DISCUSSION

Biodiversity of the study area

The Indian subcontinent with its vast geographical area, varied topography and climate harbors rich biodiversity. The country has 172 threatened species of animal globally threatened by IUCN, or 2.9% of the world's total number of threatened species. These include 53 species of mammals, 69 species of birds, 23 species of reptiles and 3 species of amphibians (Groombridge, 1993). Physically the massive country is divided into four relatively well defined regions - the Himalayan mountains, the Gangetic river plains, the southern (Deccan) plateau, and the islands of Lakshadweep, Andaman and Nicobar. Bhadra sanctuary, the area selected by the author for study being located in the midst of the western ghats exhibits diverse fauna and flora. Although the study area covers only 492.46 km², has different types vegetation starting from low altitude dry and moist deciduous forests, high altitude precious tropical semi and evergreen forests and mountain grasslands to sholas. The complex topography, high rainfall and relative inaccessibility have helped this area to retain its diversity. It is estimated that more than 150 species of large plants including some of the important medicinal plants endemic to this area are found. Further, it is said that more than 250 species of
birds, about 50 species of mammals, 10 species of reptiles and 5-6 varieties of fresh water fishes are also found in the study area making it biologically complex (Raju, 2001).

Although the author has concentrated her attention to the population size, structure and dynamics of a few mega-mammals she has noticed diverse mammalian fauna in the sanctuary. The representative mammals (Table 3) found in the sanctuary includes species such as, bonnet macaque, common langur, slender loris, common mongoose, ruddy mongoose, jackal, wild dog, small indian civet, jungle cat, sloth bear, common otter, indian tree shrew, indian giant squirrel, three striped squirrel, blacknaped hare, indian porcupine, indian pangolin, indian wild boar, mouse deer, barking deer, four-horned antelope, spotted deer (chital), sambar, leopard cat, leopard, tiger, gaur, elephant etc (see table for scientific names). Most of these species are threatened as per the IUCN list. The study thus shows that the Bhadra sanctuary has rich mammalian diversity. Because the study focuses only on mega mammals, only those species noticed by the author during her study has been listed in the check list. No special effort has been made to enlist all the mammals found in the sanctuary, hence the readers should not presume that these are the exclusive mammals found in Bhadra sanctuary. The mammals like rat, mouse, chervotin etc have been omitted from this list. But yet the list is in conformity with Raju (2001).
Among the 28 species, some are abundant, represented in good numbers (A), some are commonly found but sparse in distribution (C) and others are rare or very rare (R) (Table 3). Moreover, some species such as common mongoose, three-stripe squirrel are abundant in all the four ranges. Ruddy mongoose, barking deer, and leopard are commonly found in all the four ranges while bonnet macaque, slender loris, wild dog, sloth bear, Indian porcupine, and leopard cat are rarely seen. Although, some animals are represented in good numbers, they are rarely seen because of their habitat or because of their habit. For example, slender loris is rarely seen because it is nocturnal, inconspicuous in appearance and a very shy animal. The author has not sighted a live tiger in nature but has recorded in the check list because of indirect evidence of their existence in the sanctuary. Some animals are abundant in one range and rare in other areas. The elephants, gaurs, and other animals are not at all inhabited Umblebyle range but sometimes found in this range. Perhaps they are noticed while crossing from one range to another. Thus the present study shows that even with in the sanctuary the distribution of mammals is not uniform. Even though the entire sanctuary covers an area of only 492.46 km², it encompasses variety of habitats. This ecological diversity must be the reason for diversity of mammal populations of the sanctuary.
Among the four ranges of the sanctuary, Umblebye harbors less diversity. The topography and the back waters of Bhadra reservoir must be the reason for the low diversity of this range. On the other hand, Muthodi is richest in terms of diversity. The rich vegetation, the water availability in the Somavahini river and in the natural ponds and artificial water holes present throughout the area must be the reason for its richness.

Out of the 28 mammal species have been listed here some are abundant, some are found but rarely and some are very rare. When compared to the IUCN list of endangered species majority of the species are endangered and threatened. This shows that although Bhadra sanctuary has rich mammalian diversity, conservation measures are needed for their protection. The analysis of population size, structure and density of a few mammals made by the author thus gains significance.

Hosetti (1997) and Hosetti and Kumar (1998) have listed many species of animals in India, which have been threatened, or endangered. According to him due to habitat destruction and human intervention many species have become threatened. The present study of the author shows that there is no such threat at present in the Bhadra sanctuary. The Government is making all kinds of effort to conserve the wildlife. The records show that the human population which was existed in the
sanctuary till recently has been shifted to other areas. The author feels that there is no immediate danger of depletion of wildlife in the sanctuary. However, being unique both in flora and fauna, the Bhadra sanctuary may also lose many unique species if the management practices and protection measures undertaken at present is not continued.

The absence of some species in the Umblebyle range has to be viewed seriously. The reason for the virtual absence of some species in this area is quite obvious. The back waters of the Bhadra river, and inaccessibility of the area from other sides to the animal movement or colonization due to the mountains could be the reason for the absence of these species in this locality. These species are well represented in other surrounding wildlife habitats in the sanctuary but absent in this area confirms this assumption of the author.

The tropical forests and their faunal entity are under tremendous pressure to meet the volting resource demand of growing human population (Gee, 1964 and Panwar, 1987). Due to this the conservation of wild fauna and flora and preserving them for the future of human kind is crucial. Apart from being important economic, nutritional and aesthetic resources, large herbivores to small insects directly or indirectly affect forest structure, regeneration, and consequently other animal species (Crawley 1983, Kortlandt 1984, Owen-Smith 1987). It is
estimated that the current extinction rate is 1000 species a year (Anonymous, 1994). Destruction of tropical forest proceeds at the rate of more than 20 hectares a minute, despite the fact that nearly half of the area cleared so far has been abandoned as wastelands within a period of less than 10 years (Gee, 1964). At least 10 percent of India’s recorded flora and possibly more of its wild fauna are on the list of threatened species, many on the verge of extinction. The present study particularly the absence of certain species in the Umblebyle area shows that Bhadra sanctuary is also not an exception and hence the author feels that adequate attention is required for the conservation of these animals and plants.

The census data during the study period (2008 to 2010) collected by the author from the field both by direct and indirect means is provided in the table 4. Supplementary information on the population size of some predator and prey species of mammals during 1997 to 2000 collected from the records of Department of Forests, Government of Karnataka is also given in this table. From the scrutiny of the table it is evident that there is a steady increase in the population size of all these species. The study of Raju (2001) on the existence status of most of these animals has revealed an alarming situation and he has given a warning call to wildlife managers that the populations are heading towards extinction. The comparison of the present study with the available earlier records and that
of Raju (2001) suggests that the situation is not as worse as he thinks. The steady increase in the population numbers over a period of 15 years suggests that there is all hope that the population density of different species would rise to the optimum in this sanctuary.

