1. INTRODUCTION

Since the recognition of raptors that they are "indicators" of environmental quality, biologists have made attempts not only to monitor raptor populations but also carried out many reproductive studies with a view to maintain a stable population (Bond 1940, Meng 1951, Watson 1957, Cade 1960, Mathisen 1968, Gerrard et al., 1975, Bednarz and Dinsmore 1981, and Andrew and Mosher 1982). Though such progressive research work is carried out, suburbanization, industrialization, the use of pesticides and persecution have in many cases caused the elimination or reduction of local population in every part of the world. Populations of many species of raptorial birds have been observed to be decreased in Europe and North America in the last 35 years (Kochert 1972). Peregrine falcon (*Falco peregrinus*) in England has been reported to be decreased drastically in numbers since the early 1950s (Ratcliffe 1963 and 1970). Similarly, golden eagles have been reported in Scotland (Lockie and Ratcliffe 1964 and Ratcliffe 1970). Reproductive declines in white-tailed eagles (*Halieatus albicilla*) have been reported in Europe (Henriksson et al., 1966 and Borg et al., 1969). Declines in other raptorial species of northern Europe have also been outlined by Cramp (1963), Presst (1965), and Ratcliffe (1970). The peregrine falcon in North America has experienced catastrophic population declines and reproductive failures and within the last 40 years it has become extinct in the eastern United States (Hickey 1969). Decreases in reproductive success of bald eagles (*Haliaeetus leucocephalus*) and ospreys (*Pandion haliaetus*) have been greatly accelerated since the mid-1940s along with the golden eagle which has
disappeared from much of its former range, east of the Mississippi River of United States (Cottom et al., 1961; Ames 1966; Sprunt and Ligas 1966). Moreover, the declines of prairie falcons (*Falco mexicanus*), cooper's hawk (*Accipiter cooperii*), and sharp shinned hawk (*Accipiter striatus*) have been pointed out in the United States and Canada (Fyfe et al., 1969 and Spofford 1969).

In India, as in other third world countries, raptors have been sadly neglected. Over the last few years, a significant downward trend has been noticed in some raptor species along with the disappearance of their natural habitats. A decline has also been observed on some relatively common species, which may not augur well for the future. Naoroji (1986) has reported that the red-headed falcon (*Falco chicquera chicquera*) appears to be disappearing from some of its former haunts because of its open countryside habitat changes. The once abundant white-eyed buzzard (*Butastur teesa*) has become rare throughout Saurashtra due to the unavailability of viable nest-sites, probable reduction of prey species, disturbance during nesting and hunting. King vultures (*Sarcogyps calvus*) are today scarce in Saurashtra except in the Gir where adequate habitat exists for them. True forest eagles which are narrowly specialized to their environment are the most vulnerable to habitat changes and are decreasing in numbers from areas where forest cover has been affected. Many of our common raptor species have low reproductive rates and live at low density (Naoroji 1988). Such population declines reveal a serious situation and indicate a need for assessment of norms as well as factors responsible for their declines.
Hence, understanding the ecology and biology by holistically studying the natural history of the diverse raptor populations would provide not only a valuable addition to our scientific knowledge and help us to take effective measures to protect this magnificent and finely tuned group of birds in the wild, but also throw light onto intricate ecological problems, which in the long run will eventually prove beneficial to man. A perusal of literature reveals that many extensive investigations have been carried out on the population status, nesting habits and parental behaviour of the birds of prey in the West. Such studies on Indian raptors are limited and the available literatures (Inglis 1910; Smith 1915; Lamba 1969; Ali 1969; Grubb 1972, 1978 a, b, and c; Gole, 1973, 1978; Osman 1973, 1974, 1975, 1978, 1983; Koning 1976; Desai and Malhothra 1977, 1979; Govindakrishnan et al., 1978; Ali and Ripley 1983; Naoroji and Monga 1983; Bannerji 1984; Naoroji 1986; Dharmakumarsinghji 1985; Choudhary 1986; Khacher 1986; Ingalhalikar et al., 1987 and Secher 1987 ) indicate the need for a detailed study in the above said aspects. Therefore, the present study on the breeding ecology of Brahminy kite (Haliastur indus) a resident raptor of Cauvery Delta, South India, has been carried out with the aim of filling up the lacunae to some extent in the breeding biology of the kite. The Brahminy kite H. indus is a commonly seen hawk of the Old world reaching up to Australia (Brown 1976; Hollands 1984; Bell 1985; and Schodde and Tidemann 1986). It is grouped under the order; Falconiformes, Family; Accipitridae, and Sub family; Milvinae (Brown 1976 and Ali and Ripley 1983). In the field it can be identified by its handsome rusty red or deep chestnut coloured body with white head, neck, upper back, and breast and brown abdomen (Fig.1). The
Fig.1. An adult Brahminy kite (*Haliastur indus*) perching on a tree.

