

**ORGANOCHLORINE PESTICIDES, POPULATION AND
REPRODUCTIVE SUCCESS OF FISH-EATING BIRDS IN SELECT
HERONRIES IN TAMIL NADU**

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Coimbatore



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ENVIRONMENTAL SCIENCES

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(Center aided by the Ministry of Environments & Forests, Govt. of India)

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CERTIFICATE

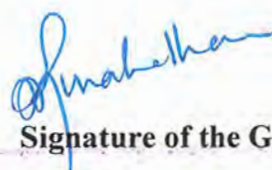
CERTIFICATE

This is to certify that the thesis, entitled “**Organochlorine pesticides, population and reproductive success of fish-eating birds in select heronries in Tamil Nadu**” submitted to the Bharathiar University, in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in **Environmental Sciences** is a record of original work done by **Mr. S. Jayakumar** during **October 2007 to December 2013** in the Department of **Ecotoxicology** at **Salim Ali Centre for Ornithology and Natural History, Anaikatty, Coimbatore – 641 108** under my supervision and guidance, and the thesis has not formed the basis for the award of any Degree/ Diploma/ Associateship/ Fellowship or any other similar title of any candidate of any University.

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DECLARATION

DECLARATION

I, **S. Jayakumar** hereby declare that the thesis, entitled “**Organochlorine pesticides, population and reproductive success of fish-eating birds in select heronries in Tamil Nadu**” submitted to the Bharathiar University, in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in **Environmental Sciences** is a record of original work done by me during **October 2007 to December 2013** under the guidance of **Dr. S. Muralidharan**, Principal Scientist, Department of **Ecotoxicology at Salim Ali Centre for Ornithology and Natural History, Anaikatty, Coimbatore- 641 108**, and it has not formed the basis for the award of any Degree/ Diploma/ Associateship/ Fellowship or any other similar title of any candidate of any University.

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INTRODUCTION



1. INTRODUCTION

Heronry refers to a nesting congregation of colonial aquatic birds belonging to the family Ardeidae which comprises herons and egrets (Ali 1996). Ray *et al.* (1996), however, defined heronry as the nesting areas of herons, egrets and other associated water birds such as storks, pelicans and ibises. According to Reza *et al.* (2010) heronries may be composed of a single or mixed species of colonial water birds, which have significant importance to ornithologists, biologists and birdwatchers.

Colonial waterbirds are the most conspicuous components which serve as an excellent indicator of wetland ecosystem (Hancock and Kushlan 1984; Sivasubramanian 1992; Subramanya 1996 a, b; 2005 and Urfi 2011). Many species of fish-eating bird in India are known to breed colonially (Ali and Ripley 1987 and Subramanya 1996 a, b). In India, breeding birds in mixed species colony are largely the Asian Openbill (*Anastomus oscitans*), Painted Stork (*Mycteria leucocephala*), Great Egret (*Casmerodius albus*), Intermediate Egret (*Mesophoyx intermedia*), Little Egret (*Egretta garzetta*), Cattle Egret (*Bubulcus ibis*), Grey Heron (*Ardea cinerea*), Purple Heron (*Ardea purpurea*), Black-crowned Night Heron (*Nycticorax nycticorax*), Indian Pond Heron (*Ardeola grayii*), Little Cormorant (*Phalacrocorax niger*), Indian Cormorant (*Phalacrocorax fuscicollis*), Darter (*Anhinga melanogaster*), Black-headed Ibis (*Threskiornis melanocephalus*) and Spot-billed Pelican (*Pelicanus philippensis*) (Subramanya 1996 a, b, 2005 and Urfi 2011).

Colonial waterbirds face significant threats to the long-term stability of their populations and habitats due to the destruction of freshwater wetlands, destruction and degradation of coastal ecosystems, depletion of the forage base in freshwater, coastal, and marine ecosystems, contaminants, sea level rise and various conflicts with human land and resource use. For some species, these threats have resulted in a decline in number (Gopi and Pandev 2011; Jakubas 2011 and Urfi 2011). Human presence in the vicinity of heronries and repeated disturbance could be detrimental to breeding outcome as the birds tend to abandon the nests at any stage of breeding resulting in possible population decline (Tremblay and Ellison 1979; Parson and Burger 1982; Carney and Sydeman 1999).

Agricultural chemicals applied to cropland may enter wetlands directly by overspray, aerial drift, or cultivation and treatment of dry wetland basins, or indirectly through volatilization and post application runoff (Grue *et al.*, 1986). Direct pesticide exposure can be lethal or teratogenic to avian reproduction and survival of wetland and its associated biota. Pesticide-induced reductions in food consumption may affect reproduction by inhibiting egg production (Stromborg 1981).

The use of pesticides in agriculture commenced in India around 1948-49 (Gupta 1986) and it increased manifold with the green revolution. Today India is the second largest manufacturer of pesticides in Asia and third largest consumer in the world. Although India is in the process of phasing out persistent organochlorine group of pesticides, a few are still being used in substantial quantities either for agriculture or civic health. India banned the agricultural use of DDT in 1989 (Anonymous 1991) with a ceiling to use a maximum of 10,000 tons of per annum for the control of malaria and *kala-azar* (Dash *et al.*, 2007). During the 9th Five Year Plan of India (1997 - 1998 to 2001 - 2002), the National Anti-Malaria Programme sprayed 42,200 metric tons (MT) of DDT (50% WP; including 11,600 MT for *kala-azar* disease control) (Sharma 2003). Hence, DDT can continue to pose problem in the environment. Pesticides, especially, organochlorine compounds have got very slow decomposition rate and long half-life, thereby they remain in the system and exert deleterious effects on birds and other biota more subtly than by outright killing.

Colonial nesting birds may get attracted by dead or dying invertebrates those congregate in agricultural areas. Consumption of contaminated fish or invertebrates under these conditions can cause mortality or long-term sub-lethal effects. Wildlife inhabiting seasonal, semi-permanent and undifferentiated tillage wetland types may have the greatest potential for exposure to agricultural chemicals. These wetlands usually are relatively small in size and commonly interspersed within agricultural fields, which increases the probability of pesticide inputs from direct overspray and aerial drift (Grue *et al.*, 1986).

The effects of organic pollutants on waterfowls and colonial nesting birds and other wildlife have been extensively studied in North America (Custer *et al.*, 1990; Hoffman *et al.*, 1998; Gao *et al.* 2009 and Morales *et al.*, 2012) and Europe (Braune 2007; Van den Steen *et al.*, 2006; 2008 and 2010). In India, declining population of colonial birds

breeding at regular sites and infrequent sightings or total absence of many species of birds in the agricultural fields in various places are being reported. Residues of persistent organochlorine pesticide in the eggs of eight species of colonial nesting birds, in Keoladeo National Park (Muralidharan *et al.*, 1992), unsuccessful breeding of Himalayan Grey-headed Fish Eagle *Ichthyophaga nana* at Corbett National Park in Uttar Pradesh (Naoroji 1997), accumulation of organochlorine in birds from South India (Tanabe *et al.*, 1998; Vijayan and Muralidharan 1999 and Dhananjayan 2009) give credence to the concerns of ornithologists. Although such definite information is not available for many species of colonial nesting birds in India, study conducted elsewhere give definite proof for the deleterious effects of pesticides on avifauna and the ecosystem. The United States Environmental Protection Agency (USEPA 1982) tests chemicals for avian reproduction hazards and also requires shell thickness measurements as part of the registration process. Therefore, measuring egg-shell quality remains a valuable tool for testing or monitoring a variety of contemporary environmental hazards (Custer *et al.*, 1990).

Breeding population of colonial nesting birds play a very important role in conservation of waterbirds in general and threatened birds in particular (Jha 2012). Successful conservation of waterbirds will depend on an improved understanding of their ecological requirements (Fellows *et al.*, 2001). Insights on heronries and colonial nesting birds are important for understanding long-term trends in breeding outcome and eventually for their conservation (Parmesan and Yohe 2003). The information available on heronries in India is restricted to a few regional studies (Subramanya 1996 a,b). Subramanya (2005) compiled available information on heronries in Tamil Nadu and listed quite a few important heronries. Comprehensive studies on the heronries to understand colonial nesting birds' population, distribution, breeding status and conservation issues including organochlorine contaminants are limited. The present work is an effort to document the current status of select heronries in the above-referred perspective in Tamil Nadu.

The original plan, at the time of initiating this work was to study only the fish-eating birds. But, subsequently the scope was extended to also include other birds those breed colonially with fish-eating birds and feed on other prey items, namely mollusk (Asian Openbill), insects (Cattle Egret, Little Egret, Intermediate Egret and Great Egret) and worms (Glossy Ibis). However, for administrative reasons, the title of the thesis as per the communication with university is retained as fish-eating birds.

LITERATURE REVIEW

2. LITERATURE REVIEW

As a survival strategy, coloniality in birds must have evolved through natural selection for certain benefits. There must also be costs associated with nesting in the company of other birds (Urfi 2011). Many species of birds are territorial and they breed solitarily, but a small number of them nest colonially. Lack (1968) estimated that approximately 13-14% of birds are colonial, although this estimate is most probably conservative (Brown and Brown 2001). The tendency to breed in colonies seems to be more common in fish-eating birds. Among the storks in India, namely Painted Stork, Asian Openbill, Lesser Adjutant and Greater Adjutant are colonial nesters, but the Woolly-necked Stork and the Black-necked Stork are solitary breeders (Urfi 2011). So as a taxonomic group, not all storks are colonial and for finding answers to the evolution of coloniality one can look elsewhere, possibly in ecology and the way the resources that birds utilize are distributed in the environment (Urfi 2003b).

The British Ornithologist Lack (1968) suggested that the major factors favoring colonial nesting in birds are chiefly enhancing avoidance of predators and enhancing more efficient exploitation of food resources. Subsequently, the subject of avian coloniality has been reviewed (Burger 1981 and Brown and Brown 2001). Coloniality can be active or passive (Betham 1904). What appear to the human eyes as “similar trees” may actually be very different substrates from the bird’s view. But it is clear that birds have in some sense, chosen to nest in close proximity to each other and therefore, this is a case of active coloniality, basically different from a situation where due to scarcity of nesting sites, the birds have no option but to breed in colonies. The latter, known as passive coloniality can happen in the case of seabirds, where suitable islands for building nests may be scarce, leading to dense concentrations of nests on islands. Such islands may be few and far between (Kharitonov and Siegel-Causey 1988). However, it must also be mentioned that the idea of the so-called active coloniality has been severely challenged. It has been argued that nesting aggregations may be merely a byproduct of many individuals selecting commodities such as habitat and mates, and not necessarily a benefit to the individuals those aggregate (Wagner *et al.*, 2000; Urfi 2003b and 2011).

Nesting colonies are what have been described as “central place systems,” i.e., an individual belonging to the colony has to perforce return to it every day during the breeding season because it may have nestlings or eggs in the nest (Urfi, 2011). On the other hand, a roosting site is not a central place system in that an individual is not bound to return to it every day and can change its roost site every now and then. A whole body of theory has developed about central place systems, particularly in the context of foraging ecology of breeding birds (Krebs and Davies 1984).

Terms like heronry, rookery and pelicanry are often used while referring to colonies of waterbirds. It may be useful to clarify upon these terms and the connotations these words have. Pelican colonies have been called as pelecanries (Gee 1960), Stork colonies probably never had a special name for themselves. A term such as storkery does not exist. Instead, the general term heronry has been used for referring to nesting colonies of storks, egrets, herons, cormorants, ibises, etc (Urfi 2011).

The distributions of heronries and heronry associated birds have been documented in India (Subramanya 1996 a, b). While Naik (1987) studied heronry at Indapur, Mahabal (1990) reported heronries of Raigad in Maharashtra. Naik and Parasharya (1988) have studied a few heronries in Western India. While Parasharya and Naik (1990) studied heronry birds in Bhavnagar city, Iyer (2004) documented nesting of birds belonging to families, namely Phalacrocoracidae, Threskiornithidae and Ardeidae in Ahemadabad Zoo, Gujarat. Heronries of Punjab were assessed by Singh and Sodhi (1986).

There is also some information available on specific heronry species in India. Space portioning in colonial nesting birds in the heronry at Kulik Bird Sanctuary, West Bengal was documented by Datta and Pal (1990). Datta and Pal (1993) studied the effect of human interference to the nesting of Openbill Stork at Raiganj Wildlife Sanctuary, West Bengal. Singha *et al.* (2002) documented breeding of Adjutant Stork in Assam. Sharma (2007) reported the population status of Asian Openbill Stork in Raiganj Bird Sanctuary. An ecological study of colonial birds in Kokkare Bellur Bird Sanctuary in Karnataka was documented by Sanjay (1993). He also studied the status breeding Spot-billed Pelican in Karnataka. Chakravarthy (2004) documented breakaway heronries in Mysore. Nesting of colonial birds of Ranganthittu Bird Sanctuary in Karnataka was documented by Sharatchandra (1980).

An ecological investigation in Keoladeo Nation Park was done by Vijayan (1991) and Sivasubramanian (1992). They documented the population and breeding ecology of 22 colonial nesting birds including threatened Painted Stork. Studies on the distribution of heronries in and around Ajmer city, Rajasthan was reported by Bhatnagar *et al.* (2004). They also studied the nesting trees used by a few colonial nesting birds. Vyas and Tomar (2004) studied winter breeding of Grey Heron *Area cinerea* in Chambal River valley, Rajasthan. Spatial and temporal distribution of nest in a heronry at Kotta city of Rajasthan was reported by Vyas (2006). Urfi (1992 and 2003 a,b) studied heronries in Delhi region. Heronries around Rajkot city, Gujarat was assessed by Mashru (2007). Narayana and Vijayan (2007) reported the status of colonial breeding waterbirds in Kumarakom heronry, Kerala. They studied the status of 11 species of colonial nesting birds. Arif and Basheer (2012) documented waterbirds of Mavoor Wetland, Kerala. The status and distribution of Spot-billed Pelican in Southern India was assessed by Kannan and Manakadan and Kannan (2003). They estimated about 4000 birds and identified 21 active breeding sites of Spot-billed Pelican in the states of Andhra Pradesh, Karnataka and Tamil Nadu.

Guptha *et al.* (2011) studied waterbirds in Neelapattu Bird Sanctuary, Andhra Pradesh, India. Breeding of Spot-billed Pelican, Painted Stork, Asian Openbill, Darter, Oriental Whit Ibis and Little Cormorant was reported by Taher (2007). Gopi and Pandav (2011) reported nest space partitioning of colonial nesting water birds in Bhitarkanika mangroves in Odisha. Some breeding and ecological aspects of colonial nesting birds at Soor Sarovar bird Sanctuary, Uttar Pradesh were reported by Jha (2012).

Detailed studies on heronries in Tamil Nadu (South-eastern state in India) are very few and much of the available literature on the heronries of the region came from Vedanthangal, a heronry of great antiquity (Paulraj 1984; Santharam and Menon 1991; Venkatraman and Muthukrishnan 1993; Baskaran 1999; Krishnan 2001; Santharam 2000, 2004 and Subramanya 2005). Nagulu and Rao (1983) reported south Indian Pelecanries. Nesting birds of Vedanthangal Birds Sanctuary, Tamil Nadu was reported by Santharam and Menon (1991). The only other century-old heronry, with a recorded history, is Koonthankulam (Johnson 1971; Kumar 1980; Beulah 2002; Subramanian 2003 and Subramanya 2005). Information on select heronries, namely Chitrangudi, Vettangudi,

Kanjirankulam and Karaivatti are also available (Islam and Rahmani, 2004). In addition, a review article on heronry is also available in Tamil Nadu (Subramanya, 2005).

Besides these, there have been scattered articles and notes on individual heronries. Many short-term studies were confined to Vedanthangal (Krishnan 1960, 1980, 1986, 1993a,b and 2001; Johnson 1971; Paulraj 1984 and 1988; Paulraj and Gunasegaran, 1988; Santharam 1981, 1986, 2000 and 2004; Venkatraman 1996a,b and 2009), Koonthankulam (Gurusami 1988, 1994 and 1999; Kumar, 1980; Chandarasekaran 1986; Johnson 2000; Subramanya 2003 and Karnan 2005).

Enormous quantities of man-made chemicals are being used in modern agriculture to increase productivity and to meet the ever increasing food demands. Despite obvious benefits, the indiscriminate use of such chemicals has resulted in accumulation of chemical residues in foods and animal tissues causing environmental and ecological impacts (Singh *et al.*, 2006; Subramanian and Tanabe 2007; Vijayan *et al.*, 2008; Muralidharan *et al.*, 2009; Dhananjayan and Muralidharan 2010; Mudiam *et al.*, 2011 and Muralidharan *et al.*, 2012). The presence of pesticide residues in air, water, soil, plant and animals has raised concern due to their persistence and long-term impacts.

Birds occupy a wide range of trophic levels in different food chains and are thereby exposed to different concentrations of pollutants through their food (Ankeley *et al.*, 1993). Rachel Carson's (1962) *Silent Spring* might be regarded as the first to bring attention to the sensitive nature of birds to the deleterious effects of toxic contaminants. Birds have been widely used as bioindicators of environmental pollution, particularly for persistent organochlorines, which have been considered as potential endocrine-disrupting chemicals in wildlife (Furness 1993; Fossi *et al.*, 1995 and Minh *et al.*, 2002).

The effects of organic pollutants on waterfowls and colonial nesting birds and other wildlife have been extensively studied in North America (Fleming *et al.*, 1984; Ambrose *et al.*, 1988; Custer *et al.*, 1990; Hoffman *et al.*, 1998; Gao *et al.*, 2009; Elliott *et al.*, 2012; Gentes *et al.*, 2012; Gomez-Ramirez *et al.*, 2012 and Morales *et al.*, 2012) and Europe (Donaldson *et al.*, 1999; Jones and de Voogt 1999; Jaspers *et al.*, 2005; Braune, 2007; Van den Steen *et al.*, 2006, 2008 and 2010).

The pesticide DDT and its breakdown product DDE gained notoriety about five decades ago in North America. Ratcliffe (1967) investigating the Peregrine Falcon *Falco peregrinus* and Sparrow Hawk in Britain *Accipiter brachyurus*, was the first to note a correlation among the magnitude of decrease in eggshell weights, decrease in breeding populations and exposure of populations of these species to persistent organic pesticides. Heath *et al.* (1969) showed experimentally that DDE impaired the reproductive performances in Mallard as early as 1969. Later it was proved to be responsible for eggshell thinning that led to population crashes and reproductive impairments in many species of birds in North America (King *et al.*, 1978 and 1991; Fleming *et al.*, 1984; Delibes 1992 and Fasola *et al.*, 1998).

Following the success of DDT in World War II, several organochlorine pesticides were discovered for the control of vector born diseases of crops. The use of pesticides in agriculture commenced in India around 1948-49 (Gupta, 1986) and it increased manifold with the green revolution. Today India is the second largest manufacturer of pesticides in Asia and third largest consumer in the world (Mathur 1999; Abhilash and Singh 2009). Annual consumption of pesticides mainly for agriculture in India has crossed 50,583 MT from a mere 5,000 MT during 1960s (www.indiastat.com; assessed on May 2013). The dramatic increase clearly shows that pesticides whether good or bad, have become a major tool in today's agriculture, although alternatives to pesticides are being tried and talked about.

Although India is in the process of phasing out persistent organochlorine (OC) group of pesticides, many are still being used in substantial quantity either for agriculture or civic health (Dash *et al.*, 2007). Pesticides, especially, OC compounds have got very slow decomposition rate and long half-life, thereby they remain in the system and exert deleterious effects on birds and other wildlife more subtly than by outright killing. Replacement of OC insecticides with shorter-lived chemicals such as organophosphates (OPs), Carbamates (Cbs), Synthetic Pyrethroids (SPs) and other compounds alleviated many problems with persistence and bioaccumulation of lipid-soluble OCs (Blus 1982 and Wiemeyer *et al.*, 1984). However, further studies revealed that serious effects, resulting from different modes of action, are also associated with use of the newer compounds, particularly from a short-term perspective where acute or sub-acute toxicity (Henny *et al.*, 1985) and reduction in the food base are major concerns (Rands 1985; Potts

1986; Tanabe *et al.*, 1991; Kannan *et al.*, 1995; Senthilkumar *et al.*, 1999 a, b and 2001; John *et al.*, 2001; Bedi *et al.*, 2005 and Aulakh *et al.*, 2006).

The US Environmental Protection Agency (USEPA, 1982) tests chemicals for avian reproduction hazards and also requires egg-shell thickness measurements as part of the registration process. Therefore, measuring egg-shell quality remains a valuable tool for monitoring the impact of a variety of contemporary environmental chemicals. Studies also support one of the basic assumptions of the sample egg technique, that the chemical residues in one egg in a clutch accurately reflects residues in the remaining eggs of the clutch (Custer *et al.*, 1990). Egg is also a non-invasive tool in assessing the impact of environmental contaminants (Mateo *et al.*, 2000).

Agriculture chemicals applied in croplands may enter wetlands directly by overspray, aerial drift, or cultivation and treatment of dry wetland basins, or indirectly through volatilization and post application runoff (Grue *et al.*, 1986; Bouregeois *et al.*, 1993, Nayak *et al.*, 1995 and Kalavathy *et al.*, 2001). Direct pesticide exposure can be lethal or teratogenic to avian reproduction and survival of wetland dependent wildlife. Further, pesticide-induced reductions in food consumption may also affect reproduction by inhibiting egg production (Stromborg 1981).

Wading birds and a few colonial nesting birds may be attracted to dead or dying invertebrates those gather near the shoreline. Consumption of contaminated fish and invertebrates under these conditions can cause mortality. Wildlife inhabiting seasonal, semi-permanent and undifferentiated tillage wetland types may have the greatest chance for exposure to agricultural chemicals. These wetlands are relatively small in size and commonly interspersed within agricultural fields, which increase the probability of pesticide inputs from direct overspray and aerial drift (Grue *et al.*, 1986). As the colonial nesting birds occupy relatively higher position in the aquatic food web, they are all the more prone to accumulation and eventually impact.

In India, declining population of piscivorous birds breeding at regular sites and infrequent sightings or total absence of many species of birds, in the agricultural fields in various places are being reported. Tanabe *et al.* (1998) documented greater amount of contaminants in inland and coastal colonial nesting birds from South India. The study also suggested that the Pond Heron and other birds are under risk due to DDT burdens. There

are reports on pesticides and other chemical residues in India on various biological components (Kaphalia *et al.*, 1981; Misra, 1989; Kulashrestha *et al.*, 1990; Vijayan, 1991; Tanabe *et al.*, 1998; Senthilkumar *et al.*, 1999 a, b and 2001; Muralidharan and Murugavel, 2001; Muralidharan 1993 and 2002; Muralidharan *et al.*, 2008, 2009 and 2012; Dhananjayan and Muralidharan 2010; Muralidharan and Dhananjayan, 2010; Dhananjayan *et al.*, 2010 and 2011 a, b) but information on birds particularly fish-eating bird is very limited. There are information available on the residue levels of pesticides in eggs of fish-eating and insectivorous birds (Siddiqui and Saxena, 1983; Reghupathy and Kuttalam, 1990; Muralidharan *et al.*, 1992 and Ranapratap, 2004; Dhananjayan *et al.*, 2011 a, b). However, they failed to bring out the exact scenario of pesticide usage in agricultural areas and residue levels in eggs, and the consequent breeding success. Further, there are no studies which investigated the residue levels in eggs and simultaneously monitored the breeding outcome and population of birds over a period of time in India.

It is needless to mention that unless there is a regular mechanism to keep tract of the problem chemicals in eggs and their impact on the population status of important species of birds, it is difficult to assess the ill effects of chemicals on birds and environment. Moreover, unless there is a modality like this, it is impossible to evaluate the fate of problem chemicals in the environment even after banning them. Colonial nesting birds inhabiting seasonal, semi-permanent wetlands may have the greatest potential for exposure to agricultural chemicals. While the annual consumption of pesticides for agriculture in India is 50,583 MT, Tamil Nadu uses about 2,512 MT (www.indiastat.com accessed on 7th September 2012).

The welcome news is that there has been a decreasing trend noticed in the consumption pattern over the last couple of years. However, mortality of wildlife, especially birds has been rampant all over the country. To workout conservation strategy for colonial nesting birds, in addition to ecological investigations, it is also essential to assess the impact of agricultural chemicals on them. Hence, the present project was conducted with the following objectives;

2.1. OBJECTIVES

- Identify the heronries in Tamil Nadu.
- Monitor the population and study breeding ecology of colonial nesting birds in select locations.
- Document the residue levels of organochlorine pesticides in fishes, eggs and tissues of colonial nesting birds and assess the impacts.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

3.1. Study Area: Tamil Nadu

Tamil Nadu is situated on the southeastern side of the Indian peninsula. It has geographical area of 1, 30,058 sq. km which is about 4% of the land area of the country (Islam and Rahmani 2004). The state has been divided into 32 administrative districts. It is also divided into three broad physiographic regions, namely the western hilly region and the plain along the coast and the north-western high elevation area parallel to the coast and gradually rising from it is the broad strip of plain country in the east. It extends a little beyond the Western Ghats in Kanniyakumari. Tamil Nadu has 45 rivers and rivulets. Major rivers are the Cauvery, Vaigai, Bhavani, Palar, Cheyyar, Ponnaiyar, Amaravati, Chittar and Tamaraparani.

Tamil Nadu is basically an agricultural state with considerable extent of fertile lands. It is one of the major producers of paddy, sugarcane, vegetables, cotton, tea and coffee. Small water storage reservoirs behind earthen dams, called tanks, dot the expanse of Tamil Nadu. Although these tanks supply many villages with drinking water, their primary purpose is irrigation. As monsoon rains fall erratically during only a few months in the year, these irrigation tanks serve to store and regulate the flow of water for agricultural use, associated mainly with the production of paddy. Paddy is the principal agricultural crop in the state, grown over nearly 63,00,000 ha (<http://www.tn.gov.in/departments/2>; assessed on 25th September 2013). Together, the rivers, reservoirs and the tanks provide major feeding grounds for the waterbirds in the state and support the heronries (Hussain and Balachandran 1993, and Vijayan *et al.*, 2004).