The census data of both predator and prey species collected by the author during 2008, 2009 and 2010 in the sanctuary and that of the data of 1997 and 2000, obtained from Department of Forests, Government of Karnataka shows that there is a steady increase in the population size of all species in the sanctuary, right from 1997. For example among the prey species, the number of tigers has increased from 33 during 1997 to 58 during 2008 and during the study period there is an increase of 5 individuals thus amounting to 63. Similarly the number of leopards also has increased both in the study period and before. It has increased from 21 in 1997 to 60 during 2010. Among the two major predators, the rate of increase of leopards is higher than that of tigers. The percentage increase of tigers from 1997 to 2010 is 90.9 while that of leopards is 185.71. The number of wild dogs has increased from 28 to 71. Similar increase has also been noticed among the prey species in the sanctuary. Gaurs and elephants are heavy bodied prey species found in the sanctuary. Although they are seldom predated by the predators, they form important wildlife species of the sanctuary. Their number has increased like other prey and predator species. For example the number
of gaur has increased from 186 to 265 (42.47%) while elephants have increased from 203 to 289 (42.36%). Scrutiny of the table 4 also shows that when the increase of predators and prey are compared, the increase of the predator is more than the prey species. For example the number of most vulnerable prey species spotted deer has increased from 780 to 1280 which is equal to 64.1%. The species of sambar, muntjac and wild boar also have increased in the same proportion. This means even the predation pressure has not affected the rate of increase of prey population.

Panwar (1987) is of the opinion that wildlife managers in India have claimed significant success in increasing animal density in nature through development of fodder and water resources in the wildlife areas. Many wildlife biologists like Johnsing (1983), Karanth (1987a&b), Schaller (1967) in India and Mishra (1982) and Tamang (1982) in Nepal have conducted studies on the assemblage of herbivore and their population estimation. The steady increase in the density of both predator and prey species in the present study is in agreement with these studies. Although the present study agrees with these, each habitat is different in its own way in terms of flora and fauna, and hence need separate management strategy. Therefore repeated capsule research on each population to assess the population density and structure is warranted to investigate and find out the field accuracy of given population (Field, 1971).
The distribution, population structure, density and dynamics of elephants (Elephas maximus) in the Bhadra wildlife sanctuary

Elephants are the large land mammals of the order Proboscidea the family Elephantidae. Indian elephant or Asian elephant (Elephas maximus) is one among the three living species. The other two species are african bush elephant (Loxodonta africanus africanus) [savanna] and the african forest elephant (Loxodonta cyclotis). The other species of elephants have become extinct. The world population of Asian elephants is estimated to be around 41,410 to 52,345 animals (Sukumar, 2003). More precisely, it is stated that around 60 - 62% of them are wild elephants, 32-34% are domesticated ones and around 6% are scattered in the zoos. Sukumar (2003) is also of the opinion that the distribution of Asian elephants is uneven in different parts of its distribution area. The present findings of the author confirm these observations.

**The distribution, population structure:** The tables 5-7 show the distribution and population structure of elephants in different ranges of Bhadra sanctuary during 2008-2010. The table 5 shows that the Umblebyle range does not possess any elephants while Muthodi range possesses highest number. The distribution of elephants proportionately decreases in Hebbe and Lakkavally ranges when compared to Muthodi range. Elephants range over large areas and home ranges in excess of
600 km² have been recorded for females in south India (Baskaran et al., 1995). In north India, female home ranges of 184–326 km² and male home ranges of 188–407 km² have been recorded (Williams, 2002). Smaller home range sizes, 30–160 km² for females and 53–345 km² for males, have been recorded in Sri Lanka (Fernando et al., 2005). Given their requirements for large areas, elephants are regarded as an “umbrella species” because their conservation will also protect a large number of other species occupying the same area. They are also a premier “flagship species” and are sometimes regarded as a “keystone species” because of their important ecological role and impact on the environment. Even though Bhadra sanctuary is spread over an area of 492.46 km² inhabits good number of elephants suggests smaller home range for them.

The sex-ratio is in favor of females in Muthodi and Hebbe ranges while it is in favor of males in Lakkavally range. Thus there are more females in Muthodi and Hebbe ranges when compared to males in the sanctuary. The overall sex-ratio also is in favor of females, with their number being almost double that of males. There are also proportionately good number of sub-adults and calves in different ranges of the sanctuary. The sex of the calves could not be ascertained. However, there are more females among the sub-adults than males. The difference in the sex-ratio of wild animals could be due to 1) hunting or poaching for the animal
products, 2) competition and struggle during sexual selection, 3) unequal births, 4) juvenile deaths and 5) other unknown reasons (Douglas-Hamilton 1972, Saraqusty et al, 2009). Bhadra sanctuary is well protected in terms of conservation and poaching is prevented because of stringent measures. Therefore the sex-ratio imbalance in the elephant population in the Bhadra sanctuary could be due to any one or more of the above natural reasons.

The overall population trend of the Asian elephant has been downwards, probably for centuries (Sukumar, 2003). This remains the case in most parts of its range, but especially in most of the countries of South-east Asia. Within India, there is evidence that the large population in the western ghats in south of the country has been increasing in recent years due to improved conservation effectiveness. The present observation of the author also agrees with Sukumar (2003). Thus comparison of tables 5 and 6, shows that there is an increase of six individuals in a span of one year. Similarly between 2009 and 2010 there is further increase of four individuals. The increase was observed in all the three ranges where the elephants are present.

Raju (2001) is of the opinion that the population survival and growth under the ecological variables in the study area reveals that the elephants though surviving are not perpetuating as expected. The
population numbering 161 during 1989 has shown the addition of 10 animals when they are counted during 1993 after span of four years. He has observed a population growth of 6.21% in four years amounting to annual growth of 1.55% which according to him is satisfactory. Further the growth during 1993 to 1995 is not satisfactory as it reveals the increase of only 3 animals in a span of two years showing the overall growth of 1.75% amounts to annual growth of 0.87% which is far below the annual growth of 1.55% noticed during 1993. Maximum growth rate reported for the Asian elephants is only 2.4% (Sukumar 1989). In the present study the author has counted 279 individuals during 2008. The census report of 2000 conducted by Government of Karnataka shows that there were 228 elephants in the sanctuary. This means over a span of eight years there is an increase of 51 individuals which amounts to an annual growth rate of 2.8%. Although this growth rate appears to be high it is not unexpected in Bhadra sanctuary because of its luxuriant flora and stringent conservation measures.

It is observed in captive condition that the mature female elephants having the gestation period of 18-21 months exhibit the parturition cycle of 5-6 years. Elephants in natural condition, owing to prevailing ecological variables, the parturition cycle should be 6–7 years. Therefore, even if 80% of adult females (126, 2000 census) reproduce
presuming the infant survivality of 80% due to the strong parental care, presently there should have been 28 young ones (calves) in the population during 2008. The author has counted 27 calves during 2008 which is almost nearer to this figure. Thus this also would agree with the growth rate of elephants observed between 2000 and 2008. 2009 and 2010 figures also agree with these figures confirming the satisfactory growth rate of elephants in Bhadra sanctuary.

Census results of the author between 2008 and 2010 revealed an increase of 10 individuals. This amounts to an annual growth rate of 1.79%. Although this growth rate is lower than the rate observed during 2000-2008, it is very well with in the limits suggested by Sukumar (1989). Thus the elephant population growth in the Bhadra sanctuary appears to be satisfactory under the flourishing ecological variables and conservation measures.