Fig.2. A sub-adult Brahminy kite (*Haliastur indus*) perching on a tree.
sub-adults are greyish brown (Fig.2) with light coloured patches under the wings. Major habitats of the Brahminy kites *H. indus* include the agricultural wet lands, freshwater ponds, rivers and canals, social forests, coconut plantations, and human habitations in the order of preference (Jayabalan 1985). Freshwater crabs (*Paratelphusa* sp.), fishes, snails, snakes and insects are the major food items of the Brahminy kites although frogs, tadpoles, toads, chicken, rats and earthworms are also consumed by them. Paddy field crab feeding might be of great economic importance as Tonapi (1980), Ayyar (1984), and David and Kumaraswamy (1988) have considered these crabs as serious pests to nurseries and standing paddy crops. Amudha (1995) has reported the occurrence of rat remains in the regurgitated pellets of communal roosting Brahminy kites at Cauvery delta in larger quantities, which show the predatory pressure of the Brahminy kites on rodents, the agricultural pests. In South India *H. indus* is a highly venerated bird, and sighting the bird is considered as auspicious since it is believed to be the Vehicle of Lord Vishnu, according to Hindu Mythology.

An important aspect of the breeding ecology of birds of prey pertains to factors that influence their population dynamics. Population status of a raptor species directly depends on the size of its clutch and brood, which determine the productivity of that species in an unit of time (Brown 1976). Lack (1968) has contented that clutch and brood sizes may be limited by food. The results from the experimental studies of Beissinger (1990) on snail kites (*Rostrhamus sociabilis*) also support Lack's contention. Variations in avian clutch size are now generally considered to be of adaptive significance (Hogstedt 1980; Drent and Daan 1980). Natural as well as experimental
variations in food supply to individual pairs are known to elicit adaptive responses in the number of eggs produced (Daan et al., 1988). Such an adjustment requires a sensitive clutch size regulatory mechanism. The nature of this mechanism remains conspicuously unknown. A classic approach to this problem has been made earlier by experimental clutch manipulations to distinguish "determinate" and "indeterminate" species (Cole 1917). Determinate layers are those birds which lay a fixed number of eggs without adjusting this to experimental removal of eggs from the nest or addition of eggs to it. Indeterminate layers do adjust their clutches to such interferences. In many species of raptors clutch size declines predictably with the progress of breeding season (Klomp 1970). This predictability can be exploited to distinguish between large and small clutch layers and to analyse when these birds switch from being indeterminate to determinate, in other words when they "decide" on the remaining number of eggs to be laid. Clutch and brood sizes of tropical birds have been manipulated by Ward (1965), Morton (1971), Mader (1982), and Tarburton (1987) to study the regulatory mechanisms. Clutch or brood size represents the expected benefit of reproduction and it also reflects to the costs of reproductive effort (Drent and Daan 1980; Beissinger 1987a). Clutch or brood size may also be considered a life-history trait co-adapted (Stearns 1976) with male and female patterns of parental care (Walters 1982; Beissinger 1986). Experimental clutch and brood manipulation studies on Indian raptors, particularly the Brahminy Kite, have not yet been fully attempted by earlier investigators and so, an attempt has been made in
the present study to determine the factors influencing the clutch size fixation of this species.

Besides the variations of clutch size among raptor species, the productivity of a breeding raptor is mostly affected by the habitat quality. Although the detrimental effects of chlorinated hydrocarbons on birds of prey are serious and pervasive (Anderson et al., 1969 and Ratcliffe 1970), habitat encroachment by man has probably the greatest negative effect on raptor populations worldwide (Olendorff and Kochert 1977). The need for designation of special areas where raptors can breed relatively free of disturbance has been reflected in resolutions passed at the 1975 World Conference on Birds of Prey in Vienna, Austria (Chancellor 1977). The conferees have urged "National conservation bodies and Governments to set aside sufficient representative nature reserves where birds of prey live in large variety and abundance and to conserve these birds while they are still plentiful". Wildlife managers have recently noted decreases in some raptor populations following timber harvest and hence a need to minimize the effects of timber harvest by knowing the specific habitat needs of the affected species (Reynolds et al., 1982). Hence, it is necessary to identify the structural characteristics of the habitat that elicit selection of a site by a species, and to identify the vegetative characteristics that produce the physical environment required for successful nesting (Hilden 1965). Buffer zones to protect nesting raptors have been prescribed in the U.S. Forest Services Land-Use Plans since 1963 (Mathisen 1968). Bald eagle buffer zones are recommended by Coffey (1977) and Steenhof (1977). Helander (1977) gives recommendations for the White-tailed sea eagle which is closely related to the above mentioned species.
Buffer zone recommendations are also available for other species of raptors; Osprey (Roberts 1970; Kahl and Garber 1971; Kahl 1972; Zarn 1974); California condor (Sibley 1969; Wilbur 1978); Peregrine falcon (Haugh and Halperin 1976; Ellis 1978); Accipiters (Tankersley 1976; Luckett 1977; Jones 1979); and Spotted owl (Gould 1974; Zarn 1974). To recommend a buffer zone for a raptor, it is essential to analyse the nest site requirements of the species concerned. Eventhough buffer zone recommendations have been made for a large number of western raptors, analysis of nest site requirements of the Brahminy Kite *H. indus* remains incomplete, and hence their nesting ecology has been studied presently.

