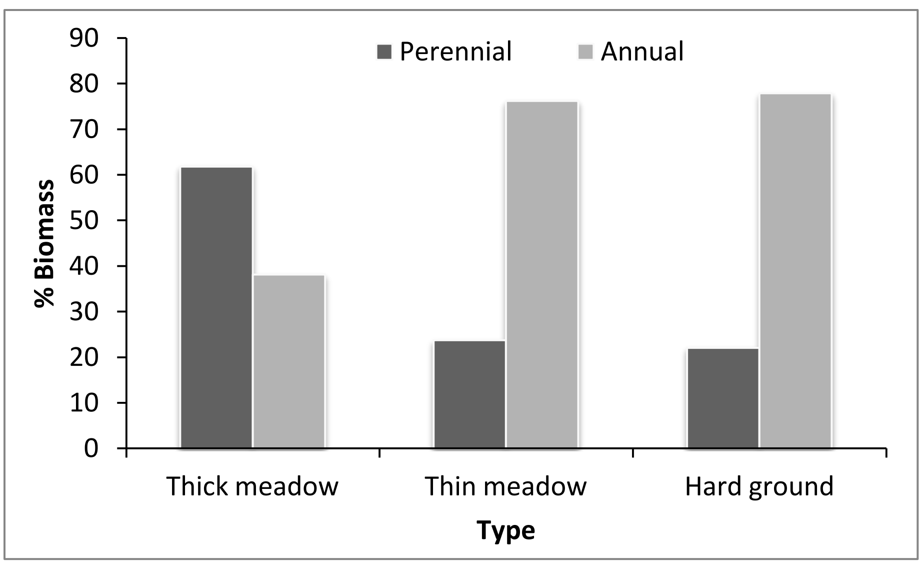


Figure 5.10. Percentage Annual above grass biomass production by annuals and perennials in different meadow types in the National Park during 2008-10.

Among the perennial herbs, between the thick and thin meadows, there was significant difference in the productivity in the burnt (Mann-Whitney U test, U =17.00, $p<0.05$) treatment but there was no significant difference in the control (Mann-Whitney U test, U =65.00, $p>0.05$) and cut (Mann-Whitney U test, U =60.00, $p>0.05$) treatments.

5.4.11 Pattern of biomass in relation to rainfall

The highest mean annual rainfall was observed in the month of August (7.8 mm) followed by the month of July (7 mm) and the highest mean aboveground biomass was also observed in the month of August (125.14 ±20.4 g m^{-2}) followed by the month of July (112.9 ±20.5 g m^{-2}). The lowest mean annual rainfall was recorded in the month of December (0.003 mm) whereas lowest annual productivity was observed in the month of February (59.05 ±12.5 g m^{-2}). During 2008-09, 2009-10 and 2008-10, there was significant variation in the aboveground biomass production in relation to rainfall (ANOVA, $p<0.05$, Figure 5.11, 5.12, 5.13), but there was no significant difference in the total rainfall in the two year study periods (ANOVA, $p>0.05$).

Regression analysis was used to see the effect of rainfall on biomass. Results of the analysis showed a significant relation between rainfall and biomass during 2008-09 (R^2 =0.487, ANOVA $p<0.05$), 2009-10 (R^2 =0.638, ANOVA $p<0.05$) as well 2008-10 (R^2 =0.659, ANOVA $p<0.05$). The R^2 value is indicative that 49%, 64% and 66% variation in the observed mean biomass during 2008-09, 2009-10 and 2008-10 respectively is explained by the regression equations,

Mean biomass = 6.149 * mean rainfall + 75.97 (Fig. 5.14),

Mean biomass = 6.373 * mean rainfall + 63.49 (Fig. 5.15) and

Mean biomass = 6.538 * mean rainfall + 68.78 (Fig. 5.16).

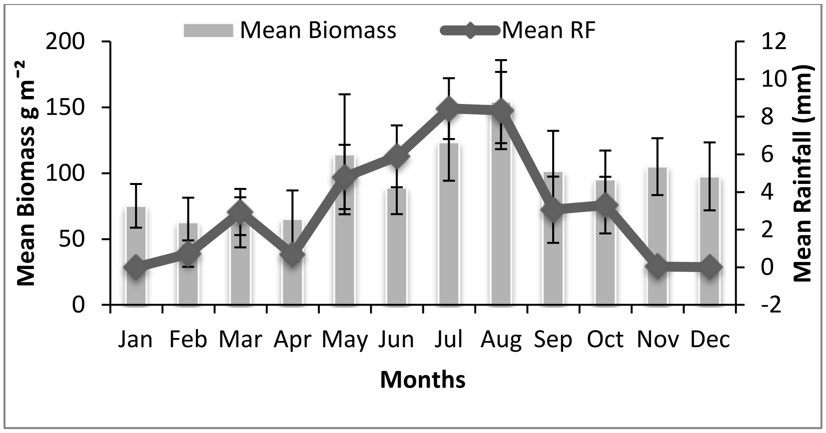


Figure 5.11. Biomass production (g m^{-2}) in relation to rainfall during 2008-09.

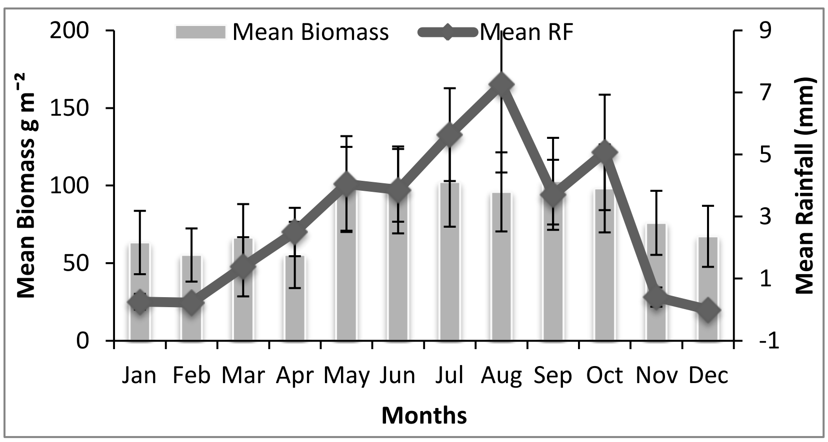


Figure 5.12. Biomass production (g m^{-2}) in relation to rainfall during 2009-10.

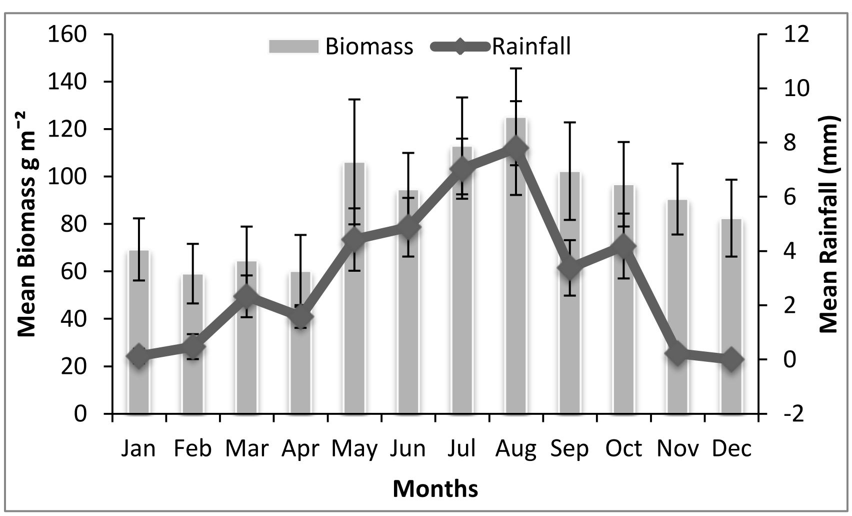


Figure 5.13. Biomass production (g m^{-2}) in relation to rainfall during 2008-10.

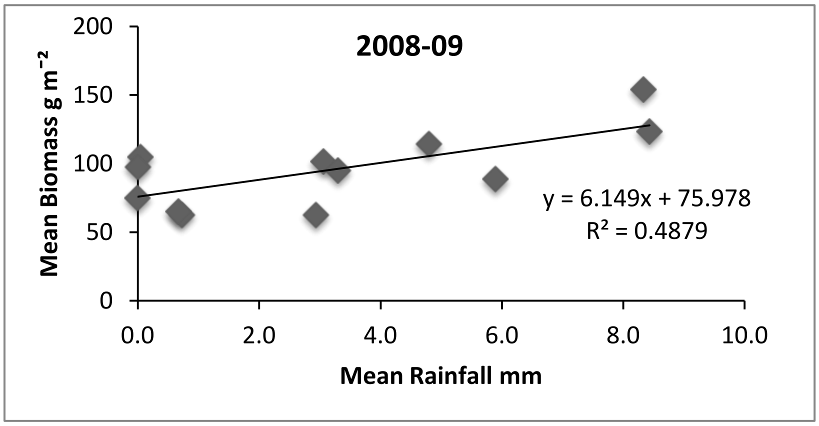


Figure 5.14. Regression analysis of rainfall and biomass produced (g m^{-2}) during 2008-09.

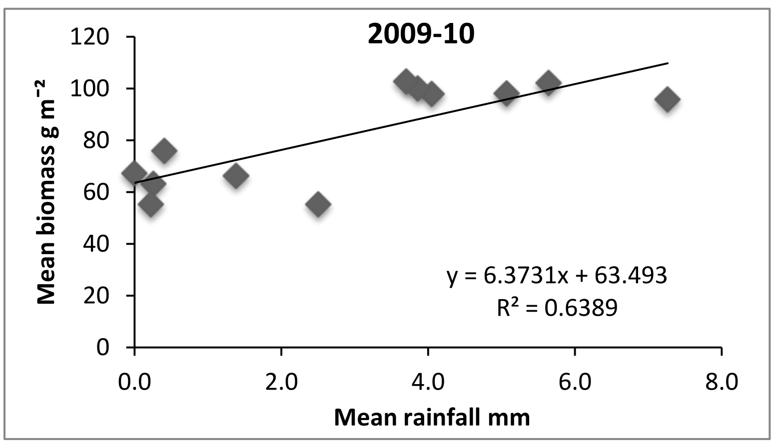


Figure 5.15. Regression analysis of rainfall and biomass produced (g m^{-2}) during 2009-10.

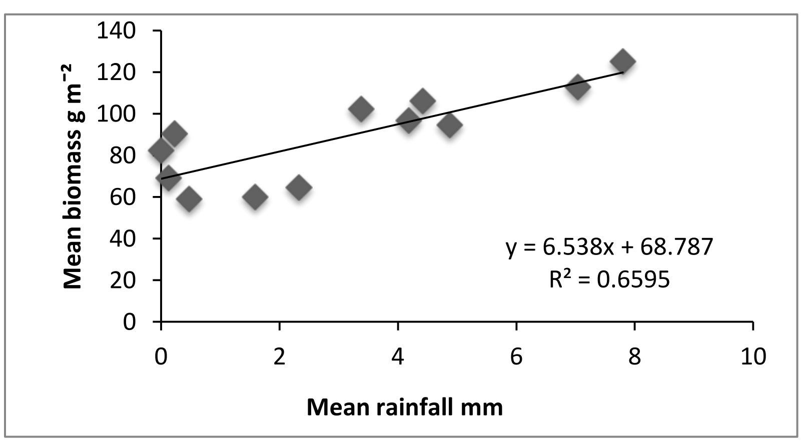


Figure 5.16. Regression analysis of rainfall and biomass (g m^{-2}) produced during 2008-10.

Linear mixed model was used to see which environmental variable explains the annual pattern of biomass productivity the best in the floating meadows. The model was run against environmental variables *viz*. maximum temperature, meadows thickness, water level, maximum humidity, meadow type, rainfall and season. Akaike's Information Criteria (AIC) was used to select the best model. The model with the lowest ΔAIC value was selected as the best model (Table 5.19). As per the best model, rainfall and temperature best explains the pattern of annual biomass production in the floating meadows. Meadows thickness and temperature also have a significant effect on the biomass productivity.

Table 5.19. AIC Models with the environmental variable that best explains the variations in the above ground biomass of the National Park.

Sl.No	Model	AIC	ΔAIC	Log Likelihood
1.	Rainfall + MaxT	1739	0	1735
2.	Rainfall + Mthickness + MaxT	1740	1	1736
3.	Rainfall + WL + Mthickness + MaxT	1742	3	1738
4.	Rainfall	1754	15	1750
5.	Rainfall + MaxT + Mthickness + Season + Mtype	1799	60	1797
6.	Rainfall + MaxT + WL + Mthickness + Season + MaxH + Mtype	1803	64	1801

(MaxT = Maximum temperature, Mthickness = Meadows thickness, WL = Water Level, MaxH = Maximum humidity, Mtype = Meadows type)

5.5. DISCUSSIONS

Biomass is a plant attribute that is time consuming and difficult to measure or estimate, but easy to interpret. Biomass is regarded as an important indicator of ecological and management processes in the vegetation. The estimation of aboveground biomass (AGB) is necessary for studying productivity, carbon cycles, nutrient allocation, and fuel accumulation in terrestrial ecosystems (Bannari et al., 2006). Plants that dominate a site, in terms of biomass, are a reflection of the plants that are controlling the nutrient, water, and solar resources on the site.

Therefore, biomass is often measured to assess the ecological status of a site (Wheeler & Shaw, 1991; Richardson, 1978). Standing biomass measured in its maximum is usually equalized with production. Our results showed that *Zizania latifolia*, *Phragmites karka* and *Arundo donax* contributed the highest annual biomass productivity indicating their dominance over the resources available in the Park. Overall, the grass species contributed maximum to the annual biomass production indicating their dominance over other species which concludes the grassland nature of the Park. Among the herb species, *Impatiens balsamina*, *Pteridium aquilinium* and *Hedychium coronarium* had the highest productivity.

In the study sites, the live shoot biomass increased gradually with the onset of favorable season with highest productivity post-monsoon (August) and least productivity during pre-monsoon (March) season. Thus, the increase in live shoot biomass parallels the pattern of rainfall and consequently soil moisture gradient (Padhan & Mohanty, 1993). Our study results have also shown that rainfall and temperature best explain the pattern of annual biomass productivity observed. With the onset of favorable soil moisture and temperature conditions, the rainy season annuals come up and new shoot arise from dormant perennials resulting in rapid biomass build up (Singh & Singh, 1980). The recording of minimum biomass values during the summer season could be attributed to the unfavorable temperature and drier conditions. Moreover, most of the species complete their life cycle during winter season and new shoots arise following winter. But the difference in the productivity across the seasons was not significant, as there is no shortage of moisture and nutrients. Productivity was also highest in monsoon in both annual and perennial grasses and herbs.

Across the meadow types (thick, thin & hard ground), productivity varied with the highest productivity in the thick meadows followed by thin meadows and hard ground respectively. The high percentage biomass contribution of the thick meadows of Thangbirel study site could be due to its less disturbed status of the Park and it was dominated by *Arundo donax*. The least percentage biomass contribution of the hard ground may be due to the contribution of only four plant species *i.e. Hemarthria compressa, Leersia hexandra, Setaria* spp. and *Oryza rufipogon*. But the difference is not significant in the control enclosures and significant only in the treatment enclosures with the treatment enclosures showing higher productivity in the meadows compared to the hard ground. The floating meadows are thus comparatively more productive than the terrestrial hard ground of the Park making it more favorable for the plants after the treatments. Also, the number of species in the hard ground is significantly less than the meadows.

The minimum and maximum values of live shoot biomass were within the range of live shoot biomass data for tropical grasslands (minimum 0 - 871.0 g m^{-2} & maximum 76 - 3296.0 g m^{-2}) compiled by Singh & Joshi (1979) and also within the world average (50.0 g m^{-2} to 827.0 g m^{-2}) as reported by Coupland (1979). Most of the dominant species reached their peak biomass values during rainy season. This is in conformity with the findings of Trivedi (1983) and Devi (1994). Highly comparable live shoot biomass values ranging from 53.97 g m^{-2} (February) to 140.58 g m^{-2} (August) have been reported from the grasslands of Manipur by Sharma (2003).

In monsoonal wetlands of northern India, the productivity of wetlands changed seasonally in response to changing water level and temperature. The maximum above ground biomass productivity of dominant species *Paspalum distichum* in Keoladeo National Park (KNP) ranged from 850 g m^{-2} at the shallowest site to 3400 g m^{-2} at a deep water site (van der Valk et al., 1993). The productivity of above ground biomass of other aquatic vegetation in the KNP ranged from 1400 g m^{-2} at a deep water site to only 240 g m^{-2} a deep-water submersed site to 400 g m^{-2} at shallow emergent site depending on dominant species (*Ipomoea aquatica, Hydrilla verticillata, Cyperus alopecuroides, Scirpus tuberosus, Sporobolus helvolus*).

In studies conducted in major river basins *viz* Gangetic basin, Amazon basin and Brahmaputra basin, the present study which falls in the Chindwin-Irrawaddy basin shows a high productivity with 3545.99 ±198.2 g m^{-2}. In the Gangetic basin, the productivity was 1000 g m^{-2} (Vijayan, 1988) whereas in the Amazon basin it was 1100 g m^{-2} (Junk, 1970) and 3664 g m^{-2} (Khatri and Barua, 2011) in the Brahmaputra basin.

The management practices also play a role in the biomass production and forage availability of the ungulates. Resource availability is a direct function of the rate of growth of the forage plants. Our study on the management practices in the Park has shown that burning increases productivity as the enclosures given the burnt treatment showed the highest productivity followed by the clipping treatment and the least productivity was in the control enclosures. In an Arctic study, it was reported that among the various plant species graminoids recovered much faster from defoliation or clipping than other species and also showed an increase in productivity

(Archer & Tieszen, 1980). Since the enclosures were dominated by grass species, the increase in productivity after treatments could also be due to the quick recovery ability of the grasses. In the present study, clipping was done in the enclosures to simulate grazing and the management practices of fire-line cutting, and the results showed an increase in productivity compared to the control enclosures. The removal of older tissue by clipping will maintained a canopy of vigorously growing younger tissue with higher photosynthetic rates than unclipped plants (Delting et. al., 1979; Ruess, 1984). Thus clipping will be beneficial to the ungulates in the Park as they graze on young shoots. Also, even though burning enhances productivity, it removes the base material for the formation of meadows. So, clipping is not only beneficial to enhance the food plants of the ungulates but is also beneficial for the formation of meadows.