3.2. Selection of study sites

Study sites were selected based on the preliminary survey results and the criteria suggested by Kelly (2002) for data collection in wetland birds. According to our preliminary survey, Vedanthangal and Koonthankulam Bird Sanctuaries are the oldest heronries, while Chitrangudi near Ramanathapuram and Vettangudi Bird Sanctuary near Sivagangai are traditional sites. Based on the abundance of breeding birds and agricultural activities, three locations, namely Vedanthangal Bird Sanctuary, Koonthankulam Bird

Sanctuary and Vettangudi Bird Sanctuary were selected as intensive study sites (map 1 & plate 1).

3.2.1. Vedanthangal Bird Sanctuary

Vedanthangal Bird Sanctuary (12° 32' 02" N and 79° 52' 29" E) is located in Kancheepuram district, about 85 kms south west of Chennai. It is one of the oldest bird Sanctuaries in India. The local people have been protecting the Sanctuary for centuries because they have realized that the bird droppings falling into the tank serve as manures to their crops. Thus the water when used to irrigate crop fields the yield increases greatly and the cost of cultivation reduces. Perhaps due to this protection provided by the local populace, around 40,000 birds come here every year. The Sanctuary is spread well over 30 ha of land. The area is largely covered by the lake that makes up an ideal habitat for the birds. The countryside of Vedanthangal Sanctuary is flat, comprising primarily rocky plains. Northern and Eastern sides of the Sanctuary are sloppy and extend to agricultural fields. Southern part of Sanctuary is agriculture fields and Western part is village. Paddy is the principal crop in this area, while sugarcane and groundnut are also cultivated. This area is surrounded by quite a few big and small tanks including Madurathakam tank, which collectively act as feeding grounds for the birds of the Sanctuary. Cormorants, Darter, Cattle Egret, Grey Heron, Little Egret, Black-crowned Night Heron, Painted Stork, Asian Openbill, Indian Pond Heron and Black-headed Ibis are some of the most common species found in this Sanctuary. Majority of the colonial nesting birds are local migrants, they congregate between November and March in Vedanthangal and breed if the situation is favorable.

3.2.2 Koonthankulam Bird Sanctuary

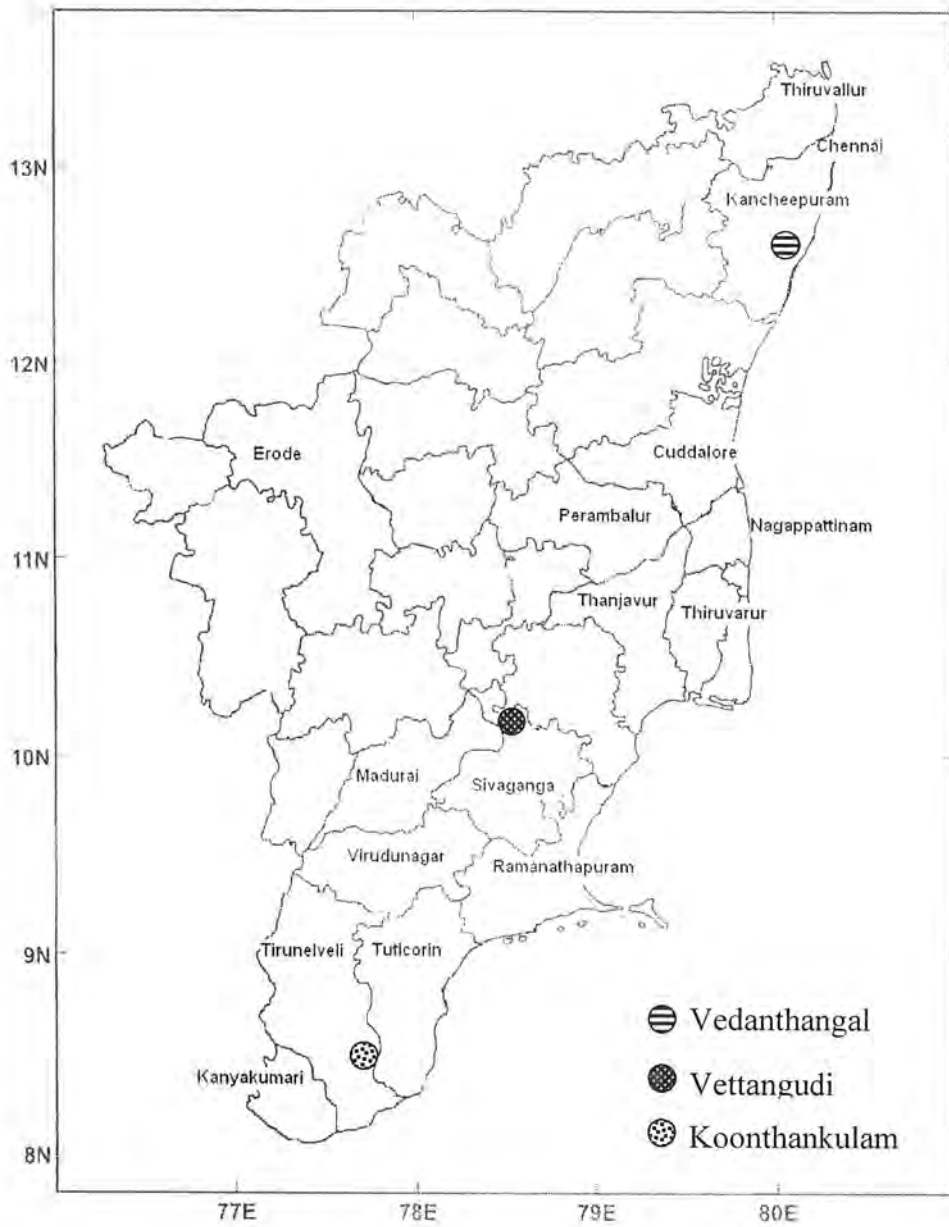
Koonthankulam Bird Sanctuary (08°28'12" N and 77°43'48" E) is a unique Sanctuary effectively protected and managed with the support of the Koonthankulam village community. It is located 35 km away from Thirunelveli on Thirunelveli-Thisaiyanvillai road comprising Koonthankulam and Kadankulam tanks covering an area of 129.33 ha. It was declared as a Sanctuary in 1994. It is significant that the local people have been showing keen interest in protecting this Sanctuary and they live together in total symbiotic relation. The birds those come to their backyards are being protected whole heartedly by villagers for generations. Assemblage of birds in large numbers for breeding

is regarded as harbinger of luck. The excreta of birds are collected by villagers in summer along with silt and used as manures in their fields. From children to grannies in the village protect the birds, their nests and fledglings. Chicks fallen off their nests are taken care in the rescue center till they are able to fly on their own. The babul plantation on 30 ha in Koonthankulam is the major breeding ground. More than 43 species of water birds, both resident and local migrants, visit this Sanctuary every year during January-February and vacate by July - August after successfully raising their young ones. Many larger waterbirds, especially Painted Stork and Spot-billed Pelican have been reported to be nesting annually around Koonthankulam village over a long period of time.

3.2.3. Vettangudi Bird Sanctuary

Vettangudi Bird Sanctuary (10°05'53" N and 78°32'23" E), situated near Tirupattur in Sivagangai district is one of the popular bird Sanctuaries in the State. It attracts thousands of local and migratory birds every winter. Trees in the 38.4 ha Sanctuary are the safest breeding sites for many species of colonial nesting birds. The area surrounding the wetland is invaded by *Prosopis juliflora*, which was introduced a few decades ago by forest department. *Acacia nilotica* trees grow in the lake and remain submerged for a few months. Trees, namely *Tamarindus indica*, *Azadirachta indica* and *Mangifera indica* present on the bunds provide roosting and breeding sites to the birds.

The Sanctuary receives water mainly during northeast monsoon between October and December. The southwest monsoon also brings some showers between June and September. Thus, from June to December, rainwater helps to sustain the breeding birds at Vettangudi. Besides this, Vaigai, the major river of the district and surrounding paddy fields also provide foraging grounds. Asian Openbill, Black-headed Ibis, Little Cormorant, Grey Heron and Darter are some of the prominent colonial nesting birds which breed in this Sanctuary. Migratory waterfowl visit this Sanctuary in huge flocks during every winter.



Map 1 shows the intensive study sites in Tamil Nadu

Vedanthangal Bird Sanctuary



Koonthankulam Bird Sanctuary



Vettangudi Bird Sanctuary



Plate 1. Select breeding habitats of colonial nesting birds in Tamil Nadu

Photos by S. Jayakumar

3.3. Pesticide Consumption in Tamil Nadu

Among all the states in the country, Tamil Nadu, Andhra Pradesh, Uttar Pradesh and Maharashtra use large quantities of pesticides. These four states alone utilize about 48.8% of the total pesticide consumption in the country. The annual consumption of pesticides mainly for agricultural in India has crossed 50,583 metric tons (MT) from a mere 5,000 MT during 1960s (www.indiastat.com retrieved on 9th May 2013) as mentioned elsewhere in the thesis. Tamil Nadu seems to be stable in its consumption pattern. The consumption was 3324 MT in 2002-2003 and suddenly declined during 2003-2004 (figure 1). It again went up to 3940 during 2007-2008 and continued to be near stable (www.indiastat.com accessed on 27th May 2013).

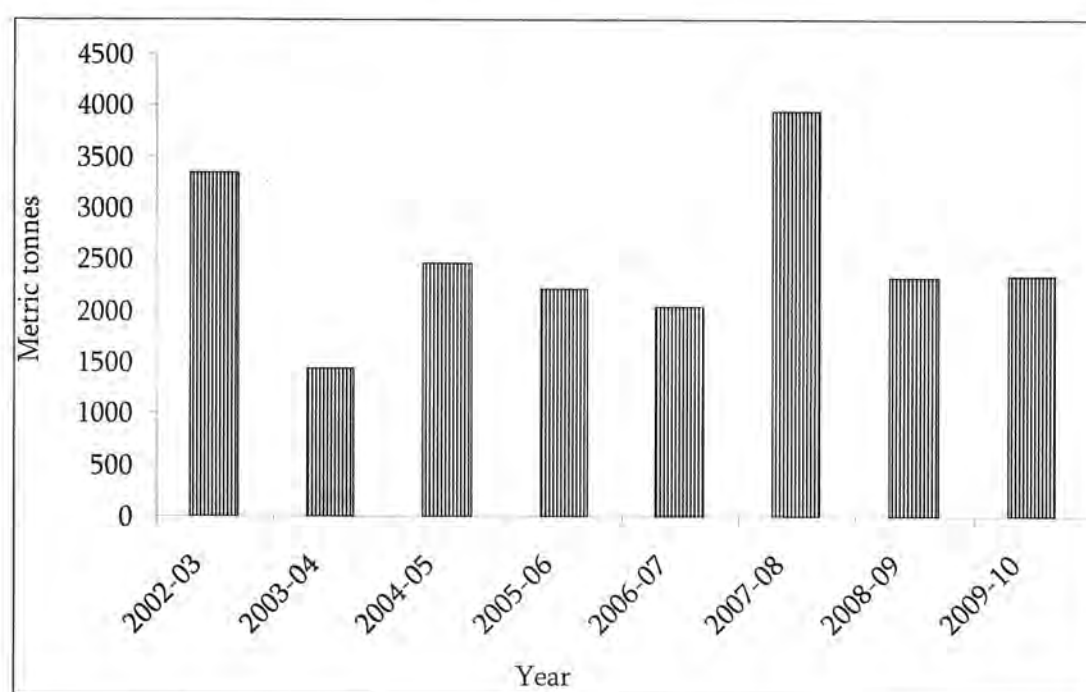


Figure 1. Pesticide consumption in Tamil Nadu (2002-2010).
(Source: www.indiastat.com accessed on 27th May 2013)

3.4. Preliminary field survey

Field surveys were conducted in Tamil Nadu to collect data on the population and breeding locations of colonial nesting birds. During the survey direct observations were made to estimate the number of species and individuals. Officials of the forest department and local people were consulted to gather historical information on breeding of birds. Data on agricultural practices, land-use pattern and pesticide application were also gathered. Additionally information available in literature was also compiled.



Spot-billed Pelican with chicks



Incubating Painted Stork

Plate 2. Major breeding birds in the study sites

Photos by S. Jayakumar



Intermediate Egret with chicks



Little Egret with chicks

Plate 2. Major breeding birds in the study sites

Photos by S. Jayakumar



Black-headed Ibis with chicks



Asian Openbill with chicks.

Plate 2. Major breeding birds in the study sites

Photos by S. Jayakumar

3.5. Rainfall and water depth

Rainfall data were gathered from the meteorological stations near Vedanthangal, Koonthankulam and Vettangudi Bird Sanctuaries in Tamil Nadu. A measuring tape attached to a 20 ft section of PVC pipe was used to measure the water depth at various zones in the Sanctuaries.

3.6. Population estimation

Population of colonial nesting birds was estimated by direct count method as has been employed by several workers for aquatic and other birds (Weller 1975; Shah *et al.*, 1983 and Sivasubramanian 1992). A pair of binoculars (Nikon 8 x 42) was used for counting birds. Care was taken to avoid double count by watching the birds' direction of flight and landing in case they are disturbed by predators or people. Population was estimated during breeding and non-breeding seasons. Density of colonial nesting birds was calculated using the following formula;

$$\text{Density} = \text{Number of individuals/ species /unit area}$$

3.7. Breeding biology

Direct observations using a pair of binoculars were made in the nesting areas. Counting of nests and adult birds in the nest, and observations on other aspects of breeding in nesting areas was made by approaching the colony by wading through water (Sivasubramanian 1992 and Kelly 2002), if the nesting trees were deep in wetlands. Monitoring effort involved the following four major steps:

Determine number of active nests early in the season: A nest was considered active if both the adults were present or if one adult was seen carrying nest material or incubating (plate 2).

Create a nesting panorama: The nesting panorama is a landscape sketch or photograph that indicates the location of the numbered nests. These nests were followed throughout the breeding season. Each panorama included an exact description of the viewing position, which was located far enough from the colony to avoid disturbance to the nesting birds.

Identify focal nests: Focal nests are numbered nests which were monitored through the season to measure nest survival. Observations were made in all three years (2007-2010) during breeding season. Breeding success of colonial nesting birds was calculated by number of chicks fledged /number of eggs laid in a nest.

3.8. Sample collection

Samples of fish were collected seasonally from Vedanthangal, Vettangudi and Koonthankulam Bird Sanctuaries. Questionnaire survey was conducted in the study area to know about the cropping pattern, application of pesticides and abundance of avian species. Sample collection was carried out seasonally from December 2007 to March 2010. Samples collected were fishes, dead birds and eggs. Collection of dead birds was opportunistic, while fishes and eggs were collected following standard methods.

a) Fish

Standard fishing gear, such as gill net and cast net were used for sampling. The gear net largely depended on the study site, vegetation cover and species of fishes to be caught. It may be noted that the number of species collected depended upon their availability. Totally 300 individuals belonging to nine species of commonly available fishes (plate 3) were collected seasonally i.e. non-breeding (April to September) and breeding season (October to March) every year with the help of local fishermen of the region. Morphometric measurements such as body weight and total length were recorded at the site of collection. All the samples were transported to the laboratory over ice.

b) Dead birds

Fortnight-surveys and extensive searches were made for dead birds in the study sites. About 76 individuals belonging to 14 species of birds found dead were collected from the intensive sites (plates 4 & 4.1) during the project period. All the birds collected were subjected to postmortem examination at the collection site itself, if possible. All the samples were preserved and sent to the laboratory at SACON over ice by courier without any delay, for contaminant analysis.



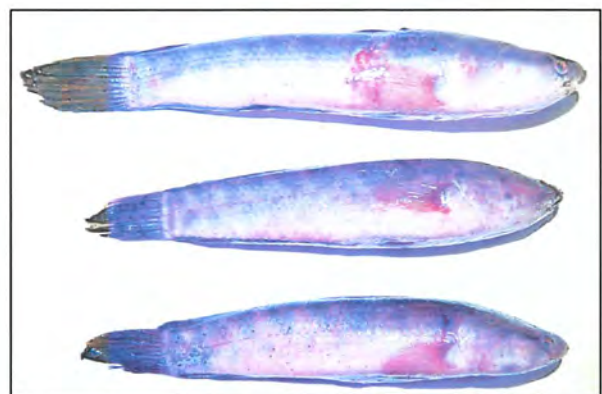
I) *Labeo rohita*



II) *Anabas testidineus*



III) *Heteropneustes fossilis*



IV) *Channa punctatus*



V) *Mystus vitatus*



VI) *Oreochromis mossambica*

Plate 3. Major species fishes collected from the study sites



I) Spot-billed Pelican



II) Little Egret



III) Indian Pond Heron



IV) Black-headed Ibis



V) Indian Cormorant



VI) Painted Stork

Plate 4. Notable species of colonial nesting birds collected dead from the study sites

Photos by S. Jayakumar



I) Grey Heron



II) Indian Cormorant



III) Spot-billed Pelican



IV) Painted Stork



V) Black-headed Ibis



VI) Great Egret

Plate 4.1. Various species of nestlings found dead during study period

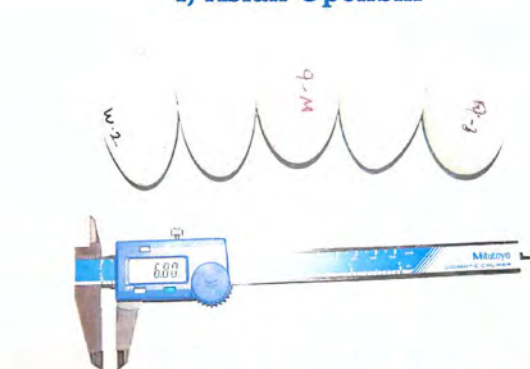
Photos by S. Jayakumar



I) Asian Openbill



II) Indian Pond Heron



III) Black-headed Ibis



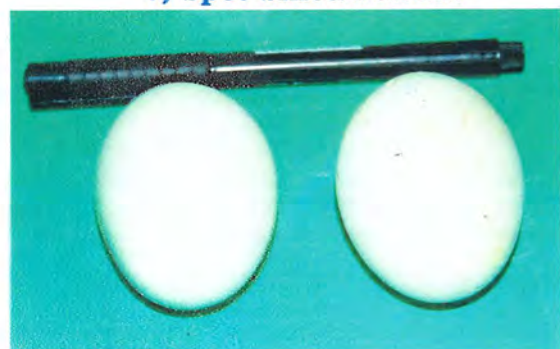
IV) Little Egret



V) Spot-billed Pelican



VI) Black-crowned Night Heron



VII) Painted Stork

Plate 5. Eggs of select species of colonial nesting birds collected from the study sites

Photos by S. Jayakumar

c) Eggs

Extensive searches were made during the breeding season to collect unhatched eggs from the study sites (plate 5). Additionally, systematic collection following 'sample egg method' was adapted to collect eggs from nest of seven species of birds (Custer *et al.*, 1990). Among the species studied, Painted Stork, Spot-billed Pelican and Black-headed Ibis were notable and near threatened species (IUCN, 2010). The collected eggs were wrapped in aluminum foil, transported over ice to the laboratory and refrigerated at 3-4°C until they were opened for chemical analysis. Egg samples were examined for cracks and other abnormalities. Each egg was cleaned with detergent in warm water and air dried prior to processing.

3.9. Sample processing

All the collected samples were processed in the laboratory using standard protocols.

I) Tissue of fishes and dead birds

About 10 g of tissue was weighed; ground with anhydrous sodium sulphate and the mixture was packed in a thimble (Whatman), and desiccated over night prior to extraction (El Nemr *et al.*, 2003). The desiccated thimble was loaded in a Soxhlet extractor and extracted with 250 ml of pesticide grade hexane (Merck) for 6 hr. The extract was condensed in a rotary flask evaporator to a specific aliquot (5 ml). The aliquot was then subjected to acid treatment by adding 2 ml of concentrated sulphuric acid then neutralized with saturated sodium hydroxide solution for high fat content tissues, if necessary. Further the sample was cleaned by placing on a glass column packed with silica gel (60-120 mesh size) and eluted with 250 ml of hexane. The eluate was again condensed in a rotary flask evaporator and stored in deep freezer at -20°C till the analysis with gas chromatograph.

II) Eggs

Each egg was weighed using top loading electronic balance, Metler AE420. Length and diameter were measured by Mitutoyo, 150 mm; Digimetric Caliper (Model 500-144). Egg samples were cut open along the equator with the help of scalpel and the contents were weighed and placed in well cleaned, and hexane rinsed glass jars. Until analysis samples were stored in deep freezer at -20°C. Eggshells were cleaned thoroughly and allowed to

dry in room temperature for four weeks prior to measuring thickness. Known quantity of egg contents were dried with required amount of anhydrous sodium sulphate (1:4) and ground with the help of pestle and mortar. Subsequently, Celite 545 and deactivated) aluminum oxide (5% water) (1:1) were added and mixed thoroughly. The resultant dry powder was loaded in a clean glass column (30 x 1.5 cm) for extraction and cleanup and eluted with 250 ml of dichloromethane and hexane in 1:3 ratio. The extracts with high fat contents were subjected to sulfuric acid treatment (Wardall 1977). The extracts were evaporated with rotary flask evaporator to almost dryness and reconstituted in 1 ml of hexane. Processed samples were stored in deep freezer at -20°C until analysis with gas chromatograph (GC).

III) Egg-shell measurement

Eggshell thickness was measured using digital micrometer (Mitutoyo, IP65, No. 395-271). Six measurements of the shell inclusive of shell membranes were taken at the equator; a mean thickness value for each egg was derived from these three measurements (Capein 1977).

3.10. Chemical analysis

Quantification of organochlorine pesticide residues was done with Hewlett-Packard 5890 Series II Gas Chromatograph equipped with Ni⁶³ Electron Capture Detector (ECD) and DB-608 fused silica capillary column (30 m x 0.32 mm x 0.5 µm) coated with 35% phenyl methyl polysiloxane. Chromatographic conditions were as follow: detector 300°C; injector 250°C; oven temperature was programmed as 180°C -3min; 4°C /min-260°C -15 min. All the samples were analysed for α -HCH, β HCH, δ HCH, γ HCH, Heptachlor epoxide, Dieldrin, p,p' DDT, p,p' DDE, p,p' DDD, α Endosulfan, β Endosulfan and Endosulfan sulfate. An equivalent mixture procured from Sigma Aldrich was used as standard. The concentrations of the individual compounds were quantified from the peak area of the samples to that of the corresponding external standard.

Recoveries of the compounds from fortified samples (50 ng/g) ranged from 91 to 102% and the results were not corrected for percent recovery and the results were expressed in wet weight basis. Analyses were run in batches of 10 samples plus four quality controls (QCs) including one reagent blank, one matrix blank, one QC check sample and one

random sample in duplicate. The minimum detection limit for compounds analysed was 1 ng/g.

3.11. Statistical analysis

Ranges were compiled from minimum and maximum values for levels detected in individuals for each toxicant studied. One, two or three way analysis of variance (ANOVA) was carried out. When there were significant differences, the Tukey's multiple comparison procedure was used to determine significant variations among means (Custer and Custer 1995 and Zar 1984). Kuruskal Wallis (1952) test also was carried to examine the significance in variation in colonial nesting birds population. The probability level determining significant differences was $P < 0.05$ for all statistical tests. Pearson's correlation coefficient was determined to test relationship. Cluster analysis was carried out to test the nesting and distribution association among birds. All these calculations were performed using statistical software, SPSS student version 10. The diversity (Shannon Wiener Index; Shannon and Wiener, 1949) and species richness was computed using Diversity and Richness Software 2.65.

4. Rainfall and water depth of the study sites

4.1. Rainfall

Rainwater is the lifeline of Sanctuaries and it is the deciding factor for the visiting migratory birds. Therefore the rainfall data were gathered from the meteorological stations near Vedanthangal, Koonthankulam and Vettangudi Bird Sanctuaries in Tamil Nadu. All the three sites received rainfall during North-east and South-west monsoons. It is noted that North-east monsoon which sets in October and continues up to December brought about 75% of the total rainfall. Only during 2008, there was more variation in rainfall with relatively high rainfall in March.

4.1.1. Vedanthangal

A decreasing trend was noticed in the total annual rainfall from 2007 to 2009. The maximum total rainfall was recorded during 2007, whereas the minimum was observed in 2009. Generally, Vedanthangal received higher rainfall from October to December except 2008. The highest rainfall (487 mm) was recorded in November 2009, whereas the lowest (9.5 mm) was recorded in March 2009 (Table 1).

Table 1: Monthly total rainfall (mm) observed in the Vedanthangal Bird Sanctuary during January 2007 to March 2010

Month	Year			
	2007	2008	2009	2010
January	0	34	11	0
February	40	65	0	0
March	0	203	9.5	0
April	40	0	0	*
May	37	28	33	*
June	76	38	27	*
July	122	37	0	*
August	288	161	146	*
September	91	90.3	156	*
October	424	268	31	*
November	99	397	487	*
December	382	53	111	*
Overall rainfall	1599	1374.3	1011.5	0

* Project was completed in March 2010

4.1.2. Koonthankulam

The maximum annual total rainfall was recorded during 2008, whereas the minimum was noted in 2010. Koonthankulam Bird Sanctuary had received higher rainfall between October and November. The highest total annual rainfall (395 mm) was recorded in November 2009, whereas the lowest (1 mm) was recorded in July and August 2007 (Table 2).

