I. INTRODUCTION

The Asian elephant (*Elephas maximus* Linnaeus) is globally categorized as Endangered (A1 cd) (IUCN 1996) and is placed under Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). In India it is listed under Schedule 1 of the Indian Wildlife (Protection) Act, 1972. Historically, the range of the Asian elephant extended from the Euphrates and Tigris rivers in West Asia to the Yangtze-Kiang river and perhaps beyond in China (Olivier 1978). The Asian elephant is an important flagship species for the conservation of biodiversity as well as a cultural symbol of the people of this region. Elephants once had a broad distribution in the Indian subcontinent and both continental and insular Southeast Asia, but has been reduced markedly.

Today the Asian elephant is believed to number about 45,000 in the wild and is distributed across several populations over South and Southeast Asia (Sukumar 2003). The population of elephants has been affected adversely by a growing human population and the resultant destruction of natural habitats for settlement and cultivation. Besides habitat loss, the large-scale capture of elephants in the past has also caused its decline. Thus, the Asian elephant has suffered due to enormous loss of its habitat and continued captured for taming over a 4000-year period in human history. In India its range today covers only 3% of the geographical area of the country (Sukumar 2003) as opposed to virtually the entire landscape in the historical past. Apart from these threats, ivory poaching has also become a major threat for their

Although ivory poaching is widespread in Asian countries where substantial proportions of male elephants are tuskers, one region that has been particularly affected in recent times is southern India (Sukumar 1989). This region also has the largest regional concentrations of elephants in Asia (Sukumar and Santiapillai 1996). Given the very high proportion of tusked male elephants here, the southern Indian region was also home to perhaps the largest numbers of tuskers until recent times when this situation changed (Ramakrishnan *et al.* 1998). Rampant poaching for ivory since about the 1970s has resulted in many populations in southern India suffering from extremely skewed sex ratios among adults (Ramakrishnan *et al.* 1998) that could have deleterious demographic consequences.

Further, the loss of elephant habitat through spread of agriculture, commercial activities such as plantations of tea and coffee, and developmental activities such as hydroelectric and irrigation projects, roads, railway lines and mining, have resulted in an escalation of elephant–human conflict as elephants make forays into agricultural lands to feed on cultivated crops (Sukumar 1989). Manslaughter by elephants and injuries to or killing of elephants by irate farmers accompany these conflicts. It is estimated that an average of 50
people are killed in southern India alone by elephants every year, a significant proportion of these occurring within settlements and cultivation (Venkataraman et al. 2002). In the country the figures are much higher, averaging about 200 cases of manslaughter annually (Bist 2002). These conflicts create adverse sentiments against the setting up of Protected Areas and other conservation strategies for wildlife especially large charismatic species such as elephants and tigers.

The largest and most viable populations of the Asian elephant in the wild today are in India (Santiapillai and Jackson 1990). Here, the elephant’s range includes the northeastern states of Arunachal Pradesh, Assam, Meghalaya (a few elephants are also found in Tripura, Mizoram and Nagaland) and West Bengal, the northern states of Uttaranchal and Uttar Pradesh, the east–central states of Orissa and Jharkhand (carved out of Bihar) and the four southern states of Tamilnadu, Karnataka, Kerala and Andhra Pradesh (Sukumar 1989). Based on a recent update by Sukumar (2003) the population of elephants in India is between 26,390 and 30,770, distributed in the country’s five regions viz. South (13,000-15,000), Central (2,400-2,700), Northwest (750-1,000) and Northeast 10,200-12,000) and Andaman Islands (40-70). The southern Indian elephant populations, among the largest in Asia, are spread over a large area along the Western Ghats, one of the “global hot spots of biodiversity”, and a part of Eastern Ghats. Even within India, elephants became extinct in recent centuries in the states of Punjab, Rajasthan, Gujarat, Madhya Pradesh, Maharashtra and Andhra Pradesh (Sukumar 1989). The population in islands of Andaman and Nicobar is not a natural one and
has been founded by captive elephants released in the wild in the 1960s (Bist 2002). The past and present distribution of the elephants in India is an indicator of the drastic deterioration of the elephant's habitat, large scale captures historically and ivory poaching, all of which have led to the progressive decline and reduction of the elephant population in the country. Conservation action requires a strategic framework based on an objective assessment of the variations in elephant habitats and population attributes of elephants, and threats to their well being. Project Elephant instituted and funded by the Government of India since 1992, aims to conserve elephant populations, their habitats and overall biodiversity in eleven designated elephant reserves across the country (Anon 1993, Sukumar and Santiapillai 1996, Bist 2002). For the successful implementation of these conservation projects, it is essential to assess the current demographic status of elephants.