The analysis of different age classes of the elephant population in the Bhadra sanctuary reveals the proportionate composition of all age groups in the habitat, which is believed to be the good sign of healthy population. In 2008, the adult, sub-adults and calves are in the ratio of 217:35:27. In the population, 16.12% of individuals are sub-adults while 12.44% are calves. Almost the proportion of sub-adults and calves are maintained during the study period. In other words, the same proportion
of breeding and non breeding individuals is maintained during this period. This also confirms the above observation of the author on the growth rate. This means an equal number of new ones are added every year and an equal number of calves grow and become sub-adults and sub-adults are transformed into adults. This dynamicity of elephant population indicates the healthy growth of elephant population in the Bhadra sanctuary.

Male to female ratio found in the sanctuary is very promising providing 1:2.02 among reproductive adults and 1:3.37 among adults and sub-adults of 2008 (Table 5). The adult male to female sex-ratio during 2009 is 1:2 and sub-adults ratio is 1:2.36 (Table 6). In 2010 the adult male to female ratio is 1:1.99 and for sub-adults 1:2.36. According to Sukumar (1985) the ideal sex-ratio for elephants is 1:2. Elephants are social animals living in groups and the dominant male can mate more than one female, this 1:2 sex-ratio assures the mating of all reproductive females in the herds (Caughley, 1976). If number of females is less than the males, then it would affect the reproductive fitness of males because some of the males would fail to obtain mates (Nair and Gadgil, 1978; Nair and Jayson 1978, 88, 90). Though all these characters in the population presently showing the hope of survival, under the changed situation in habitat due to enrichment and assured protection how the
population responds has to be observed in due course as the process of habitat protection and enrichment started few years back would take some more time to yield results.

**Population density of elephants:** The density of a large mammalian species in an ecosystem is dependent on the ecological status and versatility of the environment in which it lives. Bhadra wildlife sanctuary, being unique in its ecological status should have harbored large number of mega mammals. In the present study, the author has noticed the presence of 279 elephants (Table 4). With rich bamboo vegetation - the fodder for elephants, the carrying capacity of Bhadra sanctuary definitely is higher than what actually is present. Raju (2001) is of the opinion that the situation is alarming because of imbalance of sex-ratio. The present study also shows the sex-ratio imbalance in favor of females. One positive sign is that there is slight improvement in the sex-ratio when the situation is compared to 2000 (Tables 4 and 5). Furthermore the imbalance is in favor of females, which is also a positive aspect of the population growth because females are the ones which give birth to young ones, and the role of males is only to assure the mating. It has already been mentioned that the ideal sex-ratio is 1:2 (Sukumar, 1985). Although there is discrepancy in the sex-ratio at the three ranges, the overall sex-ratio in the sanctuary is 1:2.02 which is also satisfactory.
The spatial distribution of elephants is not uniform throughout the sanctuary. As per table 8, Muthodi and Hebbe have high ecological density of 0.903 and 0.847 respectively. The ecological density during 2009 and 2010 is also almost similar (Tables 9 and 10) which is a satisfying situation. The sanctuary with thick vegetation and perennial water source provides all the necessary requirements to the growing population of elephants. It is also interesting to note that the Lakkavally range has the lowest density of 0.155. This means at least Lakkavally range has the higher potentiality of housing few more elephants. The low density of elephants in the Lakkavally range may perhaps be due to more biotic pressure than the other areas. Here one has to agree with the suggestion of Raju (2001) that the Bhadra sanctuary can hold more elephants in all the three ranges, with Umblebyle acting as a corridor for the movement of elephants to cross from one range to another. The census statistics of 2000 and 2008 are very much similar to each other and reveal the biological reality in increase of population at each age class by recruiting new members from corresponding group.

**Dynamics of elephant population:** When compared to 2000 census there is an increase of 51 individuals over a period of eight years (Table 11). This increase is optimal when gestation period and the reproductive pattern of elephants are considered. Thus the population
growth of 18.28% in eight years amounting to annual growth of 2.285% is satisfactory. Maximum growth rate reported for the Asian elephants is only 2.4% (Sukumar 1989) per year. The increase of 51 individuals in a span of eight years is thus satisfactory. The present study thus contrasts that of Raju (2001) who has opined that the population growth and survival under the ecological variables in the study area reveals that the elephants though surviving are not perpetuating as expected. In contrast to this, the present study shows that under stringent protective conditions, the elephant population in Bhadra sanctuary is increasing satisfactorily.

Although the Bhadra sanctuary has 279 elephants, all of them are not involved in reproduction. Effective population size ($N_e$) is a measure of the total number of breeding individuals present in the population. It also indicates the viability of the population (Franklin, 1980). Despite of the fact that Bhadra wildlife sanctuary is exposed for various adverse biotic pressures still the viable population is being housed in the habitat. The effective population size at Muthodi, Hebbe and Lakkavally ranges during 2008 is 105.60, 67.96 and 11.68 respectively. Similarly, the overall effective population size is 185.24 which is most satisfying figure. Further with this effective population size and annual growth rate of 2.285%, the elephant population of Bhadra sanctuary appears to be stable.
Having large size, elephants exhibit extensive movement in their habitat mainly to obtain their basic needs like forage, water and mates (Daniel 1987, Mc Kay 1973, Eisenberg and Lockhart 1972, Sukumar 1985). The once vast range of the Asian elephant has now been reduced to smaller fragmented populations in India in the west to Vietnam in the east. Under this situation investigation on this small population and their biological existence is especially relevant to the conservation of Asian elephant (Campbell, 1954). Loss and fragmentation of habitat still continues, hence given rise to numerous small, isolated elephant populations in most Asian countries (Sukumar 1989, Santiapillai and Jackson 1990). As factors that have led to the decline of the number and range of the Asian elephants are still play in, conservation of this species would require protection of adequate areas with viable populations, on a specific management strategy.

**Habitat and Ecology:** Asian elephants are generalists and they occur in grassland, tropical evergreen forest, semi-evergreen forest, moist deciduous forest, dry deciduous forest and dry thorn forest, in addition to cultivated and secondary forests and scrublands. Over this range of habitat types elephants are seen from sea level to over 3,000 msl. In the eastern Himalayas in northeast India, they regularly move up above 3,000 msl in summer at a few sites (Choudhury, 1999). The Asian elephant is
one of the last few mega-herbivores still extant on earth (Owen-Smith, 1988). Given their physiology and energy requirements, elephants need to consume large quantities of food per day. They are generalists and browse and graze on a variety of plants. The proportions of the different plant types in their diet vary depending upon the habitat and season. During dry season in southern India, Sukumar (1991) observed that 70% of the elephant's diet was browse, while in wet season, grasses make up about 55%. However, in an adjoining area, Baskaran et al (2010) observed that browse formed only 15% of the diet in dry deciduous forest and 47% of the diet in the thorn forest in the dry season, while the annual diet was dominated by grass (84%). In Sri Lanka, elephants may feed on more than 60 species of plants belonging to 30 families (McKay, 1973). In southern India, Baskaran et al (2010) recorded that elephants fed on 82 species of plants (59 woody plant species and 23 grass species). Elephants may spend up to 14–19 hrs a day feeding, during which they may consume up to 150 kg of wet weight (Vancuylenberg, 1977). They defecate about 16–18 times a day, producing about 100 kg of dung. Dung also helps disperse germinating seeds.

Raju (2001) has noticed that the elephants in Bhadra sanctuary are mostly feeding on the bamboo breaks which forms major source of food. The bamboo species usually undergo mass flowering and fruiting and get
vanished simultaneously after flowering. It requires at least 8-10 years to grow fresh. The author has noticed that bamboo has completed flowering in 2007-08 and presently there is no bamboo serving as food for elephants. However, the loss of bamboo has not caused any decline in elephant population in Bhadra sanctuary. Elephants being generalists have been able to sustain the lack of bamboo and switch over to other plant species for food.