Table 2. Monthly total rainfall (mm) observed in the Koonthankulam Bird Sanctuary during January 2007 to March 2010

Month	Year			
	2007	2008	2009	2010
January	21.60	4.00	0.00	33.60
February	26.00	54.80	0.00	0.00
March	0.00	350.20	18.00	0.00
April	111.60	83.40	80.00	*
May	3.00	0.00	13.00	*
June	23.20	0.00	0.00	*
July	1.00	40.40	0.00	*
August	1.00	49.00	9.60	*
September	33.60	0.00	99.80	*
October	256.80	319.40	79.20	*
November	240.80	153.80	395.00	*
December	65.60	77.40	88.00	*
Overall rainfall	784.20	1132.40	782.60	33.60

* Project was completed in March 2010

4.1.3. Vettangudi

Usually, Vettangudi received higher rainfall during October to December. The highest total annual rainfall (296 mm) was recorded in October 2008, whereas the lowest (7 mm) rainfall was recorded in April 2007 (Table 3).

Table 3. Monthly total rainfall (mm) observed in the Vettangudi Bird Sanctuary during January 2007 to March 2010

Month	Year			
	2007	2008	2009	2010
January	0	0	0	0
February	0	35	0	0
March	0	219	0	0
April	7	63	54	*
May	0	64	68	*
June	208	76	38	*
July	52	167	30	*
August	257	134	139	*
September	44	113	143	*
October	187	296	82	*
November	62	183	34	*
December	191	67	94	*
Overall rainfall	1599	1374.3	1011.5	0

* Project was completed in March 2010

4.2. Water depth

Water level recorded in Vedanthangal, Koonthankulam and Vettangudi are given in tables 4 to 6. Among the study sites' the highest water depth was recorded in Vedanthangal (239.2 cm) followed by Vettangudi (178.4 cm) and Koonthankulam (148 cm). In all the three sites' the maximum water depth was noticed between December and February. All the three study sites are the major source of irrigation to adjacent crop fields. Therefore the water depth decreased after February. During summer the wetlands were dry, leaving only a few pools and puddles in deeper areas.

4.2.1. Vedanthangal

Monthly average water depth recorded in Vedanthangal Bird Sanctuary during 2007 - 2010 was varied. An increasing trend was noticed in water depth from 2009 to 2010. While maximum depth (248.1 cm) was recorded during February 2010, the minimum (92.8cm) was in September 2008. Vedanthangal holds higher water during monsoon and post monsoon periods (November to March) (table 4).

4.2.2. Koonthankulam

Monthly average water depth significantly varied in Koonthankulam Bird Sanctuary during 2007 - 2010. Koonthankulam Bird Sanctuary had more water during December to March. The highest (146.5 cm) average level was recorded in January 2010, whereas the lowest (25.7 cm) was in August 2009 (table 5).

4.2.3 Vettangudi

Monthly average water depth varied in Vettangudi Bird Sanctuary during 2007-2010. Vettangudi had the highest water level during monsoon and post monsoon periods (November to March). The highest (258.3 cm) average water depth was recorded during February 2009 and the lowest (25 cm) during July and August 2008 (table 6).

Table 4. Average water level (cm) recorded in Vedanthangal Bird Sanctuary during October 2007 to March 2010

Month	Year											
	2007			2008			2009			2010		
	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
January	-	-	-	247.4	45.7	609.6	245.2	45.7	609.6	237.3	76.2	320.0
February	-	-	-	245.2	45.7	600.0	244.3	45.7	609.6	248.1	60.9	320.0
March	-	-	-	239.8	45.7	598.0	244.9	45.7	609.6	246.2	60.9	320.0
April	-	-	-	182.4	45.0	598.0	155.4	30.5	289.6	*	*	*
May	-	-	-	156.0	38.0	240.0	202.7	91.4	289.6	*	*	*
June	-	-	-	146.5	30.0	182.9	219.8	182.9	259.1	*	*	*
July	-	-	-	122.9	30.0	243.8	206.6	121.9	243.8	*	*	*
August	-	-	-	108.6	28.0	200.0	182.1	121.9	200.0	*	*	*
September	-	-	-	92.8	28.0	130.0	92.8	28.0	140.0	*	*	*
October	180.4	70.0	318.0	187.2	75.0	212.0	188.8	120.0	210.0	*	*	*
November	232.3	75.0	320.0	237.9	60.0	324.0	239.3	75.0	320.0	*	*	*
December	238.3	75.0	320.0	239.2	55.0	320.0	238.8	75.0	320.0	*	*	*

Not available; Avg-Average; Min- Minimum; Max- Maximum, * Project was completed in March 2010

Table 5. Average water level (cm) recorded in Koonthankulam Bird Sanctuary during October 2007 to March 2010

Month	Year											
	2007			2008			2009			2010		
	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
January	-	-	-	101.0	25.0	220.0	146.5	50.0	190.0	146.5	45.0	185.0
February	-	-	-	116.5	25.0	230.0	147.9	50.0	200.0	145.5	45.0	185.0
March	-	-	-	112.2	25.0	230.0	141.3	48.0	195.0	138.8	40.0	185.0
April	-	-	-	107.0	25.0	200.0	77.4	28.0	89.0	*	*	*
May	-	-	-	61.5	35.0	90.0	64.0	10.0	86.0	*	*	*
June	-	-	-	45.2	35.0	58.0	44.7	30.0	60.0	*	*	*
July	-	-	-	30.2	25.0	35.0	31.5	25.0	35.0	*	*	*
August	-	-	-	26.8	20.0	30.0	25.7	20.0	30.0	*	*	*
September	-	-	-	Dry	Dry	Dry	Dry	Dry	Dry	*	*	*
October	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	*	*	*
November	50.0	20.0	60.0	44.3	35.0	55.0	60.3	14.0	100.0	*	*	*
December	100.9	30.0	220.0	148.0	90.0	230.0	73.0	15.0	140.0	*	*	*

- Not available; Avg-Average; Min- Minimum; Max- Maximum, * Project was completed in March 2010

Table 6. Average water level (cm) recorded in Vettangudi Bird Sanctuary during October 2007 to March 2010

Month	Year											
	2007			2008			2009			2010		
	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
January	-	-	-	51.7	25.0	64.0	189.7	65.0	295.0	Dry	Dry	Dry
February	-	-	-	51.6	25.0	64.0	258.3	63.0	840.0	Dry	Dry	Dry
March	-	-	-	30.4	25.0	35.0	178.3	70.0	260.0	Dry	Dry	Dry
April	-	-	-	29.9	25.0	34.0	73.8	20.0	120.0	*	*	*
May	-	-	-	28.6	20.0	31.0	71.9	30.0	100.0	*	*	*
June	-	-	-	26.8	23.0	29.0	42.4	25.0	55.0	*	*	*
July	-	-	-	25.0	23.0	26.0	35.8	25.0	46.0	*	*	*
August	-	-	-	25.0	23.0	26.0	34.0	25.0	40.0	*	*	*
September	-	-	-	65.9	30.0	90.0	57.2	30.0	90.0	*	*	*
October	98.4	30.0	151.5	79.1	30.0	110.0	45.9	25.0	65.0	*	*	*
November	97.9	30.0	150.5	94.9	30.0	150.0	43.8	25.0	58.0	*	*	*
December	76.4	30.0	95.0	178.4	46.0	285.0	30.8	25.0	35.0	*	*	*

- Not available; Avg-Average; Min- Minimum; Max- Maximum, * Project was completed in March 2010

RESULTS AND DISCUSSION



5. RESULTS AND DISCUSSION

5.1.1. Distribution of heronries in Tamil Nadu

Field surveys were conducted between March and September 2007 in 41 known heronries in 14 districts. Nineteen out of forty one heronries were reported as Important Bird Area in Tamil Nadu (Islam and Rahmani 2004) and the details are given in the table 7. The distribution of heronries shows that not all the districts in Tamil Nadu have ideal breeding locations for colonial nesting birds. Number of heronries located in Thirunelveli (8), Kanyakumari (7) and Ramanathapuram (6) (figure 2) was relatively more. The remaining districts held between one and three sites which are similar to what Subramanya (2005) had reported. This does not mean that there are no heronries in other districts. There may be a few smaller ones, but additional surveys may be needed. For example Pudukottai, a district with many irrigation tanks in the villages (Vijayan *et al.*, 2004) might support a few smaller heronries.

The present inventory of heronries in Tamil Nadu may not be complete. Based on the three physiographic zones, it can be differentiated into four distinct clusters of heronries. Starting from the northern border, these clusters are distributed as given below; four heronries in Tiruvallur-Chennai-Kancheepuram; 11 heronries (along the Cauvery River from Erode through Tiruchirapalli and Thanjavur) in the entire Cauvery delta spread over the districts of Perambalur-Nagapattinam-Thiruvarur and Thanjavur; four in Madurai and Sivagangai plains; six in Ramanathapuram district, 18 in Thirunelveli-Thoothukudi-Virudunagar districts and in the extreme south around Kanyakumari. The effect of the alluvial plains of the Cauvery delta, favoring paddy cultivation and heronries appear to be similar to that of Krishna and Godavari deltas in Andhra Pradesh (Subramanya 2003 and 2005). Moreover looking at the distribution of heronries based on the physiographic divisions as mentioned earlier, very interestingly, more than seventy five percentage of the heronries listed in table 10 are found in lower plains along the east coast. According to Subramanya (2005), the distribution of heronries matched with occurrence of major wetlands within Tamil Nadu. It is understood from the present study, that more number of heronries are located in Thirunelveli, Kanyakumari and Cauvery delta. Similarly large numbers of irrigation tanks present in the Cauvery delta serve as major foraging and nesting sites for many species of colonial nesting birds.

Table 7. Details of heronries in various districts of Tamil Nadu.

S. No.	Name of the heronry	District	Nesting species	Breeding Season
1	Udayamarthandapuram Bird Sanctuary	Thiruvavarur	LC, GH, BCNH, IPH,	October-January
2	Vaduvoor Bird Sanctuary (IBA)		LE, GH, AOB, IPH, BCNH	October to March
3	Muthupet Mangrove		-	-
4	Vellode Bird Sanctuary	Erode	LC, IC, D, LE, GH, IME	November-January
5	Avalpoondarai Lake		LC, LE, BCNH, IPH	November-March
6	Veeranam Lake (IBA)	Cuddalore	LE, GH, AOB, BCHN, PS	November - March
7	Pitchavaram Mangrove		-	-
8	Vedanthangal Bird Sanctuary (IBA)	Kancheepuram	SBP, LC, IC, D, LE, GH, GE, IPH, BCNH, PS, AOB, BHI, GI, ESB, WTK,	October - March
9	Karikili Bird Sanctuary (IBA)		SBP, LC, IME, BCNH, PS, AOB	October - March
10	Guindy National Park	Thiruvallur	LE, BCNH, BHI, PS, SBP,	November-March
11	Aringer Anna Zoological Park		LE, BCNH, BHI, PS, SBP,	November-March
12	Point Calimere Wildlife Sanctuary (IBA)	Nagappattinam	BCNH	October-December
13	Karaivetti Bird Sanctuary (IBA)	Perambalur	SBP, D, LC, LE, GH, BCNH, PS, AOB, BHI, ESB	November-March
14	Vandioor Wetland (IBA)	Madurai	-	-
15	Kunnathur Wetland (IBA)		-	-
16	Vettangudi Bird Sanctuary (IBA)	Sivagangai	LC, D, LE, IME, BCNH, AOB, BHI	October-February
17	Periyakollugudipatti Kanmai		LC, D, LE, IME, BCNH, AOB, BHI	October-February
18	Big Tank (Parai Kanmai) (IBA)	Ramanathapuram	AOB, IME, LE, BHI	October-January
19	Sakkarakottai Kanmai (IBA)		-	-
20	Kanjirankulam Bird Sanctuary (IBA)		SBP, LC, D, LE, GH, BCHN, AOB, PS, BHI	November to March
21	Chitrangudi Bird Sanctuary (IBA)		SBP, LC, D, LE, GH, BCHN, AOB, PS, BHI, ESB	October - March

Table 7. Continued...

S. No.	Name of the heronry	District	Nesting species*	Breeding Season
22	Melaselvanoor Bird Sanctuary	Ramanathapuram	SBP, LC, D, LE, GH, BCHN, AOB, PS, BHI	October - March
23	Keelaselvanoor Bird Sanctuary		SBP, LC, D, LE, GH, BCHN, AOB, PS, BHI	October - March
24	Uthirakasakulam Kanmai	Thirunelveli	-	-
25	Ariyakulam Kanmai		-	-
26	Nainarkulam Kanmai		-	-
27	Moondradaippu Kanmai		-	-
28	Poolam Kanmai		-	-
29	Manikakulam Kanmai		-	-
30	Koonthankulam Bird Sanctuary (IBA)		SBP, LC, IC, D, LE, IME, GH, GE, IPH, BCNH, PS, BHI, AOB, GI, ESB, WTK, BI	November-June
31	Thirupudaimaruthur Bird Sanctuary	Tuticorin	LC, CE, LE, IME, PS,	December-January
32	Vallanadu Black Buck Sanctuary		-	-
33	Watrap Periyakulam Kanmai (IBA)	Virudhunagar	-	-
34	Veerakasamuthirakulam Kanmai (IBA)		-	-
35	Sankarapandipuram Kanmai	Kanyakumari	PS, LE, IME, BCNH	September-January
36	Pudhukiramam Kanmai		-	-
37	Suchindram Wetland (IBA)		-	-
38	Theroor Wetland (IBA)		-	-
39	Vembanoor Wetland (IBA)		-	-
40	Manakkudi Tank		-	-
41	Nagercoil-Municipal park		-	-

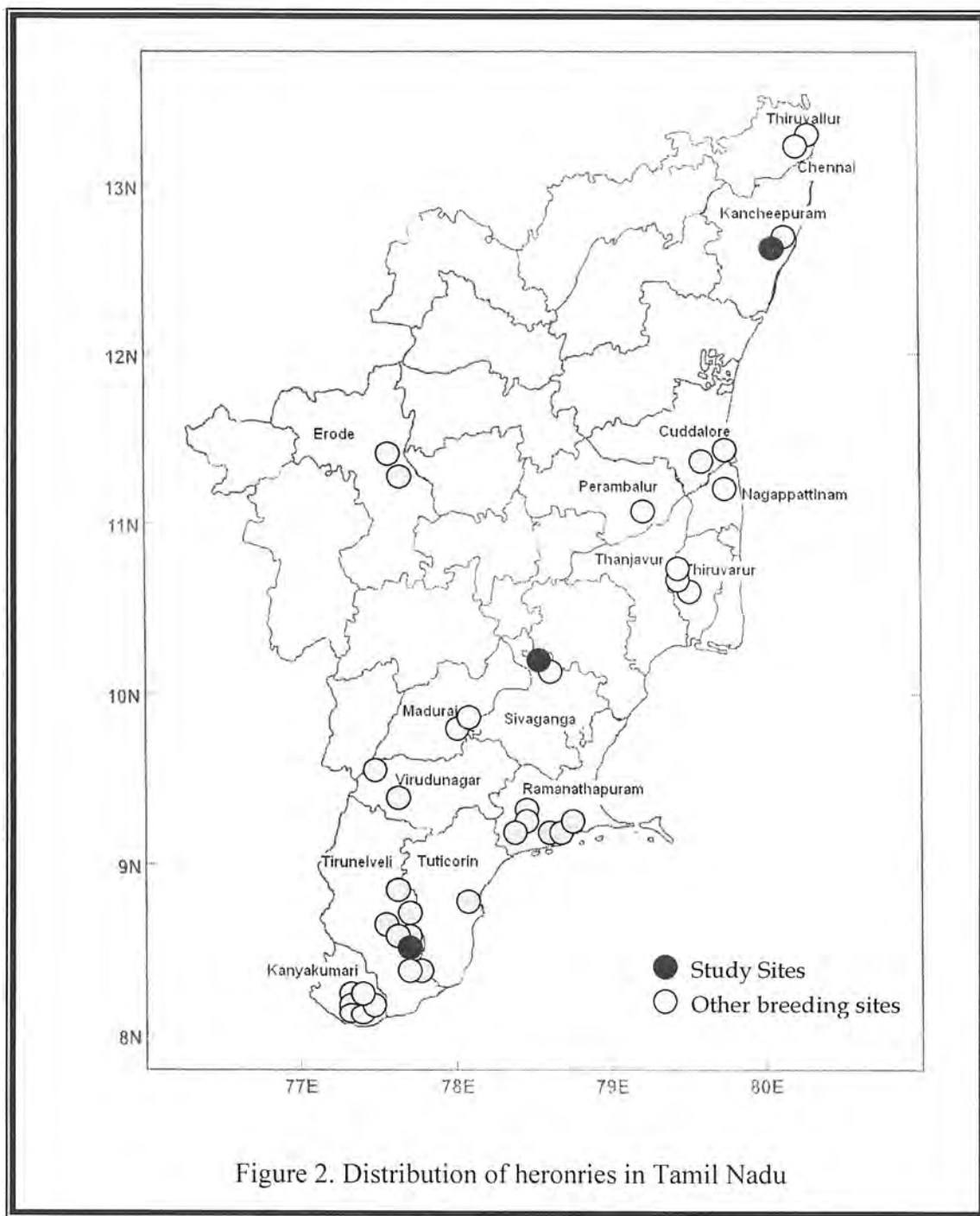
LC- Little Cormorant, IC- Indian Cormorant, D-Darter, GH- Grey Heron, BCHN- Black-crowned Night Heron, IPH- Indian Pond Heron, LE- Little Egret, IME- Intermediate Egret, AOB- Asian Openbill, PS- Painted Stork, SBP- Spot-billed Pelican, BHI - Black-headed Ibis, GI- Glossy Ibis, BI- Black Ibis, WTK- White-throated Kingfisher, ESB- Eurasian Spoonbill, IBA- Important Bird Area, - Not known.

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5.1.2. Richness and diversity of colonial nesting birds in different districts in Tamil Nadu

During the surveys, around 40 species of wetland birds were recorded (figure 3). Of which 24 were colonial nesting birds. 17 species of colonial nesting birds were recorded in Kanyakumari district followed by Cuddalore (16), Kancheepuram (14), Perambalur (14), Thiruvarur (14) and Thirunelveli (14). While no bird was found in any of the wetlands surveyed in Virudhunagar district due to lack of water, three species of birds were found in Tuticorin district. Most of the species recorded were largely from six locations, namely Karaivetti Bird Sanctuary in Perambalur, Pitchavaram Mangroves in Cuddalore, Vedanthangal Bird Sanctuary in Kancheepuram, Koonthankulam Bird Sanctuary in Thirunelveli, Vettangudi Bird Sanctuary in Sivagangai and Udayamarthandapuram Bird Sanctuary in Thiruvarur district.

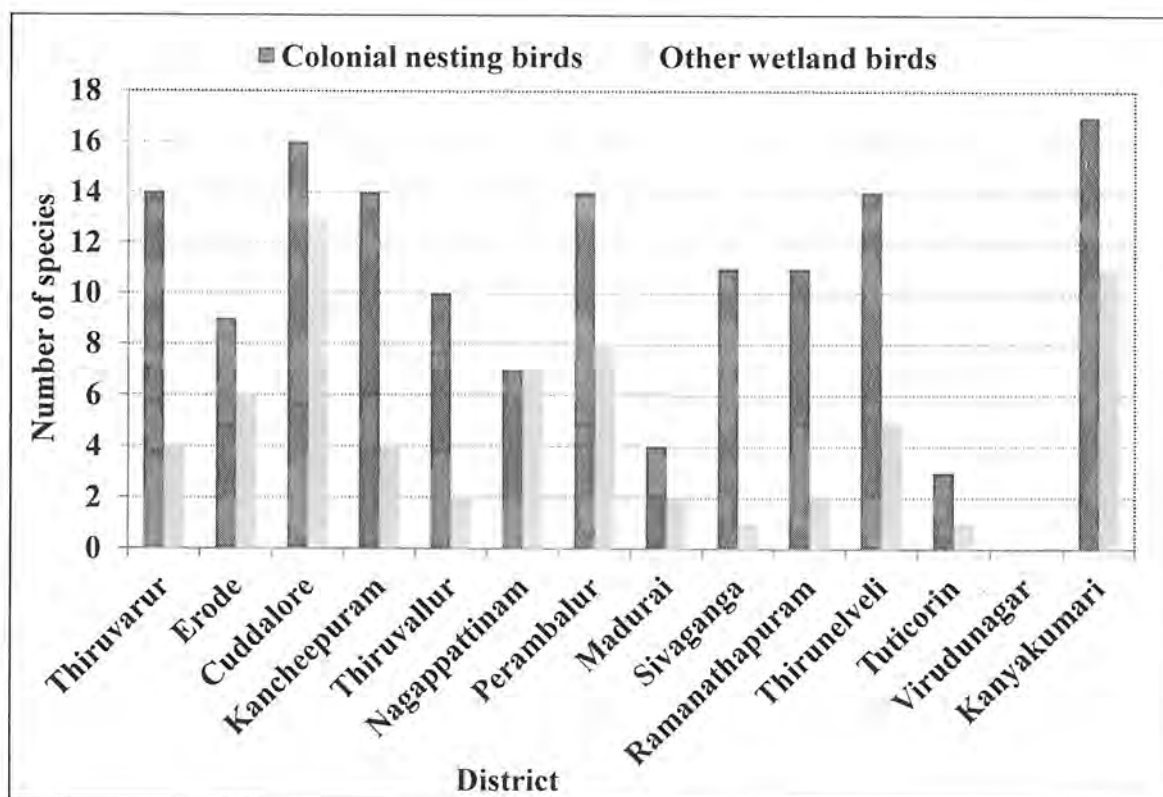


Figure 3. Number of colonial nesting and other species of birds in the wetlands surveyed in Tamil Nadu (March- September 2007).

Shannon Wiener Index was estimated to know the diversity of colonial nesting birds in various districts in Tamil Nadu and the results are given in table 8. Among the 14 districts surveyed, Kanyakumari had the highest diversity (H' 2.16) followed by Cuddalore (H'

2.15) and Ramanathapuram ($H' 2.09$), whereas Nagapattinam ($H' 0.69$) had the least. Virudhunagar and Tuticorin districts did not have any birds.

Table 8. Diversity of colonial nesting birds in various districts between March and September 2007

S. No.	District	Shannon Wiener Diversity (H')	Variance H
1	Thiruvarur	1.90	0.001
2	Erode	1.40	0.001
3	Cuddalore	2.15	0.000
4	Kanchipuram	1.67	0.000
5	Thiruvallur	1.45	0.000
6	Perambalur	1.65	0.001
7	Nagapattinam	0.69	0.000
8	Madurai	0.82	0.003
9	Sivagangai	1.71	0.003
10	Ramanathapuram	2.09	0.002
11	Thirunelveli	1.98	0.002
12	Tuticorin	0	0
13	Virudhunagar	0	0
14	Kanyakumari	2.16	0.001

Species richness recorded in the present study is almost similar to what Guptha *et al.*, (2011) had reported in various wetlands in Coimbatore, Trichirappalli, Perambalur, Thiruvarur, Kanyakumari, Nagapattinam, Cuddalore and Thanjavur districts in Tamil Nadu. They had reported 47 species of wetland birds various districts in Tamil Nadu. Among them, Perambalur had 31 species followed by Cuddalore with 27 species. Thiruvarur and Thanjavur districts had 14 and 13 species, respectively.

Similar to richness, diversity index recorded in the present study (Kanyakumari (2.16) followed by Cuddalore (2.15), which is comparable to the diversity index (1.59 to 2.66 H') reported by Guptha *et al.* (2011) in various wetlands of Tamil Nadu. Diversity of wetland birds recorded in the present study matches with the number of heronries and other wetlands in Tamil Nadu. For examples, Kanyakumari and Ramanathapuram districts had six to seven heronries along with many village ponds and lakes. Among the 13 heronries situated in these districts, seven have been already declared as Import Bird Area (Islam and Rahmani 2004). Further, Kanyakumari district has 2633 freshwater ponds which irrigate around 55,000 hectares of land. The area also supports a rich array

of floral and faunal diversity including birds (Sathia Geetha 2010). Although Cuddalore district had fewer heronries, Veeranam Lake and Pitchavaram mangrove were the two important IBS sites which had the highest bird diversity. Virudhunagar and Tuticorin districts do not appear to support bird life due to scarcity of water. Felling of nesting trees was also noticed during the study period.

According to Weller (1999), wetlands are the most important habitats to water birds for their feeding, roosting and breeding. Vijayan *et al.* (2004) studied the importance of wetlands and their future conservation needs in Tamil Nadu. According to their survey, Chengalpattu district contained larger area of wetlands (114.09 sq. km) followed by Cuddalore with 73.47 sq. km and Tirunelveli (28.15 sq. km). Therefore, it is obvious that water logged areas such as ponds, lakes, reservoirs, tanks and rivers are the prime factor determining the distribution of wetland dependent birds including colonial nesting birds in Tamil Nadu.

5.1.3. Richness and diversity of colonial nesting birds in different heronries in Tamil Nadu

Abundance among the Sanctuaries studied, was the highest in Karaivetti Bird Sanctuary and Pitchavaram mangrove with 14 species each. While Udayamarthandapuram Bird Sanctuary had an abundance of 12, four sanctuaries had just one. The remaining 13 Sanctuaries as shown in figure 4 did not have any birds probably due to lack of water during the survey.