Further, information on the population of a species in the wild is an important attribute for judging its future for conservation and management. Theory and empirical studies suggest that demography is usually of immediate importance in determining the minimum viable size of a wild population. This is especially true for a species like the elephant, which is larger in size and contributes to a high proportion of biomass and also often coming into conflict with people.

Populations of many animal species worldwide are threatened with loss of genetic variation due to substantial reductions in population size. The genetically effective population size may also decrease due to another
demographic factor - a skewing of the ratio of reproducing males to females, the more unequal the sex ratio the lower the effective population size (Ramakrishnan et al. 1998). While the sex ratios of polygynous mammals are naturally female-biased in most instances, the selective hunting of males would further exacerbate this situation.

According to Lande (1998) the demographic consequences of population subdivisions on genetic variations has been the subject of increasing interest among conservationists. ‘O’ Ryan et al. (1998) has stated that knowledge of the extent of genetic differentiation among a set of populations is useful, but understanding of demographic context in which it developed is often more important. Goodman et al. (2001) have highlighted the need to consider demographic history in studies of genetic differentiation. According to Woodruff (1990) extinction is fundamentally a demographic process, and for many very small and endangered natural populations, demography is more important than genetics. Further, population viability analysis requires the consideration of both genetics and demography.

So, for conserving the species it is important to know not only the current trends in the population numbers – whether the population is increasing, stable or declining – but also other demography parameters, such as age structure, sex ratio, fertility, mortality and physiological condition, which would ultimately influence the size and viability of a population (Sukumar 1989).
Age structure is an important parameter in the analysis of population dynamics for several reasons. Knowledge of the age structure of a population is useful for understanding dynamics of population growth and estimating life history parameters (Stearns 1992) and in the management of endangered species (Fiedler and Kareiva 1998). The age structure of a population, expressed as the distribution of the number of individuals in each age group reflects not only the net fecundity and mortality schedules of a population (Lindeque 1991) but can also be used as an indicator of population increase. Further, it has value as a basis for comparison between populations in differing environments (Croze 1972). As such, age structure is an important way of measuring demographical changes over time, and also for comparing different populations of a species (Caughley 1977). Knowledge of the age structure of elephant population is essential for investigating trends in recruitment, mortality, reproductive status of the population and the possible influence of direct exploitation. Age structure information also provides some of the data needed for population viability analysis and subsequent management implications (Sukumar 1995).

For example, in Tsavo National Park, Kenya, where elephant age structure has been well studied (e.g. Laws 1969, Leuthold 1976, Ottichilo 1986, Poole 1989) it was applied together with additional criteria to study the impacts of drought and poaching pressure, and also to formulate proper management strategies. Calving interval, age of first parturition, rate of increase, poaching, rainfall and intra-specific competition are the factors that have previously been noted to be among the most important factors
influencing age distribution and numbers in savanna populations of the African elephant (Croze 1972, Corfield 1973, Bhima and Bothma 1997, Ottichilo 1986, Poole 1989). Reduction in the age at first conception and the mean calving interval (Caughley 1977, Laws 1981) and mass mortality due to drought or disease (Laws and Parker 1968; Corfield 1973, Moss 1988) are also likely to affect age categories. Indiscriminate poaching, diseases such as anthrax and drought are the mortality factors that affect selected sex and age groups more strongly than others (Lindeque 1989). Intense poaching was reported to have made a major impact upon elephant populations (Poole 1989, Barnes and Kapela 1991). This will result in not only the number of elephants being reduced, but also changes in age structure, grouping patterns, gene frequencies, and perhaps even health status (Watte and Sukumar 1997).

According to Barnes and Kapela (1991) ivory poaching has a more insidious effect upon elephant populations than had been previously realized: it has a fundamental impact upon every aspect of elephant population biology.

Natality and mortality rates are important constituents in describing demography of a population. Dodds and Patton (1968) in describing the reproductive state of the large mammal populations in the Luangwa Valley, Zambia, stated, “Natality is one of the best productive indicators for wild animal populations”. Many workers have considered the annual birth rate to be one of the most important factors to estimate an index of the demographical status of an elephant population (Buechner et al. 1963, Buss and Savidge 1966, Laws 1966, Dodds and Patton 1968, Field 1971). Recruitment is dependent on the rate at which females are in reproductive condition. The
fertility of an individual female usually varies with age, and each age class has its age-specific fertility. With small samples, only a mean birthrate can be calculated, usually expressed as a mean calving interval. The number of reproductive females depends on the age at which females attain puberty, and the age of menopause at which they stop reproducing. The mean calving interval and mean age of female puberty may be directly density dependent (Laws 1969, 1970). It has been suggested that proximate factors affecting fertility are nutritional deficiencies and heat stress (Laws and Parker 1968, Laws 1970). It has also been suggested that social factors might also play a part in depressing fertility (Laws and Parker 1968, Laws 1969, 1970).