The distribution, population structure, density and dynamics of gaurs (Bos gaurus) in the Bhadra wildlife sanctuary

Gaur (Bos gaurus) is also a mega mammal belonging to the Bovine family. It is the largest species of wild cattle, bigger than African buffalo. It is also called Indian bison listed as vulnerable species in the red data book. According to Raju (2001) Bhadra sanctuary is a paradise of gaurs. The lush green vegetation, the tall and luxuriantly grown bamboo streaks, the green grass and perennial water source provide most congenial climate for the existence of gaurs. Tables 12 to 14 show the pattern of distribution of gaurs in the Bhadra sanctuary during 2008-2010. Although Bhadra is known as paradise of gaurs, it is surprising to note the absence of gaurs in Umblebyle range. Only some traces of movement of gaurs are noticed in Umblebyle range, but no sign of their residence in this range. These foot prints must be those formed while herds crossing
from one area to another. As no gaurs could be observed during physical count, it is assumed that there are no resident gaurs in this range. Muthodi range possesses highest number. The distribution of gaurs proportionately decreases in Hebbe and Lakkavally ranges when compared to Muthodi range. This differential distribution in different ranges indicates the ecological versatility of these areas.

According to Raju (2001) the ecological variables, prevailing in the habitat normally determine the distribution, growth and structure of population. He is of the opinion that the gaur population in the study area seems to have been under pressure of natural stochasticity which ultimately causing the demographic erosion. He has noticed a drastic decline in the density of gaurs from 3057 in 1983 census of the Department of Forests, Government of Karnataka to just 177 in 1993 census. High density of gaurs in 1983 confirms that Bhadra sanctuary was once a paradise of gaurs. However this paradise lost its pride within ten years. Based on inquiry with local people he is of the opinion that Rinderpest – the most dreaded viral disease must be the cause for such decline. Due to lack of evidence, he himself has expressed the doubt on the cause of decline of gaur population in the sanctuary. More over, he has also expressed doubt about the census figures available for the year 1983.
The causes for the decline in the density of many wild animals are poaching, habitat destruction and degradation, overexploitation, predation etc., (Forbes, 1887; Transley, 1935; Lindeman, 1941; Schaller, 1967 & 72; Norton-Griffiths, 1979; Johnsingh, 1983; Mc Naughton and Georgiadis, 1986; Dinerstein, 1987; Mishra and Wemmer, 1987; Newton, 1987; Ngampongsai, 1987; and Tamang, 1982). These factors do not seem to be responsible for sudden decline of gaur population in Bhadra sanctuary because the extinction rate for wild animals due to such reasons is much lower than the rate of decline during 1980-1990. Further if these were the reason for the decline, the other wild animals also should have been affected by them. The present study of the author during 2008-2010 (Tables 12 -14) also shows the stable growth of gaur population. 2008-2010 census figures when compared to the census figures of Raju (2001) and that of others confirms this. The gaur population in the sanctuary being more stable does not allow one to subscribe this view. Thus high rate of shrinkage of population size of gaurs in the sanctuary should be due to natural catastrophes like the outbreak of the endemic disease of these hoofed animals.

**Distribution of gaurs in Bhadra sanctuary:** Scrutiny of tables 12 to 14 shows that the Umblebyle range does not posses any gaurs. In this respect both elephant and gaur population are identical in their distribution. Muthodi range possesses highest number. The distribution
of gaur proportionately decreases in Hebbe and Lakkavally ranges when compared to Muthodi range. The availability of fodder, water and shelter are the determining factors for the distribution of gaurs. The submergence of most part of Umblebyle range with the back waters of the Lakkavally dam could be the reason for the absence of gaurs in this area. Muthodi range has highest number of water bodies along with number of grass lands which provides fodder for them. Raju (2001) is also of the opinion that the gaurs also feed on the bamboo leaves, brought down by the elephants and therefore one can see the pattern of movement of gaurs along with elephants.

**Population structure of gaurs:** It has already mentioned that the most ideal male to female sex-ratio is 1:2. In the present studies, the author has noticed that the sex-ratio of gaurs in most cases range between 1:1.4 and 1:2. Although there is some difference in the sex-ratio between the ideal sex-ratio and the observed value, the over all sex-ratio is in favor of females in all the three ranges. The sex-ratio in most individual cases also is in favor of females, with their number being almost double that of males. The presence of more females than males is a healthy sign. Although the values are slightly lower than expected, the future of gaurs in Bhadra is not bleak, but is satisfactory. If most of these females found at present breed, the gaur population could steadily increase in future in Bhadra sanctuary so as to reach a stable state.
The characteristic feature of any healthy and dynamic population is to exhibit alteration in population structure as time advances. The author has noticed a steady growth of the population. For example, the number of sub-adults increased from 17 to 18 from 2008 to 2009 and while the number of calves decreased from 28 to 23 during the same period. Similar figures are recorded during 2010 (18 sub-adults and 27 calves) also. This change indicates that the number of births has decreased between 2008 and 2009. Furthermore some calves counted during 2008 must have grown as sub-adults and some sub-adults must have grown as adults. Further the most satisfying observation is the increase of total population size by addition of seven and nine individuals during 2008-2009 and 2009-2010 respectively. In this respect also the gaur population exhibits a healthy state in the Bhadra sanctuary.

**Population density of gaurs:** The census data of the author shows that there are 249, 256 and 265 gaurs during 2008, 2009 and 2010 respectively. When the ecological density is estimated based on these figures in different ranges, as usual the Umblebyle range which does not possess any gaurs (Tables 15-17). The Hebbe range has higher density in all the three years than the other ranges. In terms of the actual numbers Muthodi range houses more number of gaurs but yet density wise Hebbe range is rich in terms of gaur population. The animal density in a given
area depends on its carrying capacity and not just the physical area it covers. The carrying capacity on the other hand depends on the ecological versatility in addition to overall area (Baily and Poulton 1968).

In Bhadra sanctuary, in lieu of the ecological versatility and carrying capacity both Muthodi and Lakkavally ranges should have had more number of gaur species. Considering this, the author is of the opinion that the Bhadra sanctuary can hold some more gaur species than actually present now. Perhaps the continuation of stringent management practices that are being followed now leaves a hope that the gaur population size would continue to increase in future in Bhadra sanctuary.

Raju (2001) expresses doubt regarding the validity of census results. According to him the steady increase in the census results since 1990 might also be due to human error while counting. At the same time he is also of the opinion that the population size, structure, male-female ratio still ensures long survivability of gaur population. The author has followed three different census methods so as to ascertain greater accuracy. According to the author the gaur population in Bhadra sanctuary is well balanced having 1:1.4 to 1:2 male to female ratios, representing all age group. Presence of 23-28 calves in the population reveals the promising growth, but still the population viability analysis need to be done to assess the viable population size for preservation, with the sole intention of perpetuating them in their existing habitat.
**Population dynamics of gaur**s: The survivality of any animal species depends on the composition of its population. Any population consisting of only old and non-breeding individuals has no future. Smaller the size of species population higher is the risk of it becoming extinct (Dougall *et al* 1964). The extinction need not be caused merely by ecological processes such as habitat destruction and hunting, but also by chance factors operating on birth and death process. Thus many of the matured females in a small population may be infertile or may fail to reproduce in a given year leading to the “extinction vortex”. The habitat, forage, birth, growth, sex-ratio, reproduction, population size, mortality, natality, natural catastrophes and death should all occur at known rates which make the population viable for long durations. To understand the viability of the gaur population the author has carried out population viability analysis. This analysis also throws light on the dynamics of gaur population.