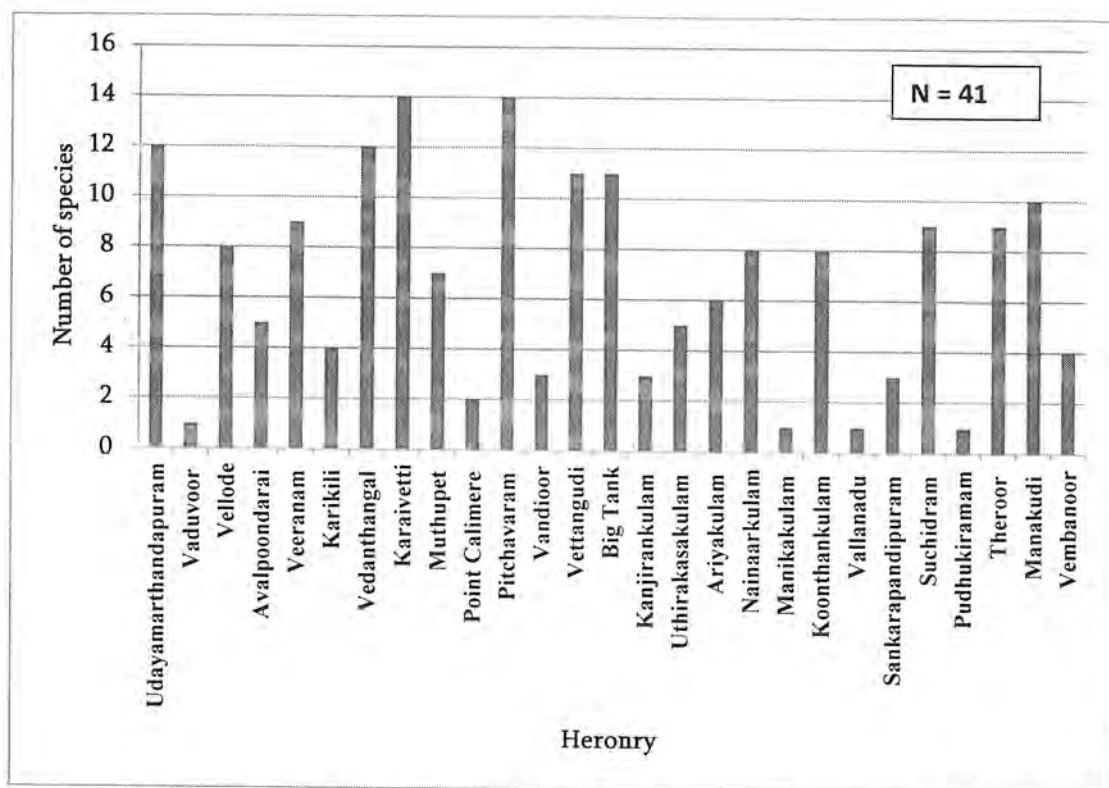


Figure 4. Species richness in different heronries of Tamil Nadu

Shannon Wiener Index was estimated to know the diversity of colonial nesting birds in various heronries in Tamil Nadu and the results are given in table 9. Among the 41 heronries studied, the highest diversity (H' 2.09) was recorded in Big Tank in Ramanathapuram district followed by Manakudi Tank (H' 1.974) in Kanyakumari district and Pitchavaram mangroves (H' 1.909) in Cuddalore district, while the lowest diversity was observed in Avalpoondarai Lake in Erode district and Point Calimere Wildlife Sanctuary in Nagapattinam district. Due to lack of birds diversity index could not be calculated for the remaining 16 heronries.

Table 9. Diversity of colonial nesting birds in various locations in Tamil Nadu between March and September 2007

S. No.	Location	Shannon Wiener Diversity (H')	Variance H
1	Udhayamarthandapuram Bird Sanctuary	1.46	0.001
2	Vaduvloor Bird Sanctuary	0	0
3	Vellode Bird Sanctuary	1.50	0.002
4	Avalpoondarai Lake	0.65	0.001
5	Veeranam Lake	1.67	0.000
6	Karikili Bird Sanctuary	1.33	0.017
7	Vedanthangal Bird Sanctuary	1.64	0.000
8	Karaivetti Bird Sanctuary	1.65	0.001
9	Muthupet Mangrove	1.65	0.002
10	Point Calimere Wildlife Sanctuary	0.69	0.000
11	Pitchavaram Mangrove	1.90	0.001
12	Vandiyur Wetland	0.82	0.003
13	Kunnathur Wetland	0	0
14	Vettangudi Bird Sanctuary	1.71	0.003
15	Periya Kollukudi Tank	0	0
16	Big Tank	2.09	0.002
17	Sakarakottai Tank	0	0
18	Kanjirankulam Bird Sanctuary	0.93	0.040
19	Chitrakudi Bird Sanctuary	0	0
20	Melaselvanoor Bird Sanctuary	0	0

Table 9. Continued...

S. No.	Location	Shannon Wiener Diversity (H')	Variance H
21	Melaselvanoor Bird Sanctuary	0	0
22	Uthirakasakulam Tank	1.42	0.017
23	Ariyakulam Tank	1.54	0.022
24	Nainaarkulam Tank	1.62	0.003
25	Moondradaippu Tank	0	0
26	Thirupudaimaruthur Reserve	0	0
27	Poolam Tank	0	0
28	Manikakulam Tank	0	0
29	Koonthankulam Bird Sanctuary	1.58	0.016
30	Vallanadu black Buck Sanctuary	0	0
31	Watrap-Periyakulam Tank	0	0
32	Veerakasamuthirakulam Tank	0	0
33	Sankarapandipuram Tank	0.77	0.005
34	Suchidram Wetland	1.48	0.003
35	Pudhukiramam Wetland	0	0
36	Theroor Wetland	1.29	0.003
37	Manakudi Tank	1.97	0.001
38	Nagarcoil-Municipal Park	0	0
39	Vembanoor Wetland	0.96	0.018
40	Guindy National Park	1.16	0.010
41	Aringer Anna Zoological Park	1.61	0.004

Number of species reported in the present study is lower than the species reported by Guptha *et al.* (2011) in the same sites during 2006. They had reported the species richness to be 27, 25, 15, 24, 17, 31 and 22 in Sucindram, Theroor, Vembanoor, Vaduvor, Veeranam, Karaivetti and Udhayamarthandapuram respectively. The variation in species richness from that of the present study could be due to the local movements of waterbirds to the neighboring wetlands and agricultural fields as reported by Subramanya (2005). Moreover, Guptha *et al.* (2011) reported all the wetland birds including ducks, coots and

jacana, while in the preset study we have compiled richness of only the heronry birds such as herons, egrets, storks, pelicans, cormorants and ibises.

The highest diversity (2.09) of birds was recorded in Big tank (Ramanathapuram district), which is one among the well maintained and protected IBAs in Tamil Nadu, whereas the lowest bird diversity (0.65) was observed in Avalpoondarai lake (Erode district), which is in human disturbed area. Variations in diversity among various locations studied were observed. This might be due to differing habitat conditions for roosting/ nesting/ feeding and availability of food as reported by several researchers in India (Sampath and Krishnamoorthy 1989; Sivasubramanian 1992; Sridharan 2003 and Guptha *et al.*, 2011).

Based on the results of the study, we could conclude that timely availability of water, safe habitats and food sources for both adults and nestlings along with essential nesting and roosting sites in and around the heronries are important for the occurrence and abundance of aquatic birds. Other factors, such as water depth and water quality could also influence the abundance and diversity of aquatic birds.

5.1.4. Distribution of colonial nesting birds in Tamil Nadu

With respect to species distribution, Little Egret, Little Cormorant and Indian Pond Heron were found in nearly twenty heronries in Tamil Nadu followed by Black-headed Ibis, Darter, Cattle Egret, Asian Openbill and Painted Stork. Black-crowned Night Heron, Common Kingfisher, Glossy Ibis, Great Egret, Grey Heron, Indian Cormorant, Intermediate Egret, Oriental Stork, Pied Kingfisher, Purple Heron, Spot-billed Pelican and Eurasian Spoonbill were observed in less than 10 heronries. Black Ibis and Woolly-necked Stork were found only in one place (figure 5).

An analysis of the frequency of occurrence of colonial nesting birds across different districts revealed four distinct groups (figure 6). While the Little Egret, Little Cormorant and Indian Pond Heron were species with wide spread distribution in Tamil Nadu, the group that had highly restricted distribution was Indian Cormorant, Little Heron, Great Egret, Oriental Stork, Black Ibis, Eurasian Spoonbill and Woolly-necked Stork. The group that had partially restricted distribution included Pied Kingfisher, Purple Heron, Glossy Ibis, Grey Heron and Spot-billed Pelican. The rest of the species were highly restricted.

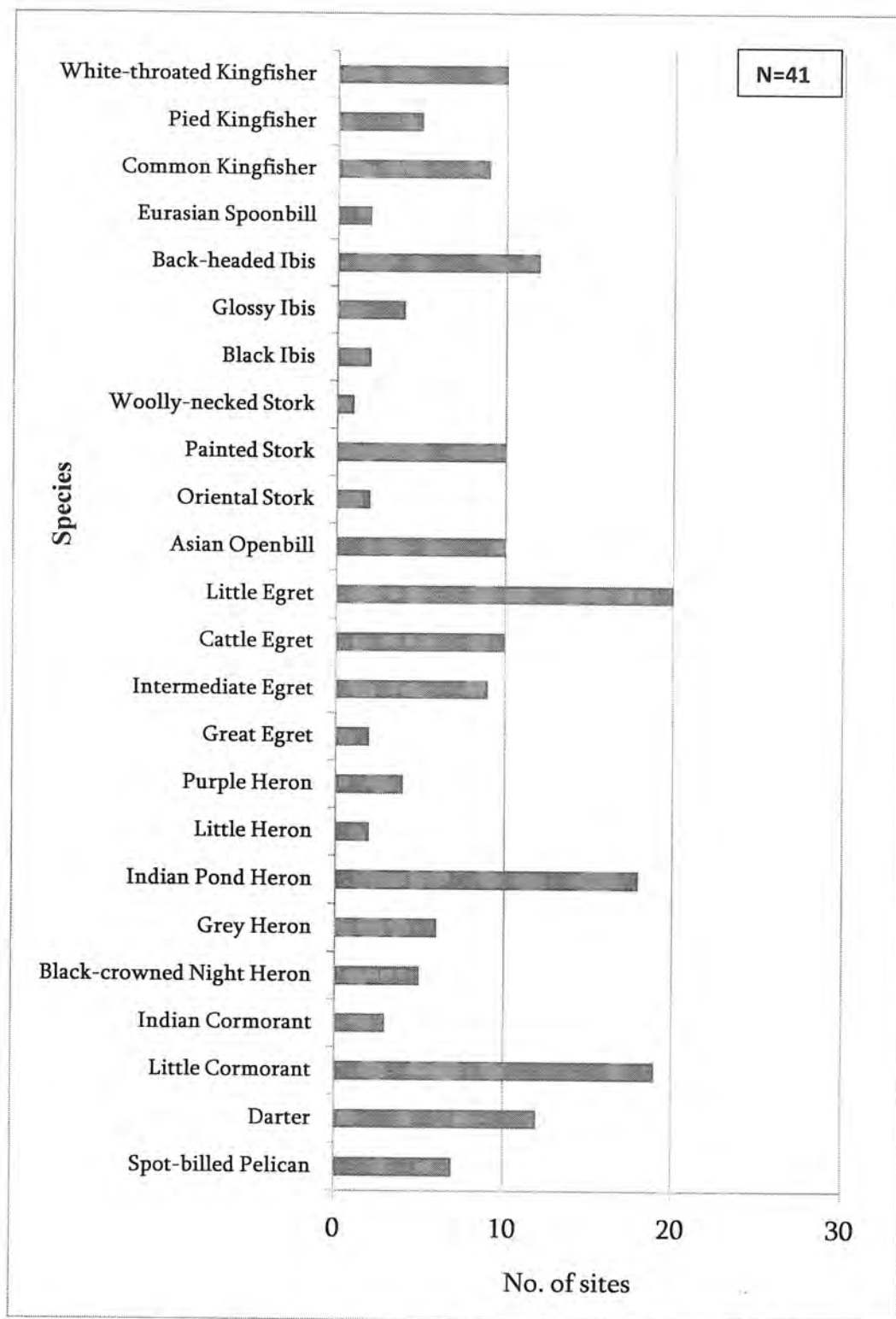


Figure 5. Species distribution in different heronries in Tamil Nadu.

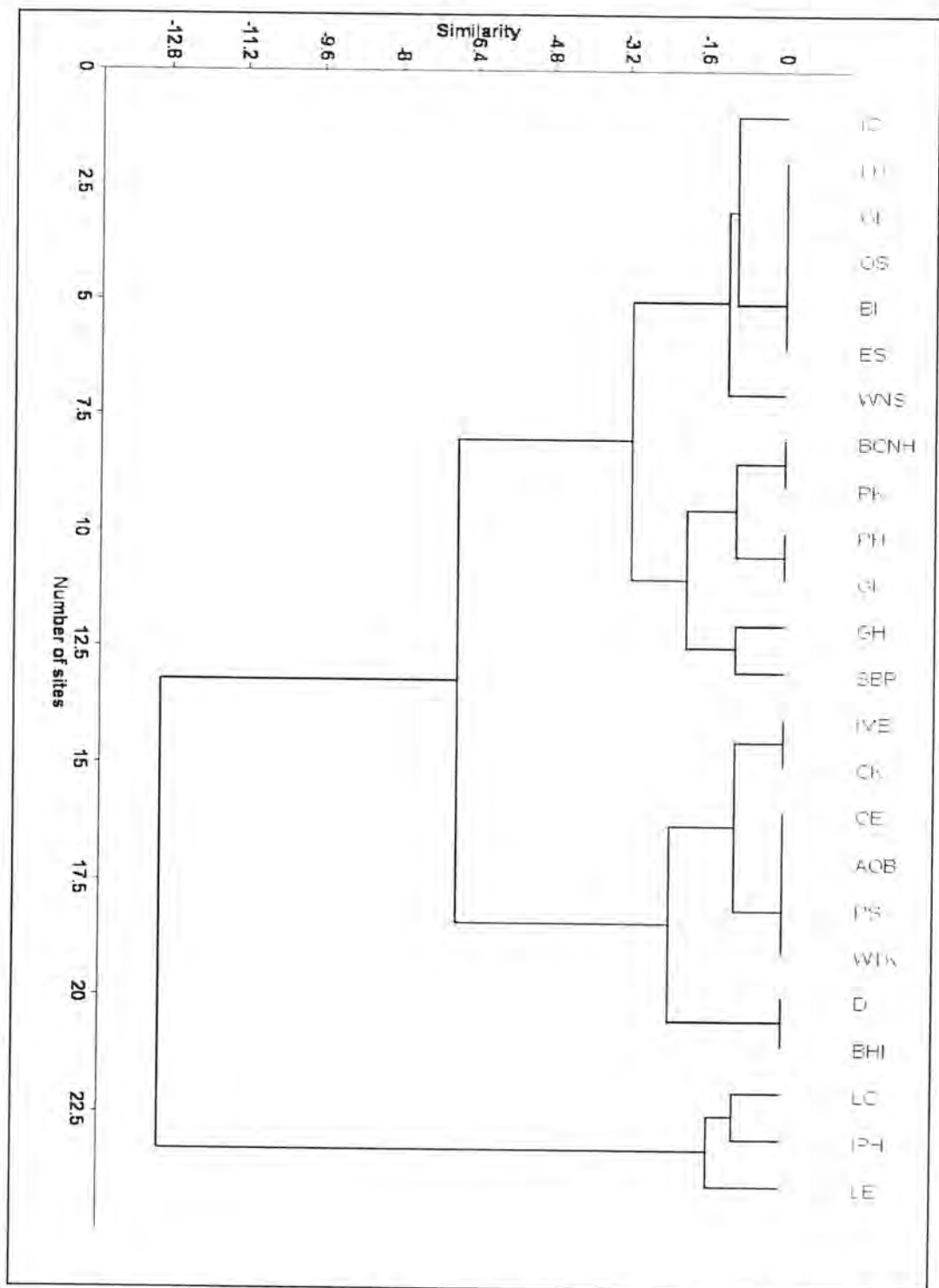


Figure 6. Dendrogram showing the grouping of different species of birds in terms of distribution in Tamil Nadu

LC-Little Cormorant, IC-Indian Cormorant, D-Darter, GH-Grey Heron, BCHN- Black-crowned Night Heron, IPH- Indian Pond Heron, LE-Little Egret, IME-Intermediate Egret, AOB-Asian Openbill, PS-Painted Stork, SBP-Spot-billed Pelican, BHI, Black-headed Ibis, GI-Glossy Ibis, BI-Black-Ibis, WTK-white-throated Kingfisher, ESB-Eurasian Spoonbill.

5.1.5. Distribution of colonial nesting birds in the heronries in Tamil Nadu

Eighteen out of 26 species of colonial nesting water birds, namely Spot-billed Pelican (SBP), Indian Cormorant (IC), Little Cormorant (LC), Darter (D), Little Egret (LE), Great Egret (GE), Cattle Egret (CE), Intermediate Egret (IME), Black-crowned Night Heron (BCNH), Grey Heron (GH), Indian Pond Heron (IPH), Asian Openbill (AOB), Painted Stork (PS), Black Ibis (BI), Glossy Ibis (GI), Black-headed Ibis (BHI), Eurasian Spoonbill (ESB) and White-throated Kingfisher (WTK) are known to breed in Indian heronries (Subramanya 1996 a, b). Black-crowned Night Heron is the most common nesting species. It breeds in about 18 sites in Tamil Nadu.

Similarly, the Little Egret, Little Cormorant, Asian Openbill, Painted Stork and Black-headed Ibis breed in 17, 14, 13, 11 and 11 sites respectively. Spot-billed Pelican and Darter were found to nest in 10 sites each and rest of the species in less than 10 sites. Black Ibis, Cattle Egret, Glossy Ibis and Great Egret were the least common of all the nesting species, found only in less than two sites (figure 7) which are almost similar to what Subramanya (2005) had reported in Tamil Nadu.

An analysis of the information currently available on the breeding of colonial nesting birds across different districts in Tamil Nadu revealed five distinct groups (figure 8). While the Painted Stork, Black-headed Ibis, Darter and Spot-billed Pelican were wide spread breeding species in Tamil Nadu, the group that had a few breeding of species included Cattle Egret, Black Ibis, Indian Cormorant, Great Egret, Glossy Ibis and White-throated Kingfisher. Near threatened species, namely Spot-billed Pelican, Black-headed Ibis, Darter and Painted Stork appeared to be doing well in Tamil Nadu with 10 active nesting sites. In Tamil Nadu, Koonthankulam is the only heronry where all the three species of ibises nest together.

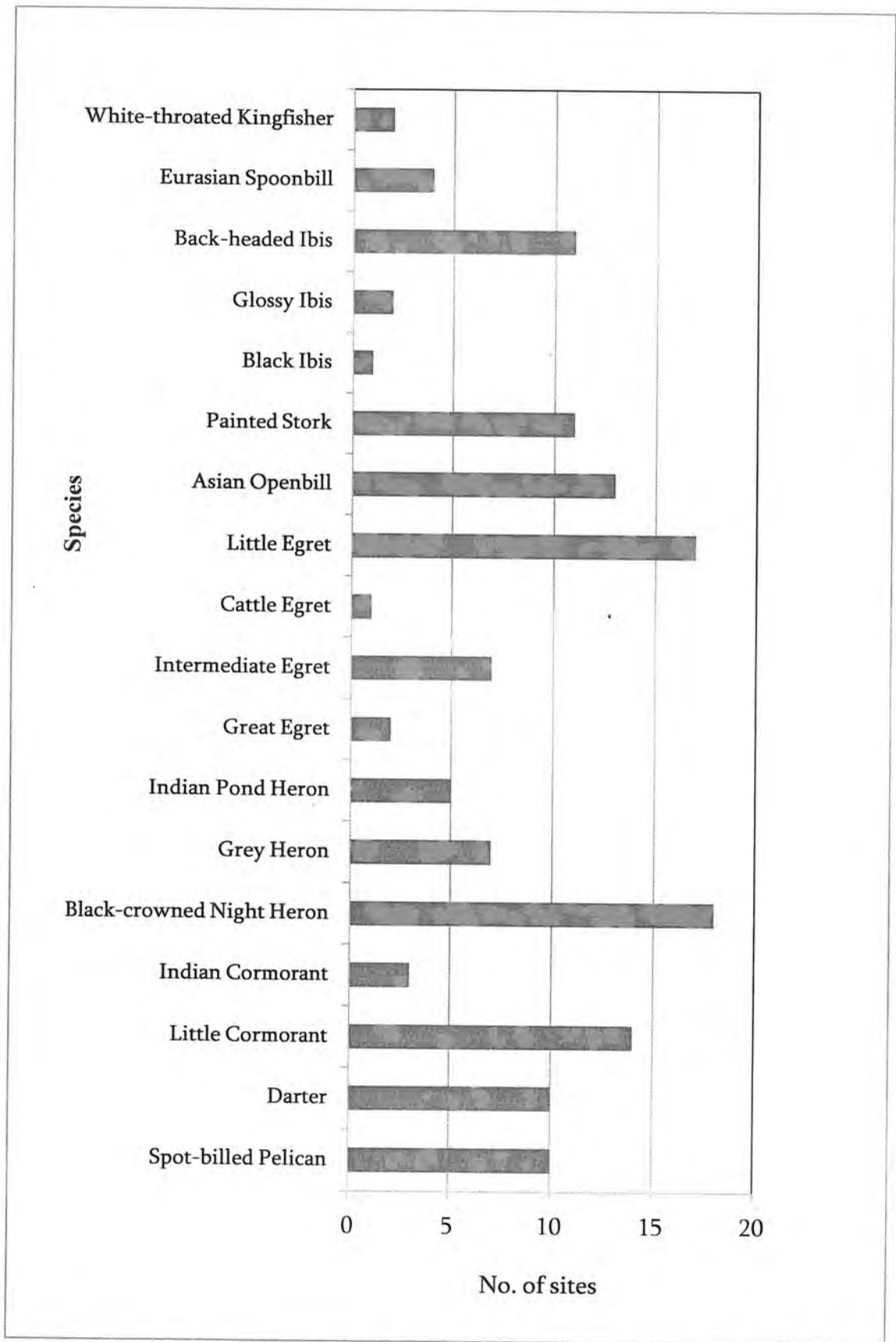


Figure 7. Distribution of nesting species in different heronries in Tamil Nadu.

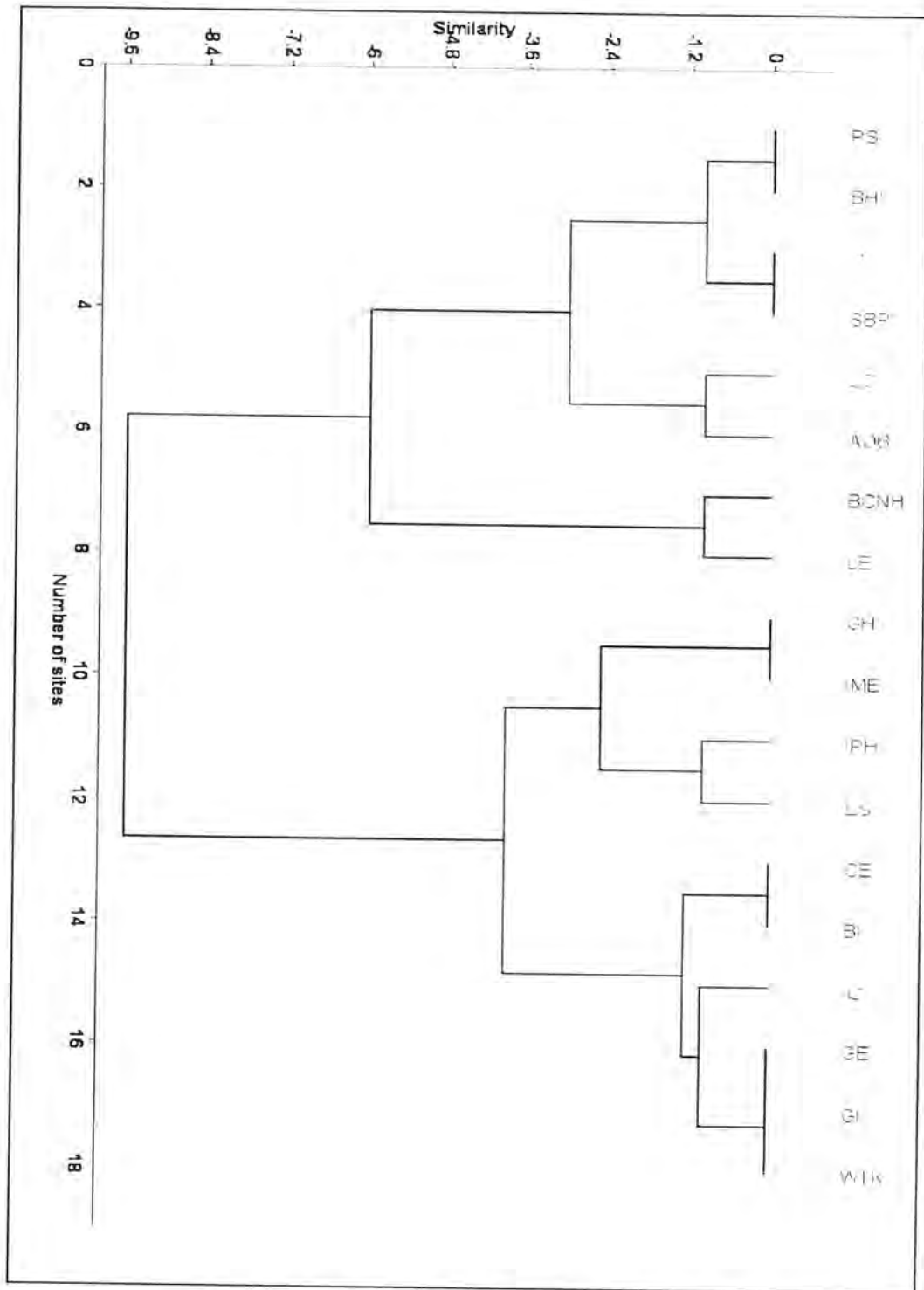


Figure 8. Dendrogram showing the grouping of different species of birds based on their nesting distribution in Tamil Nadu.