The role of management practices was also studied on both the annual grasses and herbs and the perennial grasses and herbs. There was no significant difference in the annual grass productivity given different treatments but there was significant difference between the burnt and cut treatments of the annual herbs, perennial grasses and perennial herbs with the control treatment. The burning and cutting treatments in the Park are usually done in the month of January or February when the plants have completed their life cycle. Hence, no significant difference was observed in the annual grasses.

Vegetation of wetland meadows varies depending on the environmental (soil, water) conditions and management regime (Mitsch & Gosselink, 2000). The vegetation of the floating meadows has been used by the people but a great part of them is in the succession stage due to the recent environmental changes in the water regime (Trisal & Manihar, 2002). On low-productive sites, plant species richness is primarily limited on abiotic conditions (water level, mineral content of soil and water, availability of plant nutrients). The main limitation in highly productive sites is competition for light. Tall graminoids or herbs compete out low-growing plants, enabling even the development of monospecies vegetation as has been observed in the Park with continuous patches of *Phragmites karka*, *Zizania latifolia*, *Leersia hexandra*, *Capillipedium* spp etc.

Different plant species shows different growth pattern. Most of the plant species are in peak flowering in June-July, a period of low relative growth rate. Prior to the period of high relative growth rates, most of the species are in peak growth initiation and some are in vegetative phase during the month of May (Ram et al., 1988). Early in the growing season, response to increase in shoot growth is mostly at the expense of the belowground parts (Ram et al., 1991). This may be a major reason for the reduced biomass yield during the period i.e. February-April. In wetlands also, different flowering times can be noticed: the sedges usually stop growing and flower in May and June (Leht, 1999) while common reed continues growing up to the August. This is why the monthly production of each species varies with different species having peak biomass in different months. So even though productivity was much higher in monsoon as compared to summer and winter, there was no significance in the variation due to the high monthly variation of individual species.

The management status determines plant species richness and the above-ground biomass production. Availability of photosynthetic radiation is not as strong determinant for biomass production of wet grasslands as the local hydrological, nutritional and management status. The enclosures given the burnt treatment had the highest productivity as burning enhances the soil nutrient making it more favorable for plants to grow vigorously. Clipping increase species richness and shoot density but decrease above-ground biomass, thus creating more favorable conditions for more plant species. Bakker et al. (2005) demonstrated that cutting reduces the vigor of tall competitive species, allowing smaller species to coexist. So as to maintained the productivity of the Park to sustain the wild ungulates and maintain the thickness of the meadows to support their weight, clipping as a management practice is recommended over burning for the long termed survival of the wild ungulates.

Plate 4. Aboveground biomass study in the National Park. a) Barbed wire for enclosure construction, b) Enclosure, c) Cut plant species from the enclosure and d) Drying of plant samples in the oven.

CHAPTER 6
FORAGE AVAILABILITY

SUMMARY

Standing crop biomass is most often measured to set stocking rates or assess an ecosystem's capability to support grazing animals. The term "forage availability" describes biomass as an amount available to be used for grazing animals. The forage available to the wild ungulates in Keibul Lamjao National Park was assessed using the harvest method. The actual forage available to the wild ungulates was derived by subtracting the biomass extracted by the local people and taking into account only the percentage plant part utilized by the ungulates. The consumable dry matter was derived by calculating the dry matter consumption of individual Sangai and Hog deer from microhistological analysis. Stocking density was calculated from the consumable dry matter and the forage demand of individual Sangai and Hog deer.

Only the 20 forage plant species contributes to the forage availability which accounts for 77.9% of the mean annual biomass of the 41 species recorded from the enclosures. The mean annual biomass of the 41 species was 3545.99 ±198.2 g m^{-2} and 20 forage species was 2764.26 ±139.93 g m^{-2}. Of the forage biomass, 13.3% is extracted by the local people. The overall mean biomass available to the wild ungulates after extraction was 2396.613 ±315.97 g m^{-2} of which only 26.32 ±2.8% was actually used by the wild ungulates as forage. More than 85% of the foraging biomass was contributed by *Z. latifolia, A. donax, Setaria* spp., *Capillipedium* spp., *P. karka, L. hexandra* and *S. spontaneum*. *Zizania latifolia* contributed maximum percentage to the foraging biomass with 35.4% followed by *Arundo donax* (12.5%). The highest percentage plant part utilized by wild ungulates was found to be *Zizania latifolia* (45.8%) followed by *Oenanthe javanica* (40.6%) and the least was *Scirpus lacustris* (6.3%). The highest biomass utilized was also found to be *Zizania latifolia* (3297.77 g m^{-2}) followed by *Arundo donax* (1163.32 g m^{-2}) and the least utilized was *Alternanthera philoxeroides* with only 0.59 g m^{-2}.

Since ungulates consumed 2.5% of their body weight daily, the annual forage demand for individual species of Sangai weighing 110 kg and Hog deer weighing 50 kg was 1003.75 kg year^{-1} and 456.25 kg year^{-1}, respectively.

The total forage biomass available in thick meadows (864.29 ha) after extraction by the local people was higher during 2008-09 (2811236.32 kg) compared to 2009-10 (2425382.9 kg). The actual total biomass available as forage in thin meadows (732.34 ha) was also higher during 2008-09 (2201489.44 kg) compared to 2009-10 (1915206.37 kg). The actual total biomass available as forage in hard ground (58 ha) was higher during 2009-10 (48898.85 kg) compared to 2008-09 (34584.54 kg). The percentage consumable dry matter by Sangai ranged between 6.21 ±1.6 to 7.11 ±1.9 in thick meadows; between 5.65 ±1.7 to 6.35 ±1.8 in thin meadows and between 3.84 ±2.4 to 5.77 ±3.2 in hard ground. Whereas the percentage consumable dry matter by Hog deer ranged between 5.38 ±1.6, to 6.15 ±1.7 in thick meadows; between 4.87 ±1.5 to 5.43 ±1.7 in thin meadows and between 4.76 ±3.1 to 6.91 ±4.3 in hard ground.

Based on the amount of biomass available and its consumption by wild ungulates, the stocking density was calculated. The overall stocking density for Sangai during 2008-09 (N =9) and 2009-10 (N =9) was 0.136 ±0.03 individual ha^{-1} and 0.130 ±0.02 individual ha^{-1}, respectively, whereas for Hog deer it was 0.265 ±0.05 individual ha^{-1} and 0.254 ±0.04 individual ha^{-1}, respectively. Across the seasons, the stocking density for Sangai and Hog deer was estimated to be highest in monsoon (N =6) at 0.154 ±0.04 individual ha^{-1} and 0.300 ±0.06 individual ha^{-1}, respectively. Across the meadow types, stocking density for Sangai and Hog deer was highest in the thick meadows (N =6) at 0.197 ±0.1 individual ha^{-1} and 0.370 ±0.03 individual ha^{-}1, respectively. The overall stocking density for the two study years for Sangai was 0.133 ±0.02 individual ha^{-1} (N =18) and for Hog deer was 0.260 ±0.03 individual ha^{-1} (N =18).

6.1. INTRODUCTION

6.1.1. Forage biomass

Ungulates are an important component of most terrestrial ecosystems. Their main feeding behavior includes grazing and browsing. There is also a difference in the foraging behavior in terms of the relationship between resource abundance and intake rate, which is linear in browsers but asymptotic in grazers. The spatial distribution of the food resource is also different for the different types of herbage, browse being more patchily distributed than grass, and thus browsers and grazers are likely to have a very different perception of food resources in any given ecosystem (Gordon, 2003). Ungulates like other herbivores are generally prey species providing food to many mammals further up the food chain. Efficient management of ungulate herds requires extensive knowledge of their diets and food habits (Holechek et al., 1982; Mofareh et al., 1997; Sandoval et al., 2005). It is essential to determine browse patterns and identify quantity as well as quality of food items. This information is important in determining many aspects of management including; stability of a particular system, whether introducing livestock will be sustainable, selecting species for reseeding, deteriorated habitat, and predicting the result of overgrazing in an area (Holechek et al., 1982).

Phytomass or standing crop biomass are most often measured to set stocking rates or assess an ecosystem's capability to support grazing animals. In fact, the term "forage availability" is a way to describe biomass as an amount to be used for grazing animals. Biomass can also be monitored throughout the grazing season to make necessary adjustments to stocking rates. Some measures of production may also be necessary to assess the value of a site for wildlife habitat. In other words, it is important to know the abundance, availability and usage of the food plants by the ungulates for successful management of ungulates. Abundance is the quantity present in the environment independent of the consumer, availability is the accessibility to the consumer and usage is the quantity utilized by the consumer in a specific time period. It is also important to know the preferred food species as it is independent of availability but depends on the choice made at equal availabilities of all the plant species by the consumer (Ellis et al., 1976).

Earlier research on large ungulate abundance mainly focused on top-down control of ungulate populations by their predators (Hairston et al., 1960) ignoring the general low suitability of plant matter as food for ungulates (Murdoch, 1966). Plant material available for herbivores, apart from often being of poor quality, is also very diverse, both in its morphological and chemical structure (Short, 1971; Robbins et al., 1987). Plant material generally consumed by large herbivores is mainly composed of soluble cell contents and the cell wall (Van Soest, 1982). Nutrients available to herbivores from a particular plant are determined by the ability of the herbivore to break down its chemical structure into digestible products. In terms of forage for ungulates, plants may be broadly categorized as graminoids (monocots belonging to families like Poaceae, Cyperaceae and Juncaceae) and non-graminoids or browse (the other monocots and all dicots). According to Hoffman (1989), the natural differences that exist in the chemical structure of graminoids and browse plant types, the herbivore species is expected to be specialized in digesting graminoids or browse. He also classified herbivores into grazers, browsers and intermediate feeders based on the adaptations required for specialized feeding on graminoids or browse.

Determining the correct stocking rate of a rangeland has been one of the basic problems faced by managers (Holechek, 1988). Timely and accurate estimation of pasture biomass production and forage quality during the grazing season is important for managers to determine appropriate stocking rate and pasture utilization which has been a problem since the early 1900's. Specific procedures or approaches to solve this problem beyond trial and adjustment are generally unavailable. According to Holechek (1988), on yearlong ranges, most decisions regarding adjustment in stocking rates are made at the end of the growing season in the fall. The standing crop is estimated and animal numbers are adjusted, so a minimum residue of dry matter remains prior to the time that growth is initiated the following year. The basis here is that a certain minimum level of dry matter should always be present on a particular range to maintain the soil, forage plant vigor, livestock diet quality, and wildlife habitat.

Ecological research in recent times often involves the comparison of the usage of habitat types or food items to the availability of these resources to the animal. According to Johnson (1980), the study of animal ecology is centered on two main factors, the kinds of foods it consumes and the varieties of habitats it occupies *i.e.* the study of animal ecology is the study of how an animal makes usage of its environment. Fluctuations in forage availability can affect foraging behaviors and movement of individual animals across a landscape (Western, 1975; Rautenstrauch & Krausman, 1989).

Understanding of the causal link between a species and the factors affecting it can be achieved when habitat studies are regarded as the study of an animal's niche

(Morrison, 2001). In this context the resources and conditions that make up an animal's habitat are treated as niche parameters. Of several resources that could determine the distribution of animals, those commonly considered for deer are availability and nutritional quality of forage (Albert & Krausman 1993, Marshal et al., 2005).

For any estimate of long-term grazing capacity, it is important to know the average forage production on a range over a series of years as they tend to fluctuate considerably between years in response to changing climatic conditions. On ranges dominated by perennial forages, a 30% downward adjustment of standing crop at the end of the growing season should give a reasonable estimate of average long-term forage production, if growing conditions are considered good (more than 125% of annual average precipitation), whereas an upward adjustment of 30% should work well when growing conditions are poor (less than 70% of average annual precipitation). In years, when precipitation deviates by 50% or more from the average, reliable estimates of grazing capacity in most cases will not be possible. These adjustments are suggested after reviewing several studies that show forage fluctuations of about 30% from the mean in good and poor years (Hutchings & Stewart, 1953; Klipple & Costello, 1960; Pearson & Witaker, 1974; Smoliak, 1971).

6.1.2. Carrying Capacity/Stocking Density

In this study the carrying capacity is defined as stocking rate in relation to available food resources. It is an issue of an ecosystem concerning both Protected Areas with wildlife communities and rangelands with livestock. Its definition is often confusing and poses a problem because it involves subjective, goal related value judgments (Fritz & Duncan, 1994). Carrying capacity for wildlife is often defined as the maximum number of animals that can be maintained in an area for long term conservation without deteriorating the habitat condition (Eltringham, 1979). Caughley (1979) defined it as “the equilibrium eventually reached between herbivores and plants at which point the rate of growth of plants equals the rate of consumption by herbivores”. It is now well recognized in all parts of the world that the most economic system of raising livestock is through maximum utilization of the available plant materials, particularly the grassland or a grass cover. In deterministic systems, the interaction between plant growth and plant consumption by herbivores and herbivore growth will often lead to equilibrium. Carrying capacity as applied to deer can be defined as the number of animals which a given unit of land area can support without deterioration of the forage resource. A population is limited in size by the factor(s) which exerts the greatest resistance to continued growth like food, cover; water and human interaction which are some of the more important factors limiting population growth of deer.

Wildlife management objectives include the conservation of species and biological processes in natural areas, using wildlife for a sustained yield, or control if it is a pest (Shepherd & Caughley, 1987). Quantification of carrying capacity is usually an important part of these objectives. The dynamics of a plant-herbivore system can be represented by three components (Caughley, 1979): 1) the functional response of the herbivore, which describes plant biomass intake by herbivores as a function of standing plant biomass, 2) the numerical response of the herbivore, which describes the rate of increase of herbivores as a function of standing plant biomass, and 3) the plant growth response, which describes the rate of increase of plant biomass as a function of plant density.

Forage demand can be measured as the amount of forage consumed per day and is often standardized as animal-units. In contrast to seasonal livestock grazing, management of forage for wild ungulates requires forage to be characterized at the scale of an "animal-unit-year" as they remain present on the landscape over a full twelve-month period without supplementation. As such, monthly or seasonal diets and intakes of wild ungulates are summed to annual totals. Despite the fact that most wild ungulates co-exist in multispecies systems (Wallis De Vries, 1995; Wegge et al., 2006), there is limited information associated with concurrent daily intakes of sympatric species (Holechek et al., 2004).

In the absence of predation in natural communities, the numbers of herbivores depend on the food supply and the balance between herbivores and carrying capacity of the environment is secured by auto-regulation mechanisms (Putman, 1996). Specialization of the individual ungulate species in certain components of food supply enables optimal and economic utilization of all accessible food sources (Hofmann, 1989). Reliable estimates of the daily dry matter intake by ungulates are central to assessing carrying capacity and determining animal unit equivalents (Holechek et al, 2004; Owen-Smith & Mills, 2008). In a multi-species system, dry matter intake varies among species, but can be generalized from their digestive capacity and body size (Van Soest, 1994).

Caughley (1979) distinguished two separate meanings for carrying capacity and introduced the terms 'ecological carrying capacity' and 'economic carrying capacity'. The former is defined as the maximum number of animals a defined area can support in relation to available resources where carrying capacity is limited primarily by forage whereas the latter is defined as stocking rates in relation to available vegetation that achieve sustained productivity and profitability. An economic carrying capacity can be imposed upon a system if the herbivore population is sustainably harvested. Under sustainable harvesting a new equilibrium will be formed, the density of herbivores will be lower and the biomass of plants will be higher than the equilibrium in the un-harvested system.

Since standing crop biomass are most often measured to set stocking rates or assess an ecosystem's capability to support grazing animals, the issue is being address in this chapter. In view of the recent changes in hydrology and deteriorating habitat conditions of the National Park, it is important to determine the capability of the Park to support the wild ungulates.

6.2. METHODOLOGY

6.2.1. Determination of forage biomass available to wild ungulates

For estimation of forage biomass in mixed species and naturalized pastures, standard quadrat harvesting remains the most reliable method, provided that enough quadrats are clipped to adequately represent a given area (Martin et al., 2005). In the present study, to estimate the forage biomass available to the wild ungulates, the forage species were harvested from a quadrat (1 m x 1 m) in control enclosures (Chapter 4). Since the date of sampling can also affect the accuracy of forage biomass predicting methods due to seasonal changes in the sward's botanical composition, phonological stage, herbage accumulation below the grazing horizon and accumulation of dead material (Donkor et al. 2003), monthly harvesting was done. The data from the harvested quadrat was entered and analyzed by: (1) listing all available forage species (2) the biomass (kg/ha, dry weight) of each forage species.

6.2.2. Utilization of forage species

Measurement of foraging part of the plant species/leaf was done from field observations of feeding sign and biomass estimation was done following the Harvest method (Chapman et al., 2009). Percentage utilized was derived by comparing the quantity utilized from each stalk of feeding sign observed in the field and comparing the part eaten from the whole stalk in the undisturbed control plots. The biomass of the individual species after feeding recorded from field observations of the feeding sign was subtracted from the total biomass of the food plants from the control plots (n=10). This determined the foraging biomass available for use by wild ungulates from the total forage biomass produced by the floating meadows.

6.2.3. Carrying capacity/ Stocking density

To determine how many animals a land area will support (stocking rate), answers to two important questions are required: 1) How much forage the particular animal or group of animals will consume, and 2) How much forage is available. Stocking density is calculated from an estimation of annual production of consumable vegetation, linked to animal requirements for feed and nutrients. To calculate stocking density it is required to determine the *total available forage* in the pasture and the *animal demand for forage*. In recent years, considerable information has become available on daily forage intake by ruminant animals. Ruminants consume about 2% of their body weight per day in dry matter when data are averaged across periods when forage is dormant and actively growing (Holechek, 1988). If a range is to be grazed only during the dormant period when forage is low in quality, it is suggested that daily forage demand is 1.5% of body weight, while during active growth when forage is high in quality, 2.5% is suggested (Holechek, 2004).

The body weight of an adult matured Sangai was taken as 110 kg based on the information collected from literature (e.g. Prescott, 1987; McCracken, 1996; Aung, et al., 2001; Macdonald, 2001; McShea, et al., 2001, Hussain et al., 2006). The body weight of an adult matured Hog deer was taken as 50 kg based on the information collected from literature (Prater, 1980; Mishra, 1982; Putman 1988; Michelin, 2002; Biswas, 2004; Macdonald, 2009) for the present study.