The effective population size indicates the actual number of breeding individuals found in the population. The present study shows that the effective population size of gaur for 2008 in the Bhadra sanctuary is 192.392 (Table 15). The value has increased to 198.809 (Table 16) and 204.709 (Table 17) during 2009 and 2010 respectively. This means although there are 249, 256 and 265 gaur in Bhadra
sanctuary all of them are not able to breed and produce the offspring. A similar picture also exists in different ranges. This indicates that during 2008, out of the 249 individuals present in the Bhadra sanctuary, only 192 of them are able to perpetuate. The sex-ratio during the year is 1:1.79. Accordingly out of 192 individuals, 69 males and 123 females alone can participate in reproduction. Although 123 females are able to reproduce, all of them may not reproduce because some of them may carry young ones (28, see table 12), some might be in early stage of pregnancy, etc. Thus the actual rate of reproduction is much lower than the expected. The actual number of breeding individuals in a population is often denoted as breeding size of the population.

To avoid the complexities, a population ecologist would estimate the potentiality of a population in terms of minimum viable population (MVP). Minimum viable population (MVP) is the one that has 99% chance of surviving for 1000 years (Desai, 1991). A wildlife biologist or wildlife manager may deem it fit to continue in-situ conservation measures for a population that has 90% chance of surviving for 100 years. Thus population viability analysis is a process that can yield different values of minimum viable population (Boyce, 1992). According to Boyce (1992) the adult and sub-adults gaurgs constitute the minimum viable population. Calves have not been considered under MVP as they are subjected for predation and natural catastrophes, which results in high
mortality. Thus the MVP for gaurs in Bhadra during 2008 is 221 (adults and sub-adults as in table 12), which ensures the survivality of this population for next 100 years. Similarly the MVP for elephants in the same year is 252 which also indicate good survivality. The MVP values for elephants and gaurs indicate that these two species have good future from the point of their survival.

The present study demonstrates the satisfactory viability of gaur population. Sukumar (1995) states that several simulation studies of the large carrying capacity areas shows $N_e$ {effective population size} in the range of 50-100 is needed for a population to be safe from purely demographic and environmental stochasticity driving it to extinction. Further he also states that the genetically effective population size ($N_e$) of 50 suggested as the minimum number to keep inbreeding below a tolerable 1% per generation can thus be taken as a useful guide for management. This statement is more valid from the point of elephant management, but the same analogy could be applied to guars also, as both are mega herbivores always invariably co-existing in all dry, moist and evergreen forest habitats and their population and behavioral biology also remains similar. Therefore the $N_e$ estimated for elephants (185) gaurs in Bhadra sanctuary (192) thus seem to maintain all genetic potential to keep up the long-term viability.
From the 2008 census figure available on gaur of Bhadra sanctuary the male female ratio (M:F) 76:133 which forms 1:1.75 when accounted for the entire population available for the sex-structure, excepting the unidentified sex group i.e. calves which are 28 in number. If the unidentified sex group are just divided on random according to above actual M:F ratio then the ratio for the unidentified groups would be 10:18. Thus summary of the total population of gaur in Bhadra is 86 : 151. Adult sex-ratio of this population reveals the effective population as 73:131, which amounts to 1:1.79. Therefore every adult male in the sanctuary will approximately have 2 adult females to formulate the effective population size. The study thus concludes that this population still has the broad base of gene pool and no genetical erosion has yet taken place.

**Population Growth:** Out of 249 individuals counted in 2008 census, 73 are males, 131 are females among adults, 17 are sub-adults and 28 are calves (Table 12). Presuming all the 73 breeding bulls have mated all 131 cows, out of 131 cows 28 have reproduced, because 28 calves are counted which reveals the growth of 14.58% for the effective population size (EPS). The total adult female found in the effective population for the said year are 131 (Nf), but the productive females or the mothers with calf are only 28, which reveals the productive
potentiality of the effective female population in the EPS is 21.37%. Therefore 21.37% of productive females in the effective population makes the overall growth of population to the extent of 14.58%.

According to Sukumar (1889) small population requires more attention from the point of conservation. He says destruction of habitat in addition to many biotic pressures such as human and domestic cattle has given rise to isolated gaur populations in the southern peninsular region of this sub-continent. This fact is found true in case of Asiatic elephant populations in most of the Asian countries (Sukumar 1989, Santiapillai and Jackson 1990). Small size becomes a bottleneck for the survival of such populations. Although the elephant and gaur population in Bhadra sanctuary have good survival, have threat because of their small size.

**Habitat and Ecology:** The gours are largely confined to evergreen or semi-evergreen and moist deciduous forests or dry deciduous forest areas at the periphery of their range. In the present study they have been found to be present in three ranges where such habitat prevails. Availability of water and an abundance of forage in the form of grasses, bamboo, shrubs, and trees also determine their distribution (Schaller, 1967). Where gaur has not been disturbed, they are basically diurnal while in other areas they are nocturnal (Naveh, 1974, 74a). The author has noticed the herds grazing during day time and night they must be resting underneath the trees and other shelter.
The spatial distribution of gaur population in Bhadra sanctuary is also quite interesting. They are found only in three ranges viz, Muthodi, Hebbe and Lakkavally respectively. Out of 492.46 km², the hilly terrain with high altitude where the gaur could hardly occupy during any part of the year formulates 10% of the total geographical area, where the animals move to these areas during fire season and pinch period, mainly for forage and security. Further about 9% of the total geographical area is occupied round the year by impounded water body forming about 44 km². Another 6% of the total geographic area i.e. Umblebyle, consisting of about 20.52 km² has become a corridor. Further Umblebyle area is denuded and presently devoid of gaur population but can become good corridor habitat if protection against fire, grazing and illicit cutting is assured. In addition to this other habitat enrichment activities like gap planting, soil and water conservation measures, creation of water holes and fodder plots would definitely revive the condition and become as potential as other blocks form the point of wildlife particularly of gaurs.

The study reveals more congregations of gaurs in Muthodi and Hebbe blocks (Tables 12-14) because these two troughs like valleys exhibit favorable climatic conditions round the year. Further, due attention on protection and management is given to these areas from the point of eco-tourism, population management as it has close proximity to Chikamagalur, the ultimate management head quarters. Ecological
conditions of these areas are best because of its characteristic grasslands (open meadows) or hadlus, paddy fields cultivated by inhabitants and lofty and lush green bamboo breaks. The open meadows and the foreshore areas of Bhadra backwater remains green with always new flush of grass, as they are characteristically marshy areas. These swampy grasslands not only act as feeding ground but also act as breeding ground and escape areas from the predators. Predators normally do not take chance of the feeding ground as the area would be vast and prey animal has more chance to escape and posing retaliation or fight (Eisenberg, 1980; Hudson, 1984; Karanth, 1987b; Srikosamtata, 1994). Therefore these hadlus (open meadows) also act as escape areas.