Mortality rates in most animals vary with age (Odum 1959). Laws (1966, 1969ab) has shown that the mortality of most elephant populations can be divided into three phases, early calf mortality, constant adult mortality, and old age mortality, and that in areas of heavy hunting pressure the males with their heavier ivory decline more rapidly. The population dynamics models have emphasized that although variations in the reproductive performances of the different elephant populations must play their part in regulating population growth, a variation in mortality, especially neo-natal mortality, is of far greater importance as a population controlling mechanism (Hanks and McIntosh 1973). Another form of mortality that has had great historical consequences for elephant populations is human predation for meat or ivory. Very little is known about the relative importance of different kinds of mortality on elephant populations. Apart from reports of shooting elephants either for sport, ivory, meat, or for crop protection, few quantitative reports exist of the cause
of death in the wild. Diseases in elephants have been referred to by Laws and Parker (1968) who relate mandibular abscesses to stress and habitat conditions. Arteriosclerosis has been described by McCullagh (1967), and Sikes (1968, 1971) relates it to habitat conditions. Anthrax has been reported in African elephants (Douglas-Hamilton 1972, Lindeque 1989) and the notes on the diseases of Indian elephants (Gilchrist 1851, Evans, 1910, Steele 1985, Watve 1992, Vidya and Sukumar 2002) suggest that Asian elephants are vulnerable to a wide range of diseases.

In some populations of the Asian elephant, population sizes have been fairly well documented for a period of about 2500 years (Digby 1971, Trautmann 1982). Within this period, human impact on elephant populations, i.e. capturing or hunting, was characterized by considerable temporal and local variations (Sukumar 1989, Kurt 1992). This has led to various mortality schedules, which often also differed between sexes and, in some periods, were biased towards tusk bearing males (Kurt et al. 1995). The increasingly female-biased adult and sub-adult sex ratios, particularly in southern India, could affect elephant populations seriously, by lowering the effective population size, lowering birth rates and decreasing genetic viability due to inbreeding (Ramakrishnan et. al. 1998). It is thus imperative that sex ratios are monitored on a regular basis in addition to age structure and population sizes.

Age-specific survivorship is basic to many population models used by ecologists (Leslie 1945, Beverton and Holt 1957, Gadgil and Bossert 1970, Schaffer 1974, Stearns 1976, Gulland 1977). Life-table parameters for
mammal populations are difficult to estimate from field data. In particular, age-specific survivorship can be determined directly only by observing the fate of ≥ 1 cohort of animals. Since this is rarely possible for wild populations, wildlife biologists have generally relied on indirect methods. Two of the methods that are used most frequently estimate age-specific survivorship from either (A) the standing age distribution \( s_x \), the ratio of the number of age \( x \) individuals in the live population to the number of newborn young), or (B) the standing distribution of ages at death i.e., animals that die during a specified time interval to the total number of deaths) (Caughley 1977). One can estimate survivorship indirectly by sampling the age distribution of live animals; i.e., the standing age distribution. An indirect estimate can also be obtained from the age distribution of natural deaths as implied by a field collection of carcass remnants, usually skulls (Sickle et al. 1987). In species with overlapping generations, it is rarely possible to monitor the fates of true cohorts over their entire life-spans (e.g., Lowe 1969, Connell 1970, Sherman and Morton 1984) and so instead many studies have estimated survivorship from samples of the population age structure (Seber 1973, Ricker 1975, Caughley 1977). These indirect methods of calculating "static" life tables assume that the population rate of increase \( r \) has remained constant for several generations, producing a stable age distribution.