6.2.4. Biomass available to ungulates

Determination of utilization of forage species in terms of percentage eaten for each species is based on 20 forage species used by Sangai and Hog deer. Measurement of foraging part of the plant species/leaf was done from field observations of feeding signs. The length of the stalk eaten by the ungulates was compared with the undisturbed length in the control plots. The percentage eaten from the whole stalk was thus calculated. Percentage utilized was derived by comparing the quantity utilized from each stalk (Chapman et al., 2009), i.e. by subtracting the biomass of the individual species after feeding recorded from field observations of the feeding sign from the total biomass of the food plants from the control plots (n=10). This determined the foraging biomass available for wild ungulates from the total biomass produced.

Biomass available to ungulates is total biomass of the forage plants produce (g m^{-2}) minus the biomass of non-palatable species and biomass extracted by local communities. For each ungulate species, forage intake (kg ha^{-1}) and% dry matter in the diet were summed to annual totals. The total usable forage biomass available for utilization by the wild ungulates was calculated by the equation developed by Holechek (1988) which is:

$$TFA_e = (FP) – (PB_e)$$ ……………. equation (1)

Where, TFA_e = Total forage (kg for 20 species) available for grazing after human extraction

FP = Forage production (kg ha^{-1} of 20 plant species) from the control plot

PB_e = Percentage biomass extracted by humans

Forage available to Sangai and Hog deer for 864.29 ha of thick meadows was calculated as,

$$FA = TFA_e \times PP \times A$$ .... equation (2)

Where, FA = Actual forage (kg) available for ungulates in 864.29 ha

TFA_e = Total forage (kg) available for grazing after human extraction

PP = Percentage plant part utilized by the ungulates

A = Area (ha)

To derive the actual intake by ungulates, percentage of dry matter consumed of each food plant species was calculated using the micro-histological analysis (Sparks & Malecheck, 1968). Five slides each were prepared separately for each food plant species for both Sangai and Hog deer and 20 microscopic fields per slide were observed, resulting in 100 observations for each species. Dry weight consumed was calculated from density and relative density of each observation. Fragments recognized as epidermal tissue were noted as positive evidence for the presence of a plant species at a location in the slide. Frequency percentages were tabulated for each species in the mixture. The frequency percentages were converted to particle density per field using a table developed by Fracker and Brischle (1944) and the relative density, expressed as a percentage, of each species in the mixture was calculated. The relative density of a species was used to estimate the percentage dry weight of that species in the mixture. Regression equations that express the relationship between estimated percentage dry weight (X) and actual percentage dry weight (Y) were developed as follows.

Sangai: Relative density* 0.811+1.179; ($R^2 = 0.906$, $p<0.05$) and

Hog deer: Relative density* 0.831+0.099; ($R^2 = 0.871$, $p<0.05$)

Using the above equations, the percentage dry weight consumed by Sangai & Hog deer was calculated. Thus,

CDM = (FA) – (DW) …………………. equation (3)

Where, CDM = Consumable dry matter in individual meadow types

FA = Forage available after extraction

DW = Percentage dry weight consumed

Forage dry matter consumption in gram per animal per year is calculated with the following equation (Holechek, 1988):

FD = W x DDI x 365 ……equation (4)

Where, FD = Forage demand (kg) per animal per year

W = Weight of animal (kg) [Sangai (110 kg), Hog deer (50 kg)]

DDI = Daily dry matter intake (i.e., 2.5% body weight)

365 = Number of days pasture will be grazed

Estimated populations of Sangai and Hog deer was calculated on the basis of consumable dry matter available in the Park under different meadow conditions as,

Estimated population = CDM / FD [equation (3) / equation (4)]……equation (5)

Where, EP = Estimated population

CDM = Consumable dry matter in different meadow types

FD = Forage demand (kg) per animal per year

Stocking density of the area was calculated by the equation:

SD = EP/A [equation (5)/ Area]

Where, EP = Estimated population

A = Area (864.29 ha)

6.3. RESULTS

6.3.1 Overall forage biomass

Of the total annual biomass of 3545.99 ± 198.2 g m^{-2} (n=41 species, 24 months), the forage biomass was 2764.26 ± 139.93 g m^{-2} (n=20 species, 24 months) which constitutes 77.9% of the overall annual biomass. From the forage biomass, 13.3% (367.65 ± 148.25 g m^{-2}) was extracted by the local communities and 86.7% (2396.613 ± 315.97 g m^{-2}) was available to the wild ungulates (Table 6.1). Of the 86.7% of the mean annual biomass available to the wild ungulates, only 26.32% (630.79 ± 111.5 g m^{-2}) is utilized by them (Figure 6.1). More than 85% of the foraging biomass was contributed by *Z. latifolia, A. donax, Setaria* spp., *Capillipedium* spp., *P. karka, L. hexandra* and *S. spontaneum*. *Zizania latifolia* contributed maximum percentage to the foraging biomass with 35.4% followed by *Arundo donax* (12.5%), *Setaria* spp (9.2%) and *Capillipedium* spp (8.4%). *Zizania latifolia* being an invasive plant can re-grow even from a small rhizome and streamside plant communities by over stopping and suppressing other marginal species (Table 6.2, Figure 6.2).

Table 6.1. Percentage of annual forage biomass (g m^{-2}) available to the wild ungulates in the National Park.

	Mean	%
Mean biomass (N =41 sp, 24 months)	3545 ±198.2	
Mean forage (N =20 sp, 24 months)	2764.26 ±139.93	77.9
Biomass extracted	367.65 ±148.25	13.3
Biomass after extraction	2396.613 ±315.97	86.7
Actual biomass consumed	630.79 ±111.5	26.32 ±2.8
Left after consumption	1765.825 ± 222.17	73.68

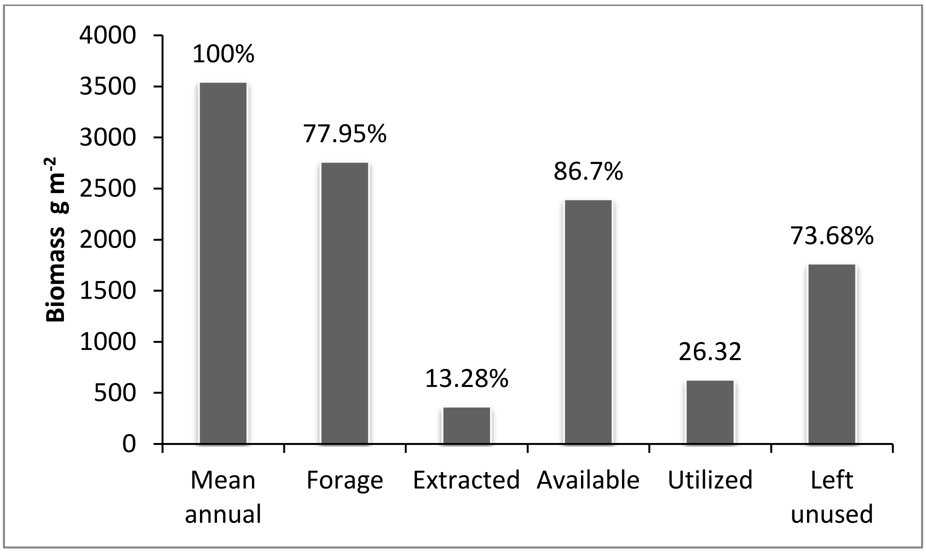


Figure 6.1. Percentage of biomass (g m^{-2}) utilized by Sangai and Hog deer.

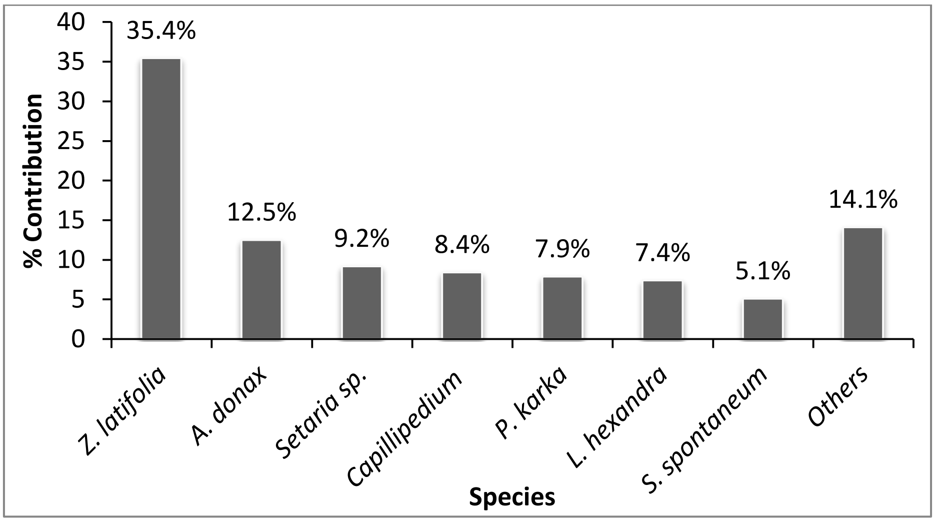


Figure 6.2. Percentage contribution of individual species to forage biomass.

Table 6.2 Percent forage biomass contributed by individual species of the food plants for wild ungulates in the National Park.

Food plants	% of biomass utilized
Zizania latifolia	35.43
Arundo donax	12.50
Setaria sp.	9.19
Capillipedium spp	8.42
Phragmites karka	7.87
Leersia hexandra	7.39
Saccharum spontaneum	5.09
Hedydhium coronarium	3.84
Carex cruciata	2.86
Imperata cylindrica	1.37
Oenanthe javanica	1.28
Coix lacrymajobi	0.90
Oryza rufipogon	0.87
Persicaria perfoliata	0.77
Hemarthria compressa	0.69
Kylinga triceps	0.49
Osbeckia stellata	0.42
Scirpus lacustris	0.38
Cyperus spp	0.22
Alternanthera philoxeroides	0.01

The highest percentage plant part utilized was *Zizania latifolia* with 45.8% being utilized by the wild ungulates followed by *Oenanthe javanica* (40.6%), *Setaria* spp. and *Carex cruciata* (37.3%) and the least was of *Scirpus lacustris* with only 6.3% being utilized by the wild ungulates (Table 6.3). The highest biomass utilized was also found to be *Zizania latifolia* with 3297.77 g m^{-2} followed by *Arundo donax* with 1163.32 g m^{-2} and *Setaria* spp. with 855.53 g m^{-2} and the least was found to be *Alternanthera philoxeroides* with only 0.59 g m^{-2}.

Table 6.3. Species wise forage biomass (g m^{-2}) utilized by wild ungulates in the National Park.

Food plants	Annual biomass	% Plant part consumed	Biomass utilized
Zizania latifolia	7197.11 ±338.09	45.8	3297.77
Arundo donax	3928.41 ±554.64	29.6	1163.32
Setaria sp.	2290.72 ±455.33	37.3	855.53
Capillipedium spp	2636.84 ±395.11	29.7	783.28
Phragmites karka	4089.83 ±247.03	17.9	732.51
Leersia hexandra	2182.18 ±508.5	31.5	687.39
Saccharum spontaneum	2603.21 ±79.11	18.2	474.19
Hedydhium coronarium	2187.36 ±682.66	16.4	357.84
Carex cruciata	712.48 ±43.86	37.3	265.84
Imperata cylindrica	399.46 ±58.55	32.0	127.68
Oenanthe javanica	293.96 ±1.09	40.6	119.37
Coix lacrymajobi	395.71 ±376.82	21.3	84.16
Oryza rufipogon	389.89 ±219.06	20.8	80.91
Persicaria perfoliata	222.05 ±90.34	32.3	71.67
Hemarthria compressa	317.35 ±22.85	20.4	64.62
Kylinga triceps	206.81 ±114.67	22.1	45.69
Osbeckia stellata	144.94 ±107.79	24.5	35.48
Scirpus lacustris	623.29 ±101.52	6.3	38.96
Cyperus spp	191.33 ±125.58	10.6	20.34
Alternanthera philoxeroides	1.86 ±1.86	31.9	0.59

6.3.2. Carrying capacity/ Stocking Density

Daily intake of the wild ungulates was calculated by considering the weight of Sangai as 110 kg and Hog deer as 50 kg. Since ungulates consumed 2.5% of their body weight daily, the annual forage demand for individual species of Sangai and Hog deer was 1003.75 kg $year^{-1}$ and 456.25 kg $year^{-1}$ respectively (Table 6.4).

Table 6.4. Annual forage demand for Sangai and Hog deer in the National Park.

	Body weight W (kg)	% Body weight DDI	Daily intake (kg)	Annual forage demand FD =W x DDI x 365 (kg)
Sangai	110	2.5	2.75	1003.75
Hog deer	50	2.5	1.25	456.25

The stocking density of the Park was calculated across the seasons and meadow types based on the consumable forage available for use by Sangai and Hog deer in each season and meadow types for the two study years. The actual total biomass available for use in thick meadows (864.29 ha) was higher during 2008-09 (2811236.32 kg) compared to 2009-10 (2425382.9 kg) (Table 6.5). The actual total biomass available for use in thin meadows (732.34 ha) was also higher during 2008-09 (2201489.44 kg) compared to 2009-10 (1915206.37 kg) (Table 6.6). However, the actual total biomass available for use in hard ground (58 ha) was higher during 2009-10 (48898.85 kg) compared to 2008-09 (34584.54 kg) (Table 6.7). The percentage dry weight consumed by Sangai ranged between 6.21 ±1.6 to 7.11 ±1.9 in thick meadows; between 5.65 ±1.7 to 6.35 ±1.8 in thin meadows and between 3.84 ±2.4 to 5.77 ±3.2 in hard ground. Whereas the percentage dry weight consumed by Hog deer ranged between 5.38 ±1.6, to 6.15 ±1.7 in thick meadows; between 4.87±1.5 to 5.43±1.7 in thin meadows and between 4.76±3.1 to 6.91 ±4.3 in hard ground (Tables 6.5, 6.6, 6.7).

Table 6.5. Percent forage available, usable biomass and percentage consumable dry matter for Sangai and Hog deer in thick meadows (864.29 ha) across the seasons of the study years.

Year	Season	% Utilized	Usable biomass (kg)	% Consumable dry matter	
				Sangai	Hog deer
2008-09	Summer	27.52 ±2.7	3216683.05	6.74 ±1.8	5.73 ±1.7
	Monsoon	27.52 ±2.7	2983008.38	6.26 ±1.7	5.38 ±1.6
	Winter	27.18 ±2.9	2263929.00	6.74 ±1.8	5.73 ±1.7
	Overall	27.52 ±2.7	2811236.32	6.26 ±1.7	5.38 ±1.6
2009-10	Summer	29.37 ±2.7	2692871.56	7.11 ±1.9	6.15 ±1.7
	Monsoon	29.37 ±2.7	2714715.73	7.11 ±1.9	6.15 ±1.7
	Winter	29.37 ±2.7	2035837.53	7.11 ±1.9	6.15 ±1.7
	Overall	27.04 ±2.6	2425382.9	6.21 ±1.6	5.16 ±1.5

Table 6.6. Percent forage available, usable biomass and percentage consumable dry matter for Sangai and Hog deer in thin meadows (732.34 ha) across the seasons of the study years.

Year	Season	% Utilized	Usable biomass (kg)	% Consumable dry matter	
				Sangai	**Hog deer**
2008-09	Summer	26.08 ±3.1	1791410.18	6.06 ±1.7	5.15 ±1.6
	Monsoon	26.08 ±3.1	2647540.49	6.06 ±1.7	5.15 ±1.6
	Winter	26.47 ±2.9	1882248.01	5.65 ±1.7	4.87 ±1.5
	Overall	26.47 ±2.9	2201489.44	5.65 ±1.7	4.87 ±1.5
2009-10	Summer	27.27 ±3.1	1723016.24	6.35 ±1.8	5.43 ±1.7
	Monsoon	27.27 ±3.1	2441962.91	6.35 ±1.8	5.43 ±1.7
	Winter	27.60 ±2.9	1348181.81	5.89 ±1.8	5.11 ±1.6
	Overall	27.60 ±2.9	1915206.37	5.89 ±1.8	5.11 ±1.6

Table 6.7. Percent forage available, usable biomass and percentage consumable dry matter for Sangai and Hog deer in hard ground (58 ha) across the seasons of the study years.

Year	Season	% Utilized	Usable biomass (kg)	% Consumable dry matter	
				Sangai	Hog deer
2008-09	Summer	27.49 ±4.2	25989.47	5.77 ±3.2	6.91 ±4.3
	Monsoon	27.49 ±4.2	52580.19	5.77 ±3.2	6.91 ±4.3
	Winter	27.49 ±4.2	18536.29	5.77 ±3.2	6.91 ±4.3
	Overall	27.49 ±4.2	34584.54	5.77 ±3.2	6.91 ±4.3
2009-10	Summer	27.49 ±4.2	63712.82	5.77 ±3.2	6.91 ±4.3
	Monsoon	27.49 ±4.2	36309.4	5.77 ±3.2	6.91 ±4.3
	Winter	25.32 ±2.6	50115.33	4.61 ±2.7	5.22 ±3.7
	Overall	27.33 ±2.9	48898.85	3.84 ±2.4	4.76 ±3.1

The stocking density for Sangai during 2008-09 was 0.136 ±0.03 individual ha^{-1} and Hog deer was 0.265 ±0.05 individual ha^{-1}. The stocking density for Sangai during 2009-10 was 0.130 ±0.02 individual $ha^{-1}$and Hog deer was 0.254 ±0.04 individual ha^{-1}. The overall stocking density for the two study years for Sangai was 0.133 ±0.02 individual $ha^{-1}$and Hog deer was 0.260 ±0.03 individual ha^{-1}. Across the seasons, the stocking density for Sangai was highest in monsoon with 0.154 ±0.04 individual ha^{-1} followed by summer with 0.140 ±0.03 individual ha^{-1} and least in winter with 0.105 ±0.03 individual ha^{-1}. The stocking density for Hog deer was also highest in monsoon with 0.300 ±0.06 individual ha^{-1} followed by summer with 0.275 ±0.06 individual ha^{-1} and winter with 0.204 ±0.04 individual ha^{-1} (Table 6.8).

Across the meadow types for the two study years, stocking density for Sangai was highest in the thick meadows with 0.197 ±0.1 individual ha^{-1} followed by thin meadows with 0.163 ±0.02 individual ha^{-1} and hard-ground with 0.039 ±0.01 individual ha^{-1}. It was also highest in the thick meadows for Hog deer with 0.370 ±0.03 individual ha^{-1} followed by thin meadows with 0.308 ±0.03 individual ha^{-1} and hard ground with 0.102 ±0.02 individual ha^{-1} (Table 6.8).