Perennial water source is another important parameter for more congregation and multiplication of gaurs in Muthodi block. River Somavahini, Tadabehalla and Kesavehalla are the lotic water source in addition to many lentic water holes artificially created in this block. Further the biological reasons like the male-female ratio, security to young ones, infant mortality, prey-predator relationship and co-existence of other herbivore partners like elephant, sambar and spotted deers make the entire ecosystem potential and dynamic.
Comparison between density of gaurs in different ranges of Bhadra (Table 15-17) shows that spatial distribution of gaurs is promising and reveals potentiality of housing few more individuals. The density is highest in Hebbe range although it covers a smaller area. Muthodi has a density slightly less than Hebbe and the density of gaurs or elephants are very low in Lakkavally range. This means Muthodi and Lakkavally ranges can hold some more individuals making the Bhadra sanctuary rich in terms of these mega mammals.

The distribution, population structure, density and dynamics of spotted deer (Axis axis) in the Bhadra wildlife sanctuary

In the Bhadra sanctuary, amongst the herbivores counted spotted deer [chital] was dominant in terms of number. This species (Axis axis) often called chital belongs to the family Cervidae. It is a monotypic species with fairly good distribution. Except for a few studies no information on the population structure, density or dynamics is available and therefore the present study of the author represents a maiden attempt of the wildlife biology of this animal. Moreover it serves as an important prey animal and hence plays an important role not only on its own population but also on the carnivores found in the sanctuary.
**Distribution of spotted deer in Bhadra sanctuary:** Spotted deer being most sought prey attracts the attention of wildlife managers and the visitors in the sanctuary. The author was able to count a total of 1230 spotted deer by both direct and indirect counts (Table 19). There are 1251 individuals during 2009 and 1280 individuals during 2010 (Table 20 and 21). These figures indicate that the Bhadra sanctuary has rich spotted deer fauna. Within the sanctuary, Muthodi has highest number of spotted deer compared to other ranges. The number gradually declines in Hebbe and Lakkavally ranges respectively. It is surprising to note that the Umblebyle range which has no elephants and gaur s has two herds of spotted deer with 26 individuals. When compared to elephants and gaurs, spotted deer is a smaller animal with little ecological requirement. Perhaps this is the reason they are able to survive even in the Umblebyle range in the sanctuary.

The spotted deer is found in large numbers in dense deciduous or semi-evergreen forests and open grasslands (Schaller, 1967). The highest numbers of them are found in the forest of India where they feed upon tall grass and shrubs (Geist, 1998). They do not occur at higher elevation forests where they are usually replaced by other species such as the sambar. They also prefer heavy forest cover for shade and are intolerant of direct sunlight. The habitat selection may also be the reason for uneven distribution of spotted deer in Bhadra sanctuary.
**Population structure of spotted deer:** Like elephant and gaur population the sex-ratio of spotted deer in Bhadra sanctuary is also in favor of females. Although the total number of spotted deer is more in Muthodi range, the number of sub-adults exceed in Hebbe range when compared to Muthodi and other ranges. In contrast to this, the number of calves is more in Muthodi range. The ratio between adult female to calves and sub-adults is almost 5:1 in all the three years (2008-2010) which is unsatisfactory because the spotted deer have a gestation period of about 220 days and each female is expected to reproduce once in two years. The predation pressure must have been the reason for this imbalance because it is mostly the sub-adults and calves are weak and they fall easy prey for the predators than the adults.

The present study reveals satisfactory distribution and density of spotted deer in the Bhadra sanctuary. According to Duckworth *et al* (2008) chital is listed by the IUCN as least concern because it occurs over a very wide range within which there are many large populations. Currently there are no range-wide threats to spotted deer and they live in many protected areas. However population densities are below ecological carrying capacity in many places due to hunting and competition with domestic livestock. Hunting for the deer's meat has caused substantial declines and local extinctions (Duckworth *et al*, 2008).
The Chital is protected under Schedule III of the Indian Wildlife Protection Act (1972) (Sankar and Acharya 2004) and under the Wildlife (Preservation) (Amendment) Act, 1974 of Bangladesh. Two primary reasons for its good conservation status are its legal protection as a species and a network of functioning protected areas.

**Population density of spotted deer:** The mean herd size of spotted deer in Bhadra sanctuary during 2008, 2009 and 2010 was 19.83, 19.85 and 19.69 respectively. Area wise also there is difference in the herd size. For example the mean herd size varies from 20.91±1.00 in Hebbe range to 13.00±3.00 in Umblebyle range (Table 23). There is not much difference in the herd size during the study period. It is said that the spotted deer most commonly occur in herds of ten to fifty individuals of both sexes. They have their own social structure and distribution of individuals with in the herds (Geist, 1998). Large dominant stags without velvet stay in the center of the herd and are surrounded by the females and their young. Smaller stags with velvet occupy the boundaries of the herd. The herds found in the Umblebyle are smaller than the others. The author is of the opinion that the herds in Umblebyle are the ones which have been separated recently and might have entered into these new areas.
The ecological density of spotted deer also is different in different areas. The density is high in Hebbe range and very low in Umblebyle. During 2008 the density in Hebbe range is 4.888 (Table 22), while it is just 0.350 in Umblebyle. Even the Muthodi range which has highest number of spotted deer has a density of only 2.739 during this year. A similar picture is seen in the density during 2009 and 2010 (Tables 23 and 24). Duckworth et al (1998) have reported that the ecological densities of Chital mostly fall within 3–50 animals per km² in India. For Bhadra sanctuary density reported is 4.51±1.05 (SE) per km² (Jathanna et al. 2003). Two things are clear from these reports, 1) the density reported by the author is lower than these estimates and secondly both the values reported by the author and that reported by Jathanna are much lower than the estimates of Duckworth et al (1998). The reason for this difference could be either due to inaccuracy in the density estimates of the author or the over estimation by the other workers.

The highest population densities, of around 200 Chitals per km², are reported for the Bardia National Park, Nepal (Naess and Andersen 1993; Moe and Wegge 1994, 97) and for the reintroduced population in Guindy National Park, southern India (Menon 1982; Shankara Raman 1997). These high densities reflect habitat and food availability in the former area (Moe and Wegge 1994), and supplementary feeding and low
predation in the latter (Shankara Raman 1997). The recorded low density of spotted deer in Bhadra also perhaps reflects the predation pressure and the competition for food exerted by the other ungulates.

**Population dynamics of spotted deer:** Table 22 shows the density, mean herd size and effective population size of spotted deers in Bhadra wildlife sanctuary during the year 2008. The same observation is made in all the three years of study (Table 23 and 24). The mean herd size varies from $20.91 \pm 1.00$ in Hebbe range to $13.00 \pm 3.00$ in Umblebyle range. This means the herds inhabiting Hebbe range are larger than other ranges. Although numerically more spotted deers are counted in Muthodi range, the density is higher in Hebbe range than in Muthodi range. Probably, the herd size is related to density rather than other aspects while the density is dependent on the congenial ecological factors.