Generally, the selection of nest site by raptors may involve local factors such as the thermal environment of the nest to broader factors including the proximity to foraging areas (James 1985). The importance of food abundance for raptor population dynamics is also well documented (Cave 1968, Hagen 1969, Southern 1970, and Newton 1979). Other than the prey density, accessibility, and distance which may determine the energy needed for prey transport have to be considered along with other minor factors for nest site (Central Place) selection. Such a view is reflected in the Central Place Foraging Model based on Optimal Foraging behaviour (Orians and Pearson 1979). In the treatment of "Central Place Foraging" (CPF) Orians and Pearson (1979) have also considered two types of foragers, such as animals which return with only a single food item ("single prey loaders") and others which take more than one food item per trip ("multiple-prey loaders"). However, increases in foraging and travel costs due to load size have usually been assumed to be negligible (De Benedicts *et al.*, 1978).
However, this prey transporting cost in terms of energy should be less when compared to the reward in the form of prey biomass transported. This effect should be especially important for animals whose locomotion is energetically expensive such as raptors. In the present study it has been assessed how the increased travel and foraging costs influence both the type and amount of food brought back from feeding areas at different distances from a Central Place (Nest). Consequently, the proximity to foraging sites depends upon the nest substrate availability. Generally, raptors utilize a variety of substrates for nesting; the Ferruginous hawk nests in trees, small cliffs and on the ground (Smith and Murphy 1973). However, trees are apparently preferred by this species (Woffinden and Murphy 1983). Others, such as Prairie Falcon (*Falco mexicanus*) and Swainson’s hawk, nest almost exclusively on a single substrate, like cliffs and trees respectively (Bent 1937). Preferences are sometimes expressed at an even finer level. For example, Red-tailed hawks prefer elms over other tree species in Wisconsin (Orians and Kuhlman 1956), and Broad-winged hawks (*Buteo platypterus*) select Yellow birch in New England (Matray 1974). In Utah, Ferruginous hawks seek out the taller trees in an area for nesting (Woffinden and Murphy 1983). The association of a particular vegetation type or structure with the location of the raptor nests has been routinely observed by many authors (Tubbs 1967, Platt 1976, Schipper 1977, 1978, Bednarz and Dinsmore 1981, Titus and Mosher 1981, Reynolds et al., 1982, Gilmer and Stewart 1983, and Morris and Lemon 1983). Cauvery delta offers an opportunity to examine the Brahminy kite nest site preferences, for which only anecdotal information (Jayabalan 1985) is available about their use of taller trees in this agricultural wetland landscape. As basic information is lacking about patterns of nesting or descriptions of nest sites used by
Brahminy kites *H. indus*, wildlife biologists have been unable to design proper management strategies to conserve the nesting habitats of this species. So, the present investigation encloses the analysis of Brahminy kite *H. indus* nest site characteristics along with topographic features, which influence the nest site selection of this species.