The area of thick meadows suitable for Sangai and Hog deer was 864.29 ha and thin meadows was 732.34 ha as calculated from the meadows thickness meadured during transect (Chapter 4). The hard ground considered in this study is the dry patch of grassland in Thangbirel located on the western part of the Park. Area of this dry grassland was 58 ha as derived from the habitat classification of the Park (Chapter 4).

Table 6.8. Stocking density of Sangai and Hog Deer, across the meadow types, seasons and the study years.

Parameters		Sangai	Hog deer
Meadow type	Thick meadows	0.197 ±0.01	0.370 ±0.03
	Thin meadows	0.163 ±0.02	0.308 ±0.03
	Hard ground	0.039 ±0.01	0.102 ±0.02
Seasons	Summer	0.140 ±0.03	0.275 ±0.06
	Monsoon	0.154 ±0.04	0.300 ±0.06
	Winter	0.105 ±0.03	0.204 ±0.04
Years	2008-09	0.136 ±0.03	0.265 ±0.05
	2009-10	0.130 ±0.02	0.254 ±0.04
	2008-10	0.133 ±0.02	0.260 ±0.03

6.4. DISCUSSIONS

Quantitative evaluations of habitat have become increasingly important in forest, range, and wildlife management. The concept of carrying capacity originally was developed for domestic grazers and thus did not have provision for the wide variety of diets found in wild herbivores. Determination of above ground biomass and the stocking density of the Keibul Lamjao National Park was important for the improved conservation of Sangai and Hog deer in the Park. In recent years, many procedures for evaluating habitat have been suggested. In this study, resource based carrying capacity was used to determine the number of Sangai and Hog deer the Park, that can be supported by the current rate of biomass production. The availability and quality of forage available are important constraints influencing the survival and viability of wild ungulate populations. The study area has three separate types of meadows as well as hard ground which gets inundated during few months period in a year. Forage standing crop on the three management units was found to be diverse (Chapter 4 & 5).

Impact of current levels of grazing on the ecological stability and secondary succession of vegetation comprising the seasonal plant communities of the Park is not known. A primary concern of resource managers is maintaining or enhancing ecological stability of vegetation that comprises the forage resource for wild ungulate grazers (Sheehy, 1988; Holechek, 1988). A synergistic relationship does exist between the ungulate grazers whereby one ungulate species improves forage quantity and quality for a second ungulate species. It is possible that removal of one ungulate grazer will alter behavior and or distribution of the other. Such alteration could locally decrease the community stability and increase the intra- specific competition (Sheehy, undated).

A further critical step is to understand how forage characteristics are affected by environmental factors and to predict forage quality and availability based on environmental conditions. Forage characteristics have important consequences for habitat quality (Rautenstrauch et al., 1988). Because quality declines with plant maturation, and intake declines at low biomass, ungulates are predicted to select intermediate forage biomass to maximize energy intake by following phenological gradients during the growing season. Forage quality is highest in new plant growth because of high cell soluble content, which declines as plants mature and fiber accumulates (Van Soest, 1982). Modest increases in forage quality can increase nutrient intake for ruminants because of the multiplier effects of higher nutrients and accompanying reductions in rumination and passage time (White, 1983).

The emergence of ecosystem management as a central focus of land managers (Christensen et al., 1996) has increased the importance of efforts to manage ungulates in reasonable balance with the vegetation that supports them. The coexistence of wild ungulates with large populations of domestic livestock further complicates the issue, forcing wildlife and range managers to consider the effects of all herbivores on the ecosystem, rather than those of just one species at a time. Competition between the wild ungulates and domestic cattle has also been observed in the present study especially during drier months of summer when the forage quantity is less compared to monsoon and winter when forage quantity is more. Similar competition has also been observed in the western United States between elk and cattle where the elk consumes standing dead biomass in winter and green biomass in early spring directly reducing the amount of forage available for cattle (Hogan, 1990; Cool, 1992; Hobbs et al., 1996; Werner & Urness, 1998).

Maintaining the correct animal stocking rate of an area is important in maximizing animal health and productivity. Overstocking an area is damaging not only to the animal but also to the environment leading to soil erosion and nutrient pollution of the water bodies (Greene & Fultz, 2002). Maintaining a balance between the stocking rate and the productivity of an area by correct estimation of the carrying capacity is an important step in establishing a sustainable habitat. In the present study, even though the Park is 4000 ha only 864.29 ha had suitable meadow thickness best suitable for Sangai, the remaining 732.34 ha was covered by meadows < 120 cm thickness which can support the weight of Sangai, but is not the best habitat. The 58 ha stretch of dry hard ground grassland present in the western side of the Park also plays a crucial role especially during high water level in monsoon and early winter when the Park remains inundated. As per the results of the stocking density, the thick meadows had the highest stocking density followed by the thin meadows and the hard ground indicating that maintaining the thickness of the meadows is crucial for maintaining a steady population of Sangai in the Park. The results of the study show that food is not a constraint in the Park but space seems to be a constraint.

As wildlife populations are re-established and increased, it becomes necessary to set limits to their population size to keep them in balance with their food resources and provide for their social needs. In essence, the ecological grazing and browsing capacity for herbivores of a habitat is the maximum number of grazers and browsers that a given area of land can sustain, based on the biophysical resources of the area. Together they form the ecological capacity of the habitat to support wild herbivores. Proposed stocking densities are seldom as high as the ecological grazing and browsing capacities. For maximum wildlife production on a ranch, an economic grazing or browsing capacity is therefore usually set at 70-80% of the ecological grazing or browsing capacity (Van Rooyen, 2002a). In the case of the Keibul Lamjao National Park, of the total forage available to the wild ungulates, only 26.32% is being utilized by them.

As mentioned earlier, overstocking a particular habitat can be detrimental to the ecosystem and the wild animals. By comparing the actual animal numbers present on the ranch with those that are recommended based on the available plant resources, the overstocking detected on the ranch can be rectified by harvesting wildlife selectively without disturbing the ratio of the different feeding classes. In the case of the Keibul Lamjao National Park, the actual number of Sangai and sympatric Hog deer is far lower than the number recommended through stocking density based on the available plant resources. So there is a scope to increase the population of the wild ungulates of the National Park based on food resources. However, the problem face by the wild ungulates of the Park is the deteriorating habitat conditions in terms of space. For the long term survival of the wild ungulates in the National Park, maintaining the thickness of the meadows is imperative so as to increase the suitable area available.

Other aspects considered when setting stocking densities for the different types of wildlife are plant phenology, range size, and territoriality. On smaller wildlife ranches, minimum herd sizes and sex ratios are important aspects to include when stocking wildlife. By basing wildlife stocking densities on the ecological capacity of the range to support herbivores, quantitative and clearly defined parameters exist on which to develop wildlife management decisions. In doing so, vegetation composition, quantity, and quality at a specific time and place dictate management actions that should be taken. Available grazing and browse biomass can be used to estimate the population size of each type of wildlife that can survive the critical period of a particular habitat (Van Rooyen, 2002b).

The concept of carrying capacity has been applied to the management of domestic and wild herbivores in a wide range of habitats. The analysis of carrying capacity in this study indicates that the concept is useful in deterministic and slightly variable environments. In environments where plant-herbivore dynamics do not reach or closely approach equilibrium levels, carrying capacity is more a mathematical abstraction than a measurement of sustainable population size (Macnab, 1985). In systems that are insensitive to variation, or any system that reaches or closely approaches equilibrium, carrying capacity is a useful measure of sustainable density. Measurement of carrying capacity is an implicit part for maximum sustainable yield models (Caughley 1976).Carrying capacity can then be calculated on a time scale of interest, over which the potential dynamics of the population are studied. In this sense, carrying capacity is not a measurement of long-term equilibrium density but of short-term potential density as a function of resource availability.

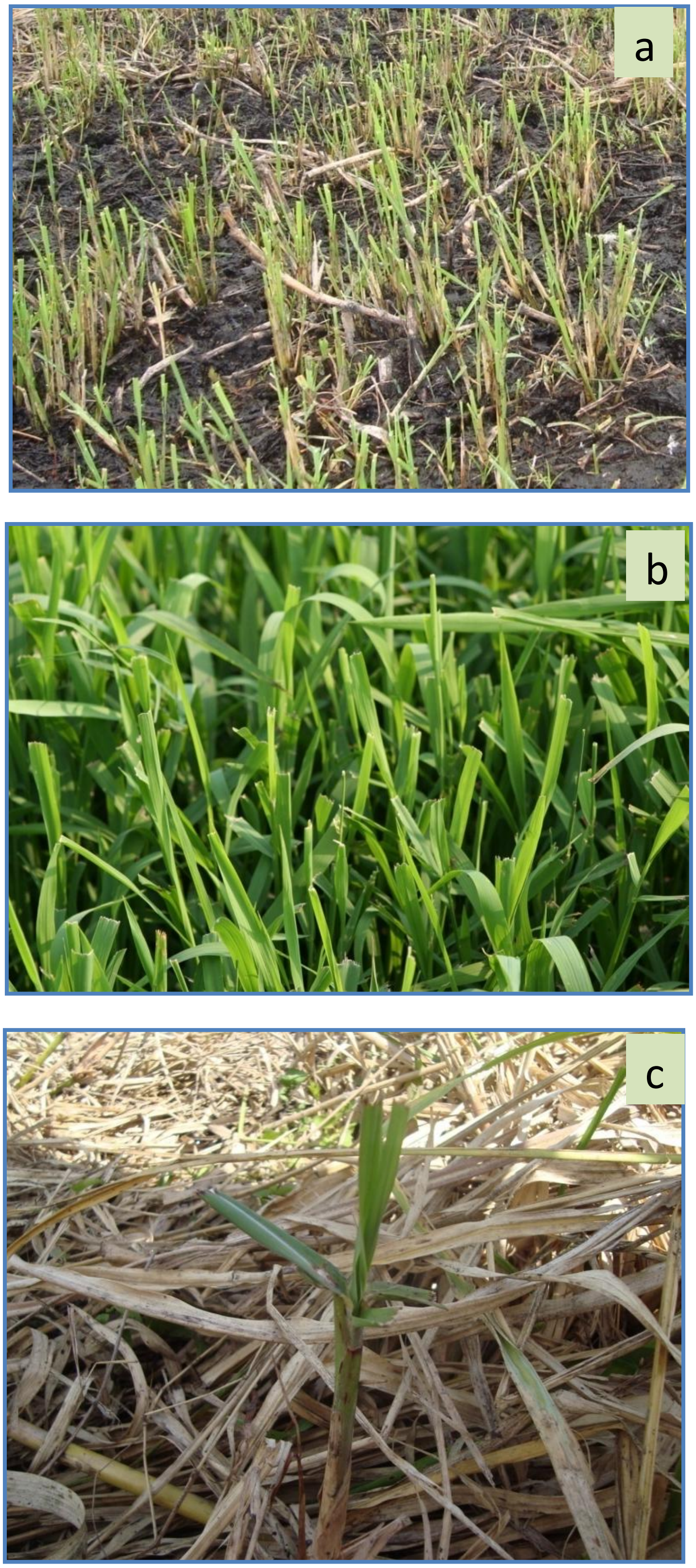


Plate 5. Feeding sign of Sangai and Hog deer in the National Park. (a) *Zizania latifolia*, (b) *Oryza rufipogon* and (c) *Saccharum spontaneum*

CHAPTER 7

CONSERVATION IMPLICATIONS

7.1. INTRODUCTION

Habitat loss is the primary environmental cause of biodiversity decline at local, regional and global scales (Bibby, 1995; Ehrlich, 1995; Fahrig, 2001; Dirzo & Raven 2003; Balmford et al., 2005; Schipper et al., 2008). Loss and fragmentation of habitat results in reduced population size that increases the probability of extinction by demographic and/or environmental stochasticity (Burkey, 1995). Among land species, habitat loss is prevalent across the tropics, which coincides with areas of high deforestation in the America, Africa, and Asia (Schipper, et al., 2008). The recent increase in habitat loss is due to growth of the human population leading to expansion of human activities into formerly natural areas (Sisk et al., 1994). At the same time, there has been a growing concern for conservation of species and ecosystems (Gore, 1992). Given the pressures on habitat, for conservation efforts to be successful, the most important question that must be answered is how much habitat must be conserved to ensure persistence of populations? (Fahrig, 2001). Such question is often addressed at the patch scale, *i.e.* what is the minimum (or 'critical') patch size necessary to maintain a viable population (e.g. Beier, 1993; Wenny et al., 1993; Howells & Edwards-Jones, 1997; Marshall & Edwards-Jones, 1998; Fahrig, 2001)? Modeling studies suggest that the critical patch size depends on a combination of quality of patch (habitat), reproductive rate of the organism, rate of emigration from the adjacent patches, population genetics of the organism, and stochastic factors such as disturbances (Soulé & Simberloff, 1986, Lande, 1987, Schneider & Yodzis, 1994, Wissel & Zaschke, 1994, Bevers & Flather, 1999, Fahrig, 2001).

In India, the floating meadows of the Loktak Lake and Keibul Lamjao National Park, Manipur is the only remaining habitat of the Eld's deer *Rucervus eldii* locally known as Sangai. It is considered as one of the most endangered deer species in India. Once widely distributed throughout the State of Manipur, it is now restricted to the southeastern fringe of Loktak Lake. The purpose of the present study was to improve upon the existing ecological knowledge base of the severely fragmented, small and isolated population of Eld's deer in the Park, so as to develop appropriate measures for the conservation of this species and related cervids.

Among deer, the population characteristics and dynamics vary in relation to physical and biological characteristics of individual habitats (Mackie, 1981). The main elements of the interaction between a herbivore and the plants that it eats can be summarized as: (a) The rate of increase of edible plant biomass per unit area as a function of its standing density and environmental attributes such as the temperature of the air and the amount of moisture in the soil (plant growth response). (b) Rate of intake of food per herbivore as a function of the standing density of the edible vegetation (functional response). (c) The rate of increase of herbivore population as a function of the standing density of the edible vegetation, and (4) The rate of increase of the herbivore population as causal function of its own density (intrinsic response) (Caughley & Gunn, 1993).

Keeping in view the above discussion, the following synthesis has been made based on the findings of the study for effective conservation of Sangai and associated cervids in the Keibul Lamjao National Park.

7.2. Water quality and nutrient status

'Loktak' is a very common word for the people of Manipur denoting the importance of the Lake for the people of Manipur. This name is used in multiple ways in various aspects of the society –education, culture, folklore and economy of the state. Exploitation of the Lake for various interests has resulted in a rapid deterioration of the Lake ecosystem. Since an ecosystem function is governed by the biotic and abiotic elements of the systems, it becomes critical to study these elements of the ecosystem (Prasad et al., 2007). Hence, the present study was undertaken to assess the water quality and nutrient status of the soil sediment of the Loktak Lake and Keibul Lamjao National Park and discuss the impact of this overexploitation on the Lake ecosystem. The results of the study are indicative of the excess nutrient load on the Lake. The water quality of the Lake is deteriorating due to excess nutrient and pollutant from the rivers *viz.* Nambul, Nambol, Moirang, Potsangbam and Naranseina that drain into the Lake. The sites where the Nambul and Nambol rivers drain into the Lake were found to be highly polluted, in terms of water quality and nutrient load. Besides, the surface runoffs from the catchment brings large amount of nutrient due to forest degradation and jhuming resulting in hypereutrophic conditions of the Lake. The construction of the Ithai barrage has also played a significant role in the present status of the Lake ecosystem, as the barrage blocks both the outlet channels, Ungamel and Khordak. As a result of this blockage nutrients entering the Lake and the Park do not flow out. The excess nutrient retention by the meadows is resulting in their proliferation and resultant decrease in their thickness, which is detrimental for the survival of Sangai. The anthropogenic activities, such as livestock rearing, aquaculture, deforestation and jhumming in the catchment area increase the influx of sediments and nutrients enhancing the siltation of the Lake.

A need for holistic approach is felt to save the lake from the present trend of rapid deterioration. The outflow of nutrients through its outlets channels needs to be restored especially during monsoon. Restoration of flushing mechanism of the lLake will reduce the nutrient load in the Lake as well as the Park. Athaphum fishing, where the meadows are cut off from its continuous mass to create fish farms in the open water bodies are not only destroying the integrity of the meadows but are also deteriorating the water quality from the household waste disposed from the floating huts constructed for these purpose of farming. An awareness campaign amongst local people involved in resource extraction and meadows fishing should be organized to educate them to minimize extraction and to reduce the number of athaphum and minimize its impact on the Lake.

Activities in the catchment area enhancing siltation need to be checked. Establishment of a treatment plant on the most polluted rivers entering the Lake and watershed management along the catchment area will go a long way in maintaining the integrity of the Lake.

7.3. Vegetation composition and plant community structure

The plant community plays a significant role in the understanding a particular habitat. Vegetation, particularly of the floating meadows plays a key role in governing the wetland processes and function of the Loktak Lake. The vegetation of the floating meadows include emergent, submerged and floating type life forms. They influence hydrological regimes, harbor rich biodiversity, support productive fisheries and provide several economically important plant species to the communities. In the present study, as many as 185 plant species belonging to 121 genera and 50 families have been recorded. The most dominant families, Poaceae and Cyperaceae indicate the grassland nature of the Park. The dominant grass species like *Phragmites karka*, *Saccharum spontaneum*, *Zizania latifolia*, *Leersia hexandra*, *Capillipedium* spp, and herb species like *Alternanthera philoxeroides*, *Oenanthe javanica* and *Hedychium coronarium* also contribute maximum to the forage diet of the wild ungulates (Sangai and Hog deer) in the Park. The dominance of *Hemarthria compressa*, *Oryza rufipogon*, *Setaria* spp and *Leersia hexandra* in the dry hard ground of the Park indicates the distinct habitat type exhibited by the hard ground compared to the floating meadows. These grass species also contribute maximum to the diet of the wild ungulates emphasizing the importance of these dry patch of hard ground in the Park.

The dominant grass species which contribute maximum to the forage diet of the ungulates in the Park are also being extracted by the local people. The plant species of the Park provide food, fodder, fuel, medicinal, handicraft and thatching material for hut construction. People living in the periphery of the Park collect these economically important plants daily for their own use as a means of livelihood. *Hedychium coronarium* and *Oenanthe javanica* are extracted in huge quantities everyday throughout the growing season mainly for commercial purposes. *Phragmites karka*, *Arundo donax* and *Saccharum spontaneum* are extracted in large quantities for fuel and fencing. Extraction of these economically important plants is done almost all year round which is degrading the habitat and is a threat for the survival of Sangai. In view of these, restriction on extraction of biomass from the Park needs to be imposed in strict sense. Simultaneously, development of sustainable livelihood options for the local people will greatly reduce the anthropogenic pressure on the Park. A balance needs to be maintained whereby the anthropogenic pressure and hydrological regime do not disturb the habitat of the wildlife and the Park integrity is maintained.