LC-Little Cormorant, IC- Indian Cormorant, D-Darter, GH-Grey Heron, BCHN- Black-crowned Night Heron, IPH- Indian Pond Heron, LE-Little Egret, IME-Intermediate Egret, AOB-Asian Openbill, PS-Painted Stork, SBP-Spot-billed Pelican, BHI, Black-headed Ibis, GI-Glossy Ibis, BI-Black-Ibis, WTK-white-throated Kingfisher, ESB-Eurasian Spoonbill.

With respect to species distribution, Little Egret, Little Cormorant and Indian Pond Heron were found in nearly twenty heronries in Tamil Nadu followed by Black-headed Ibis, Darter and Painted Stork. Occurrence of these species in the present study is similar to what Subramanya (2005) had reported in Tamil Nadu. Ali and Ripley (1969) also highlighted that these species are the most common heronry birds found in almost all sort of wetlands in India. According Subramanya (2005) the distribution of threatened birds, namely Darter, Painted Stork, White-headed Ibis and Spot-billed Pelican were restricted to their breeding locations. In the present study all these threatened birds were sighted in and near to their breeding colonies similar to what Subramanya (1996 a, b and 2005) had reported.

Koonthankulam and Vedanthangal are the only traditional colonies of the Spot-billed Pelican which are in existence well over a century (Krishnan 1980, Nagalu *et al.*, 1983, Paulraj and Gunasekaran 1988). Among these, Black-headed Ibis is the most common nesting species. The Glossy Ibis is reported to be a resident in southern India (Ali and Ripley 1987). Two nests of this species were recorded for the first time in Koonthankulam Bird Sanctuary (Subramanya 2005). The Glossy Ibis is known to nest in Vedanthangal Bird Sanctuary as well (Santharam 2000 and Venkatraman 2009). Hence, Tamil Nadu is one of the few states where Glossy Ibis has been found to nest within Indian limits in recent time. Nests of Black Ibis are usually seen alone or in very small numbers, particularly on Palmyra trees as reported by (Ali and Ripley, 1987).

5.1.6. Loss of heronries in Tamil Nadu

Among 41 known heronries in the state, 11 heronries, namely Uthirakasakulam Kanmai, Ariyakulam Kanmai, Moondradaippu Kanmai, Poolam Kanmai, Vallanadu Black Buck Sanctuary, Watrap Periyakulam Kanmai, Vandioor Wetland, Kunnathur Wetland, Veerakasamuthirakulam Kanmai, Sakkarakottai Kanmai and Nagercoil-Municipal Park are almost lost in Tamil Nadu. Available information indicates that the disturbance by people living close to the heronries, removal of nesting substrates by local people and poaching of eggs and chicks were the major reasons for the loss (table 10). For example Naduiyakulam Kanmai, Moondradaippu Kanmai and Poolam Kanmai which used to be important nesting sites of Spot-billed Pelican have seen dramatic decline in their breeding

populations. It is learnt that the villagers protected the birds breeding here till 1980, but subsequently due to poaching and felling of nesting trees, birds almost deserted the area.

Among the 15 erstwhile heronry sites, namely Kunnathur and Vandioor Wetlands from Madurai, Sakkarakottai Kanmai, Kanjirankulam Bird Sanctuary and Chitrangudi Bird Sanctuary from Ramanathapuram, Watrap Periyakulam Kanmai and Veerakasamuthirakulam Kanmai from Virudhunagar are the notable Important Bird Areas which are under anthropogenic pressure. Failure of monsoon and subsequently water scarcity and natural predators also play major role in the survival of heronries in Tamil Nadu.

Table 10. Details of erstwhile heronries of Tamil Nadu.

S.No.	Name of the heronry	District	Probable reason for loss
1	Kunnathur Wetland (IBA)	Madurai	Disturbance by people
2	Vandioor Wetland (IBA)		Disturbance by people
3	Sakkarakottai Kanmai (IBA)	Ramanathapuram	Disturbance by people and water scarcity
4	Kanjirankulam Bird Sanctuary (IBA)		Water scarcity
5	Chitrangudi Bird Sanctuary (IBA)		Water scarcity
6	Melaselvanoor Bird Sanctuary		Water scarcity
7	Keelaselvanoor Bird Sanctuary		Water scarcity
8	Uthirakasakulam Kanmai	Thirunelveli	Felling of (<i>Acacia</i> sp.) nesting trees
9	Ariyakulam Kanmai		Poaching and felling of (<i>Acacia</i> sp.) nesting trees
10	Moondradaippu Kanmai		Poaching and felling of (<i>Acacia</i> sp.) nesting trees
11	Poolam Kanmai		Poaching and felling (<i>Acacia</i> sp.) of nesting trees
12	Vallanadu Black Buck Sanctuary	Tuticorin	Water Scarcity
13	Watrap Periyakulam Kanmai (IBA)	Virudunagar	Water Scarcity and felling (<i>Acacia</i> sp.) of nesting trees
14	Veerakasamuthirakulam Kanmai (IBA)		Water Scarcity and felling (<i>Acacia</i> sp.) of nesting trees
15	Nagercoil-Municipal park	Kanyakumari	Disturbance by local people

In a way Forest Department of Tamil Nadu has been instrumental in creation of quit a few heronries in the state since 1990. A programme to meet the firewood requirement of villagers was initiated. Under this activity, large number of *Acacia nilotica* sapling were planted (Subramanya 2005). Once these samplings grew up they may provide safe and ideal condition for the nesting of colonial waterbirds.

5.1.7. Conservation of heronries in Tamil Nadu

Nesting habitat protection with adequate availability of nesting substrate would encourage nesting birds in a heronry. One of the best examples of this has been Vedanthangal Bird Sanctuary which has been in existence over a century. It has grown in size both with respect to species and number of birds. Although it suffered a setback around 45 years back, due to massive loss of the nesting trees (*Barringtonia*); from 500 to just 70 trees. Subsequent plantation initiative has only revived the heronry.

Heronries, namely Vedanthangal, Vettangudi, Koonthankulam and Udhayamarthandapuram in Tamil Nadu are found within or close to human settlements. Therefore there is need to educate local people living close to the sites and to involve them in conservation activities. State Forest Department and select NGOs play a vital role in developing community-based conservation programmes. In Kokkare Bellur, Karnataka and Uppalapadu, Andhra Pradesh, such efforts have been successful.

The government of Tamil Nadu has been doing well in protecting a considerable number of heronries. Of the 25 Sanctuaries and national parks those form the protected area network in the state, 12 heronries are Sanctuaries and one (Thiruppudaimaruthur) is a community reserve. A majority of these sites, namely Vedanthangal, Vettangudi, Koonthankulam, Udhayamarthandapuram and Karikili have received protection ever prior to 1990.

One of the benefits villages get from heronries in villages is the large quantities of guano that accumulate beneath nesting trees. At Kokkare Bellur in Karanatakka, every year during the nesting season, local villagers regularly spread farmyard refuse, and several cart loads of soil below the nesting tree to collect bird droppings. At the end of the nesting season, the partially or completely decomposed guano-enriched manure is removed from below these trees and used for fertilizing crops (Manu and Jolly 2000). But this is not practiced in Tamil Nadu these days. But, it is learnt that in earlier days in Koonthankulam and Vedanthangal village practice of harvesting guano existed and it helped in protecting nesting birds (Johnson 1971 and Paulraj 1988).

Although the present study has brought to notice about the existence of additional heronries, including those once existed, this could have missed out a few heronries in Tamil Nadu. Hence, periodical surveys need to be made to develop regional inventories of heronries at district and taluk level. In this direction, birdwatchers, governmental and non-governmental organizations and local communities could contribute immensely.

5.2. Population of colonial nesting birds in the study sites

Colonial nesting birds play a vital role in the functioning of fresh water ecosystems, as they are relatively placed higher in the aquatic food chain. Further, the health of a wetland ecosystem could be assessed by monitoring the population of birds. Most ecological studies use abundance or number of birds in an area as a tool to assess the status. The number or relative abundance of most species of birds is generally easy to obtain because of their relatively large size and diurnal habits. Birds belonging to families, namely Pelecanidae (Pelicans), Phalacrocoracidae (Cormorants and Darter), Ardeidae (Hérons and Egrets), Ciconiidae (Storks), Threskiornithidae (Ibises and Spoonbill) and Alcedinidae (Kingfishers) were included in this study.

5.2.1. Abundance of colonial nesting birds in Vedanthangal Bird Sanctuary

Population of colonial nesting birds recorded during the study is summarized in table 11. During the study (October '07 - March '10), 18 species of colonial nesting birds were observed in Vedanthangal Bird Sanctuary. The total population was the maximum (30,551) during March 2010 and minimum (118) during September 2009. Of all the species observed, while Cattle Egret, Glossy Ibis, Painted Stork, Spot-billed Pelican, Indian Cormorant and Little Cormorant were the predominant species, White-throated Kingfisher and Pied Kingfisher were only a few.

In the family Pelecanidae, Spot-billed Pelican was the only species observed, which was the maximum (3547 ± 90) during March 2010 and minimum (3 ± 1) during July 2009. Among the three species recorded in the family Phalacrocoracidae, Little Cormorant was the maximum (4288 ± 364) during May 2009 followed by Indian Cormorant (3215 ± 83) during June 2008. Of the six species of birds recorded in the family Ardeidae, Cattle Egret (9986 ± 14) showed the highest population followed by Black-crowned Night Heron (2329 ± 264) during March 2010. Out of the two species recorded in the Ciconiidae, Asian Openbill (4118 ± 68) was the highest in February 2010. In Threskiornithidae, out of three species, the Black-headed Ibis (3388 ± 51) was recorded to be the maximum during January 2009 followed by Glossy Ibis (2617 ± 124) during December 2008. In the family Alcedinidae, White-throated Kingfisher had the maximum number (26 ± 0) during July 2008.

In an earlier study, Venkatraman (1996) recorded 12 species of colonial nesting birds in Vedanthangal Bird Sanctuary during 1991- 1994. Among these 12 species, Little Cormorant and Cattle Egret were reported to be the maximum. Although, the present study too showed maximum number of individuals in the same species, the number of individuals was three times higher than the previous study. Population of the near threatened species, namely Darter, Black-headed Ibis, Spot-billed Pelican and Painted Stork was more than the population reported by Venkatraman (1996) during 1991-1994.

Santharam (2000) reported the abundance of Spot-billed Pelican (249), Cormorants (3612), Darter (12), Grey Heron (302), Egrets (4668), Night Heron (791), Spoonbill (66), White Ibis (1093), Glossy Ibis (127), Openbill Stork (1202) and Painted Stork (183) in Vedanthangal. In this study, the abundance of all these species was higher than the number reported earlier. It is to be noted that Santharam (1981) did not report Spot-billed Pelican in Vedanthangal Bird Sanctuary. Besides colonial nesting birds, large numbers of migratory waterfowl, such as Northern Pintail, Garganey and Northern Shoveller were seen in Vedanthangal. Vedanthangal Bird Sanctuary has seen lot of developments over the years towards attracting birds. A number of islands have been created and planted with trees to provide ideal nesting sites for herons, egrets and other colonial nesting birds (Islam and Rahmani 2004). Vedanthangal Bird Sanctuary together with the satellite wetlands and vast stretch of agricultural fields around it supports a large population of birds.

Table 11. Population of colonial nesting birds in Vedanthangal Bird Sanctuary during October 2007 to September 2008 (Mean $\pm$ SE)

S. No.	Species	Oct-07	Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	Apr-08	May-08	Jun-08	Jul-08	Aug-08	Sep-08
I Pelecanidae													
1	Spot-billed Pelican	18 $\pm$ 15	245 $\pm$ 0	832 $\pm$ 72	1807 $\pm$ 92	2327 $\pm$ 60	2063 $\pm$ 34	2003 $\pm$ 14	251 $\pm$ 40	135 $\pm$ 5	145 $\pm$ 0	131 $\pm$ 5	5 $\pm$ 0
II Phalacrocoracidae													
2	Darter	18 $\pm$ 10	24 $\pm$ 0	23 $\pm$ 2	87 $\pm$ 4	43 $\pm$ 2	33 $\pm$ 3	14 $\pm$ 7	21 $\pm$ 5	46 $\pm$ 4	87 $\pm$ 0	90 $\pm$ 23	62 $\pm$ 13
3	Indian Cormorant	0	0 $\pm$ 0	40 $\pm$ 40	0 $\pm$	0 $\pm$	0 $\pm$	464 $\pm$ 64	2754 $\pm$ 150	3215 $\pm$ 83	2937 $\pm$ 0	626 $\pm$ 86	532 $\pm$ 58
4	Little Cormorant	123 $\pm$ 76	432 $\pm$ 0	1412 $\pm$ 252	2643 $\pm$ 32	2764 $\pm$ 107	2632 $\pm$ 88	1876 $\pm$ 104	1922 $\pm$ 203	3036 $\pm$ 130	3027 $\pm$ 0	506 $\pm$ 99	1170 $\pm$ 163
III Ardeidae													
5	Black-crowned Night Heron	20 $\pm$ 20	56 $\pm$ 0	119 $\pm$ 12	162 $\pm$ 12	965 $\pm$ 44	1129 $\pm$ 16	256 $\pm$ 129	237 $\pm$ 25	309 $\pm$ 21	390 $\pm$ 0	546 $\pm$ 73	247 $\pm$ 4
6	Grey Heron	13 $\pm$ 1	45 $\pm$ 0	124 $\pm$ 15	247 $\pm$ 5	255 $\pm$ 6	214 $\pm$ 9	46 $\pm$ 12	21 $\pm$ 6	35 $\pm$ 4	76 $\pm$ 0	87 $\pm$ 4	41 $\pm$ 4
7	Indian Pond Heron	8 $\pm$ 4	23 $\pm$ 0	42 $\pm$ 3	52 $\pm$ 2	62 $\pm$ 8	107 $\pm$ 5	43 $\pm$ 7	33 $\pm$ 8	37 $\pm$ 4	102 $\pm$ 0	20 $\pm$ 3	26 $\pm$ 6
8	Cattle Egret	0	564 $\pm$ 0	984 $\pm$ 120	3698 $\pm$ 264	6562 $\pm$ 122	6506 $\pm$ 166	5113 $\pm$ 2560	4722 $\pm$ 644	376 $\pm$ 82	485 $\pm$ 0	58 $\pm$ 39	218 $\pm$ 56
9	Great Egret	0	0	0	0	0	0	31 $\pm$ 1	39 $\pm$ 4	25 $\pm$ 3	16 $\pm$ 0	107 $\pm$ 79	59 $\pm$ 17
10	Little Egret	0	44 $\pm$ 0	292 $\pm$ 31	288 $\pm$ 22	246 $\pm$ 18	102 $\pm$ 8	81 $\pm$ 13	131 $\pm$ 22	123 $\pm$ 10	215 $\pm$ 0	621 $\pm$ 134	416 $\pm$ 55
IV Ciconiidae													
11	Asian Openbill	340 $\pm$ 94	768 $\pm$ 0	1887 $\pm$ 251	3087 $\pm$ 18	3354 $\pm$ 33	3083 $\pm$ 27	2575 $\pm$ 200	1784 $\pm$ 125	1401 $\pm$ 78	1476 $\pm$ 0	322 $\pm$ 124	318 $\pm$ 10
12	Painted Stork	0	5 $\pm$ 0	54 $\pm$ 13	342 $\pm$ 25	1173 $\pm$ 81	2299 $\pm$ 66	2324 $\pm$ 75	1183 $\pm$ 81	668 $\pm$ 50	517 $\pm$ 0	1 $\pm$ 0	0
V Threskiornithidae													
13	Glossy Ibis	4 $\pm$ 4	433 $\pm$ 0	869 $\pm$ 135	1658 $\pm$ 118	1112 $\pm$ 46	1313 $\pm$ 49	741 $\pm$ 123	1155 $\pm$ 214	1031 $\pm$ 104	1958 $\pm$ 0	730 $\pm$ 144	266 $\pm$ 0
14	Black-headed Ibis	88 $\pm$ 88	789 $\pm$ 0	403 $\pm$ 33	640 $\pm$ 31	1178 $\pm$ 16	1370 $\pm$ 87	1125 $\pm$ 37	2408 $\pm$ 165	1687 $\pm$ 138	2166 $\pm$ 0	761 $\pm$ 56	286 $\pm$ 143
15	Eurasian Spoonbill	0	4 $\pm$ 0	154 $\pm$ 14	273 $\pm$ 22	456 $\pm$ 31	378 $\pm$ 3	154 $\pm$ 85	36 $\pm$ 2	28 $\pm$ 2	62 $\pm$ 0	0	0
VI Alcedinidae													
16	Common Kingfisher	0	0 $\pm$ 0	0	0 $\pm$	0 $\pm$	0 $\pm$	0 $\pm$	0 $\pm$	0 $\pm$	0	2 $\pm$ 1	0 $\pm$ 0
17	Pied Kingfisher	0	0 $\pm$ 0	1 $\pm$ 0	1 $\pm$ 0	0 $\pm$	0 $\pm$	1 $\pm$ 0	0	0	0	7 $\pm$ 2	0
18	White-throated Kingfisher	1 $\pm$ 1	1 $\pm$ 0	1 $\pm$ 0	1 $\pm$ 0	1 $\pm$ 0	1 $\pm$ 0	5 $\pm$ 1	5 $\pm$ 1	5 $\pm$ 1	26 $\pm$ 0	12 $\pm$ 1	3 $\pm$ 1

Table 11. Population of colonial nesting birds in Vedanthangal Bird Sanctuary during October 2008 to September 2009 (Mean $\pm$ SE)

S. No.	Species	Oct-08	Nov-08	Dec-08	Jan-09	Feb-09	Mar-09	Apr-09	May-09	Jun-09	Jul-09	Aug-09	Sep-09
I													
Pelecanidae													
1	Spot-billed Pelican	152 $\pm$ 26	1378 $\pm$ 85	2155 $\pm$ 23	2203 $\pm$ 61	2646 $\pm$ 32	3496 $\pm$ 66	1673 $\pm$ 25	566 $\pm$ 17	232 $\pm$ 1	3 $\pm$ 1	0 $\pm$	0
II													
Phalacrocoracidae													
2	Darter	65 $\pm$ 7	130 $\pm$ 5	124 $\pm$ 19	116 $\pm$ 1	118 $\pm$ 5	73 $\pm$ 10	24 $\pm$ 3	47 $\pm$ 1	61 $\pm$ 1	58 $\pm$ 1	40 $\pm$ 2	5 $\pm$ 1
3	Indian Cormorant	738 $\pm$ 57	691 $\pm$ 190	961 $\pm$ 78	973 $\pm$ 37	1020 $\pm$ 60	980 $\pm$ 39	203 $\pm$ 6	223 $\pm$ 45	215 $\pm$ 23	15 $\pm$ 2	3 $\pm$ 1	0
4	Little Cormorant	1395 $\pm$ 21	3592 $\pm$ 294	3993 $\pm$ 49	3909 $\pm$ 22	3532 $\pm$ 52	4080 $\pm$ 173	3523 $\pm$ 3	4288 $\pm$ 264	2179 $\pm$ 32	178 $\pm$ 12	183 $\pm$ 19	8 $\pm$ 3
III													
Ardeidae													
5	Black-crowned Night Heron	624 $\pm$ 61	336 $\pm$ 17	1170 $\pm$ 38	1360 $\pm$ 183	1008 $\pm$ 29	1017 $\pm$ 63	871 $\pm$ 28	483 $\pm$ 39	350 $\pm$ 50	507 $\pm$ 168	166 $\pm$ 6	48 $\pm$ 11
6	Grey Heron	254 $\pm$ 38	124 $\pm$ 9	609 $\pm$ 1	646 $\pm$ 5	560 $\pm$ 56	413 $\pm$ 32	26 $\pm$ 1	34 $\pm$ 4	26 $\pm$ 2	15 $\pm$ 1	9 $\pm$ 3	5 $\pm$ 1
7	Indian Pond Heron	54 $\pm$ 9	68 $\pm$ 21	57 $\pm$ 2	100 $\pm$ 2	127 $\pm$ 13	131 $\pm$ 18	174 $\pm$ 28	168 $\pm$ 44	98 $\pm$ 35	28 $\pm$ 4	15 $\pm$ 7	4 $\pm$ 1
8	Cattle Egret	641 $\pm$ 47	4890 $\pm$ 265	7575 $\pm$ 300	8071 $\pm$ 118	8750 $\pm$ 144	9233 $\pm$ 145	8927 $\pm$ 39	2758 $\pm$ 179	1200 $\pm$ 239	14 $\pm$ 2	9 $\pm$ 3	12 $\pm$ 3
9	Great Egret	81 $\pm$ 7	66 $\pm$ 2	58 $\pm$ 7	63 $\pm$ 5	55 $\pm$ 3	62 $\pm$ 11	35 $\pm$ 3	35 $\pm$ 2	13 $\pm$ 3	4 $\pm$ 1	0	0
10	Little Egret	333 $\pm$ 23	191 $\pm$ 10	209 $\pm$ 4	299 $\pm$ 11	418 $\pm$ 56	435 $\pm$ 89	235 $\pm$ 45	300 $\pm$ 44	95 $\pm$ 1	30 $\pm$ 1	25 $\pm$	1 $\pm$
IV													
Ciconiidae													
11	Asian Openbill	841 $\pm$ 39	1581 $\pm$ 274	1790 $\pm$ 40	3461 $\pm$ 214	2774 $\pm$ 34	2893 $\pm$ 276	3475 $\pm$ 372	1164 $\pm$ 28	416 $\pm$ 4	37 $\pm$ 4	0	0
12	Painted Stork	2 $\pm$ 0	1 $\pm$ 0	81 $\pm$ 23	381 $\pm$ 12	624 $\pm$ 1	1845 $\pm$ 27	1865 $\pm$ 24	1228 $\pm$ 247	844 $\pm$ 5	53 $\pm$ 4	12 $\pm$	0
V													
Threskiornithidae													
13	Glossy Ibis	480 $\pm$ 82	289 $\pm$ 27	2617 $\pm$ 124	2567 $\pm$ 218	2214 $\pm$ 215	1588 $\pm$ 170	2191 $\pm$ 37	2222 $\pm$ 24	384 $\pm$ 16	17 $\pm$ 3	0	0
14	Black-headed Ibis	1559 $\pm$ 148	1612 $\pm$ 214	3133 $\pm$ 13	3388 $\pm$ 51	3132 $\pm$ 119	2724 $\pm$ 281	3345 $\pm$ 171	2250 $\pm$ 64	697 $\pm$ 3	2 $\pm$ 1	0 $\pm$	27 $\pm$ 6
15	Eurasian Spoonbill	0	39 $\pm$ 2	221 $\pm$ 3	387 $\pm$ 3	384 $\pm$ 7	428 $\pm$ 47	98 $\pm$ 3	0	0	0	0	0
IV													
Alcedinidae													
16	Common Kingfisher	3 $\pm$ 1	0	0	0	0	0	0	2 $\pm$ 0	1 $\pm$ 0	0	0	0
17	Pied Kingfisher	0	0	0	0	0	0 $\pm$	4 $\pm$ 1	0	0	7 $\pm$ 1	0	4 $\pm$ 0
18	White-throated Kingfisher	5 $\pm$ 2	7 $\pm$ 2	8 $\pm$ 1	10 $\pm$ 1	9 $\pm$ 1	9 $\pm$ 2	7 $\pm$ 1	11 $\pm$ 4	10 $\pm$ 2	9 $\pm$ 0	10 $\pm$	2 $\pm$ 0

Table 11. Population of colonial nesting birds in Vedanthangal Bird Sanctuary during October 2009 to March 2010 (Mean $\pm$ SE)

S. No.	Species	Oct-09	Nov-09	Dec-09	Jan-10	Feb-10	Mar-10
I Pelecanidae							
1	Spot-billed Pelican	0	657 $\pm$ 42	1707 $\pm$ 52	2946 $\pm$ 15	2964 $\pm$ 54	3547 $\pm$ 90
II Phalacrocoracidae							
2	Darter	12 $\pm$ 0	45 $\pm$ 5	47 $\pm$ 3	100 $\pm$ 4	96 $\pm$ 5	37 $\pm$ 4
3	Indian Cormorant	8 $\pm$ 0	562 $\pm$ 44	824 $\pm$ 86	972 $\pm$ 41	1038 $\pm$ 62	838 $\pm$ 127
4	Little Cormorant	36 $\pm$ 0	1817 $\pm$ 60	1447 $\pm$ 212	2914 $\pm$ 33	3380 $\pm$ 66	3099 $\pm$ 149
III Ardeidae							
5	Black- crowned Night Heron	30 $\pm$ 0	240 $\pm$ 23	304 $\pm$ 69	1457 $\pm$ 25	2017 $\pm$ 50	2329 $\pm$ 264
6	Grey Heron	6 $\pm$ 0	66 $\pm$ 8	172 $\pm$ 39	499 $\pm$ 13	331 $\pm$ 35	101 $\pm$ 14
7	Indian Pond Heron	16 $\pm$ 0	142 $\pm$ 22	106 $\pm$ 14	163 $\pm$ 21	362 $\pm$ 41	303 $\pm$ 8
8	Cattle Egret	39 $\pm$ 0	2068 $\pm$ 610	6119 $\pm$ 1075	7428 $\pm$ 1837	8649 $\pm$ 361	9986 $\pm$ 14
9	Great Egret	0	52 $\pm$ 8	68 $\pm$ 7	79 $\pm$ 18	61 $\pm$ 3	50 $\pm$ 11
10	Little Egret	12 $\pm$ 0	240 $\pm$ 50	126 $\pm$ 16	457 $\pm$ 51	483 $\pm$ 20	497 $\pm$ 14
IV Ciconiidae							
11	Asian Openbill	5 $\pm$ 0	1844 $\pm$ 51	968 $\pm$ 118	3031 $\pm$ 85	4118 $\pm$ 68	3844 $\pm$ 28
12	Painted Stork	0	0	6 $\pm$ 1	267 $\pm$ 4	371 $\pm$ 6	2385 $\pm$ 3
V Threskiornithidae							
13	Glossy Ibis	4 $\pm$ 0	553 $\pm$ 75	1718 $\pm$ 358	2412 $\pm$ 74	986 $\pm$ 51	958 $\pm$ 37
14	Black-headed Ibis	0	1858 $\pm$ 52	1895 $\pm$ 83	2587 $\pm$ 46	2579 $\pm$ 184	2437 $\pm$ 37
15	Eurasian Spoonbill	0	33 $\pm$ 10	147 $\pm$ 4	350 $\pm$ 9	306 $\pm$ 2	130 $\pm$ 31
IV Alcedinidae							
16	Common Kingfisher	0	2 $\pm$ 1	0		1 $\pm$ 0	1 $\pm$ 0
17	Pied Kingfisher	0	0	0	0	0	0
18	White-throated Kingfisher	8 $\pm$ 0	4 $\pm$ 1	3 $\pm$ 2	7 $\pm$ 1	10 $\pm$ 1	9 $\pm$ 1

5.2.2. Abundance of colonial nesting birds in Koonthankulam Bird Sanctuary

Population of colonial nesting birds in Koonthankulam during the study period is given in table 12. Between October 2007 and March 2010, 21 species of colonial nesting birds were observed. Total population was maximum (28,190) during March 2010 and minimum (52) during October 2009. Cattle Egret, Painted Stork, Glossy Ibis, Spot-billed Pelican, Indian Cormorant and Black-headed Ibis were the predominant species. White-throated Kingfisher and Pied Kingfisher were only a few in numbers.