Apart from the nest site itself, the habitat in the immediate vicinity of the nest may be important for a variety of reasons (Morris and Lemon 1983). Generally raptors prefer a nest site secluded from human activities. Human activities can affect both raptor behaviour and breeding success during the nesting cycle (Fyfe and Olendorff 1976). Raptors are more sensitive to disturbances during courtship and egg-laying and less responsive towards the end of the incubation period or when they have young one(s) (Newton 1979). Human activities that may affect raptors include agriculture (Schmutz 1984); livestock grazing (Kochert *et al.*, 1988); construction works (Bednarz 1984); and traffic (Holthuijzen 1989). Human activities may flush incubating adults from nests resulting in loss of eggs or nestlings (Platt 1977, Harmata *et al.*, 1978) and nest abandonment (Grier and Fyfe 1987). Recreation activities have affected red-tailed hawks (Wiley 1973), accipiters (Hall 1984), European kestrels (Van der zande and Verstraël 1985), prairie falcons (Boyce 1977), gyrfalcons (Platt 1977), bald eagles (Steenhoff 1978), ospreys (Levenson and Koplin 1984) as well as many raptor communities (Craighead and Mindell 1981). Although information on seclusion rate of nesting Brahminy kite from disturbance activities is available for the Australian race (Foanca 1980), information is scarce for the population in the Cauvery delta. Therefore, the rate of seclusion by nesting Brahminy Kite
H. indus has been measured to draw management strategies to minimise the disturbances to the breeding kites.

Raptors, like other free-living organisms, are limited by natural and man-made factors which induce substantial variability in population parameters and behaviour of individuals particularly during their breeding cycle. Hence it is worthwhile to study the reproductive behaviour of either sex in a breeding pair to know their "normal" behaviour in their breeding system. Raptors differ from many other birds in their "breeding system" (Olsen and Olsen 1978). In particular, the female generally cannot successfully hatch and raise a brood in the absence of a male which has a higher reproductive investment in the breeding attempt when compared to any other avian species. The male is the sole provider of food for the female from courtship to nestling period (Newton 1979). Breeding success of a pair is not only depending on the ability of the male to supply his mate and offspring with food, but also on the capacity of the female to retain such a male. Perhaps this may be the reason for the occurrence of monogamy in most of the raptors (Lack 1968). He has also stated that the main advantage of monogamy is that both the male and female leave, on average, more offspring if both parents help to raise a brood. Such a bi-parental care may require substantial investments of time and energy (Drent and Daan 1980; Walsberg 1983; Thompson and Nichol 1986). In the monogamous breeding system of raptors, a parent bird must invest "Reproductive Effort" in a breeding bout without considering the costs and benefits involved. "Reproductive Effort" (RE) is the total expenditure of risk and energy incurred by a parent in reproduction (Williams 1966; Gadgil and Bossert
1970; Hirschfield and Tinkle 1975). Many authors (Trivers 1972, 1985; Wilson 1975; Dawkins 1976) have suggested that, because of Anisogamy (in which females produce a few energy-rich eggs and males produce many energetically cheaper sperms), females usually invest more RE than do males by the time of fertilization. Trivers (1972) has formalised these ideas into a "Theory of Parental Investment", which denotes that breeding systems may be a function of the relative disparity in RE invested by the sexes. (Trivers 1972) has recognised that when the disparity of reproductive effort between the sexes is large, sexual selection could result in different strategies by the sexes to optimize the life time expenditure of reproductive effort. Trivers' (1972) hypothesis predicts that the sex whose cumulative investment is exceeded by its mate should be more tempted to desert because the deserter loses less than its partner if no offsprings are raised. Thus, desertion by any sex often may lead to polygyny or polyandry in most vertebrates (Kleiman 1977, Ridley 1978, Perrone and Zarret 1979, Wells 1981 and Davis 1985). In birds, however, mate desertion is especially rare and most species are monogamous, (Beissinger 1987b) with biparental care as in Bald eagles (Haliaetus leucocephalus) (Lack 1968, Oring 1982). Such disparity in RE and mate desertion in Brahminy kite have not been established so far and hence an attempt has been made in the present study in view of the above factors.

The "Parental Investment Theory" attempts to explain the interactions between a parent and its offsprings, its mate, the environment, and predators in terms of allocating its resources to its young (Coleman 1987). "Parental Investment" is defined as any investment by the
parent in an individual offspring, that increases the offspring's chance of survival at the cost of the parent's ability. It implies that a decrease of the "Parental Investment" of a raptor in its offspring, as a result of disturbance activities, will directly affect the raptor's reproductive success. Disturbances may occur at any time and therefore affect any behaviour related with the breeding cycle of the raptor. The reaction to a disturbance activity may be related to the strength of the stimulus or its perception which may change over the course of the nesting cycle (Montgomerie and Weatherhead 1988). Many raptors show a great tenacity to their reproductive effort and an increasing willingness to defend their eggs or young as the nesting season progress (Fyfe and Olendorff 1976 and Newton 1979). Later on, the effect of the same stimulus may decline through the nesting cycle. Trivers (1972) and Barash (1975) are of the opinion that parent birds should defend nestlings more aggressively as nestling age increases. Almost the same view has been expressed by Montgomerie and Weatherhead (1988) by pointing out the necessity of defense behaviour for the survival of the offsprings.