Since the Park remains flooded during monsoon to early winter making some of the areas inaccessible to the ungulates, maintaining the water level of the Lake and Park is imperative for the survival of Sangai.

7.4. Extent and the thickness of floating meadows

The habitat of Sangai in the Park is deteriorating primarily due to the change in water regime negatively affecting the thickness of the floating meadows. The floating meadows which used to settle during lean season and get replenished with soil and nourishment, are now continuously floating resulting in their thinning, making them increasingly defunct in supporting the weight of the Sangai. In this study, an attempt was made to examine the changes in floating meadows thickness and the resultant impact on the habitat. The study revealed that the thickness of the floating meadows is decreasing at rate of 9% per annum in the Park. The floating meadows thickness in the northern and southern zone is decreasing at the rate of 6% and 12% per annum respectively. The meadows in the northern zone are dynamic due to close proximity to open water and tend to float around depending on the direction of the wind where as the meadows in the southern zone of the Park are fixed. The higher rate of decline in meadows thickness in the southern zone could be due to the reason that meadows proliferation is taking place from the inside towards the northern zone as the northern zone is close to open water and there is no open space for the meadows to proliferate in the southern zone.

The frequent or prolonged presence of water at or near the soil (hydrology) is the dominant factor determining the process of soil development and composition of plant and animal communities living in the soil and on its surface in wetlands. Thus alteration of wetland hydrology can change the soil chemistry and the plant and animal community (Mitsch & Gosselink, 1993). In the case of the Park, the change in hydrology resulting in its effect on meadows thickness is man-made i.e. the construction of the Ithai barrage in 1983 for the generation of power. The changes in the hydrology have greatly reduced the carrying capacity of the Lake ecosystem, enhanced siltation, changed the whole nature of the Lake and adversely affected the livelihoods of the local people dependent on this Lake (Singh & Khundrakpam, 2009). Apart from affecting the thickness, change in hydrology has also resulted in the proliferation of the meadows so much so that it has become a problem in some areas of the Loktak Lake. These newly formed meadows are thin due to proliferation and cannot support the weight of Sangai. For the successful conservation of Sangai, the meadows thickness needs be to be maintained at least at 1 m or >1 m thickness (Singh, 2002). Out of the 40 km² of the Park, floating meadows occupy only 26 km² and the rest 14 km² is open water. Transects laid out during 2005-2010 covering the entire Park to map the habitat use of Sangai during the present study revealed that although floating meadows cover 26 km², signs of habitat use were observed only in 22.3 km² of the Park (Angom, 2012). Based on these transects, the habitat most suitable for Sangai in terms of meadows thickness was found to be only 8.64 km². So, even though the area under meadows is increasing due to proliferation, the same might not be beneficial for Sangai. The change in meadows thickness due to the change in hydrology and meadows proliferation is of great concern for the survival of Sangai. To maintain the integrity of the floating meadows it is important to allow major portion of the floating meadows to settle during lean seasons by reducing water level of the Lake and minimize burning, walking, trampling, resource extraction and grazing in the meadows.

7.5. Aboveground biomass productivity (AGB) and forage availability

Standing biomass measured in its maximum is usually equalized with production (Richardson, 1978). Plants that dominate a site, in terms of biomass, are a reflection of the plants that are controlling the nutrient, water, and solar resources on the site. Therefore, biomass is often measured to assess the ecological status of a site. In the present study, a total of 41 plant species (six enclosures which were used as control) belonging to 18 families were recorded from the 16 enclosures, of which 27 species were recorded on thick, 33 species on thin meadows and only 6 species were recorded in the hard ground indicating the high species diversity of the meadows. Productivity of the grass species was higher compared to the herbs indicating the dominance of grasses in the Park. The grass species *Zizania latifolia*, *Phragmites karka* and *Arundo donax* which contribute maximum to the annual productivity are also important food plants for Sangai and Hog deer.

Vegetation of wetland meadows varies depending on the environmental (soil, water) conditions and management regime. In monsoonal wetlands of Northern India, the productivity of wetlands changed seasonally in response to changing water level and temperature (van der Valk et al., 1993). In the present study, productivity was highest in the month of August and least in February but there was no significant difference in the productivity across the seasons probably because of the present hydrological regime whereby the meadows remain afloat throughout the year. Since the Park remains inundated all throughout the year, there is no shortage of nutrients and moisture. Also due to the Ithai Barrage, very less amount of nutrient entering the Park flows out, as there is no outlet and the water in the Park remains stagnant. The easy availability of nutrients and moisture and lack of abundant tall grasses has resulted in weak competition in the Park.

To study the impact of management practices in the Park, the 16 enclosures were given different management treatments (control, cut and burnt). Highest productivity was observed in the enclosure subjected to the burnt treatment followed by cutting treatment and the least productivity was observed in the control enclosures. Though burning enhanced AGB production, it fails to provide base materials for maintaining the thickness of the meadows. Thus cutting of grasses and leaving it as such is recommended. Besides, burning is mostly done to increase the nutrients in the soil which is not required in the present study since the Park is already facing excess nutrient load in the water and soil sediments.

The utilization of the AGB by the wild ungulates was also studied since apart from the abundance and availability it is important to know the usage of the food plants and preferred food species of the ungulates for successful management (Ellis et al., 1976). The present study has revealed that although food is in abundance, only 26.32% was utilized by the wild ungulates. The productivity in the thick meadows was more with 61.8% contribution from the perennials compared to the thin meadows where annual plant species contributed 76.2% to productivity. The perennial grass of the thick meadows provides food and act as shelter grass for the ungulates. In other words, food is in abundance in the thick meadows and is thus a suitable habitat for Sangai and Hog deer. But the scenario of the meadow thickness predicted shows that in ten years time, even the present days' most suitable habitat will become unsafe to support the weight of Sangai. Therefore, it is important to maintain the integrity of the meadows thickness for long term conservation of Sangai. As evident from sustained breeding of Sangai in many zoos, Sangai will survive and breed in wild where habitats are swampy having adequate food supply.

7.6. Recommendations for improved conservation of the Loktak Lake and the Park

The present study identifies eutrophication, deterioration of water quality, heavy soil sediment nutrient load, change in hydrologic regime due to construction of Ithai barrage, pollution from Nambul and Nambol rivers and degradation of catchment area and inflow of silt every year during monsoon are the salient problems affecting the integrity of the Loktak Lake and the Keibul Lamjao National Park. Apart from these, encroachments into the Lake, shallowing due to siltation, excessive proliferation and thinning of meadows and increase in its horizontal dimensional growth is decreasing the open water area of the Lake, These problems need to be addressed immediately for the long term survival of Sangai and for maintaining the integrity of the Lake ecosystem.

The water quality is deteriorating due to excess nutrients and pollutants from the rivers viz. Nambul, Nambol, Moirang, Potsangbam and Naranseina that drains into the Lake and also from the catchments. The outflow of nutrients through its outlets channels needs to be restored especially during monsoon. Maintaining outflow of excess nutrient will reduce the nutrient load on the Park as well as on the Lake which can check the rate at which meadows are proliferating.

The construction of the Ithai barrage has played a significant role in the present status of the Lake ecosystem, as the barrage blocks both of the outlet channels, Ungamel and Khordak. Since the Park remains flooded during monsoon to early winter making some of the areas inaccessible to the ungulates, therefore maintaining the water level through consultative process is imperative for the survival of Sangai.

The changes in the hydrology and siltation of the Lake has reduced the carrying capacity of the Lake ecosystem, adversely affected the livelihoods of the local people who depend on the Lake. To maintain the integrity of the floating meadows it is important to allow major portion of the floating meadows to settle during lean seasons by reducing water level of the Lake and minimize burning, walking, trampling, resource extraction and grazing on the meadows.

Availability of the forage seems to not be a limiting factor for the Sangai. Forage is in abundance in the thick meadows and crucial for the existence of Sangai in the Park. Therefore, it is important to maintain the integrity of the meadows thickness for long term conservation of Sangai. Due to fire as a part of management practice and also by the local people, the base material for the formation of meadows is getting lost. Hence, cutting of the grasses and leaving it as such is recommended so as to maintain the thickness of the meadows.

The dominant grass species which contributes maximum to the forage diet of the wild ungulates in the Park are also being extracted by the local people. Extraction of these economically important plants is done almost all year round which is degrading the habitat and is a threat for the survival of Sangai. In view of these the restriction on extraction of biomass from the Park needs to be improved. Simultaneously, development of sustainable livelihood options for the local people will greatly reduce the anthropogenic pressure on the Park. A balance needs to be maintained whereby the anthropogenic pressure and hydrological regime do not disturb the habitat of the wildlife and the Park integrity is maintained.

Encroachment in the periphery by the local people especially for fish farming needs to be checked through a consultative process with local communities and by monitoring the land use change in the peripheral areas. An awareness campaign amongst local people involved in resource extraction and meadows fishing should be organized to educate them, to minimize extraction and to reduce the number of athaphum fishing and minimize its impact on the Lake.

APPENDIX I

TABLE 1. List of the plant species from the Keibul Lamjao National Park, Manipur, India.

Note: Habit: Herb (H), Climber (C), Shrub (S), Sedge (Sd), Grass (G), Floating or Phumdi (P), Terrestrial (T), Phumdi/Terrestrial(P/T); Nativity: Africa (Afr), America (Am), Amphigaea (Amphig), Asia (As), Australia (Austr), Boreal (Bor), Brazil (Braz), Central (Centr), China (Chi), Cosmopolitan (Cosmop), Europe (Europ), Gerontia (Geront), Himalayan Region (Reg Himal), Japan (Jap), Indian Oriental (Ind Or), Insular (Ins), Madagascar (Madag), Mediterranean (Mediterr), Occidentalis (Occ), Oriens (Oriens), Oriental (Orient), Pacific (Pacif), Philippines (Philipp), Subtropical (Subtrop), Temperate (Temp), Territorial (Terr), and Tropical (Trop); et = and.). Voucher No. is based on herbarium catalouging of Wildlife Instituute of India, Dehra Dun. Nativity of the plants known up to genus was not known.

Scientific Name	Family	Habit	Habitat	Nativity	Voucher No.
Apluda mutica L.	Poaceae	G	P/T	As. trop.; Polynes.; Austral	22570
Arundo donax L.	Poaceae	G	P/T	Reg. Mediterr.; Oriens	22444
Capillipedium assimile (Steud.) A.Camus	Poaceae	G	P/T	As. or	22499
Coix aquatica Roxb.	Poaceae	G	P	Ind. or	22562
Coix lacryma-jobi L.	Poaceae	G	P	As. trop	22416

Scientific Name	Family	Habit	Habitat	Nativity	Voucher No.
Cymbopogon sp.	Poaceae	G	P/T	Not available	22437
Cynodon dactylon (L.) Pers.	Poaceae	G	T	Cosmop.	22573
Cyrtococcum sp.	Poaceae	G	P/T	Not available	22547
Dactyloctenium aegyptium (L.) Willd.	Poaceae	G	T	Cosmop Trop et Sub Trop	22403
Echinochloa colona (L.) Link	Poaceae	G	P/T	Jamaica	22552
Echinochloa crus-galli (L.) P.Beauv. var. *breviseta* (Döll) Podp.	Poaceae	G	P	Europ.; As. temp	22507
Echinochloa crusgalli var. *crus-galli* (L.) P. Beauv.	Poaceae	G	P	Europ.; As. temp	22530
Eragrostis gangetica (Roxb.) Steud.	Poaceae	G	P/T	As. trop.; Afr. trop. et austr	22434
Eragrostis sp.	Poaceae	G	P	Not available	22414
Erianthus ravennae P.Beauv.	Poaceae	G	P/T	Reg. Mediterr.; Oriens; Ind. or	22461
Hemarthria compressa (L.f.) R.Br.	Poaceae	G	P	Reg. calid	22427
Hygroryza aristata (Retz.) Nees ex Wight & Arn. (*Hygroryza aristata* Nees)	Poaceae	G	P/T	Ind. or	22407

Scientific Name	Family	Habit	Habitat	Nativity	Voucher No.
Imperata cylindrica (L.) Raeusch.	Poaceae	G	P/T	Reg Calid	22559
Isachne globosa (Thunb.) Kuntze	Poaceae	G	P	Japan.	22417
Leersia hexandra Sw.	Poaceae	G	P/T	Amphig. trop	22467
Oryza rufipogon Griff.	Poaceae	G	P	Ind. or.	22565
Oryza sativa L.	Poaceae	G	P/T	As. trop	22522
Panicum paludosum Roxb.	Poaceae	G	P/T	As. trop	22515
Panicum sp.	Poaceae	G	P	Not available	22527
Paspalum scorbiculatum Steud.	Poaceae	G	P	Geront Trop	22491
Phragmites karka (Retz.) Trin. ex Steud.	Poaceae	G	P/T	As.; Afr; Austr.	22555
Saccharum bengalense Retz.	Poaceae	G	T	Ind. or	22446
Saccharum munja Roxb.	Poaceae	G	P/T	Ind. or	22453
Setaria glauca P.Beauv.	Poaceae	G	P/T	Europ.; As. temp	22483
Setaria pallidefusca (Schumach.) Stapf & C.E.Hubb.	Poaceae	G	P/T	Trop. Africa	22475
Setaria verticillata (L.) P.Beauv.	Poaceae	G	T	Cosmop	22406

Scientific Name	Family	Habit	Habitat	Nativity	Voucher No.
Vetiveria zizanioides (L.) Nash	Poaceae	G	T	As Trop	22424
Zizania latifolia (Griseb.) Turcz. ex Stapf	Poaceae	G	P	Russia	22539
Bulbostylis barbata (Rottb.) C.B.Clarke	Cyperaceae	Sd	P	Ind, Ind Subcont, As-Trop	22548
Carex cruciata Wahlenb.	Cyperaceae	Sd	P	Ind. or	22532
Carex sp.	Cyperaceae	Sd	P	Not available	22412
Cyperus alopecuroides Thunb.	Cyperaceae	Sd	P	Not known	22479
Cyperus alulatus J.Kern	Cyperaceae	Sd	P	Ind. or.	22495
Cyperus brevifolius Hassk.	Cyperaceae	Sd	P	Amphig. trop	22419
Cyperus compressus L.	Cyperaceae	Sd	P	Cosmop. trop	22409
Cyperus cyperoides (L.) Kuntze	Cyperaceae	Sd	P/T	Austral	22558
Cyperus difformis L.	Cyperaceae	Sd	P	Geront. trop	22442
Cyperus globosus Baldw. ex Torr.	Cyperaceae	Sd	P	Cosmop	22471
Cyperus iria L.	Cyperaceae	Sd	P	Geront. trop	22449
Cyperus niveus Retz.	Cyperaceae	Sd	P	Ind. or	22511
Cyperus nutans Vahl	Cyperaceae	Sd	P	Ind. or	22503

Scientific Name	Family	Habit	Habitat	Nativity	Voucher No.
Cyperus pygmaeus Rottb.	Cyperaceae	Sd	P/T	Cosmop. trop	22463
Cyperus rotundus L.	Cyperaceae	Sd	P	Cosmop	22429
Cyperus triceps F.N.Williams (*Kyllinga triceps* Rottb.)	Cyperaceae	Sd	P/T	Geront. trop.	22487
Eleocharis acutangula Schult.	Cyperaceae	Sd	P	Ind. or.	22535
Eleocharis atropurpurea (Retz.) J. Pres.	Cyperaceae	Sd	P	Reg. temp. et trop	22579
Eleocharis dulcis (Burm.f.) Trin. ex Hensch.	Cyperaceae	Sd	P	Afr, As & Austr	22457
Eleocharis palustris F.Muell.	Cyperaceae	Sd	P	Europe	22518
Fimbristylis bisumbellata Bubani	Cyperaceae	Sd	P	Egypt	22543
Fimbristylis dichotoma (L.) Vahl	Cyperaceae	Sd	P	Europ. austr.; Afr. bor	22422
Fimbristylis miliacea (L.) Vahl	Cyperaceae	Sd	P	Not known	22569
Fimbristylis schoenoides Vahl	Cyperaceae	Sd	P	As. et Austral. trop	22526
Fimbristylis tetragona R.Br.	Cyperaceae	Sd	P	As. et Austral. trop	22439
Fuirena umbellata Rottb.	Cyperaceae	Sd	P	Amphig. Trop. et subtrop	22402
Scirpus juncoides Roxb.	Cyperaceae	Sd	P	Ind. or	22577

Scientific Name	Family	Habit	Habitat	Nativity	Voucher No.
Scirpus lacustris L.	Cyperaceae	Sd	P	Cosmop	22432
Scirpus mucronatus Roxb.	Cyperaceae	Sd	P	Europe; adventive in the USA	22556
Scleria oblata S.T.Blake ex J.Kern	Cyperaceae	Sd	P	As. austr.-or	22566
Ageratum conyzoides (L.) L.	Asteraceae	H	P/T	Reg. trop	22486
Artemisia nilagirica (C.B.Clarke) Pamp.	Asteraceae	H	T	Ind, Ind Subcont, As-Trop	22494
Blumea sp.	Asteraceae	H	P/T	Not available	22582
Centipeda minima (L.) A. Br. & Asch.	Asteraceae	H	P/T	As et Austr Trop Ins Pacif	22470
Crassocephalum crepidioides (Benth.) S.Moore	Asteraceae	H	P/T	Afr. trop	22542
Enydra fluctuans Lour.	Asteraceae	H	P	Cochinch	22448
Eupatorium odoratum L.	Asteraceae	H	P/T	Am. trop	22534
Grangea maderaspatana (L.) Desf.	Asteraceae	H	P/T	As. et Afr. trop	22456
Gynura sp.	Asteraceae	H	P	Not available	22581
Mikania micrantha Kunth	Asteraceae	C	P/T	Trop. America	22462
Siegesbeckia orientalis (LINN.)	Asteraceae	H	P/T	Southeast As	22510