Similar to Vedanthangal, Spot-billed Pelican was the only species observed from Pelecanidae, which was the maximum (4312 ± 33) during March 2010 and minimum (5 ± 1) during October 2009. Among the three species of birds recorded from the family Phalacrocoracidae, Indian Cormorant (3216 ± 58) showed the maximum population size during April 2009 followed by Little Cormorant (814 ± 649) during March 2009. Of the eight species of birds from the family Ardeidae, Cattle Egret (9680 ± 299) was the highest during March 2010 followed by Little Egret (932 ± 9) during May 2008. Out of the two species of birds recorded from Ciconiidae, Painted Stork (7252 ± 49) was the predominant species during March 2010. Out of the three species of birds in Threskiornithidae, Black-headed Ibis (1979 ± 189) was the maximum in number followed by Glossy Ibis (1821 ± 61) during March 2010. In the family Alcedinidae, White-throated Kingfisher was the maximum in number (7 ± 2).

Beulah (2002) had recorded 16 species of colonial nesting birds in Koonthankulam Bird Sanctuary during 1998 - 2000, whereas the number of species has increased in the present study to 21 species. Beulah (2002) recorded abundance of birds, namely Spot-billed Pelican (2600), Little Cormorant (700), Darter (10), Grey Heron (10), Pond Heron (50), Large Egret (10), Cattle Egret (1000), Little Egret (30), Night Heron (28), Painted Stork (1500), Openbill Stork (100), White Ibis (430), Glossy Ibis (370) during 1998 - 1999. Among the species, Cattle Egret, Painted Stork, Spot-billed Pelican and Indian Cormorant were more in number. In the present study, it was observed that the number of Cattle Egret, Painted Stork, Spot-billed Pelican and Indian Cormorant to be four-fold higher than the previous records. Population of the near threatened species, namely Darter, Spot-billed Pelican and Black-headed Ibis were also higher in numbers than the numbers reported by Beulah (2001) during 1998 - 2000. Another threatened species, namely Painted Stork did extremely well in Koonthankulam Bird Sanctuary with the breeding

population reaching a maximum of 7252 birds in 2010. Koonthankulam is one of the oldest known pelicanries in south India, having existed for about 200 years (Islam and Rahmani 2004). Rhenius (1907) first reported this pelicanry in 1906. In the early 1990s, around 1000 Spot-billed Pelicans were recorded (Anon. 1993). According to BirdLife International 2006 report, Spot-billed Pelican population has been revised upwards from a low of 5,500-10,000 birds in 2002 to an estimated 13,000-18,000 individual in 2006. Abundance of Spot-billed Pelican recorded in the present study was comparable with the earlier report (BirdLife International 2006).

Koonthankulam also supports large flocks of Glossy Ibis *Plegadis falcinellus*. At times up to 1,000 birds were seen together, foraging in the water logged crop fields or flying from one foraging area to another (Islam and Rahmani 2004). Abundance of Glossy Ibis recorded in the present study is almost same as reported by Islam and Rahmani (2004). Koonthankulam has a large tank within the village precincts, and several smaller tanks scattered in its vicinity. These water bodies and the agricultural fields are the main foraging grounds for birds (Islam and Rahmani 2004). Koonthankulam is basically an agricultural area, and there is no natural forest nearby. *Acacia nilotica* planted in about 35.5 ha inside the Sanctuary serves as nesting habitat for most of the birds. The villagers believe that the birds those come to Koonthankulam are harbingers of good luck and their early arrival every year ensures good rainfall. Farmers also collect nutrient rich guano deposited in the breeding colonies and it is used to fertilize the adjoining paddy fields.

5.2.3. Abundance of colonial nesting birds in Vettangudi Bird Sanctuary

During the study period (October '07 - March '10), 16 species of colonial nesting birds were observed over here. The population and number of species were relatively less when compared to Vedanthangal and Koonthankulam Bird Sanctuaries. Total population was the maximum (3989) during December 2008 and minimum (17) during March 2010 (table 13). Among the species observed, Cattle Egret, Little Egret, Asian Openbill and Black-headed Ibis were predominant while White-throated Kingfisher was less common. Initially five species of birds, namely Asian Openbill, Little Cormorant, Black-headed Ibis, Intermediate Egret and Little Egret settled in to begin nesting in November 2009, but due to inadequate water input and disturbance exclusively by Black Eagle all of them left the Sanctuary in December 2009 and never returned to resume breeding.

Among the three species recorded from the family Phalacrocoracidae, Little Cormorant (271 ± 13) had the maximum population during December 2008. Of the seven species recorded from Ardeidae, Cattle Egret (1121 ± 221) was the highest in population during February 2009 followed by Little Egret (488 ± 43) during December 2008. Asian Openbill was the only species from the family Ciconiidae. It was the predominant species as well during December 2008. Out of two species of birds from Threskiornithidae, Black-headed Ibis (414 ± 23) was the maximum during December 2008. In the family Alcedinidae, White-throated Kingfisher was the notable species.

Table 12. Population of colonial nesting birds in Koonthankulam Birds Sanctuary during October 2007 to September 2008 (Mean $\pm$ SE)

S. No.	Species	Oct-07	Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	Apr-08	May-08	Jun-08	Jul-08	Aug-08	Sep-08
I Pelecanidae													
1	Spot-billed Pelican	0	0	0	11 $\pm$ 6	82 $\pm$ 14	157 $\pm$ 16	472 $\pm$ 143	1255 $\pm$ 62	672 $\pm$ 53	672 $\pm$ 0	125 $\pm$ 7	32 $\pm$ 2
II Phalacrocoracidae													
2	Darter	0	0	0	9 $\pm$ 3	10 $\pm$ 2	8 $\pm$ 2	30 $\pm$ 12	32 $\pm$ 1	11 $\pm$ 2	11 $\pm$ 0	0	0
3	Indian Cormorant	0	0	5 $\pm$ 5	4 $\pm$ 4	12 $\pm$ 10	49 $\pm$ 9	697 $\pm$ 145	1831 $\pm$ 91	2269 $\pm$ 69	23 $\pm$ 0	3 $\pm$ 1	0
4	Little Cormorant	2 $\pm$ 0	0	1 $\pm$	23 $\pm$ 7	14 $\pm$ 5	7 $\pm$ 2	17 $\pm$ 5	104 $\pm$ 7	471 $\pm$ 80	494 $\pm$ 0	0	0
III Ardeidae													
5	Black-crowned Night Heron	30 $\pm$ 0	36 $\pm$ 0	47 $\pm$ 42	8 $\pm$ 8	8 $\pm$ 5	1 $\pm$ 0	21 $\pm$ 6	26 $\pm$ 2	15 $\pm$ 2	20 $\pm$ 0	59 $\pm$ 2	0
6	Grey Heron	0	0	2 $\pm$ 1	2 $\pm$ 0	1 $\pm$ 0	1 $\pm$ 0	3 $\pm$ 1	8 $\pm$ 1	6 $\pm$ 1	6 $\pm$ 0	3 $\pm$ 0	1 $\pm$ 1
7	Indian Pond Heron	2 $\pm$ 0	10 $\pm$ 0	2 $\pm$ 1	6 $\pm$ 6	11 $\pm$ 5	9 $\pm$ 2	170 $\pm$ 40	245 $\pm$ 4	235 $\pm$ 2	200 $\pm$ 0	19 $\pm$ 2	10 $\pm$ 0
8	Purple Heron	0	2 $\pm$ 0	1 $\pm$ 1	0	0	0	0	0	0	0	0	0
9	Cattle Egret	0	0	0	41 $\pm$	74 $\pm$ 18	39 $\pm$ 3	4293 $\pm$ 1557	7269 $\pm$ 177	2802 $\pm$ 850	107 $\pm$ 0	0	0
10	Great Egret	0	0	0	1 $\pm$ 1	1 $\pm$ 1	2 $\pm$ 1	1 $\pm$ 1	0	0	0	0	0
11	Intermediate Egret	0	0	3 $\pm$ 3	2 $\pm$ 2	3 $\pm$ 1	2 $\pm$ 1	129 $\pm$ 26	203 $\pm$ 15	45 $\pm$ 20	35 $\pm$ 0	12 $\pm$ 0	0
12	Little Egret	4 $\pm$ 0	2 $\pm$ 0	4 $\pm$ 2	0	77 $\pm$ 21	53 $\pm$ 16	621 $\pm$ 127	932 $\pm$ 9	195 $\pm$ 95	204 $\pm$ 0	54 $\pm$ 3	31 $\pm$ 1
IV Ciconiidae													
13	Asian Openbill	0 $\pm$ 0	0	1 $\pm$ 1	4 $\pm$ 4	5 $\pm$ 2	2 $\pm$ 1	7 $\pm$ 4	113 $\pm$ 9	187 $\pm$ 16	201 $\pm$ 0	3 $\pm$ 1	0
14	Painted Stork	8 $\pm$ 0	0	2 $\pm$	20 $\pm$ 9	172 $\pm$ 36	231 $\pm$ 40	3537 $\pm$ 724	5398 $\pm$ 41	5454 $\pm$ 36	5700 $\pm$ 0	4205 $\pm$ 5	1455 $\pm$ 53
V Threskiornithidae													
15	Black Ibis	7 $\pm$ 0	0	4 $\pm$	8 $\pm$ 2	4 $\pm$ 1	5 $\pm$ 1	29 $\pm$ 12	35 $\pm$ 16	17 $\pm$ 6	17 $\pm$ 0	0	0
16	Glossy Ibis	0	0	12 $\pm$ 12	84 $\pm$ 21	150 $\pm$ 41	332 $\pm$ 61	281 $\pm$ 120	640 $\pm$ 9	945 $\pm$ 79	960 $\pm$ 0	86 $\pm$ 2	0
17	Black-headed Ibis	4 $\pm$ 0	0	3 $\pm$ 2	23 $\pm$ 12	62 $\pm$ 25	107 $\pm$ 18	102 $\pm$ 46	487 $\pm$ 23	929 $\pm$ 55	949 $\pm$ 0	73 $\pm$ 1	62 $\pm$ 2
18	Eurasian Spoonbill	0	0	5 $\pm$ 3	4 $\pm$ 4	5 $\pm$ 2	8 $\pm$ 2	4 $\pm$ 3	36 $\pm$ 4	14 $\pm$ 14	0	0	0
VI Alcedinidae													
19	Common Kingfisher	0	0	3 $\pm$ 3	0	0	0	0	0	0	0	0	0
20	Pied Kingfisher	0	0	0	0	0	0	0	0	0	0	0	0
21	White-throated Kingfisher	2 $\pm$ 0	2 $\pm$ 0	3 $\pm$ 3	1 $\pm$ 1	0	0	7 $\pm$ 1	0	0	0	0	0

Table 12. Population of colonial nesting birds in Koonthankulam Birds Sanctuary during October 2008 to September 2009 (Mean $\pm$ SE)

S. No.	Species	Oct-08	Nov-08	Dec-08	Jan-09	Feb-09	Mar-09	Apr-09	May-09	Jun-09	Jul-09	Aug-09	Sep-09
I													
1	Spot-billed Pelican	11 $\pm$ 0	28 $\pm$ 1	399 $\pm$ 179	1256 $\pm$ 140	3036 $\pm$ 78	3137 $\pm$ 16	3444 $\pm$ 69	2293 $\pm$ 59	312 $\pm$ 42	59 $\pm$ 3	16 $\pm$ 0	12 $\pm$ 0
II													
2	Phalacrocoracidae												
3	Darter	18 $\pm$ 5	21 $\pm$ 1	19 $\pm$ 4	56 $\pm$ 6	51 $\pm$ 2	52 $\pm$ 4	15 $\pm$ 2	8 $\pm$ 2	2 $\pm$ 0	0	0	0
4	Indian Cormorant	10 $\pm$ 5	139 $\pm$ 3	478 $\pm$ 160	1388 $\pm$ 169	2827 $\pm$ 108	2743 $\pm$ 685	3216 $\pm$ 58	2924 $\pm$ 157	360 $\pm$ 159	2 $\pm$ 0	0	0
5	Little Cormorant	12 $\pm$ 4	23 $\pm$ 7	95 $\pm$ 64	127 $\pm$ 27	114 $\pm$ 8	814 $\pm$ 649	215 $\pm$ 13	101 $\pm$ 9	11 $\pm$ 1	1 $\pm$ 0	0	0
III													
6	Ardeidae												
7	Black-crowned Night Heron	3 $\pm$ 2	42 $\pm$ 10	128 $\pm$ 18	87 $\pm$ 7	214 $\pm$ 108	123 $\pm$ 18	39 $\pm$ 6	15 $\pm$ 3	9 $\pm$ 1	4 $\pm$ 1	0	0
8	Grey Heron	3 $\pm$ 1	6 $\pm$ 0	0	1 $\pm$ 0	8 $\pm$ 7	3 $\pm$ 1	5 $\pm$ 2	4 $\pm$ 2	1 $\pm$ 1	1 $\pm$ 0	2 $\pm$ 0	0
9	Indian Pond Heron	9 $\pm$ 1	58 $\pm$ 7	303 $\pm$ 90	199 $\pm$ 22	168 $\pm$ 12	183 $\pm$ 10	231 $\pm$ 19	317 $\pm$ 3	156 $\pm$ 48	81 $\pm$ 3	14 $\pm$ 0	14 $\pm$ 0
10	Purple Heron	0	0	0	0	5 $\pm$ 4	2 $\pm$ 0	0	0	0	0	0	0
11	Cattle Egret	557 $\pm$ 178	1278 $\pm$ 165	3724 $\pm$ 1454	4530 $\pm$ 260	6813 $\pm$ 402	7369 $\pm$ 124	7159 $\pm$ 488	5678 $\pm$ 622	1600 $\pm$ 400	360 $\pm$ 34	11 $\pm$ 0	7 $\pm$ 0
12	Great Egret	2 $\pm$ 1	8 $\pm$ 2	10 $\pm$ 4	5 $\pm$ 1	15 $\pm$ 11	6 $\pm$ 2	7 $\pm$ 2	4 $\pm$ 1	2 $\pm$ 1	2 $\pm$ 2	0	0
13	Intermediate Egret	4 $\pm$ 1	19 $\pm$ 5	16 $\pm$ 2	16 $\pm$ 1	12 $\pm$ 1	63 $\pm$ 30	294 $\pm$ 3	196 $\pm$ 4	18 $\pm$ 0	4 $\pm$ 1	0	0
14	Little Egret	66 $\pm$ 18	59 $\pm$ 10	99 $\pm$ 9	36 $\pm$ 8	477 $\pm$ 384	133 $\pm$ 19	833 $\pm$ 49	812 $\pm$ 197	511 $\pm$ 3	98 $\pm$ 17	8 $\pm$ 0	11 $\pm$ 0
IV													
15	Ciconiidae												
16	Asian Openbill	75 $\pm$ 1	90 $\pm$ 23	30 $\pm$ 19	11 $\pm$ 1	16 $\pm$ 1	18 $\pm$ 4	227 $\pm$ 8	78 $\pm$ 25	17 $\pm$ 5	1 $\pm$ 0	0	0
17	Painted Stork	506 $\pm$ 3	3 $\pm$ 2	4 $\pm$ 2	92 $\pm$ 29	682 $\pm$ 80	5278 $\pm$ 546	6062 $\pm$ 4	5551 $\pm$ 90	2639 $\pm$ 162	942 $\pm$ 35	22 $\pm$ 0	29 $\pm$ 0
V													
18	Threskiornithidae												
19	Black Ibis	6 $\pm$ 4	13 $\pm$ 5	74 $\pm$ 37	36 $\pm$ 7	30 $\pm$ 9	36 $\pm$ 20	50 $\pm$ 10	19 $\pm$ 2	2 $\pm$ 2	9 $\pm$ 6	4 $\pm$ 0	3 $\pm$ 0
20	Glossy Ibis	481 $\pm$ 162	1092 $\pm$ 96	686 $\pm$ 142	394 $\pm$ 44	775 $\pm$ 11	873 $\pm$ 40	1423 $\pm$ 95	907 $\pm$ 348	80 $\pm$ 12	9 $\pm$ 1	0	0
21	Black-headed Ibis	280 $\pm$ 62	721 $\pm$ 75	453 $\pm$ 210	400 $\pm$ 57	706 $\pm$ 50	830 $\pm$ 84	929 $\pm$ 92	443 $\pm$ 166	120 $\pm$ 8	2 $\pm$ 1	0	0
22	Eurasian Spoonbill	1 $\pm$ 1	32 $\pm$ 7	29 $\pm$ 5	53 $\pm$ 2	50 $\pm$ 3	61 $\pm$ 2	13 $\pm$ 2	2 $\pm$ 2	0	0	0	0
VI													
23	Alcedinidae												
24	Common Kingfisher	0	0	0	0	33 $\pm$ 33	0	0	0	0	0	1 $\pm$ 0	1 $\pm$ 0
25	Pied Kingfisher	0	0	0	0	2 $\pm$ 2	0	0	1 $\pm$ 1	0	1 $\pm$ 0	0	0
26	White-throated Kingfisher	1 $\pm$ 1	2 $\pm$ 1	1 $\pm$ 1	2 $\pm$ 0	1 $\pm$ 0	2 $\pm$ 1	7 $\pm$ 2	9 $\pm$ 2	6 $\pm$ 3	7 $\pm$ 1	3 $\pm$	5 $\pm$ 0

Table 12. Population of colonial nesting birds in Koonthankulam Birds Sanctuary during October 2009 to March 2010 (Mean $\pm$ SE)

S. No.	Species	Oct-09	Nov-09	Dec-09	Jan-10	Feb-10	Mar-10
I	Pelecanidae						
1	Spot-billed Pelican	5 $\pm$ 1	40 $\pm$ 1	1047 $\pm$ 32	1404 $\pm$ 29	2830 $\pm$ 20	4312 $\pm$ 33
II	Phalacrocoracidae						
2	Darter	0	32 $\pm$ 1	6 $\pm$ 1	11 $\pm$ 1	10 $\pm$ 1	16 $\pm$ 2
3	Indian Cormorant	0	74 $\pm$ 1	123 $\pm$ 9	599 $\pm$ 45	1170 $\pm$ 19	1187 $\pm$ 22
4	Little Cormorant	0	181 $\pm$ 9	153 $\pm$ 23	71 $\pm$ 16	100 $\pm$ 13	187 $\pm$ 7
III	Ardeidae						
5	Black-crowned Night Heron	0	37 $\pm$ 2	15 $\pm$ 2	42 $\pm$ 3	93 $\pm$ 9	99 $\pm$ 9
6	Grey Heron	0	2 $\pm$ 0	1 $\pm$ 0	0	0	5 $\pm$ 1
7	Indian Pond Heron	9 $\pm$ 1	104 $\pm$ 1	270 $\pm$ 6	252 $\pm$ 11	408 $\pm$ 11	500 $\pm$ 27
8	Purple Heron	0	0	0	0	0	0
9	Cattle Egret	11 $\pm$ 1	2637 $\pm$ 94	3122 $\pm$ 267	4749 $\pm$ 91	4891 $\pm$ 305	9680 $\pm$ 299
10	Great Egret	0	4 $\pm$ 1	39 $\pm$ 2	33 $\pm$ 5	25 $\pm$ 4	28 $\pm$ 3
11	Intermediate Egret	0	22 $\pm$ 0	52 $\pm$ 5	120 $\pm$ 20	75 $\pm$ 4	339 $\pm$ 19
12	Little Egret	18 $\pm$ 2	153 $\pm$ 4	113 $\pm$ 7	128 $\pm$ 7	172 $\pm$ 12	716 $\pm$ 91
IV	Ciconiidae						
13	Asian Openbill	0	34 $\pm$ 4	8 $\pm$ 2	25 $\pm$ 2	22 $\pm$ 5	25 $\pm$ 4
14	Painted Stork	6 $\pm$ 3	0	2 $\pm$ 1	117 $\pm$ 4	591 $\pm$ 15	7252 $\pm$ 49
V	Threskiornithidae						
15	Black Ibis	2 $\pm$ 1	9 $\pm$ 0	10 $\pm$ 1	44 $\pm$ 3	28 $\pm$ 2	29 $\pm$ 6
16	Glossy Ibis	0	839 $\pm$ 20	1355 $\pm$ 96	1360 $\pm$ 15	1344 $\pm$ 45	1821 $\pm$ 61
17	Black-headed Ibis	0	871 $\pm$ 47	539 $\pm$ 76	1842 $\pm$ 71	1807 $\pm$ 29	1979 $\pm$ 189
18	Eurasian Spoonbill	0	21 $\pm$ 1	7 $\pm$ 1	12 $\pm$ 3	8 $\pm$ 1	6 $\pm$ 2
VI	Alcedinidae						
19	Common Kingfisher	0	1 $\pm$ 0	0	0	1 $\pm$ 0	2 $\pm$ 1
20	Pied Kingfisher	0	0	0	0	0	0
21	White-throated Kingfisher	3 $\pm$ 1	4 $\pm$ 1	0 $\pm$	6 $\pm$ 1	5 $\pm$ 1	5 $\pm$ 2

Table 13. Population of colonial nesting birds in Vettangudi Bird Sanctuary during October 2007 to September 2008 (Mean $\pm$ SE)

S. No.	Species	Oct-07	Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	Apr-08	May-08	Jun-08	Jul-08	Aug-08	Sep-08
I	Phalacrocoracidae												
1	Darter	4 $\pm$ 4	4 $\pm$ 0	0	5 $\pm$ 1	1 $\pm$ 1	0	2 $\pm$ 0	3 $\pm$ 2	0	0	0	0
2	Indian Cormorant	4 $\pm$ 2	4 $\pm$ 1	0	15 $\pm$ 3	0	2 $\pm$ 2	0	0	0	0	0	0
3	Little Cormorant	47 $\pm$ 17	47 $\pm$ 1	19 $\pm$ 5	53 $\pm$ 27	38 $\pm$ 2	12 $\pm$ 10	6 $\pm$ 0	2 $\pm$ 1	0	0	0	6 $\pm$ 4
II	Ardeidae												
4	Black-crowned Night Heron	101 $\pm$ 1	106 $\pm$ 6	17 $\pm$ 1	0	0	25 $\pm$ 12	3 $\pm$ 1	0	0	0	0	6 $\pm$ 1
5	Grey Heron	0	0	0	0	0	0	0	0	0	0	0	2 $\pm$ 0
6	Indian Pond Heron	4 $\pm$ 2	4 $\pm$ 0	30 $\pm$ 1	54 $\pm$ 21	36 $\pm$ 3	40 $\pm$ 5	39 $\pm$ 9	19 $\pm$ 1	15 $\pm$ 0	9 $\pm$ 0	0	8 $\pm$ 1
7	Cattle Egret	32 $\pm$ 3	32 $\pm$ 0	910 $\pm$ 91	247 $\pm$ 4	510 $\pm$ 7	738 $\pm$ 104	554 $\pm$ 25	0	0	0	0	0
8	Great Egret	0	0	0	0	0	0	0	4 $\pm$ 0	3 $\pm$ 0	3 $\pm$ 0	0	0
9	Intermediate Egret	0	0	12 $\pm$ 3	13 $\pm$ 7	16 $\pm$ 0	4 $\pm$ 4	2 $\pm$ 0	3 $\pm$ 0	0	1 $\pm$ 0	0	0
10	Little Egret	95 $\pm$ 32	93 $\pm$ 3	325 $\pm$ 44	69 $\pm$ 7	146 $\pm$ 25	50 $\pm$ 20	61 $\pm$ 7	9 $\pm$ 1	8 $\pm$ 0	6 $\pm$ 0	0	12 $\pm$ 2
III	Ciconiidae												
11	Asian Openbill	421 $\pm$ 55	436 $\pm$ 15	62 $\pm$ 3	117 $\pm$ 13	111 $\pm$ 2	43 $\pm$ 20	22 $\pm$ 2	5 $\pm$ 0	4 $\pm$ 0	2 $\pm$ 0	0	378 $\pm$ 1
IV	Threskiornithidae												
12	Glossy Ibis	0	0	0	0	0	0	0	0	0	0	0	0
13	Black-headed Ibis	223 $\pm$ 5	236 $\pm$ 14	113 $\pm$ 3	241 $\pm$ 4	5 $\pm$ 1	1 $\pm$ 1	0	0	0	0	0	0
V	Alcedinidae												
14	Common Kingfisher	1 $\pm$ 1	1 $\pm$ 0	2 $\pm$ 0	2 $\pm$ 1	2 $\pm$ 0	2 $\pm$ 1	1 $\pm$ 0	0	0	0	0	2 $\pm$ 0
15	Pied Kingfisher	0	0	0	0	0	0	0	2 $\pm$ 0	1 $\pm$ 1	1 $\pm$ 0	0	0
16	White-throated Kingfisher	0	0	5 $\pm$ 1	5 $\pm$ 2	5 $\pm$ 1	3 $\pm$ 2	4 $\pm$ 2	1 $\pm$ 1	0	0	0	4 $\pm$ 1