The tables 19-21 show that there is an increase of 21 spotted deers during the period 2008-2009 and 29 individuals during 2009 - 2010. The number of adult males and females has increased during this period. This indicates that the spotter deer population in Bhadra sanctuary is showing an increasing trend. The effective population size also correspondingly is showing an increase during these three years. 1997 and 2000 census of Government indicates that there are only 780 and 920 spotted deer respectively during those years. Spotted deer is a prolific breeder, as
documented by several empirical studies of the speed of increase by newly introduced populations or in those where a factor restraining populations is removed. In Bhadra, following the departure of human settlements from the park and consequent removal of anthropogenic pressures on chital and its habitat, chital populations bounced back by nearly seven times in fewer than four years (K.U. Karanth and N.S. Kumar unpublished data). Karanth et al. (1999) earlier documented their empirical observations of the recovery of chital populations in Rajiv Gandhi National Park, Nagarahole. This and its diverse diet and habitats allow high density where threats are controlled. It is even considered to be a pest in Andamans (Bahuguna 1986). In contrast to this, in Bhadra sanctuary, spotted deer forms a prey base and the fact that in spite of predation there is an increase in the population density indicates the good progress of the management practices.

The distribution, population structure, density and dynamics of sambar (Cervus unicolor) in the Bhadra wildlife sanctuary

Except for stray reports on the number, no scientific approach has been made to estimate the density of sambar, spotted deer, wild boar, barking deer and other herbivorous animals in Bhadra sanctuary. Obviously, no earlier scientific data was available on the density of sambar in the sanctuary. The present study of the author therefore forms
the maiden attempt to count these animals. When compared to other sanctuaries of the state there is variation in the density of these animals but in the study area they are found in considerable numbers (729 during 2010, see table 4). Probably the assured protection against fire, poaching and live stock grazing etc., in some parts of the sanctuary, might be the reason for the occurrence of these small herbivores in considerable densities.

Table 25 shows the distribution of sambar during the year 2008 in Bhadra wildlife sanctuary. Since Muthodi range is area wise larger, the number of individuals of sambar is also more with 337 including adults sub-adults and calves. Hebbe range possessed 281 individuals which is the second highest. This is followed by Lakkavally with 76 and the least number 16 in Umblebyle. The number of females is more in all the ranges except in Umblebyle. Thus the sex-ratio is highest in Hebbe and lowest in Umblebyle. The ratio between adult female to sub-adults and calves was 3:1 which shows a satisfactory breeding rate when compared to spotted deer where this ratio was 6:1.

**Distribution of sambar in Bhadra sanctuary:** Sambar is also one of the important prey species found in the sanctuary. A total of 710, 721 and 729 sambars could be counted during 2008, 2009 and 2010 respectively (Tables 25-27). These figures indicate that the Bhadra
sanctuary is rich in terms of sambar population. The study shows that there are more sambars in Muthodi range than others in all the three years of study. Even the Umblebyle range where there are no elephants and gaur, sambars are present. The author was able to count 16 individuals in this area. Being a herbivore, sambar has little ecological requirement. Sambar primarily lives in woodland and feeds on a wide variety of vegetation, including grasses, foliage, browse, fruit, and water plants, depending on the local habitat (Geist, 1998). They also consume a great variety of shrubs and trees (Leslie, 2011). Therefore they are able to survive in the Umblebyle range where other animals are absent.

Like other animals the distribution of sambar in the sanctuary is also not uniform throughout. The number of sambar gradually declines in Muthodi, Hebbe and Lakkavally range respectively. The ecological conditions of these three areas in terms of living space, grass lands, water sources are varied. Although the food habit of sambar is varied, they prefer the dense cover of deciduous shrubs and grasses (Leslie, 2011). Moreover, the exact nature of their environment also enormously varies with the environment (Leslie, 2011) and that these three areas have vide range of difference in their habitats. Perhaps this is the reason for the difference in the distribution of sambar in different area of the sanctuary.
Population structure of sambar: Like elephant, gaur and spotted deer population the sex-ratio of sambar in Bhadra sanctuary is also in favor of females. This is a positive sign for the growth of the sambar population. Although males are less it can inseminate all fertile females and contribute to the growth of the population. The overall adult sub-adults ratios in all the ranges during the study period are 10:1. According to Karanth and Nichols (2000) the adult and sub-adults ratio in a healthy population of herbivores shall not exceed 5:1. Although the population size and density of sambar in Bhadra sanctuary is satisfactory, there is an imbalance in the adult and sub-adults ratio. Similarly the ratio of adults versus calves is also unsatisfactory which is almost 20:1.

This ratio is also showing a positive sign for the future growth of the population. The herd size of sambar in the sanctuary range from 7.6 in Umblebyle area during 2008 to 15.29 in Hebbe range during 2010 (Table 28-30). Bagchi et al (2008) have reported an average group size of 6 in sambar in a tropical forest of western India. The present observation of the author shows that the group size of sambar is Bhadra sanctuary is almost double this figure. Therefore the group size for sambar in Bhadra sanctuary is also satisfactory. Bagchi et al (2008) have also reported that group size varies in different season in Ranathambore wild life sanctuary. They are of the opinion that the group size reduces in
the winter and increases in the summer. The author is of the opinion that the group size can decrease at different times if there is predation, or group splitting, or natural death or death due to diseases etc. The author in the present study has noticed gradual increase in herd size without any group splitting during the course of study. According to Leslie, (2011), sambar are nocturnal or crepuscular, they live in small herds of up to sixteen individuals. Indeed, in some areas, the average herd consists of only three or four individuals, typically consisting of an adult female, her most recent young, and perhaps a subordinate, immature female. This is an unusual pattern for deer, which more commonly live in larger groups. They often congregate near water, and are good swimmers (Leslie, 2011).

In contrast to this observation, the author has noticed consistency in the herd size with gradual increase in the number of individuals during the study period.

**Population density of sambar:** In the present study the author has noticed sambar in all the four ranges. Its ecological density varies from 0.215 to 2.906 (Tables 28-30). According to Sankar and Acharya (2004), in India, although the Sambar occurs widely and in many habitat types, and large populations occur in well-secured protected areas, nowhere is it now regionally abundant. It has been recorded in 208 protected areas (National Wildlife Database, Wildlife Institute of India, cited in Sankar
and Acharya 2004); its distribution outside protected areas is now highly scattered. The reported ecological densities of sambar in India mostly fall within 1–10 animals per km$^2$ within the protected area network, and depending on the varying levels of protection efficacy [e.g. Madhya Pradesh, Pench National Park dry deciduous forest, 9.6 animals per km$^2$ (Karanth and Nichols 2000); Kanha moist deciduous forest, 1.5 animals per km$^2$ (Karanth and Nichols 2000); Nagarhole moist deciduous forest, 5.5 animals per km$^2$ (Karanth et al. 1999); Bandipur dry deciduous forest, 5.6 animals per km$^2$ (Karanth and Nichols 2000); Tadoba-Andhari dry deciduous forest, 3.3 animals per km$^2$ (Karanth and Kumar 2005); Melghat dry deciduous forest, 2.7 animals per km$^2$ (Karanth and Kumar 2005); Maharashtra Pench dry deciduous forest, 5.9 animals per km$^2$ (Karanth and Kumar 2005); Ranthambore semi-arid dry deciduous forest, 10.7 animals per km$^2$ (Kumar 2000); and Gir semi-arid dry deciduous forest, two animals per km$^2$ (Khan et al. 1996)]. The average density of about 1.5 animals per km$^2$ observed by the author thus appears to be satisfactory. Similar surveys at Kaziranga found too few sambar to estimate populations there (Karanth and Nichols 2000), this presumably representing habitat characters rather than defective protection, given the buoyant populations of other deer at that site (Hog Deer [Axis porcinus] and Barasingha [Rucervus duvaucelii]). Outside the protected areas, sambar is present mostly in very low numbers, although larger numbers
can still be found where its habitat is almost inaccessible to people (Flook 1964). Jathanna et al. (2003) have recorded a density of 0.89±0.23 in Bhadra sanctuary which is very low when compared to the present density. They have suggested that this low density reflects poaching and forest-resource extraction (Jathanna et al. 2003). The author is of the opinion that with the stringent conservation measures against poaching and forest resource harvest, the population density is steadily increasing.