Scientific Name	Family	Habit	Habitat	Nativity	Voucher No.
Sonchus spp.	Asteraceae	H	P/T	Not available	22502
Spilanthes acmella (L.) L.	Asteraceae	H	P/T	Cosmop. trop. et subtrop	22478
Xanthium strumarium L.	Asteraceae	H	P/T	Cosmpo	22517
Persicaria sp.	Polygonaceae	H	P	Not available	22473
Polygala arvensis Willd.	Polygalaceae	H	P/T	China Ind Or	22451
Polygonum barbatum L.	Polygonaceae	H	P	Geront. trop	22481
Polygonum chinense L.	Polygonaceae	H	P/T	As. or.; Malaya	22465
Polygonum flaccidum Roxb.	Polygonaceae	H	P	Ind, Ind Subcont, As-Trop	22513
Polygonum lapathifolium L.	Polygonaceae	H	P	Reg. bor. et austr	22497
Polygonum sp.	Polygonaceae	H	P	Not available	22489
Polygonum sp.	Polygonaceae	H	P	Not available	22505
Borreria pusilla DC.	Rubiaceae	H	P/T	Ind Or	22563
Galium mollugo L.	Rubiaceae	H	P	Europ.; As. temp	22546
Galium sp.	Rubiaceae	H	P/T	Not available	22528
Galium sp.	Rubiaceae	H	P/T	Not available	22571

Scientific Name	Family	Habit	Habitat	Nativity	Voucher No.
Oldenlandia corymbosa L	Rubiaceae	H	P/T	Reg. trop	22404
Paederia foetida L.	Rubiaceae	C	P/T	Ind. or.; Malaya	22554
Spermacoce hispida L.	Rubiaceae	H	P/T	Geront. trop	22564
Wendlandia wallichii Wight & Arn.	Rubiaceae	S	P/T	Reg. Himal	22560
Commelina appendiculata C.B.Clarke	Commelinaceae	H	P/T	Ind. or	22509
Commelina benghalensis L.	Commelinaceae	H	P/T	Geront. trop	22401
Commelina longifolia Lam.	Commelinaceae	H	P/T	Reg. trop.	22575
Cyanotis barbata D.Don	Commelinaceae	H	P/T	Reg. Himal	22567
Floscopa scandens Lour.	Commelinaceae	H	P/T	As. et Austral. trop	22550
Murdannia nudiflora (L.) Brenan	Commelinaceae	H	T	Ind.	22533
Argyreia nervosa (Burm.f.) Bojer	Convolvulaceae	H	P/T	Ins Mascar	22485
Ipomoea aquatica Forssk.	Convolvulaceae	H	P	Geront. trop	22469
Ipomoea fistulosa Mart. ex Choisy	Convolvulaceae	S	P/T	Braz, South Am	22477
Ipomoea hederifolia L.	Convolvulaceae	H	T	Ind. occ	22541
Ipomoea nil (L.) Roth	Convolvulaceae	H	T	Amphig Trop	22524

Scientific Name	Family	Habit	Habitat	Nativity	Voucher No.
Ipomoea pentaphylla Jacq.	Convolvulaceae	H	P/T	Amphig. trop	22516
Aeschynomene indica L.	Fabaceae	H	P	Ind. or	22561
Atylosia scarabaeoides Benth.	Fabaceae	C	P/T	Austral	22476
Crotalaria sp.	Fabaceae	H	P	Not available	22540
Desmodium gyrans DC.	Fabaceae	H	T	As. trop	22484
Desmodium heterocarpon (L.) DC.	Fabaceae	H	T	Cosmop. trop. et subtrop	22523
Rhynchosia minima (L.) DC.	Fabaceae	C	P/T	Cosmop. trop. et subtrop	22492
Ludwigia prostrata Roxb	Onagraceae	H	P	Burma (Myanmar)	22458
Ludwigia adscendens (L.) H. Hara	Onagraceae	H	P	Reg Trop	22480
Ludwigia clavellina M. Gómez (*Jussiaea repens* L.)	Onagraceae	H	P	Amphig. trop	22504
Ludwigia octovalvis (Jacq.) P.H.Raven (*Oenothera octovalvis* Jacq.)	Onagraceae	H	P/T	Amphig trop.	22512
Ludwigia sp.	Onagraceae	H	P	Not available	22519
Lindernia cordifolia Merr.	Scrophulariacea	H	P/T	Ind. or.; Malaya	22466
Lysimachia javanica Blume	Scrophulariacea	H	P	Not known	22514

Scientific Name	Family	Habit	Habitat	Nativity	Voucher No.
Limnophila heterophylla (Roxb.) Benth.	Scrophulariacea	H	P	As. trop	22529
Lindenbergia sp.	Scrophulariacea	H	P	Not available	22538
Limnophila rugosa (Roth) Merr.	Scrophulariacea	H	P	As Trop Ins Pacif	22553
Actinostemma tenerum Griff.	Cucurbitaceae	C	P/T	Ind. or	22455
Benincasa hispida (Thunb.) Cogn.	Cucurbitaceae	C	P/T	As. et.; Afr. trop.	22493
Zehneria wallichii (C.B. Clarke) C. Jeffrey	Cucurbitaceae	C	T	Burma	22501
Zehneria scabra (L.f.) Sond	Cucurbitaceae	C	T	Am. bor; Ind. occ.	22580
Euryale ferox Salisb.	Nymphaeaceae	H	P	Ind. or.; China	22585
Nymphoides cristata (Roxb.) Kuntze	Nymphaeceae	H	P	Ind. or.	22464
Nymphaea nouchali Burm.f.	Nymphaeceae	H	P	As et Afr Trop	22488
Nymphaea sp.	Nymphaeceae	H	P	Not available	22496
Hydrocotyle sibthorpioides Lam.	Apiaceae	H	P	N. Zel	22420
Centella asiatica (L.) Urb.	Apiaceae	H	P/T	Reg Trop et Sub Trop	22430
Oenanthe javanica (Blume) DC.	Apiaceae	H	T	Ind Or Java China	22440

Scientific Name	Family	Habit	Habitat	Nativity	Voucher No.
Phyllanthus urinaria L.	Euphorbiaceae	H	T	Ind. or.	22468
Glochidion multiloculare (Rottler ex Willd.) Voigt	Euphorbiaceae	S	P/T	Ind. or	22531
Euphorbia hirta L.	Euphorbiaceae	H	P/T	Amphig Trop	22551
Urena lobata L.	Malvaceae	H	P/T	Cosmop. trop	22418
Sida rhombifolia L.	Malvaceae	H	T	Amphig. trop	22428
Sida acuta Burm.f.	Malvaceae	H	P/T	Amer Centr.	22438
Alternanthera philoxeroides (Mart.) Griseb.	Amaranthaceae	H	P	Reg. Argent	22421
Alternanthera sessilis (L.) R.Br. ex DC.	Amaranthaceae	H	P/T	Reg. trop	22431
Pistia stratiotes L.	Araceae	H	P	Reg. trop	22410
Colocasia antiquorum Schott	Araceae	H	P/T	As. trop	22441
Impatiens balsamina L.	Balsaminaceae	H	P	As. trop	22549
Impatiens sp.	Balsaminaceae	H	P	Not available	22568
Eriocaulon sp.	Eriocaulaceae	H	P	Not available	22508
Eriocaulon truncatum Buch.-Ham. ex	Eriocaulaceae	H	P	Ind. or	22574

Scientific Name	Family	Habit	Habitat	Nativity	Voucher No.
Mart.					
Lemna perpusilla Torr.	Lemnaceae	H	P	Am. bor	22413
Spirodela polyrhiza (L.) Schleid.	Lemnaceae	H	P	Reg. bor. et austr	22447
Cissampelos pareira L.	Menispermaceae	C	T	Reg. trop	22443
Cyclea sp.	Menispermaceae	C	T	Not available	22450
Salvinia cucullata Roxb.; Wall.	Salviniaceae	F	P	Ind. W. Austr.	22506
Salvinia molesta D.Mitch.	Salviniaceae	F	P	Afr.	22572
Solanum torvum Sw.	Solanaceae	S	T	Cosmop. trop	22474
Solanum nigrum L.	Solanaceae	H	P/T	Amphi	22482
Triumfetta pilosa Roth	Tiliaceae	H	P	As. et Afr. trop	22452
Triumfetta rhomboidea Jacq.	Tiliaceae	H	P/T	Reg. trop	22490
Utricularia sp.	Utriculariaceae	H	P	Not available	22460
Utricularia sp.	Utriculariaceae	H	P	Not available	22498
Stachytarpheta jamaicensis Vahl	Verbenaceae	H	P/T	Jamaica, Caribbean, South Am	22415

Scientific Name	Family	Habit	Habitat	Nativity	Voucher No.
Clerodendrum indicum (L.) Kuntze	Verbenaceae	S	P/T	Ind Or Malaya	22435
Hedychium coronarium J.König	Zingiberaceae	H	P	Ind. Or	22426
Alpinia allughas Roscoe	Zingiberaceae	H	P	Ind. Or	22436
Sagittaria sagittifolia L.	Alismataceae	H	P	Cochinch	22411
Azolla pinnata R. Br.	Azollaceae	F	P	Japonia. Asia;Austr.;Afr trop.;	22525
Cassia occidentalis L.	Caesalpiniaceae	H	T	Cosmop. trop	22557
Drymaria cordata (L.) Willd. ex Schult.	Caryophyllaceae	H	P/T	Cosmop Trop	22576
Ceratophyllum demersum L.	Ceratophyllaceae	H	P	Reg. temp. et trop	22405
Hydrilla verticillata C.Presl	Hydrocharitaceae	H	P	Ind. Or	22454
Hydrolea zeylanica (L.) Vahl	Hydrophyllaceae	H	P	Reg. trop	22500
Mosla dianthera (Buch.-Ham. ex Roxb.) Maxim.	Lamiaceae	H	P/T	Southeast Asia	22578
Lygodium flexuosum (L.) Sw.	Lygodiaceae	C	P/T	Ind Or Burma	22433
Rotala rotundifolia (Buch.-Ham. ex Roxb.) Koehne	Lythraceae	H	P	Ind. Or.; China	22423

Scientific Name	Family	Habit	Habitat	Nativity	Voucher No.
Osbeckia stellata Buch.-Ham. ex D.Don	Melstomataceae	S	P/T	Reg. Himal	22408
Monochoria vaginalis C.Presl	Monochoriaceae	H	P	As. et Afr. trop	22472
Habenaria sp.	Orchidaceae	H	P	Not available	22583
Oxalis corniculata L.	Oxalidaceae	H	P/T	Amphig. temp. et trop	22536
Passiflora foetida L.	Passifloraceae	C	P/T	Braz	22544
Eichhornia crassipes Solms	Pontederiaceae	H	P	Am. trop.	22520
Potamogeton nodosus Poir.	Potamogetonaceae	H	P	Madag, West Ind Ocean, Afr	22459
Pteris sp.	Pteridaceae	F	P/T	Not available	22537
Rubus sp.	Rosaceae	S	P/T	Not available	22545
Selaginella amblyphylla Alston	Selaginellaceae	F	P/T	China	22521
Sparganium erectum L.	Typhaceae	H	P	Brit; Am, temp;U.S.	22584
Vallisneria spiralis L.	Vallisneriaceae	H	P	Reg. temp. et calid	22445
Ampelocissus latifolia (Roxb.) Planch.	Vitaceae	C	P/T	Ind Or	22425

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Plant species composition of the floating meadows of Keibul Lamjao National Park, Manipur

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ABSTRACT

The Keibul Lamjao National Park is located in the southeastern part of the Loktak Lake, Manipur, India. The characteristic feature of the Park is the presence of floating meadows locally known as phumdi. The vegetation of the Park plays an important role for the conservation of endangered Eld's deer or Sangai (*Rucervus eldii eldii*) as well as for the local people. A floristic study was carried out during 2005-2010 to get an insight into the plant species composition of the Park. A total of 185 plant species comprising of 50 families and 121 genera were recorded. Poaceae was the dominant family followed by Cyperaceae and Asteraceae. Ninety species were recorded in the floating meadows and open water, 19 species in terrestrial habitat and 76 species were common to both the habitats. Herbs showed the highest percentage with 52.4% followed by grasses and sedges with 17.8% and 16.2% respectively. The nativity of the plant species of the Park follows the trend; Indian oriental region (37) >Asia-Africa-Australia region (28) >Cosmopolitan (16) >European/Oriental and Gerontia region (15) >Amphigaea tropical region (11) >Tropical region (10) and >America-Australia tropical region (8). The dominant species of the meadows were *Zizania latifolia*, *Hedychium coronarium*, *Impatiens* spp., *Cyperus difformis*, *Cyperus rotundus* and *Polygonum* spp. The species common to both the meadows and terrestrial habitat were *Phragmites karka*, *Capillipedium assimile*, *Leersia hexandra*, *Oenanthe javanica* and *Cyanotis barbata*. Around 26 economically important plant species were used by the local communities for subsistence and commercial purposes which might be impacting the plant species composition.

Keywords: Floating meadows, species composition, nativity, habitat specificity, Keibul Lamjao National Park.

Wetlands are highly complex ecosystems representing critical habitats for many rare and endemic species of flora and fauna (Peck 2000). Swarzenski et al (1991) used the term 'floating marsh' to refer to wetlands "in which the floating mats of vegetation are thick enough to support a person's weight". Floating meadows are defined as marsh of vascular vegetation having a significant amount of live and dead roots, peat and detritus that floats over a layer of water. They are widespread formations of vegetation located on a column of water (Azza *et al.*, 2000; Van Duzer, 2002). The meadows are compact and thick and because they float it is only rarely, if ever, inundated (Sasser *et. al.*, 1991). Based on local origin, virtually all of the major natural floating wetland ecotypes around the world have been given a different name. Usually, the floating meadows are sufficiently buoyant to rise and fall with changes in ambient water levels. This characteristic buffers them from the effects of both inundation and seasonal drawdown.

In India, the characteristic floating meadows occur in the Loktak Lake, Manipur which is a large but shrinking freshwater lake located in the upper drainage of Manipur River. The drainage forms a

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distinctive part of the Indo - Burma biodiversity hotspot. The Loktak remains one of the largest freshwater lakes in India, although in recent decades, much of it has been reclaimed for agriculture. The characteristic feature of the Loktak, the floating meadows covered with vegetation, locally known as phumdis plays a significant role in the lake ecosystem as well as in the life of the local people of Manipur. People of Manipur are socially, economically, culturally and ecologically linked with the Loktak Lake (Trishal and Manihar, 2002). The Loktak has been the source of water for domestic uses, generation of hydro-electric power, irrigation, habitat for several plants used as food, fishing ground for local people, fodder, fuel, medicines, biodiversity, recreation, etc. Hence, this lake has been referred to as the 'lifeline of Manipur'. The Loktak has no definite shoreline, the expanse of water and its depth varies with the season. The Keibul Lamjao National Park, located in the southern part of the Loktak is a unique floating wildlife reserve and the sole habitat of the endangered Eld's deer or the Manipur Brow-antlered deer locally known as Sangai (*Rucervus eldii eldii*). The Park supports the largest concentration of floating meadows covering 22.3 km² (Sanjit *et. al.,* 2005; Hussain et al., 2006). The increasing demand for goods and services provided by this lake ecosystem and its resultant pressures on the wetland have led to its degradation thereby threatening the survival of the endangered Sangai and livelihoods of the local communities' dependent on it. Wetland plants show diversity both in shape and size, ranging from microscopic to multi-cellular form, and mainly constitutes herbaceous species with an occasional shrubby species in nature and mostly perennial (Adhikari and Babu, 2008). Keeping the important role played by the vegetation of the floating meadows for the endangered Sangai and the local people as well as the natural ecosystem of the lake. The present study was conducted to gain an insight into the vegetation composition and distribution of the economically important plants of the Park. As the Park has large expenses of floating meadows interspersed with open water and hillocks, comprehensive understanding of the vegetation composition of the Park will be helpful in effectively managing the Park.

Study area

The study was conducted in the Keibul Lamjao National Park (KLNP), Manipur, India located in the Barak-Chindwin-Irrawady Basin (Figure 1). The KLNP is located in the South-eastern fringes of the Loktak Lake. The KLNP lies between latitude 24˚26´N to 24˚31´N and longitude 93˚49´E to 93˚52E. The temperature of the Park ranges from a maximum of 36.4°C to a minimum of 1.7°C. During winter, low temperature, heavy dews and early morning frost characterize the climatic condition. The temperature goes during March to May. There is heavy rain during June to September, and less or little rainfall from December to February. The annual rainfall is 1460 mm. Humidity is highest in August, with daily humidity measuring as much as 81%, and least in March at 49%.

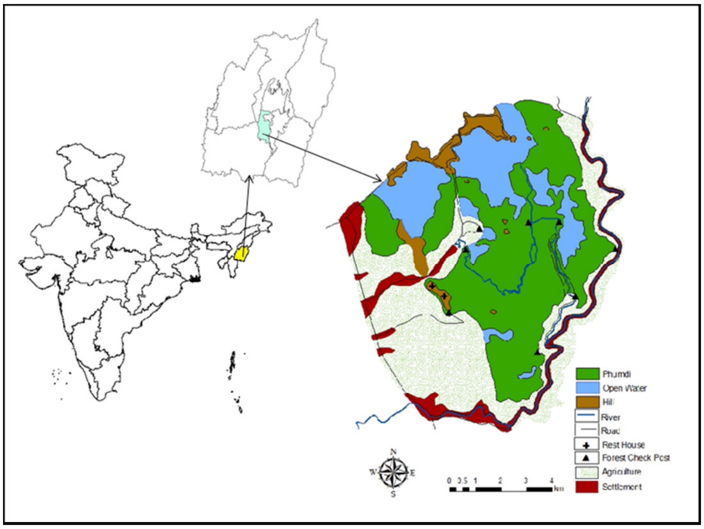

Figure 1. Location map of Keibul Lamjao National Park, Manipur and the surrounding landscape.

In 1953, the Sangai which was believed to be extinct was rediscovered by E.P. Gee. Due to the persistent efforts of E.P. Gee, the Sangai was declared a protected animal and its habitat, Keibul Lamjao covering an area of about 52 km^2 was declared a sanctuary in 1954. In 1959 the total area was reduced to about 27 km^2. With a view to ensuring protection for the species the Keibul Lamjao was declared protected in 1965, a reserved forest in 1974 and finally a national park in 1977 (Singh 1992). The Park received national and international attention when Loktak Lake was declared as a site of International importance on 23 March 1990 under the Ramsar Convention. Presently the Park occupies an area of 40.05 km² out of which 26 km² is under thick and almost contiguous mat of floating vegetation and small hillocks and 14 km² is open water (Wetland International South Asia and Loktak Development Authority, 2002). The floating meadows of the Park vary in thickness, based on which the Park can be divided into Western thick phumdi zone, Eastern thin phumdi zone and Northern open water and very thin phumdi zone. In early 1980, the construction of Ithai Barrage has affected the natural process of meadow formation (Sanjit *et. al*., 2005) which led to the rapid changes in the lake ecosystem.