Population growth models are central to modern ecological theory. One of these fundamental theoretical models is the logistic growth model (see e.g. Pielou 1977). While population dynamics of the African elephant *Loxodonta africana* have been modeled using both deterministic and
stochastic approaches (Fowler and Smith 1973, Hanks and McIntosh 1973, Wu and Botkin 1980), in Asian elephant the deterministic model of Sukumar (1989) is the only deterministic simulation available so far. This simulation covers only a period of 50 years, but already shows the extreme influence of different mortality schedules on population size. Population dynamics can also be simulated by stochastic models under differing regimes of relevant parameters, such as mean mortality, mean calving interval or mean age at first reproduction. Simulations may then be validated by comparing them with available data about historical population dynamics (Tiedmann and Kurt 1995). In another stochastic model, Sukumar (1995) investigates only survival possibilities of elephant populations according to the initial population size under a regime of stochastic alterations in mortality and birth rate. But a detailed modeling of elephant population of southern India based on recent field data is not available, as earlier reports on elephants from southern India (except Sukumar 1989) were essentially descriptions of number, herd composition and age structure (Nair et al. 1985, Nair and Balasubramanyan 1985, Easa and Balakrishnan 1995), feeding ecology (Sivaganesan 1991), Parasitology (Watve 1992, Vidya 2000) and habitat utilization (Baskaran 1998). Furthermore, after Sukumar (1989), studies on elephant populations of southern India (Daniel et al. 1987) have generally failed to look at the important aspects of elephant population (i.e. age-sex structure of the population) nor has there been any attempt to compare the past and present population and their age/sex structure.
The present study was undertaken to try and fill some of these lacuna. From the management perspective also, knowing where the population is headed and consequently what management implication this has is more important than determining the absolute densities.

One of the major habitats of elephants in southern India is the Nagarahole National Park in the Kodagu District of Karnataka. Studies carried out by Karanth and Sunquist (1992) indicate that Nagarahole supports one of the highest population densities and biomass of large herbivorous mammals anywhere in tropical Asia (with the possible exception of the Kaziranga ecosystem in northeast India). Nagarahole is still only partly affected by poaching for ivory and the ratio of adult male to female elephants is much less female-biased as compared to other areas in the south. Nagarahole (and adjoining habitats) seems to be the only major elephant region in southern India that has a relatively natural population structure indicative of only marginal poaching so far. This has also meant that the large numbers of tusked males here, both adults as well as sub-adults, are an attractant for ivory poachers in the coming years. There are already enough indications that this is beginning to happen with several tuskers having been poached in recent years (Venkataraman et al. 2002).

Another important elephant habitat of southern India is the Mudumalai Wildlife Sanctuary in the Nilgiri District of Tamilnadu State. The feeding ecology (Sivaganesan 1991), parasitology (Wathe 1992, Vidya and Sukumar, 2002) and habitat utilization (Baskaran 1998) of elephants of Mudumalai were
studied extensively. But the population dynamics and demography of elephants in this area have not been given due attention; even though long term records are available but results are unpublished (R. Sukumar, unpublished data) and there has been a short term study on population demography by Baskaran and Desai (2000). The elephant population here is highly threatened by habitat fragmentation and ivory poaching.

Ramachandran et al. (1985) have studied the distribution, ecological requirements and resource availability to elephants of Periyar Wildlife Sanctuary in Idukki District of Kerala for a period of five years from 1977 to 1982. They have stated that compared to populations in other habitats the proportion of adult male elephants appears to be very low there (Eisenberg and Lockhart 1972, Laws et al. 1975, Nair et al. 1977, Ramachandran et al. 1985, Chandran 1990). This could be due to large scale poaching of tuskers for ivory. While ivory poaching has been a problem in most southern Indian populations several reports have suggested that Periyar Tiger Reserve in Kerala is one of the worst affected (Ramakrishnan et al. 1998). The demographic and genetic consequences of a skewed sex ratio resulting from ivory poaching may thus be even more serious in Periyar. Earlier field observations indicated that, apart from a much lower average fecundity in the population, a certain proportion of females aged >15 years may be reproductively barren (Sukumar et al. 1998). They have found that certain family groups consisting of only sub adult and adult females show no signs of mammary glands activity and have retracted nipples and opined that it is possible that the reproductive physiology of such females has been disrupted, similar to that of many females kept in zoos (Sukumar et al. 1998).
Based on the above considerations the population dynamics and demography of Asian elephants were studied at three different places in southern India, viz., Mudumalai Wildlife Sanctuary (Tamil Nadu State), Nagarahole National Park (Karnataka State) and Periyar Tiger Reserve (Kerala State). The study was conducted during 2001 – 2003.

**Objectives**

The objectives of the present study were

1. To estimate and compare the fertility, mortality and age structure of elephant populations of Mudumalai, Nagarahole and Periyar regions.

2. To compare the impacts of different levels of ivory poaching on the sex ratios in these three elephant populations.

3. To predict the future trends in population, starting with the current age structure, fertility schedule, mortality and growth rates, by developing population growth models.

4. To suggest management recommendations for the conservation of Asian elephants.