Table 13. Population of colonial nesting birds in Vettangudi Bird Sanctuary during October 2008 to September 2009 (Values are in Mean $\pm$ SE)

S. No.	Species	Oct-08	Nov-08	Dec-08	Jan-09	Feb-09	Mar-09	Apr-09	May-09	Jun-09	Jul-09	Aug-09	Sep-09
I Phalacrocoracidae													
1	Darter	2 $\pm$ 0	6 $\pm$ 0	5 $\pm$ 1	12 $\pm$ 1	10 $\pm$ 1	3 $\pm$ 0	0	0	0	0	0	0
2	Indian Cormorant	0	17 $\pm$ 2	28 $\pm$ 9	43 $\pm$ 2	31 $\pm$ 1	45 $\pm$ 3	16 $\pm$ 1	11 $\pm$ 3	0	0	0	0
3	Little Cormorant	17 $\pm$ 10	197 $\pm$ 4	271 $\pm$ 13	195 $\pm$ 12	142 $\pm$ 5	269 $\pm$ 11	18 $\pm$ 3	9 $\pm$ 1	0	0	0	0
II Ardeidae													
4	Black-crowned Night Heron	2 $\pm$ 0	25 $\pm$ 1	46 $\pm$ 9	44 $\pm$ 6	34 $\pm$ 3	26 $\pm$ 4	29 $\pm$ 4	10 $\pm$ 2	10 $\pm$ 0	5 $\pm$ 1	5 $\pm$ 1	6 $\pm$ 0
5	Grey Heron	2 $\pm$ 1	0	0	0	0	0	0	0	0	0	0	0
6	Indian Pond Heron	15 $\pm$ 1	32 $\pm$ 8	63 $\pm$ 12	97 $\pm$ 3	109 $\pm$ 7	111 $\pm$ 15	106 $\pm$ 4	82 $\pm$ 4	0	0	9 $\pm$ 3	0
7	Cattle Egret	378 $\pm$ 16	460 $\pm$ 3	737 $\pm$ 70	921 $\pm$ 52	1121 $\pm$ 221	710 $\pm$ 90	116 $\pm$ 6	126 $\pm$ 25	81 $\pm$ 0	73 $\pm$ 4	0	3 $\pm$ 0
8	Great Egret	0	2 $\pm$ 0	9 $\pm$ 2	3 $\pm$ 2	0	6 $\pm$ 6	10 $\pm$ 0	6 $\pm$ 1	1 $\pm$ 0	0	0	0
9	Intermediate Egret	5 $\pm$ 0	17 $\pm$ 1	199 $\pm$ 5	215 $\pm$ 1	200 $\pm$ 2	40 $\pm$ 2	7 $\pm$ 1	7 $\pm$ 1	4 $\pm$ 0	3 $\pm$ 1	0	0
10	Little Egret	9 $\pm$ 1	58 $\pm$ 1	488 $\pm$ 43	419 $\pm$ 94	361 $\pm$ 41	277 $\pm$ 24	75 $\pm$ 5	46 $\pm$ 3	42 $\pm$ 0	50 $\pm$ 5	8 $\pm$ 0	16 $\pm$ 0
III Ciconiidae													
11	Asian Openbill	946 $\pm$ 5	1450 $\pm$ 116	1722 $\pm$ 63	1591 $\pm$ 160	1088 $\pm$ 42	277 $\pm$ 19	97 $\pm$ 6	48 $\pm$ 3	39 $\pm$ 0	41 $\pm$ 4	28 $\pm$ 2	31 $\pm$ 0
IV Threskiornithidae													
12	Glossy Ibis	0	1 $\pm$ 1	0	9 $\pm$ 9	0	0	0	3 $\pm$ 0	7 $\pm$ 0	0	0	0
13	Black-headed Ibis	51 $\pm$ 3	102 $\pm$ 1	414 $\pm$ 23	374 $\pm$ 17	293 $\pm$ 58	141 $\pm$ 2	29 $\pm$ 3	0	3 $\pm$ 0	2 $\pm$ 0	0	0
V Alcedinidae													
14	Common Kingfisher	0	2 $\pm$ 0	2 $\pm$ 0	3 $\pm$ 0	3 $\pm$ 1	0	0	0	0	0	0	0
15	Pied Kingfisher	0	0	0	0	0	2 $\pm$ 0	0	3 $\pm$ 1	0	0	0	0
16	White-throated Kingfisher	4 $\pm$ 1	4 $\pm$ 0	5 $\pm$ 1	5 $\pm$ 1	10 $\pm$ 2	3 $\pm$ 1	7 $\pm$ 1	8 $\pm$ 1	3 $\pm$ 0	3 $\pm$ 0	4 $\pm$ 1	8 $\pm$ 0

Table 13. Population of colonial nesting birds in Vettangudi Bird Sanctuary during October 2009 to March 2010 (Values are in Mean $\pm$ SE)

S. No.	Species	Oct-09	Nov-09	Dec-09	Jan-10	Feb-10	Mar-10
I	Phalacrocoracidae						
1	Darter	0	7 $\pm$ 4	0	0	0	0
2	Indian Cormorant	0	9 $\pm$ 4	0	0	0	0
3	Little Cormorant	0	78 $\pm$ 39	0	0	0	0
II	Ardeidae						
4	Black-crowned Night Heron	0	4 $\pm$ 1	0	0	0	0
5	Grey Heron	0	0	0	0	0	0
6	Indian Pond Heron	8 $\pm$ 0	21 $\pm$ 0	15 $\pm$ 0	13 $\pm$ 3	13 $\pm$ 1	8 $\pm$ 0
7	Cattle Egret	16 $\pm$ 0	848 $\pm$ 344	28 $\pm$ 0	49 $\pm$ 21	9 $\pm$ 4	5 $\pm$ 0
8	Great Egret	0	2 $\pm$ 1	0	0	0	0
9	Intermediate Egret	0	60 $\pm$ 24	2 $\pm$ 0	5 $\pm$ 3	2 $\pm$ 0	1 $\pm$ 0
10	Little Egret	10 $\pm$ 0	61 $\pm$ 28	8 $\pm$ 0	7 $\pm$ 3	7 $\pm$ 1	0
III	Ciconiidae						
11	Asian Openbill	24 $\pm$ 0	257 $\pm$ 109	0	0	0	0
IV	Threskiornithidae						
12	Glossy Ibis	0	0	3 $\pm$ 0	79 $\pm$ 1	0	0
13	Black-headed Ibis	0	355 $\pm$ 32	0	0	0	0
V	Alcedinidae						
14	Common Kingfisher	0	0	1 $\pm$ 0	2 $\pm$ 0	0	0
15	Pied Kingfisher	0	0	0	2 $\pm$ 0	0	0
16	White-throated Kingfisher	3 $\pm$ 0	2 $\pm$ 0	2 $\pm$ 0	2 $\pm$ 0	3 $\pm$ 1	3 $\pm$ 0

Population of birds in Vettangudi Bird Sanctuary is lesser than the other two sites because the number of irrigation tanks in and around the village is not many. Similarly, agricultural activities are also less when compared to Vedanthangal and Koonthankulam. Moreover, Vettangudi is one of the dry areas in southern plains of Sivagangai district and it completely depends on north-east monsoon. It is obvious that if monsoon fails consecutively, water storage in the tank will be low and it cannot support extensive agricultural operations hence available foraging and breeding habitats for birds will also shrink, and population eventually go down. No historic information is available on population of heronry birds in Vettangudi. Hence, the data on population collected in the present study could also serve as baseline information for future research.

5.2.4. Variation in density of colonial nesting birds among the study sites and years

Density was calculated to examine the variation in population of colonial nesting birds among study sites. Density of the colonial nesting birds in the study showed inconsistent pattern among the study sites. There was a significant difference in the density of colonial nesting birds among the study sites (Kruskal-Wallis $\chi^2 = 1.378$; $df=2$; $P<0.05$). The maximum density was recorded in Vedanthangal Bird Sanctuary (29.26 ± 0.85 birds/ha) followed by Koonthankulam (3.56 ± 0.17 birds/ha) and Vettangudi Bird Sanctuaries (2.06 ± 0.19 birds/ha) (figure 9). However, the number of species was the maximum in Koonthankulam (21 species) followed by Vedanthangal. Vettangudi had only few species with small population.

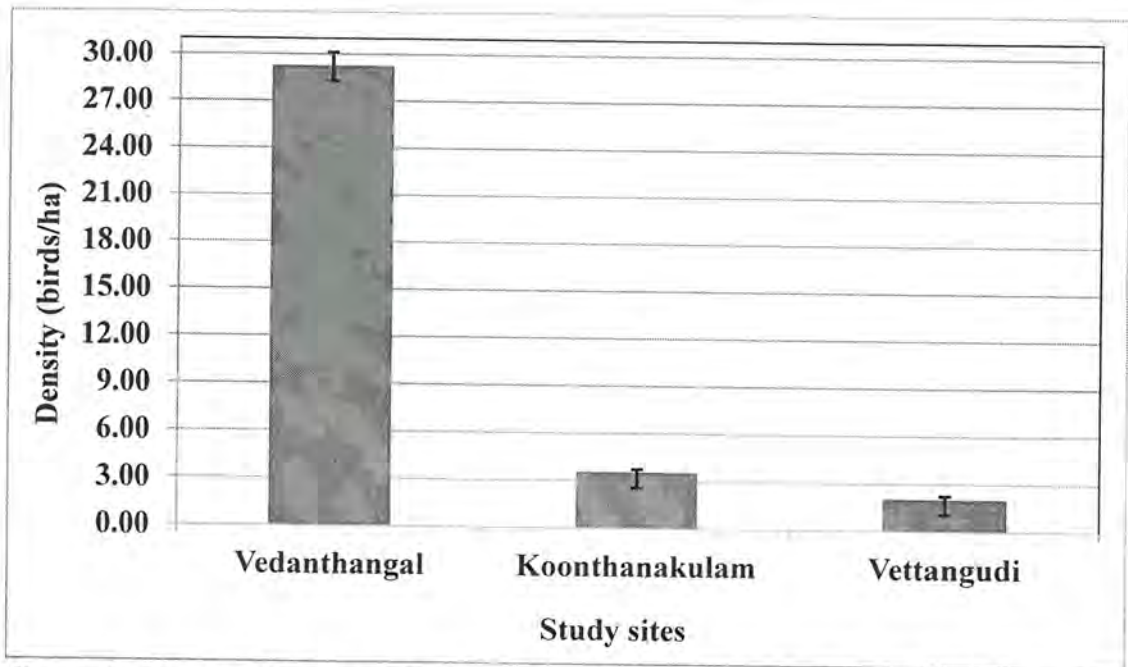


Figure 9. Density (birds/ha Mean $\pm$ SE) of colonial nesting birds among study sites (2007-'10)

Densities of birds fluctuated seasonally but were almost consistent among the years. The population was very low during August–October every year and, from November it kept increasing to reach a maximum during February–March and then it declined gradually towards June–July. There was a significant difference in density of colonial nesting birds among the years in all study sites (Kruskal-Wallis $\chi^2=16.032$; $df=2$; $P<0.05$). The maximum density was during October 2009 to September 2010 (43.66 ± 3.63 birds/ha) followed by October 2008 - September 2009 (36.78 ± 2.85 birds/ha), whereas the minimum was in October 2007 - September 2008 (31.25 ± 1.32 birds/ha). Increasing trend was also noticed in the density of colonial nesting birds among the years in all study sites except Vettangudi (figure 10). In Vettangudi, density of birds was very less during October 2009–March 2010 due to scarcity of water and disturbance due to the Greater Spotted Eagle.

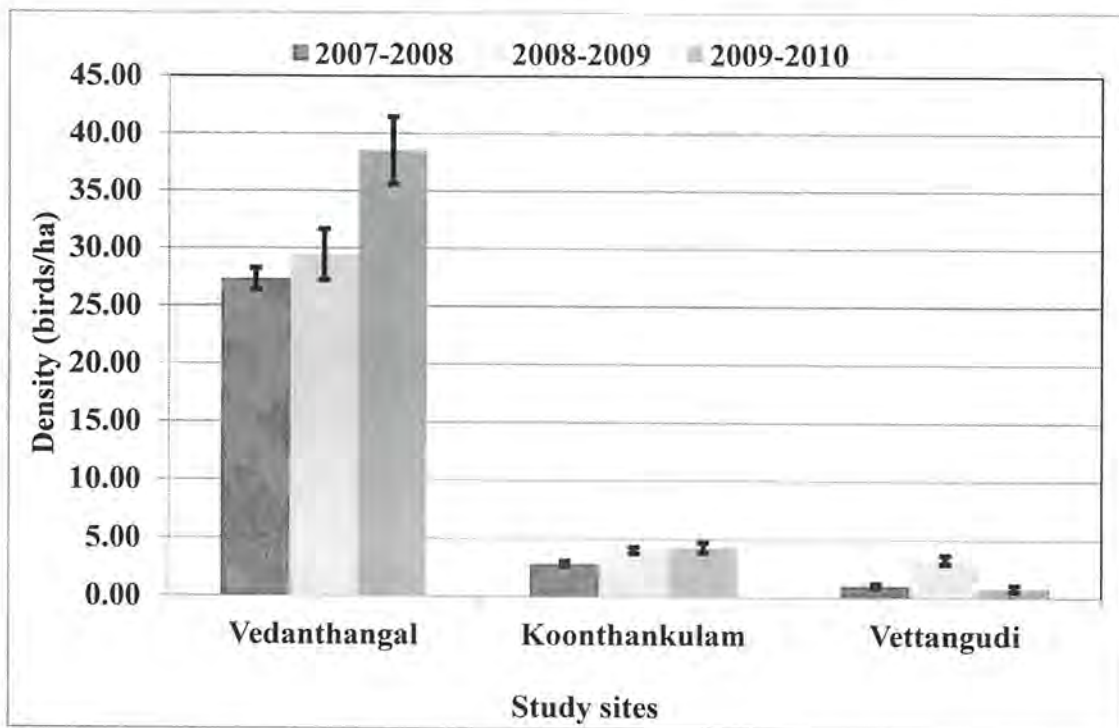


Figure10. Density (birds/ha Mean $\pm$ SE) of colonial nesting birds among years (2007-'10)

Increased abundance of water birds in the study sites is attributed to the presence of tanks with water as reported by Prashanth *et al.* (2013) in Tamiraparani River Basin. Wetlands are among the most important and productive ecosystems of the world (Prasad *et al.*, 2004) and they serve as important habitats for birds' feeding and breeding. Vijayan *et al.* (2004) documented the status of wetlands in eight districts of Tamil Nadu. The area under wetlands in the eight districts studied ranged between 0.42% (Thirunelveli) and 5.11% (Pudukkottai) of the geographical area of the respective districts. They reported 552 wetlands with a total area of 114.09 sq. km in Chengalpeta district and 173 wetlands with a total of 28.15 sq km in Thirunelveli district. Therefore the availability of numerous wetlands and water logged area around Vedanthangal followed by Koonthankulam might be the prime factor for the large congregation of birds in these two study sites than Vettangudi Bird Sanctuary. Further, the presence of large Madurantakam lake (350 ha) nearby is also a significant factor. During the present study, it was found that many species of birds such as Cormorants, Storks, Pelican and Ibises mainly used Madurantakam tank as their foraging ground.

Vedanthangal is the second most important birding area, next to Point Calimere in the state; hence, the area has been well explored by birds (Islam and Rahmani 2004). Unlike Vedanthangal, Koonthankulam had only a few wetlands around to support livelihoods of birds (Buelah 2002). Vettangudi had only two wetlands, namely Krauppur tank and Singampunari tank. However, most of the time, these wetlands were found dry. Agricultural activities in and around Vettangudi was also lesser than the other two sites. As Vettangudi is very close to human settlements, the anthropogenic pressure was more, particularly during the breeding season (Islam and Rahmani 2004). Insufficient water and foraging grounds along with anthropogenic pressure could have been the factors responsible for the comparatively small population at Vettangudi Bird Sanctuary.

5.2.5. Variation in density of birds among species and family in the study sites

Density of birds significantly varied among the species in all the study sites (Kuruskal-Wallis $\chi^2=3.406$; $df=20$; $P<0.05$). In Vedanthangal, Cattle Egret (139.3 ± 7.9 birds/ha) had the highest density followed by Little Cormorant (79.7 ± 2.7 birds/ha) and Asian Openbill (75.5 ± 2.8 birds/ha), while White-throated Kingfisher had the lowest density. In Koonthankulam, Cattle Egret (27.2 ± 1.9 birds/ha) showed the highest density followed by Painted Stork (14.6 ± 1.5 birds/ha) and Spot-billed Pelican (8.9 ± 0.7 birds/ha), while Great Egret (0.1 ± 0 birds/ha) had the least. Among the 16 species of birds recorded in Vettangudi, Asian Openbill displayed highest density (11.7 ± 2.0 birds/ha) followed by Cattle Egret (9.7 ± 1.3 birds/ha) and Little Egret (3.3 ± 0.6 birds/ha). White-throated Kingfisher, Darter and Glossy Ibis showed the lowest density in Vettangudi. Overall, Cattle Egret, Asian Openbill, Spot-billed Pelican and Painted Stork had higher density, while White-throated Kingfisher had the lowest (table 14).

Table 14. Density (birds/ha Mean $\pm$ SE) of colonial nesting birds among families in the study sites (2007-'10)

S. No.	Species	Study sites		
		Vedanthangal	Koonthankulam	Vettangudi
1	Spot-billed Pelican	46.7 $\pm$ 2.6	8.9 $\pm$ 0.7	0
2	Darter	1.7 $\pm$ 0.1	0.2 $\pm$ 0	0.1 $\pm$ 0
3	Indian Cormorant	25.5 $\pm$ 2.7	8.6 $\pm$ 0.7	0.3 $\pm$ 0.1
4	Little Cormorant	79.7 $\pm$ 2.7	1.0 $\pm$ 0.2	1.8 $\pm$ 0.3
5	Black-crowned Night Heron	20.3 $\pm$ 1.3	0.4 $\pm$ 0.1	0.5 $\pm$ 0.1
6	Grey Heron	6.0 $\pm$ 0.4	0	0
7	Indian Pond Heron	2.7 $\pm$ 0.2	1.2 $\pm$ 0.1	1.0 $\pm$ 0.1
8	Cattle Egret	139.3 $\pm$ 7.9	27.2 $\pm$ 1.9	9.7 $\pm$ 1.3
9	Great Egret	2.5 $\pm$ 1.7	0.1 $\pm$ 0	0.1 $\pm$ 0
10	Intermediate Egret	0	0.5 $\pm$ 0.1	1.2 $\pm$ 0.2
11	Little Egret	7.7 $\pm$ 0.4	2.1 $\pm$ 0.4	3.3 $\pm$ 0.6
12	Asian Openbill	75.5 $\pm$ 2.8	0.3 $\pm$ 0	11.7 $\pm$ 2.0
13	Painted Stork	25.1 $\pm$ 1.9	14.6 $\pm$ 1.5	0
14	Black Ibis	0	0.2 $\pm$ 0	0
15	Glossy Ibis	39.3 $\pm$ 1.8	5.0 $\pm$ 0.3	0.1 $\pm$ 0
16	Black-headed Ibis	47.6 $\pm$ 2.3	4.3 $\pm$ 0.3	3.1 $\pm$ 0.5
17	Eurasian Spoonbill	6.8 $\pm$ 0.4	0.2 $\pm$ 0	0
18	White-throated Kingfisher	0.1 $\pm$ 0.0	0	0.1 $\pm$ 0
		Kruskal-Wallis $\chi^2=3.406$; df=20; P<0.05		

Significant difference was observed in density of birds among families (Kruskal-Wallis $\chi^2=1.972$; df=5; P<0.05) (table 15). In Vedanthangal, the highest density of birds was recorded in Ciconiidae followed by Pelecanidae and Phalacrocoracidae, while the lowest was in Alcedinidae. Density of Ciconiidae, Pelecanidae and Phalacrocoracidae in Vedanthangal ranged from 36.68 $\pm$ 4.74 to 54.15 $\pm$ 2.46 birds/ha, 42.43 $\pm$ 6.78 to 72.67 $\pm$ 7.18 birds/ha and 35.39 $\pm$ 2.27 to 36.33 $\pm$ 4.25 birds/ha respectively. In Koonthankulam, the highest density of birds was recorded in Pelecanidae followed by Ciconiidae and Ardeidae, while the lowest was in Alcedinidae. Density of Pelecanidae, Ciconiidae and Ardeidae in Koonthankulam was in the range of 3.63 $\pm$ 0.43 to 13.56 $\pm$ 2.06 birds/ha, 4.94 $\pm$ 1.02 to 10.59 $\pm$ 1.39 birds/ha and 2.69 $\pm$ 0.43 to 5.10 $\pm$ 0.90 birds/ha respectively. Among all the families in Vettangudi, the highest density was recorded in Ciconiidae followed by Ardeidae, while the lowest was in Alcedinidae. Density of Ciconiidae and Ardeidae in Vettangudi ranged from 1.88 $\pm$ 1.14 to 21.94 $\pm$ 3.50 birds/ha, 1.13 $\pm$ 0.57 to 3.21 $\pm$ 0.41 birds/ha respectively (table 15).

Table 15. Density (birds/ha Mean $\pm$ SE) of colonial nesting birds among families in the study sites

Study sites	Family	Year		
		2007-08	2008-09	2009-10
Vedanthangal	Pelecanidae	42.51 $\pm$ 2.76	42.43 $\pm$ 6.78	72.67 $\pm$ 7.18
	Phalacrocoracidae	35.39 $\pm$ 2.27	36.12 $\pm$ 4.92	36.33 $\pm$ 4.25
	Ardeidae	25.23 $\pm$ 2.08	32.47 $\pm$ 5.25	48.43 $\pm$ 7.44
	Ciconiidae	54.15 $\pm$ 2.46	36.68 $\pm$ 4.74	49.47 $\pm$ 7.06
	Threskiornithidae	27.83 $\pm$ 1.16	36.90 $\pm$ 4.05	40.74 $\pm$ 3.78
	Alcedinidae	0.03 $\pm$ 0.00	0.11 $\pm$ 0.01	0.08 $\pm$ 0.01
Koonthankulam	Pelecanidae	3.63 $\pm$ 0.43	12.84 $\pm$ 1.26	13.56 $\pm$ 2.06
	Phalacrocoracidae	2.60 $\pm$ 0.36	4.66 $\pm$ 0.59	1.74 $\pm$ 0.30
	Ardeidae	2.69 $\pm$ 0.43	4.83 $\pm$ 0.59	5.10 $\pm$ 0.90
	Ciconiidae	10.59 $\pm$ 1.39	4.94 $\pm$ 1.02	5.32 $\pm$ 2.07
	Threskiornithidae	1.55 $\pm$ 0.14	2.29 $\pm$ 0.17	4.93 $\pm$ 0.55
	Alcedinidae	0	0.03 $\pm$ 0.02	0.01 $\pm$ 0.00
Vettangudi	Phalacrocoracidae	0.20 $\pm$ 0.05	1.28 $\pm$ 0.23	0.22 $\pm$ 0.13
	Ardeidae	1.56 $\pm$ 0.32	3.21 $\pm$ 0.41	1.13 $\pm$ 0.57
	Ciconiidae	3.40 $\pm$ 0.87	21.94 $\pm$ 3.50	1.88 $\pm$ 1.14
	Threskiornithidae	0.85 $\pm$ 0.29	2.25 $\pm$ 0.50	1.45 $\pm$ 0.69
	Alcedinidae	0.03 $\pm$ 0.01	0.06 $\pm$ 0.01	0.03 $\pm$ 0.01
Kruskal-Wallis $\chi^2=1.972$; df=5; P<0.05				

Among the families, six species of birds from Ardeidae and Ciconiidae contributed 50% to the overall population. On the other hand three species from the family Alcedinidae contributed only one percentage. According to Sivasubramanian (1992), most of the birds in Ardeidae and Ciconiidae are categorized as wading birds and are found to be feeding often more in agricultural fields and village irrigation tanks than in the Sanctuaries. Therefore, availability of many irrigation tanks and agricultural fields near the study sites could be one of the reasons for attracting huge congregation of referred species of birds. It was noted that the fertile agricultural lands around the sanctuaries offer ideal habitat for wading birds such as herons, egrets, ibises and storks as reported by (Maheswari and Thiyagesan 2013).

5.2.6. Variation in density of birds in the study sites based on their feeding habits

All the colonial nesting birds were grouped into three major categories based on their feeding habits as given below; Spot-billed Pelican, Darter, Little Cormorant and India Cormorant: Swimming birds. Herons, Egrets, Ibises, Storks and Spoonbill: Wading birds

and Common Kingfisher, White-throated Kingfisher and Pied Kingfisher: Diving birds. Significant variations were observed in the density of birds based on their feeding habits (Kruskal-Wallis $\chi^2=1.617$; $df=2$; $P<0.05$). In Vedanthangal, swimming birds had the highest density followed by wading birds and diving birds. Density of swimming, wading and diving birds in Vedanthangal ranged from 37.17 ± 1.84 to 45.41 ± 3.96 birds/ha, 31.20 ± 1.29 to 46.52 ± 4.38 birds/ha and 0.03 ± 0.00 to 0.08 ± 0.01 birds/ha respectively (table 16). In Koonthankulam, similar to Vedanthangal Bird Sanctuary, swimming birds had the highest density followed by wading birds and diving birds. Density of swimming and wading in Koonthankulam ranged from 2.86 ± 0.29 to 6.71 ± 0.58 birds/ha and 3.49 ± 0.33 to 5.08 ± 0.61 birds/ha respectively. In Vettangudi, wading birds had highest density than swimming and diving birds (table 16).