The floating meadows which used to settle during lean season and get replenished with soil and nourishment are now continuously floating. This has resulted in the rapid proliferation and thinning of the meadows. The floating meadows are spreading rapidly covering more than 70% of the total area of the Lake (Sanjit *et. al*., 2005) but mostly they are thin. In the lake the extent of the floating meadows has increased from 116.4 km² to 134.6 km² during 1989 – 2002 (WISA and LDA, 2002). Earlier a total of 13 species of grasses, 8 species of forbes including two species of weeds and 35 species of trees have been reported from the Park (Khan *et al*. 1992). According to Trishal and Manihar (2004), 132 plant species have been identified from different parts of the Loktak with the highest number of species in the Southern zone (108) followed by the Northern zone (92) and least in the Central zone (78). Sixty plant species are widespread and common on the floating meadows in all the zones.

Methods

Extensive floristic survey was carried for the entire year in the Park so as to cover all the annual as well as perennial plant species. However, during winter (November-January), due to high water level, sampling was restricted to mostly thick meadows. The KLNP and the adjacent areas of the Park were divided into 51 grids of 1000 x 1000 m. Depending on the open water and thickness of meadows 2 to 3 line transects of 500 m each were laid randomly on each of these grids. Quadrates of 0.5 x 0.5 m were laid randomly on these transect to study the dominant plant species and association among them. In each plots the number of plant species present and their number was recorded. Plant samples were collected from the different mosaic of habitats *viz*. floating vegetation, hard ground and submerged areas. The collected specimen were numbered and pressed for the preparation of herbarium (Jain and Rao, 1977). The habitat type from which the specimen was collected and the numbers of species present in each micro-habitat was also recorded. Identification of plants in the field was done with the help of 'A Manual of Aquatic Plants' (Fassett, 1997) and 'The grasses of Burma, Ceylon, India and Pakistan' (Bor, 1960). Unidentified plants specimen were brought to Wildlife Institute of India (WII), Dehra Dun for further identification. Collected specimens were cross-checked and identified at the Herbarium of WII. Classification of all the plant species was done following Bentham and Hooker's natural system of classification (1862-1883). Nativity of the species was identified following 'Index Kewensis Plantarum Phanerogamarum' (Anonymous 1883-1970) and from the web sites of International Plant Names Index (IPNI, www.ipni.org) and Tropicos (www.tropicos.org).

Results

Plant species composition

A total of 185 plant species belonging to 50 families and 121 genera were recorded in the Keibul Lamjao National Park (Table 1). These comprised of 13 species of climbers, 33 grass species, 30 species of sedges, 5 ferns species, 97 species of herbs and 7 shrub species. Out of 185 species only 90 were recorded in the floating meadows and open water, 19 in terrestrial habitats and 76 species in both terrestrial and floating habitats. The species of the floating meadows comprises of 11 grass species, 27 species of sedges, 3 species of ferns and 49 species of herbs belonging to 32 families. The terrestrial species comprise of 5 species of grasses, 4 species of climbers, 9 species of herbs and 1 species of shrub belonging to 11 families (Table 2). The species of both the floating and terrestrial habitat comprise of 16 species of grasses, 9 species of climbers, 3 species of sedges, 2 species of ferns, 40 species of herbs and 6 species of shrubs belonging to 30 families. Poaceae was the dominant family with 33 species followed by Cyperaceae with 30 species and Asteraceae with 14 species. Twenty-three families were found to have a single species (Table 2).

Table 1. List of the plant species from the Keibul Lamjao National Park, Manipur, India.

Scientific Name	Family	Habit	Habitat	Nativity	Voucher No.
Apluda mutica L.	Poaceae	G	P/T	As. trop.; Polynes.; Austral	22570
Arundo donax L.	Poaceae	G	P/T	Reg. Mediterr.; Oriens	22444
Capillipedium assimile (Steud.) A.Camus	Poaceae	G	P/T	As. or	22499
Coix aquatica Roxb.	Poaceae	G	P	Ind. or	22562
Coix lacryma-jobi L.	Poaceae	G	P	As. trop	22416
Cymbopogon sp.	Poaceae	G	P/T	Not available	22437
Cynodon dactylon (L.) Pers.	Poaceae		T	Cosmop.	22573
Cyrtococcum sp.	Poaceae	G	P/T	Not available	22547
Dactyloctenium aegyptium (L.) Willd.	Poaceae	G	T	Cosmop Trop et Sub Trop	22403
Echinochloa colona (L.) Link	Poaceae	G	P/T	Jamaica	22552
Echinochloa crus-galli (L.) P.Beauv. var. *breviseta* (Döll) Podp.	Poaceae	G	P	Europ.; As. temp	22507
Echinochloa crusgalli var. *crus-galli* (L.) P. Beauv.	Poaceae	G	P	Europ.; As. temp	22530
Eragrostis gangetica (Roxb.) Steud.	Poaceae	G	P/T	As. trop.; Afr. trop. et austr	22434
Eragrostis sp.	Poaceae	G	P	Not available	22414
Erianthus ravennae P.Beauv.	Poaceae	G	P/T	Reg. Mediterr.; Oriens; Ind. or	22461
Hemarthria compressa (L.f.) R.Br.	Poaceae	G	P	Reg. calid	22427
Hygroryza aristata (Retz.) Nees ex Wight & Arn. (*Hygroryza aristata* Nees)	Poaceae	G	P/T	Ind. or	22407
Imperata cylindrica (L.) Raeusch.	Poaceae	G	P/T	Reg Calid	22559
Isachne globosa (Thunb.) Kuntze	Poaceae	G	P	Japan.	22417
Leersia hexandra Sw.	Poaceae	G	P/T	Amphig. trop	22467
Oryza rufipogon Griff.	Poaceae	G	P	Ind. or.	22565
Oryza sativa L.	Poaceae	G	P/T	As. trop	22522
Panicum paludosum Roxb.	Poaceae	G	P/T	As. trop	22515
Panicum sp.	Poaceae	G	P	Not available	22527
Paspalum scorbiculatum Steud.	Poaceae	G	P	Geront Trop	22491
Phragmites karka (Retz.) Trin. ex Steud.	Poaceae	G	P/T	As.; Afr; Austr.	22555
Saccharum bengalense Retz.	Poaceae	G	T	Ind. or	22446
Saccharum munja Roxb.	Poaceae	G	P/T	Ind. or	22453
Setaria glauca P.Beauv.	Poaceae	G	P/T	Europ.; As. temp	22483
Setaria pallidefusca (Schumach.) Stapf & C.E.Hubb.	Poaceae	G	P/T	Trop. Africa	22475
Setaria verticillata (L.) P.Beauv.	Poaceae	G	T	Cosmop	22406
Vetiveria zizanioides (L.) Nash	Poaceae	G	T	As Trop	22424
Zizania latifolia (Griseb.) Turcz. ex Stapf	Poaceae	G	P	Russia	22539
Bulbostylis barbata (Rottb.) C.B.Clarke	Cyperaceae	Sd	P	Ind, Ind Subcont, As-Trop	22548
Carex cruciata Wahlenb.	Cyperaceae	Sd	P	Ind. or	22532
Carex sp.	Cyperaceae	Sd	P	Not available	22412
Cyperus alopecuroides Thunb.	Cyperaceae	Sd	P	Not known	22479
Cyperus alulatus J.Kern	Cyperaceae	Sd	P	Ind. or.	22495
Cyperus brevifolius Hassk.	Cyperaceae	Sd	P	Amphig. trop	22419
Cyperus compressus L.	Cyperaceae	Sd	P	Cosmop. trop	22409
Cyperus cyperoides (L.) Kuntze	Cyperaceae	Sd	P/T	Austral	22558
Cyperus difformis L.	Cyperaceae	Sd	P	Geront. trop	22442
Cyperus globosus Baldw. ex Torr.	Cyperaceae	Sd	P	Cosmop	22471
Cyperus iria L.	Cyperaceae	Sd	P	Geront. trop	22449
Cyperus niveus Retz.	Cyperaceae	Sd	P	Ind. or	22511
Cyperus nutans Vahl	Cyperaceae	Sd	P	Ind. or	22503
Cyperus pygmaeus Rottb.	Cyperaceae	Sd	P/T	Cosmop. trop	22463
Cyperus rotundus L.	Cyperaceae	Sd	P	Cosmop	22429

Cyperus triceps F.N.Williams (*Kyllinga triceps* Rottb.)	Cyperaceae	Sd	P/T	Geront. trop.	22487
Eleocharis acutangula Schult.	Cyperaceae	Sd	P	Ind. or.	22535
Eleocharis atropurpurea (Retz.) J. Pres.	Cyperaceae	Sd	P	Reg. temp. et trop	22579
Eleocharis dulcis (Burm.f.) Trin. ex Hensch.	Cyperaceae	Sd	P	Afr, As & Austr	22457
Eleocharis palustris F.Muell.	Cyperaceae	Sd	P	Europe	22518
Fimbristylis bisumbellata Bubani	Cyperaceae	Sd	P	Egypt	22543
Fimbristylis dichotoma (L.) Vahl	Cyperaceae	Sd	P	Europ. austr.; Afr. bor	22422
Fimbristylis miliacea (L.) Vahl	Cyperaceae	Sd	P	Not known	22569
Fimbristylis schoenoides Vahl	Cyperaceae	Sd	P	As. et Austral. trop	22526
Fimbristylis tetragona R.Br.	Cyperaceae	Sd	P	As. et Austral. trop	22439
Fuirena umbellata Rottb.	Cyperaceae	Sd	P	Amphig. Trop. et subtrop	22402
Scirpus juncoides Roxb.	Cyperaceae	Sd	P	Ind. or	22577
Scirpus lacustris L.	Cyperaceae	Sd	P	Cosmop	22432
Scirpus mucronatus Roxb.	Cyperaceae	Sd	P	Europe; adventive in the USA	22556
Scleria oblata S.T.Blake ex J.Kern	Cyperaceae	Sd	P	As. austr.-or	22566
Ageratum conyzoides (L.) L.	Asteraceae	H	P/T	Reg. trop	22486
Artemisia nilagirica (C.B.Clarke) Pamp.	Asteraceae	H	T	Ind, Ind Subcont, As-Trop	22494
Blumea sp.	Asteraceae	H	P/T	Not available	22582
Centipeda minima (L.) A. Br. & Asch.	Asteraceae	H	P/T	As et Austr Trop Ins Pacif	22470
Crassocephalum crepidioides (Benth.) S.Moore	Asteraceae	H	P/T	Afr. trop	22542
Enydra fluctuans Lour.	Asteraceae	H	P	Cochinch	22448
Eupatorium odoratum L.	Asteraceae	H	P/T	Am. trop	22534
Grangea maderaspatana (L.) Desf.	Asteraceae	H	P/T	As. et Afr. trop	22456
Gynura sp.	Asteraceae	H	P	Not available	22581
Mikania micrantha Kunth	Asteraceae	C	P/T	Trop. America	22462
Siegesbeckia orientalis (LINN.)	Asteraceae	H	P/T	Southeast As	22510
Sonchus spp.	Asteraceae	H	P/T	Not available	22502
Spilanthes acmella (L.) L.	Asteraceae	H	P/T	Cosmop. trop. et subtrop	22478
Xanthium strumarium L.	Asteraceae	H	P/T	Cospmo	22517
Persicaria sp.	Polygonaceae	H	P	Not available	22473
Polygala arvensis Willd.	Polygalaceae	H	P/T	China Ind Or	22451
Polygonum barbatum L.	Polygonaceae	H	P	Geront. trop	22481
Polygonum chinense L.	Polygonaceae	H	P/T	As. or.; Malaya	22465
Polygonum flaccidum Roxb.	Polygonaceae	H	P	Ind, Ind Subcont, As-Trop	22513
Polygonum lapathifolium L.	Polygonaceae	H	P	Reg. bor. et austr	22497
Polygonum sp.	Polygonaceae	H	P	Not available	22489
Polygonum sp.	Polygonaceae	H	P	Not available	22505
Borreria pusilla DC.	Rubiaceae	H	P/T	Ind Or	22563
Galium mollugo L.	Rubiaceae	H	P	Europ.; As. temp	22546
Galium sp.	Rubiaceae	H	P/T	Not available	22528
Galium sp.	Rubiaceae	H	P/T	Not available	22571
Oldenlandia corymbosa L	Rubiaceae	H	P/T	Reg. trop	22404
Paederia foetida L.	Rubiaceae	C	P/T	Ind. or.; Malaya	22554
Spermacoce hispida L.	Rubiaceae	H	P/T	Geront. trop	22564
Wendlandia wallichii Wight & Arn.	Rubiaceae	S	P/T	Reg. Himal	22560
Commelina appendiculata C.B.Clarke	Commelinaceae	H	P/T	Ind. or	22509
Commelina benghalensis L.	Commelinaceae	H	P/T	Geront. trop	22401
Commelina longifolia Lam.	Commelinaceae	H	P/T	Reg. trop.	22575
Cyanotis barbata D.Don	Commelinaceae	H	P/T	Reg. Himal	22567
Floscopa scandens Lour.	Commelinaceae	H	P/T	As. et Austral. trop	22550
Murdannia nudiflora (L.) Brenan	Commelinaceae	H	T	Ind.	22533
Argyreia nervosa (Burm.f.) Bojer	Convolvulaceae	H	P/T	Ins Mascar	22485
Ipomoea aquatica Forssk.	Convolvulaceae	H	P	Geront. trop	22469
Ipomoea fistulosa Mart. ex Choisy	Convolvulaceae	S	P/T	Braz, South Am	22477
Ipomoea hederifolia L.	Convolvulaceae	H	T	Ind. occ	22541
Ipomoea nil (L.) Roth	Convolvulaceae	H	T	Amphig Trop	22524
Ipomoea pentaphylla Jacq.	Convolvulaceae	H	P/T	Amphig. trop	22516
Aeschynomene indica L.	Fabaceae	H	P	Ind. or	22561
Atylosia scarabaeoides Benth.	Fabaceae	C	P/T	Austral	22476
Crotararia sp. ?????	Fabaceae	H	P	Not available	22540
Desmodium gyrans DC.	Fabaceae	H	T	As. trop	22484

Desmodium heterocarpon (L.) DC.	Fabaceae	H	T	Cosmop. trop. et subtrop	22523
Rhynchosia minima (L.) DC.	Fabaceae	C	P/T	Cosmop. trop. et subtrop	22492
Ludwigia prostrata Roxb	Onagraceae	H	P	Burma (Myanmar)	22458
Ludwigia adscendens (L.) H. Hara	Onagraceae	H	P	Reg Trop	22480
Ludwigia clavellina M. Gómez (*Jussiaea repens* L.)	Onagraceae	H	P	Amphig. trop	22504
Ludwigia octovalvis (Jacq.) P.H.Raven (*Oenothera octovalvis* Jacq.)	Onagraceae	H	P/T	Amphig trop.	22512
Ludwigia sp.	Onagraceae	H	P	Not available	22519
Lindernia cordifolia Merr.	Scrophulariacea	H	P/T	Ind. or.; Malaya	22466
Lysimachia javanica Blume	Scrophulariacea	H	P	Not known	22514
Limnophila heterophylla (Roxb.) Benth.	Scrophulariacea	H	P	As. trop	22529
Lindenbergia sp.	Scrophulariacea	H	P	Not available	22538
Limnophila rugosa (Roth) Merr.	Scrophulariacea	H	P	As Trop Ins Pacif	22553
Actinostemma tenerum Griff.	Cucurbitaceae	C	P/T	Ind. or	22455
Benincasa hispida (Thunb.) Cogn.	Cucurbitaceae	C	P/T	As. et.; Afr. trop.	22493
Zehneria wallichii (C.B. Clarke) C. Jeffrey	Cucurbitaceae	C	T	Burma	22501
Zehneria scabra (L.f.) Sond	Cucurbitaceae	C	T	Am. bor; Ind. occ.	22580
Euryale ferox Salisb.	Nymphaeaceae	H	P	Ind. or.; China	22585
Nymphoides cristata (Roxb.) Kuntze	Nymphaeceae	H	P	Ind. or.	22464
Nymphaea nouchali Burm.f.	Nymphaeceae	H	P	As et Afr Trop	22488
Nymphaea sp.	Nymphaeceae	H	P	Not available	22496
Hydrocotyle sibthorpioides Lam.	Apiaceae	H	P	N. Zel	22420
Centella asiatica (L.) Urb.	Apiaceae	H	P/T	Reg Trop et Sub Trop	22430
Oenanthe javanica (Blume) DC.	Apiaceae	H	T	Ind Or Java China	22440
Phyllanthus urinaria L.	Euphorbiaceae	H	T	Ind. or.	22468
Glochidion multiloculare (Rottler ex Willd.) Voigt	Euphorbiaceae	S	P/T	Ind. or	22531
Euphorbia hirta L.	Euphorbiaceae	H	P/T	Amphig Trop	22551
Urena lobata L.	Malvaceae	H	P/T	Cosmop. trop	22418
Sida rhombifolia L.	Malvaceae	H	T	Amphig. trop	22428
Sida acuta Burm.f.	Malvaceae	H	P/T	Amer Centr.	22438
Alternanthera philoxeroides (Mart.) Griseb.	Amaranthaceae	H	P	Reg. Argent	22421
Alternanthera sessilis (L.) R.Br. ex DC.	Amaranthaceae	H	P/T	Reg. trop	22431
Pistia stratiotes L.	Araceae	H	P	Reg. trop	22410
Colocasia antiquorum Schott	Araceae	H	P/T	As. trop	22441
Impatiens balsamina L.	Balsaminaceae	H	P	As. trop	22549
Impatiens sp.	Balsaminaceae	H	P	Not available	22568
Eriocaulon sp.	Eriocaulaceae	H	P	Not available	22508
Eriocaulon truncatum Buch.-Ham. ex Mart.	Eriocaulaceae	H	P	Ind. or	22574
Lemna perpusilla Torr.	Lemnaceae	H	P	Am. bor	22413
Spirodela polyrhiza (L.) Schleid.	Lemnaceae	H	P	Reg. bor. et austr	22447
Cissampelos pareira L.	Menispermaceae	C	T	Reg. trop	22443
Cyclea sp.	Menispermaceae	C	T	Not available	22450
Salvinia cucullata Roxb.; Wall.	Salviniaceae	F	P	Ind. W. Austr.	22506
Salvinia molesta D.Mitch.	Salviniaceae	F	P	Afr.	22572
Solanum torvum Sw.	Solanaceae	S	T	Cosmop. trop	22474
Solanum nigrum L.	Solanaceae	H	P/T	Amphi	22482
Triumfetta pilosa Roth	Tiliaceae	H	P	As. et Afr. trop	22452
Triumfetta rhomboidea Jacq.	Tiliaceae	H	P/T	Reg. trop	22490
Utricularia sp.	Utriculariaceae	H	P	Not available	22460
Utricularia sp.	Utriculariaceae	H	P	Not available	22498
Stachytarpheta jamaicensis Vahl	Verbenaceae	H	P/T	Jamaica, Caribbean, South Am	22415
Clerodendrum indicum (L.) Kuntze	Verbenaceae	S	P/T	Ind Or Malaya	22435
Hedychium coronarium J.König	Zingiberaceae	H	P	Ind. Or	22426
Alpinia allughas Roscoe	Zingiberaceae	H	P	Ind. Or	22436
Sagittaria sagittifolia L.	Alismataceae	H	P	Cochinch	22411
Azolla pinnata R. Br.	Azollaceae	F	P	Japonia. Asia;Austr.;Afr trop.;	22525
Cassia occidentalis L.	Caesalpiniaceae	H	T	Cosmop. trop	22557
Drymaria cordata (L.) Willd. ex Schult.	Caryophyllaceae	H	P/T	Cosmop Trop	22576
Ceratophyllum demersum L.	Ceratophyllaceae	H	P	Reg. temp. et trop	22405