The ecological density of sambar also is different in different areas. The density is high in Hebbe range and very low in Umblebyle. During 2008 the density in Hebbe range is 2.855 (Table 28) while it is just 0.215 in Umblebyle. Even the Muthodi range which has highest number of sambar, the density is only 1.719 during this year. A similar picture is seen in the density during 2009 and 2010 (Tables 29 and 30). According to Schaller (1967) no large Indian ungulate has adapted itself to a wider variety of forest types and environmental conditions than has sambar. Within India, sambar occurs in the thorn and arid forests of Gujarat and Rajasthan, in the moist and dry deciduous forests throughout peninsular India, in the pine and oak forests at the Himalayan foothills, and in the evergreen and semi-evergreen forests of northeastern India and the western ghats (Sankar and Acharya 2004). The ecological conditions of different areas of Bhadra are variable and therefore accommodate different density of sambar in these regions.
Population dynamics of sambar: Although 710 sambars are noticed in Bhadra sanctuary during 2008 all of them are not able to breed. The effective population size of sambar during this year is only 605.368 (Table 28). Similarly for the years 2009 and 2010, the effective breeding size is 614.576 and 622.310 (Tables 29 and 30). Two things are clear from these observations, although the total population size of sambar is adequate, the total number of breeding individuals which contribute to future generations is quite less. Bennet and Dahaban (1995) and Bennett and Gumal (2001) are of the opinion that habitat encroachment and hunting are both widespread in the Sundaic region and in much of the rest of sambar’s range. These two threats are often associated and all Borneo’s ungulates suffer from the increased hunting that often accompanies logging (Bennett and Dahaban 1995; Bennett and Gumal 2001), such that hunting to local extinction is the chief detrimental effect of logging on ungulates in Sarawak (Bennett and Gumal 2001). Bhadra sanctuary does not have the problem of habitat encroachment and hunting. Obviously there are other reasons for the low value of effective breeding population. 

Competition from other sympatric ungulates could be another factor which can reduce the effective population size (Steinmetz et al. 2007). Gaur, spotted deer, muntjac and a few others are the ungulates
which inhabit Bhadra sanctuary. The sambar population has to compete with these animals for fodder and shelter apart from sustaining the predation pressure. Gaur, being large is less predated upon while the spotted deer and muntjac are smaller but agile and escape from predation because of their agility. In that way sambar are more vulnerable for predation. Perhaps this could be the reason for low value of effective breeding size. One positive note is that the gradual increase in the effective population size in all the localities during 2008 to 2010.

The distribution, population structure, density and dynamics of Predator species of Bhadra wildlife sanctuary

Since sighting predator species in the wild is difficult collection of information on the sex and age classes of these species could not be done. Therefore the author could not make an in depth analysis on the population structure of the predator species. However, the census data shows that there is a steady increase in the population size of all the predator species in the sanctuary, right from 1997 (Table 4). For example the number of tigers has increased from 33 during 1997 to 58 during 2008 and during the study period there is an increase of 5 individuals thus amounting to 63. Similarly the number of leopards also has increased both in the study period and before. It has increased from 21 in 1997 to 60 during 2010. Among the two major predators, the rate of increase of
leopards is higher than that of tigers. The percentage increase of tigers from 1997 to 2010 is 90.9 while that of leopards is 185.71. The number of wild dogs has increased from 28 to 71.

Wildlife Protection Society of India has published the tiger census report of 2011. This census was carried out during February 2011. The report says that there is an increase of 290 tigers in the country. There was also a debate about the validity of these reports. When 1997 census and the present data of the author are compared, there is an increase of 26 tigers in Bhadra sanctuary over a period of 13 years. This increase is quite justifiable in Bhadra sanctuary because of stringent conservation measures. The same is true for other predator species also. Thus the increase of predator species in Bhadra sanctuary is quite satisfactory.

**Predator-prey relationship among the wildlife of Bhadra sanctuary**

Ecological densities of large herbivores in a given habitat are determined primarily by their body mass and dietary patterns (Bailey 1993, Eisenberg 1980, Hudson 1984). According to Srikosamatara (1993) the most important factor that determines the population density is the relative abundance of forage, water and other edaphic factors in addition to the degree of competition from domestic live stock and the prevalence or absence of hunting (Srikosamatara 1993). Bhadra sanctuary through its relatively stable climatic and edaphic factors harbors a good number of wild animals with adequate density (Table 4).
The survival of predators in any ecosystem depends on the number of prey species and their biomass. A balance is required for their sustainance (Kruuk, 1972, 86). Comparison of the different census results (Table 4) show that there is steady increase of both predator as well as prey species in the sanctuary indicating that there is balance in the density of these species over years. The whole sanctuary enjoys good management practices (Karanth, 1993) and it is ecologically well protected. Perhaps this is the reason for the steady increase in the density of both predator and prey animals.

The average prey-density of principal prey species during the study period in Bhadra has been computed in the tables 31a, 32a and 33a. During 2008, muntjac with an ecological density of 2.538 animals/km$^2$ is the most abundant prey in the area followed by spotted deer (2.498/ km$^2$) (Table 31a). Same observation is true for the years 2009 and 2010 (Tables 32a and 33a). Though elephants are also found in good numbers they have not been included in the present study because normally they are not predated upon due to their large size. Gaurs are represented with low density, but being large and easily be predated upon, form ample food for predators. When the food requirement of the predator species in the sanctuary is considered, the available prey biomass appears to be insufficient (Table 31a, 32a, 33a, 31b, 32b and 33b). For example the available prey biomass in the year 2010 is 641485.00 kg while the requirement of the predators is 365511.0kg. Thus the amount of biomass
available in the sanctuary appears to be enough just for two years. Even if it is assumed that there would be additions due to births in all the species, this quantity is inadequate for all the predators, and in the long run, there is the danger of these species becoming extinct in the sanctuary. It also appears that there is an imbalance in the predator prey relationship in the Bhadra sanctuary. This observation confirms the statement of Raju and Hegde (1995) that the Bhadra wildlife sanctuary is a fragile ecosystem.

However, just by considering the number of herbivore animals in the sanctuary, one need not be frustrated. There are number of other species in the sanctuary which supplement the prey demand. For example many chervotin species like rats, mice, bandicoots, hares, rabbits, mongoose and other mammals in addition to number of bird and reptiles. Moreover, there are number of villages with in and surrounding the sanctuary. The cattle and other domestic animals maintained by these villagers could also serve as source of food for the carnivores. According to Raju (2001) the domestic live stock plays a supportive role in the predator-prey relationship. Thus the biomass of these domesticated animals available for consumption by the predators is 1025810 kgs (Table 34) which is much more than the herbivorous wild animals. Considering all these facts it can be concluded that the predator-prey relationship in the Bhadra sanctuary is a balanced one which also confirms the opinion of Raju (2001).