In the incubation stage, the important variable is the total amount of time spared by parents in incubating the eggs. Disturbance activities may cause the breeding parents to temporarily vacate the nest, leaving the eggs unattended till the disturbance ceases. Raptor nestlings cannot regulate their body temperature until about 2 weeks after hatching and require brooding by a parent (Enderson et al., 1973, Ratcliffe 1980, and Poole and Boag 1988). Unattended small young ones may get chilled or overheated (Fyfe and Olendorff 1976); both scenarios may increase the mortality rate of
the young and result in lower productivity. Aggression helps the raptors to deter potential predators and usurpers (Olsen and Olsen 1978). With regard to the patrolling behaviour it has been attributed for establishing territories (Sitter 1983) and for attracting the mate Newton (1979). Once territorial boundaries are established, patrolling frequency is likely to decline during incubation and brood-rearing (Halthuijzen 1989). From the foregoing account on the nest defense behaviour it may be assumed that an increase in nest defense behaviour may reduce parental care and possibly lead to lower productivity. Anderson and Wiklund (1987) cited the "Female Nest Defense Hypothesis" which predicts that the "Reversed Sexual Size Dimorphism" (RSD), a characteristic trait among most species of Falconiformes (Snyder and Wiley 1976, Anderson and Norberg 1981, Mueller and Meyer 1985, Meenakshi 1990), to give a visual threatening to the intruders including the males having the tendency to feed on its own young ones (Filicide) (Reynolds 1972). But there is no supporting evidence for this idea (Anderson and Wiklund 1987). Information pertinent to the role of female Brahminy kite *H. indus* in nest defense is limited. Hence, in the present study, "Female Nest Defense Hypothesis" has been tested in breeding Brahminy kite.

According to Collopy (1984) the size and total biomass of prey delivered to young by male and female raptors are also considered in relation to theories of sexual size dimorphism and parental investment. During feeding, the male delivers most prey items to female (pre-incubation and incubation period) or young (brooding period) (Newton 1979). Prey delivery by the male parent is particularly critical when the female is building up her body reserves to enable her to lay eggs and reluctant to leave the nesting
territory (Newton 1979, 1986, and 1988). When the young ones are small and have to be brooded most of the time, the male has to provide food for both the female and the young, as well as for himself. Lower prey delivery rates during pre-incubation period may affect the clutch size, due to insufficiency for the female to produce eggs, or may even motivate her to abandon the nesting attempt altogether. During early brood rearing, depressed prey delivery rates may affect the physical condition of the young and the female. Over an extended period missed feedings are likely to increase the mortality rate of young, affect their physical condition, or result in a lower productivity. Because of the lack of information concerning nestling feeding and parental care of Brahminy kites *H. indus*, the present investigation has been initiated to determine the prey delivery rates of both parents during different phases of the breeding cycle.

Although investigations have been carried out on the breeding biology of raptors in the western part of the world, the literature on the breeding ecology of Brahminy kite contains general or anecdotal references only. Foanca (1980), Cupper and Cupper (1981), Hollands (1984) and Bell (1985) have described the general biology, habits and habitats of Australian Brahminy kites. Jayabalan (1985) has noted the general bionomics of Brahminy kite at Mayiladuturai, South India. Schodde and Tidemann (1986) have narrated the feeding and breeding habits of Australian Brahminy kites. Following Jayabalan (1985), work on the Brahminy kite inhabiting Cauvery delta has been carried out on communal roosting behaviour (Sekar 1989); reversed sexual size diorphism (Meenakshi 1990); foraging strategies of non-breeding kites (Sudha 1991); kleptoparasitism (Saraswathi 1992 and
Sheela 1993); effect of cyclone on the trees of communal roosting site (Murugan 1994) and regurgitated pellet analysis (Amudha 1995). Therefore, based on the ecological significance and the ethological factors related with their breeding system, the present study has been designed with the following objectives.

**Objectives of the study**

1. To study the population dynamics of breeding *H. indus* in Cauvery delta for 6 continuous breeding seasons (1986-87 to 1991-92),
2. To determine the factors influencing the clutch size fixation of the Brahminy kite,
3. To evaluate the factors involved in the habitat selection of this species for breeding,
4. To assess the "Reproductive Effort" of the parents during breeding cycle,
5. To understand the Reversed Sexual Size Dimorphic effect in nest defense of this species, and
6. To test the "Mate Desertion" hypothesis (Trivers 1972) in the breeding Brahminy kite by analysing energy budgets of "Parental Investment" for each sex.