Hydrilla verticillata C.Presl	Hydrocharitaceae	H	P	Ind. Or	22454
Hydrolea zeylanica (L.) Vahl	Hydrophyllaceae	H	P	Reg. trop	22500
Mosla dianthera (Buch.-Ham. ex Roxb.) Maxim.	Lamiaceae	H	P/T	Southeast Asia	22578
Lygodium flexuosum (L.) Sw.	Lygodiaceae	C	P/T	Ind Or Burma	22433
Rotala rotundifolia (Buch.-Ham. ex Roxb.) Koehne	Lythraceae	H	P	Ind. Or.; China	22423
Osbeckia stellata Buch.-Ham. ex D.Don	Melstomataceae	S	P/T	Reg. Himal	22408
Monochoria vaginalis C.Presl	Monochoriaceae	H	P	As. et Afr. trop	22472
Habenaria sp.	Orchidaceae	H	P	Not available	22583
Oxalis corniculata L.	Oxalidaceae	H	P/T	Amphig. temp. et trop	22536
Passiflora foetida L.	Passifloraceae	C	P/T	Braz	22544
Eichhornia crassipes Solms	Pontederiaceae	H	P	Am. trop.	22520
Potamogeton nodosus Poir.	Potamogetonaceae	H	P	Madag, West Ind Ocean, Afr	22459
Pteris sp.	Pteridaceae	F	P/T	Not available	22537
Rubus sp.	Rosaceae	S	P/T	Not available	22545
Selaginella amblyphylla Alston	Selaginellaceae	F	P/T	China	22521
Sparganium erectum L.	Typhaceae	H	P	Brit; Am, temp;U.S.	22584
Vallisneria spiralis L.	Vallisneriaceae	H	P	Reg. temp. et calid	22445
Ampelocissus latifolia (Roxb.) Planch.	Vitaceae	C	P/T	Ind Or	22425

Note: Habit: Herb (H), Climber (C), Shrub (S), Sedge (Sd), Grass (G), Floating or Phumdi (P), Terrestrial (T), Phumdi/Terrestrial(P/T); Nativity: Africa (Afr), America (Am), Amphigaea (Amphig), Asia (As), Australia (Austr), Boreal (Bor), Brazil (Braz), Central (Centr), China (Chi), Cosmopolitan (Cosmop), Europe (Europ), Gerontia (Geront), Himalayan Region (Reg Himal), Japan (Jap), Indian Oriental (Ind Or), Insular (Ins), Madagascar (Madag), Mediterranean (Mediterr), Occidentalis (Occ), Oriens (Oriens), Oriental (Orient), Pacific (Pacif), Philippines (Philipp), Subtropical (Subtrop), Temperate (Temp), Territorial (Terr), and Tropical (Trop); et = and.). Voucher No. is based on herbarium catalouging of Wildlife Instituute of India, Dehra Dun. Nativity of the plants known up to genus was not known.

Table 2. Details of the dominant families and habitat type of the plant species of Keibul Lamjao National Park, Manipur.

Criteria	Number
No. of families	50
No. of genera	121
No. of families with one species	23
No. of terrestrial species	19
No. of phumdi growing species	90
No. of both terrestrial and phumdi species	76
No. of shrub species	7
No. of herb species	97
No. of grass species	33
No. of fern species	5
No. of sedge species	30
No. of climber species	13
No. of perennial species	67
No. of annual species	118

Nativity

The nativity of a plant species reflects its origin or place of first reports of the species. The nativity of the plant species of the Park follows the trend: Indian oriental region (37) > Asia-Africa-Australia region (28) > Cosmopolitan (16) > European/Oriental and Gerontia region (15) > Amphigaea tropical region (11) > Tropical region (10) > America-Australia tropical region (8) and 32 species are from different parts of the world. Nativity of 3 species is not known and nativity of 25 species is not provided (Table 1).

Habitat specificity

Since the Park has a mosaic of micro habitats (floating meadows, open water and terrestrial), the type of plants found in specific habitat was also recorded. The percentage distributions of the species in the different habitats were: 48.6% in the floating meadows, 41.1% in both the floating meadows and terrestrial habitat and 10.3% only in terrestrial habitat (Table 3). The dominant species found in the floating meadows were *Zizania latifolia*, *Hedychium coronarium*, *Impatiens* spp., *Cyperus difformis*, *Cyperus rotundus* and *Polygonum* spp. and the dominant species in the terrestrial habitat were *Dactyloctenium aegyptium*, *Ipomoea nil* and *Cynodon dactylon*. The species common to both the floating meadows and terrestrial habitats were *Phragmites karka*, *Capillipedium assimile*, *Leersia hexandra*, *Oenanthe javanica* and *Cyanotis barbata*. The common species floating or submerged in the open water were *Azolla pinnata*, *Ceratophyllum demersum*, *Hydrilla verticillata*, *Salvinia cucullata*, *Salvinia molesta*, *Utricularia* spp., *Nymphoides cristata* and *Pistia stratiotes*.

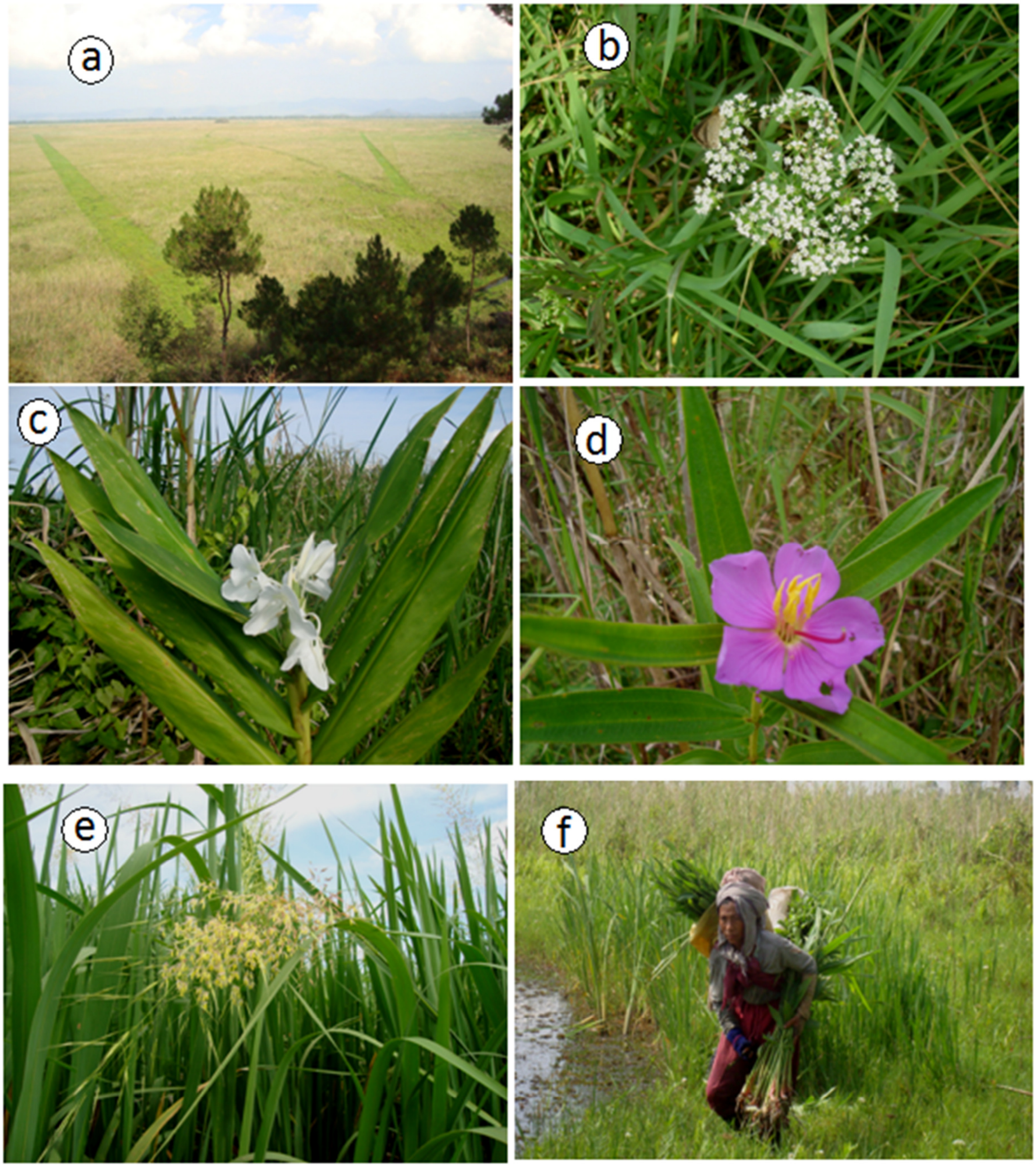

Figure 2. Some important plant species of the floating meadows of Keibul Lamjao National Park, Manipur (a) a view of the Park (b) *Oenanthe javanica* (c) *Hedychium coronarium* extensively extracted by the local communities (d) *Osbeckia stellata* is the only shrub species of the floating meadows and (e) *Zizania latifolia* is a preferred food species of Sangai (f) extraction of *Hedychium coronarium* by local people.

[Send each photograph as separate file]

Occurrence of herbs was found to be the highest in both the floating meadows and terrestrial habitats (54.4% and 47.4% respectively) followed by sedges in the floating meadows (30%) and the grasses in the terrestrial habitat (26.3%). Herbs showed the highest percentage of distribution among the species common to both floating meadows and terrestrial habitats (52.6%) followed by grasses and climbers (21.1% and 11.8% respectively). In the overall distribution of the plant species of the Park, herbs showed the highest percentage (52.4%) followed by grasses and sedges (17.8% and 16.2% respectively) (Table 3).

Use of plant species by local communities

A total of 26 economically important plant species used by the local people for various purposes has been identified in the Park (Table 4). The most important plant species extracted for subsistence use and commercial purposes were *Hedychium coronarium*, *Oenanthe javanica*, *Nymphaea* spp. and *Euryale ferox*. The plant species like *Phragmites karka*, *Zizania latifolia*, *Leersia hexandra*, *Scirpus* spp., *Saccharum spontaneum*, *Arundo donax*, *Imperata cylindrica* and *Coix lacryma-jobi* were extracted by the local people for use in fencing, fuel and thatching material in the construction of huts.

The important fodder species identified in the Park were *Zizania latifolia*, *Ceratophyllum demersum*, *Hydrilla verticillata*, *Limnophila* spp. and *Leersia hexandra*. Some of the plants species like *Ageratum conyzoides*, *Alpinia allughas*, *Hedychium coronarium*, and *Fureina umbellata* were also being used for medicinal purposes. *Cyperus* spp. and *Scirpus lacustris* were extracted for handicrafts mainly for weaving mats (Table 4).

Table 3. Percentage distribution of the different class of plant species in different habitats in Keibul Lamjao National Park, Manipur.

Classes	Phumdi		Terrestrial		Both		Overall	
	Number	%	Number	%	Number	%	Number	%
Herb	49	54.44	9	47.37	40	52.63	97	52.4
Grass	11	12.22	5	26.32	16	21.05	33	17.8
Sedges	27	30	0	0	3	3.95	30	16.2
Fern	3	3.33	0	0	2	2.63	5	2.7
Climber	0	0	4	21.05	9	11.84	13	7.0
Shrub	0	0	1	5.26	6	7.89	7	3.8
Total	90		19		76		185	

Table 4. A list of the economically important plant species of Keibul Lamjao National Park, Manipur.

Uses	Plant species	Parts used
Vegetables	*Alternanthera philoxeroides*, *Alternanthera sessilis*, *Centella asiatica*, *Oenanthe javanica*	Leaf, stem
	Alpinia allughas, *Hedychium coronarium*	Stem, young shoot
	Euryale ferox, *Nymphaea* spp	Seeds
Thatching material	*Imperata cylindrica*, *Zizania latifolia*	Leaf, stem
Fuel	*Arundo donax, Coix lacryma-jobi, Phragmites karka, Saccharum spontaneum*	Stem
Handicrafts	*Cyperus spp, Scirpus lacustris*	Stem
Medicinal purposes	*Centella asiatica, Ageratum conyzoides, Alpinia allughas, Hedychium coronarium Ludwigia adscendens , Oxalis corniculata, Vetiveria zizanioides, Fureina umbellata*	Leaf, young shoots
Fodder	*Alternanthera philoxeroides, Alternanthera sessilis, Leersia hexandra, Polygonum* spp, *Zizania latifolia*	Leaf, Stem
	Ceratophyllum demersum, Hydrilla verticillata, Limnophila spp	Whole plant

Discussion

The understanding of plant species composition in a habitat is crucial for understanding the succession and change in vegetation structure over time due to natural and anthropogenic impacts. The ecological structure of the plant species is a result of a rich array of factors relating to both the physical and biological environment. The plant community structure represents a community's ability to capture and utilize resources (i.e., sunlight, water, and nutrients) from different positions in the canopy and soil profile. Often grazing and human interferences alter plant community structure and composition of grasslands (e.g. Kala *et. al.*, 2002). These changes in composition and structure influence forage production, habitat values, and ultimately sustainability of the habitat to support itself (Kamau, 2004). The vegetation, particularly of the floating meadows plays a key role in governing the wetland processes and function of the Loktak Lake. Apart from the moisture loving, submerged aquatic plants, the presence of terrestrial plants can also be attributed to the floating mats of vegetation (Sharma *et. al.,* 2002). These floating mats of vegetation influence hydrological regimes, harbor rich biodiversity, support productive fisheries and provide several economically important plant species to the local communities (Trisal and Manihar, 2002). The floating meadows also provide biological sinks for nutrients and are critical to the maintenance of water quality of the lake. Gee (1960) reported the plant composition of the Park as *Phragmites karka* 45%, *Erianthus ravennae*, *E. pucerus* (25%), *Saccharum munja* (15%), *S. latifolium* (5%), *Alpinia allughas* (5%), *Saccharum procerum* (2%) and others (2-5%) whereas Shamungou (1999) reported the proportion of fodder grasses as 58 % and shelter grasses as 42%. Significant changes has also been observed in the composition of the important food plant and shelter plant species of Sangai and Hog deer (*Axis porcinus*) with respect to *Phragmites karka*, *Zizania latifolia* and *Saccharum munja* (Trisal and Manihar, 2004).

The Park vegetation provides food and shelter to the rich wildlife. The most important plant species associated with the wild ungulates such as Sangai and Hog deer in the Park are *Zizania latifolia*, *Leersia hexandra*, *Capillipedium* spp., *Scirpus* spp., *Saccharum spontaneum*, *Hedychium coronarium*, *Phragmites karka, Arundo donax, Oenanthe javanica*, *Coix lacryma-jobi*, *Setaria* spp. and *Hemarthria compressa*. These plant species are also extracted by the local people. The tall grass species like *Phragmites karka, Arundo donax* and *Saccharum spontaneum* which act as a shelter for Sangai are extracted on a daily basis for household used. The favorite food plants of Sangai like *Zizania latifolia*, *Leersia hexandra*, *Capillipedium* spp., *Phragmites karka, Arundo donax* and *Saccharum spontaneum* are also extracted in large quantities.

The plant species of the Park provide food, fodder, fuel, medicinal, handicraft and thatching material for hut construction. People living in the periphery of the park collect such plants daily for their own use as well as for commercial purposes as a means of livelihood. *Hedychium coronarium* and *Oenanthe javanica* are extracted in huge quantities everyday throughout the growing season mainly for commercial purposes. During the growing season, these two species provide an important source of livelihood for the local people. The people are mainly dependent on *Zizania latifolia*, *Ceratophyllum demersum*, *Hydrilla verticillata*, *Limnophila* spp. and *Leersia hexandra* as fodder for the fish farms in and around the Park. Fish farming being the main source of livelihood for the people living around the Park, the extraction of fish fodder is done all year round. *Phragmites karka, Arundo donax* and *Saccharum spontaneum* are also extracted in large quantities for household used in fencing and as fuel. The extraction of these economically important plants is done almost all year round. The extraction of the plant species is also degrading the habitat which in turn threatens the very survival of Sangai. Apart from this changes in the hydrological regime of the lake due to the construction of the Ithai barrage has caused the deterioration of the floating meadows (Shamungou 1998). Factors like pollution due to influx of high amount of nutrients from Nambul, Nambol and Moirang Rivers and anthropogenic pressures like fishing, fish farms and over-exploitation of the vegetation also contributes to the degradation of the meadows.

A balance needs to maintain whereby the anthropogenic pressure and hydrological regime do not disturb the habitat of the wildlife and also maintains the integrity of the Park. The duration of extraction should also be maintained such that it does not coincide with the rutting season of Sangai. One way of checking the over exploitation is regulating the quantity extracted and the duration (or season) in which extraction should be permitted. Since complete ban of extraction is not possible unless an alternative source of livelihood can be provided to the local people, a regulated quantity and timely extraction can be a beginning to prevent further degradation of the park and the lake ecosystem.

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