Table 16. Density (birds/ha) (Mean $\pm$ SE) of birds based on their feeding habits in the study sites

Study sites	Feeding habits	Year		
		2007-08	2008-09	2009-10
Vedanthangal	Swimming birds	37.17 ± 1.84	37.70 ± 4.05	45.41 ± 3.96
	Wading birds	31.20 ± 1.29	34.44 ± 3.19	46.52 ± 4.38
	Diving birds	0.03 ± 0.00	0.11 ± 0.01	0.08 ± 0.01
Koonthankulam	Swimming birds	2.86 ± 0.29	6.71 ± 0.58	4.69 ± 0.73
	Wading birds	3.49 ± 0.33	4.12 ± 0.37	5.08 ± 0.61
	Diving birds	0.00	0.03 ± 0.02	0.01 ± 0
Vettangudi	Swimming birds	0.20 ± 0.05	1.28 ± 0.23	0.22 ± 0.13
	Wading birds	1.60 ± 0.25	4.89 ± 0.56	1.27 ± 0.43
	Diving birds	0.03 ± 0.01	0.06 ± 0.01	0.03 ± 0.01
		Kruskal-Wallis $\chi^2=1.617$; $df=2$; $P<0.05$		

The pattern of population fluctuation depended on rainfall and water depth. The Pearson correlation gives significant positive relation with total population and water depth ($r = 0.614$; $P < 0.001$). Four species of swimming birds, namely Spot-billed Pelican, Darter, Little Cormorant and Indian Cormorant gives significant positive correlation with water depth ($r=633$; $P<0.05$) (table 17).

Table 17. Correlation matrix among colonial water bird population in relation to water depth and rainfall.

		Swimming birds	Wading birds	Diving birds
Water depth	r-value	.633**	.592**	.290**
	P-value	.000	.000	.005
	N	90	90	90
Rainfall	r-value	-.217*	-.255*	-.193
	P-value	.040	.015	.069
	N	90	90	90

** Highly significant; * Significant; P > 0.05- Not Significant; P<0.05- Significant

Population of thirteen species of wading birds including herons, egrets, storks and ibises were also positively correlated with water depth sustaining the findings of Kahl and Peacock (1963), *et al.* (1975 and 1976 a), Oden *et al.* (1978) and Sivasubramanian (1992). Pearson correlation showed negative relation with total population and rainfall. However, it was not statistically significant (table 26). During monsoon when water depth was high (average 300 cm), the birds congregated in large numbers for breeding. During winter when water depth was moderate, only the resident birds and the late breeders such as Painted Storks and Little Egret remained inside the Sanctuaries.

In summer, most of the waterlogged areas shrunk leading to dispersal of colonial nesting birds, from the Sanctuaries. While monsoon makes most of the birds to congregate for breeding, dry spell forced them to vacate the Sanctuaries and move out in search of water logged areas. Therefore, the entire seasonality and fluctuation in the population of colonial nesting birds is dependent basically on the rainfall and water regime as reported elsewhere (Ogden *et al.*, 1978; Sivasubramanian, 1992 and Venkatraman *et al.*, 2008; Sumathi *et al.*, 2008).

Weller (1979) had reported that wetland birds seem to have adapted to natural instability of their substrate by shifting their population on long term basis. Seasonal variation in waterbird population, abundance and diversity had been reported for other wetlands in different part of India as well (Sampath and Krishnamurthy 1989, 1993; Vijayan *et al.*, 2004; Sivasubramanian 1992; Maheswari and Thiyagesan 2013). Preference of shallow water by waders such as storks has also been reported by earlier researchers at different

localities. For example, extremely shallow water was found to be highly attractive to wading birds in Keoladeo National Park (Sivasubramanian 1992) and Veeranam Lake (Maheswari and Thiyagesan 2013).

According to Sinha and Chatterjee (1998), different species of waterfowls inhabit various types of wetlands and show a great deal of yearly fluctuation in population, and it depends upon both biotic and abiotic factors. Waterbird species richness is influenced by variation in water levels and nutrients. The physico-chemical properties of water determine bird numbers through their effect on prey availability (Nagarajan and Thiyagesan 1996). Bird population parameters such as species richness, relative density and diversity are frequently used as indicators of habitat quality (Sampath and Krishnamoorthy, 1990). Murphy *et al.* (1984) concluded that the slight change in hydrology in physical or chemical, limonological characteristics could exert profound effects on habitat of water birds.

A relationship between waterbird diversity and density with physico-chemical characteristics of Sanctuary water was not studied in the present investigation. However certain factors like water level and rainfall influenced bird communities. Draining of water and fish harvesting in nearby Sanctuaries attracted many birds. Adjoining Vedanthangal and Koonthankulam Bird Sanctuaries, the process of draining of water before cultivation, resulting in low water levels of approximately 0-5 cm, favored occurrence of many birds in the Sanctuary. Population of egrets and herons were recorded the maximum during this period.

Young and Chan (1997) reported the significant number of egrets feeding from draining ponds. Water fluctuation is a dominant feature in wetlands and it can determine wetland use by water birds through effects on food availability (Hafner *et al.*, 1982; Kushlan 1989; Perennou and Santharam 1990). With the onset of north-east monsoon in October and November, the condition not only in the sanctuary but also in the adjoining agricultural fields was conducive, and the population of birds was significantly high.

5.2.7. Population of threatened species of colonial nesting birds in the study sites.

i) Spot-billed Pelican: Among the three sites studied, Spot-billed Pelican was observed in Vedanthangal and Koonthankulam Bird Sanctuaries. During the study period it was not sighted even once in Vettangudi Bird Sanctuary. The maximum population of this species including their nestlings was 3,547 and 4,312 in Vedanthangal and Koonthankulam respectively during March 2010. According to BirdLife International (2001), Spot-billed Pelican was common across Asia, but suffered a widespread decline in recent years. However, owing to protection offered and increased awareness among people, its estimated population has been revised upwards from 5,500-10,000 birds in 2002 to 13,000-18,000 individuals in 2006 (BirdLife International 2006). The Indian population is reported to exceed 5,000 birds (BirdLife International 2013). Population of Spot-billed Pelican recorded in Vedanthangal and Koonthankulam Bird Sanctuaries put together is 50% more than the Indian population reported by BirdLife International (2013). There are 21 known breeding colonies of Spot-billed Pelican in the states of Andhra Pradesh, Karnataka and Tamil Nadu (Kannan and Manakalan 2005). The increasing population of Spot-billed Pelican in Tamil Nadu might be due to the availability of suitable and safe breeding and foraging grounds.

ii) Darter: It is one among the Near-Threatened birds in India, and was seen in all the three study sites. In India this resident bird is locally common only in Assam. Present status of this species is poorly known but it is generally uncommon and declining throughout Asia. However, its population has been estimated at 4000 individuals in South Asia (BirdLife International 2013). In the present study, the maximum population of Darter was observed in Vedanthangal (130 birds), followed by Koonthankulam (56 birds) and Vettangudi (10 birds). The number of birds recorded in Vedanthangal is two-fold higher than the threshold value (40) reported by Birdlife International (2013). While in Koonthankulam it is almost closer to threshold number, in Vettangudi the population is lesser than the threshold value. According to BirdLife International (2013), this species is threatened mainly due to degradation of foraging areas, felling of trees used for breeding, pollution and disturbances. Hence, detailed ecological study on this species is necessary to workout conservation measures.

iii) Painted Stork: Among the three sites studied, Painted Stork was seen only in Vedanthangal and Koonthankulam Bird Sanctuaries and not in Vettangudi. The highest population of Painted Stork was 7252 (March 2010) in Koonthankulam and 2385 (March 2010) in Vedanthangal. Although stork is one of the most abundant Asian birds, it is classified as Near Threatened due to moderately rapid population decline which is primarily because of hunting, wetland drainage and pollution (BirdLife International 2013). There are an estimated 15,000 individuals in South Asia and fewer than 10,000 in South-East Asia (Perennou *et al.*, 1994; BirdLife International 2013). The population of this species in Vedanthangal and Koonthankulam is several folds higher than the threshold number (150) reported by BirdLife International (2013).

iv) Black-headed Ibis: It is one among the commonest wetland birds in Asia, undergoing a population reduction, which is suspected to be moderately rapid. However, in India its distribution is widespread and its population is increasing due to the availability of many man-made wetlands (BirdLife International 2013). The population of this species is estimated at 10,000 individuals in south Asia, plus up to another 10,000 in South-East Asia and 100 in East Asia. Population estimated in all the three sites presently studied put together is 5450. This is a major contribution to the total population reported in South Asia and South-east Asia. Further, it is much higher than the threshold number suggested by BirdLife International (2013).

5.3. Breeding ecology of colonial nesting birds in the study sites

One of the most fascinating aspects in the life of birds is their breeding phase, which is intimately tied to the availability and abundance of food resources in their environment. One of the major priorities in conserving birds is monitoring changes in their breeding ecology to find prescription for their long time survival (Urfi 2003a,b). Hence, the present study focused on the breeding ecology of colonial nesting birds and their major requirements.

Information on breeding of 21 species of birds in about 41 nesting sites in Tamil Nadu was gathered. Breeding birds belonged to five families, namely Pelecanidae, Phalacrocoracidae, Ardeidae, Ciconiidae and Threskiornithidae. Of all the species recorded breeding in the referred number of sites, Little Cormorant, Night Heron, Indian

Pond Heron, Indian Cormorant, Cattle Egret, Little Egret, Spot-billed Pelican, Painted Stork and Asian Openbill were common. The number of birds nesting in these heronries varied greatly and only three sites, namely Vedanthangal, Vettangudi and Koonthankulam Bird Sanctuaries qualified to be considered as large heronries. Earlier studies (Subramanya 1996 a, b and 2005) also reported that these three sites provide ideal habitats for the colonial nesting birds. Hence, in the present study, information on breeding ecology was gathered from Vedanthangal, Vettangudi and Koonthankulam Bird Sanctuary.

5.3.1. Nesting Population

5.3.1.1. Vedanthangal Bird Sanctuary

Twelve species of birds, namely Spot-billed Pelican, Darter, Little Cormorant, Grey Heron, Black-crowned Night Heron, Indian Pond Heron, Little Egrets, Asian Openbill, Painted Stork, Black-headed Ibis and Eurasian Spoonbill were found to be colonially nesting in Vedanthangal Bird Sanctuary. On the whole, the total number of nests recorded was the maximum (3185) during 2009 - 2010 and the minimum (2819) during 2007 - 2008. Among the various species, Spot-billed Pelican (887) was found to be breeding more in numbers during 2009 - 2010 followed by Painted Stork (576) during 2007 - 2008 and Asian Openbill (570) during 2009 - 2010. White-breasted Kingfisher was less in number (table 18).

Table 18. Number of nests recorded in Vedanthangal Bird Sanctuary during October 2007 - March 2010.

S. No.	Name of the birds	No. of active nests/ year		
		2007-2008	2008-2009	2009-2010
1	Spot-billed Pelican	612	872	887
2	Darter	48	21	41
3	Little Cormorant	440	345	481
4	Black-crowned Night Heron	30	24	124
5	Grey Heron	84	202	123
6	Indian Pond Heron	7	30	0
7	Little Egret	10	26	70
8	Asian Openbill	547	525	570
9	Painted Stork	576	455	495
10	Black-headed Ibis	326	477	292
11	Eurasian Spoonbill	135	78	96
12	White-throated Kingfisher	4	10	6
		2819	3065	3185

As mentioned elsewhere in this thesis, Vedanthangal Bird Sanctuary is a traditional breeding site for many species of colonial breeders. The first published information dates back to early 1900 (Packard 1903). In the late 70's, Tamil Nadu Forest Department planted several *Acacia nilotica* trees and according to an estimate, there were 5000 *Acacia* and almost 1000 *Barringtonia* trees (Paulraj 1984). During 1981-1991, the population of birds remained around 5000 to 6000 (Santharam 2000). A proper count made on 2nd March 1997 revealed an increase in the number of the nesting birds to over 12500 birds (Santharam 2000). Besides colonial breeding birds those regularly nest in the trees at Vedanthangal, many other species of birds, such as Little Grebe and the Indian Moorhen also nest in the vegetation surrounding the tank (Spillett 1966). Although there are no reports on the breeding of Cattle Egret in the Vedanthangal Bird Sanctuary, large numbers of them roost over here.

In Vedanthangal, the number of nesting species is observed to be increasing when published records are perused (Chandrasekaran 1986; Santharam 2000, Krishnan 2001; Geetha 2005 and Venkatraman 2007). Spot-billed Pelican began breeding in Vedanthangal during 1984 - 86 with 12 nests but, in the present study between 2007 and 2010, they were found to be breeding in large numbers. The first published report regarding the breeding of Painted Storks was during 1984 (Paulraj and Gunasekaran 1988). He reported about 22 nests of Painted Stork on *Barringtonia* trees but, in the present study, Painted Storks were found to be breeding extremely well in Vedanthangal with 455

to 576 nests. The Glossy Ibis which was not recorded breeding earlier was later observed to nest at Vedanthangal (Santharam 2000 and Venkatraman 2009). Apart from Painted Stork and Pelican, Asian Openbill, Spoonbill, Cormorants, Black-crowned Night Heron and Grey Heron were found nesting in good numbers since 1990 (Venkatraman 1996 b). According to Krishnan (1993), Night Herons, Little Egrets and Little Cormorants were the most prominent species of birds nesting in Vedanthangal. Asian Openbill, Grey Herons, Eurasian Spoonbills, Cattle Egrets, White Ibises, Median Egrets and Pond Herons were comparatively less. He further reported that Darters breed in small numbers while Large Egrets and Large Cormorants were relatively rare. In this study, similar pattern was observed in all species except Cattle Egret and Median Egret. Further studies are essential to understand the reason for Cattle Egret and Median Egret to shift breeding out of Vedanthangal.

5.3.1.2. Koonthankulam Bird Sanctuary

Eleven out of 21 species birds found in the Sanctuary, namely Spot-billed Pelican, Darter, Little Cormorant, Indian Cormorant, Black-crowned Night Heron, Indian Pond Heron, Cattle Egret, Little Egret, Asian Openbill, Painted Stork, Black-headed Ibis and Eurasian Spoonbill were found nesting. While, the maximum number of nests (3650) were recorded during 2009 - 2010, the minimum was noticed (2169) during 2007 - 2008. Among the species, Painted Stork (1861) was the most predominant species during 2009 - 2010 followed by Spot-billed Pelican (877) during 2009 - 2010. White-treated Kingfisher and Darter were the least (table 19).

Table 19: Number of nests recorded in Koonthankulam Bird Sanctuary during October 2007 - March 2010

S. No	Name of the birds	No. of active nests/ year		
		2007-2008	2008-2009	2009-2010
1	Spot-billed Pelican	206	839	877
2	Darter	20	35	20
3	Indian Cormorant	218	230	191
4	Little Cormorant	18	31	43
5	Little Egret	178	78	163
6	Intermediate Egret	38	66	71
7	Indian Pond Heron	27	48	0
8	Painted Stork	1325	1483	1861
9	Black-headed Ibis	127	204	407
10	Eurasian Spoonbill	6	22	11
11	White-throated Kingfisher	6	5	6
	Total no. of nests	2169	3041	3650

Spot-billed Pelican is widely distributed in Tamil Nadu, and the state probably supports up to 1600 to 2000 adult birds. According to Kannan and Manakadan (2005), the largest colony of Spot-billed Pelican is at Koonthankulam, Thirunelveli district, with 450 individuals, having grown from just 30 nests in 1982. During the present study the number of active nests of Pelican was 877 (2009 - 2010). Total number of nests recorded belonged to 16 species of birds including Painted Stork and Spot-billed Pelican are comparable with number of nests reported in Koonthankulam Bird Sanctuary by Beulah (2002).

5.3.1.3. Vettangudi Bird Sanctuary

Seven species of birds, namely Asian Openbill, Black-headed Ibis, Little Cormorant, Black-crowned Night Heron, Intermediate Egret, Little Egret and Darter nested in Vettangudi Bird Sanctuary during both 2007 - 2008 and 2008 - 2009. The maximum (521) number of nests was recorded during 2008 - 2009. Among the species, Asian Openbill (326) was the most predominant breeder followed by Black-headed Ibis (104) during 2008 - 2009 (table 20).

In December 2009, all the seven species of birds settled-into begin nesting even though water availability was not promising. Unfortunately Greater Spotted Eagle started chasing the birds and ultimately the birds deserted the Sanctuary in matter of two days. Similar to population the number of nests reported in Vettangudi is lesser than in Vedanthangal and

Koonthankulam as also reported by Venkatraman (1996 b) and Beulah (2002). Vettangudi was declared as an IBA due to the presence of large breeding colony of up to 5000 birds (Islam and Rahmani 2004). Similar to population details, information on breeding of birds is also very sparse in Vettangudi. More than 250 nests of Asian Openbill were reported breeding (Islam and Rahmani 2004). Apart from Asian Openbill, Little Cormorant, Black-headed Ibis and Indian Shag were also found breeding in Vettangudi. Number of active nest of Asian Openbill recorded in the present study is higher than the numbers reported by earlier workers (Venkatraman 1996 b; Beulah 2002 and Islam and Rahmani 2004).

Table 20: Number of nests recorded in Vettangudi Bird Sanctuary during October 2007 - March 2010

S. No.	Name of the bird	No. of active nests/ year		
		2007-2008	2008-2009	2009-2010
1	Darter	10	3	0
2	Little Cormorant	20	31	0
3	Black-crowned Night Heron	5	4	0
4	Little Egret	5	5	0
5	Intermediate Egret	5	48	0
6	Asian Openbill	40	326	0
7	Black-headed Ibis	56	104	0
	Total no. of nests	141	521	0

5.3.2. Breeding season

A general account on the breeding season and timings for many species of colonial nesting birds in the Indian subcontinent was reported by Ali and Ripley (1969). However, based on specific biotic and abiotic factors, the season may vary among different species of colonial nesting birds and study sites. In the present study, the nesting seasonality of birds in the study sites is presented in table 21. It is apparent that there exists a unique pattern among the sites. A majority of waterbirds considered in the study nested during the North-east monsoon season. In Vedanthangal, birds did begin breeding in December but extended up to March except Painted Stork, which began breeding in January and extended up to June. In Vettangudi, the birds breed between October and December, whereas in Koonthankulam all the species started breeding in December and extended up to March except Painted Stork, whose breeding was over only in June (table 21).

All the species of birds except Asian Openbill Stork had only one breeding season in a year. Among all the species, Asian Openbill was the first species to arrive in all the study sites. They do so just before the onset of monsoon and continue to build their nests till the area is inundated. The Painted Stork is a late breeder. The proximate factor which prompted breeding in all the species, except the Asian Openbill was the flooding of area and the appearance of large number of fry and fingerlings in the surrounding area of the Sanctuaries. In case of Asian Openbill, appearance of the mollusk with commencement of monsoon was the major triggering factor as reported by Vijayan (1991) and Sivasubramanian (1992) in Keoladeo National Park, Rajasthan. The ultimate factor which determines the nesting season of all the wading birds appeared to be the availability of food. Moreover, concentration of prey appears to be essential for successful breeding in wading bird as reported by Kushlan *et al.* (1975).

Table 21. Breeding season of select species of colonial nesting birds in study sites in Tamil Nadu

Species	Sites	Month											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Asian Openbill	VBS	>>>	>>>	>>>	>>>	>>>							
	VTBS	>>>	>>>	>>>									
Painted Stork	VBS				>>>	>>>	>>>	>>>	>>>	>>>			
	KBS				>>>	>>>	>>>	>>>	>>>	>>>	>>>		
Black-headed Ibis	VBS			>>>	>>>	>>>	>>>						
	KBS			>>>	>>>	>>>	>>>						
	VTBS	>>>	>>>	>>>									
Eurasian Spoonbill	VBS			>>>	>>>	>>>	>>>						
Darter	VBS			>>>	>>>	>>>							
	KBS			>>>	>>>	>>>							
Little Cormorant	VBS			>>>	>>>	>>>							
	KBS			>>>	>>>	>>>							
	VTBS	>>>	>>>	>>>									
Spot-billed Pelican	VBS			>>>	>>>	>>>	>>>						
	KBS			>>>	>>>	>>>	>>>						
Black-crowned Night Heron	VBS			>>>	>>>	>>>							
	KBS			>>>	>>>	>>>							
	VTBS	>>>	>>>	>>>									
Indian Pond Heron	VBS						>>>	>>>	>>>	>>>	>>>		
Grey Heron	KBS						>>>	>>>	>>>	>>>			
	VBS			>>>	>>>	>>>							
Intermediate Egret	KBS						>>>	>>>	>>>				
	VTBS	>>>	>>>	>>>									
Little Egret	VBS			>>>	>>>	>>>							
	KBS			>>>	>>>	>>>	>>>						
	VTBS	>>>	>>>	>>>									

VBS - Vedanthangal Bird Sanctuary; KBS - Koonthankulam Bird Sanctuary; VTBS - Vettangudi Bird Sanctuary;

5.3.3. Clutch size and incubation period

Clutch size of birds vary greatly among species, sometimes even within the same genus. It also differs within the same species due to factors such as, health, nutrition, predation pressures and time of year (Urfi and Kalam 2006). In the present study, the clutch size did not vary among the sites and years. Among the species, Painted Stork, Asian Openbill, Little Egret and Little Cormorant laid the maximum number of eggs in their clutch (table 22).

Incubation period also differed among the species, and it ranged from 15 to 24 days. Both male and female shared the responsibility of incubation in most of the colonial nesting birds in the present study. When the female incubated, the male was spending its time in other activities such as collecting food, preening and soaring. Same was the situation when male was on the job. Among the species, the maximum average incubation period was in Spot-billed Pelican (24 ± 3 days) followed by Black-headed Ibis with 23 ± 2 days, while the minimum was in Black-crowned Night Heron and Grey Heron with 15 ± 1 days each (table 22).

Table 22. Clutch size and incubation period of colonial nesting birds in study sites.

S. No.	Name of the species	Clutch size (eggs/ nest)	Incubation period In Day (Mean $\pm$ SD)
1	Spot-billed Pelican	2-3	24 ± 3
2	Darter	3	20 ± 2
3	Little Cormorant	3-4	21 ± 2
4	Black-crowned Night Heron	3	15 ± 1
5	Grey Heron	2-3	15 ± 1
6	Indian Pond Heron	2-3	16 ± 1
7	Little Egret	3-4	19 ± 1
8	Intermediate Egret	2-3	19 ± 1
9	Asian Openbill	3-4	22 ± 2
10	Painted Stork	3-4	21 ± 1
11	Black-headed Ibis	3	23 ± 2
12	Eurasian Spoonbill	2-3	19 ± 1

Ali (1996) reported the clutch size (eggs/ nest) of various water bird species, namely Spot-billed Pelican (3 eggs), Darter (3-4 eggs), Little Cormorant (3-6 eggs), Black-Crowned Night Heron (4-5 eggs), Grey Heron (3-6 eggs), Indian Pond Heron (3-5 eggs), Little Egret (4 eggs), Intermediate Egret (3-4 eggs), Asian Openbill (2-4 eggs), Painted Stork (3-5 eggs), Black-headed Ibis (2-4 eggs) and Eurasian Spoonbill (4 eggs). Clutch size of colonial nesting birds recorded in the present study is comparable with clutch size reported by Ali (1996). Dayananda *et al.* (2008) studied the nesting pattern of Darter, Little Cormorant and Black-crowned Night Heron. They reported the mean clutch size in Darter (3.6 ± 0.52), Little Cormorant (4.1 ± 0.74) and Black-crowned Night Heron (3.4 ± 0.52) in Gudavi Bird Sanctuary, Western Ghats. Clutch size in Asian Openbill Stork studied in all three intensive sites is comparable with the clutch size (4 eggs/ nest) reported in the same species in Raiganji Bird Sanctuary, West Bengal (Sharma 2007). The number of eggs laid/ nests by Black-headed Ibis in the three study sites, namely Vedanthangal, Koonthankulam and Vettangudi Bird Sanctuaries in Tamil Nadu is lower than number of eggs/ nest (6.0 ± 2.16) reported from the same species in Bhitarkanika Mangroves, Odisha by Gopi (2007 a). They also reported the clutch size of Painted Stork, Asian Openbill and Lesser Adjutant Stork in the same study site and observed that the clutch size of Painted Stork and Asian Openbill found to be 4.55 ± 1.36 and <4 eggs respectively. This is comparable with the present study.

According to Seedikkyo *et al.* (2012), the clutch size of Indian Pond Heron varied from 2 to 5 eggs. Clutch size of Little Egret ranged from 2 to 6, 4 being the most common number (Seedikkyo and Azeez, 2012). Clutch size of Indian Pond Heron and Little Egret recorded in the current study is comparable with study referred above. According to Eldridge and Krapu (1988), the production of eggs in many of the birds may depend upon the ability of females to collect and store nutrients prior to the nesting.

There are only limited studies available on the incubation period of colonial nesting birds in India. Available information is compiled below. The incubation period of Asian Openbill in Raiganji Bird Sanctuary was 30- 40 days (Sharma 2007), Little Cormorant was 14- 21 days (Naher *et al.*, 2009), Asian Openbill and Painted Stork were 25- 26 and 29- 32 days respectively (Gopi and Pandav 2007 b). Incubation periods reported for Asian Openbill, Little Cormorant and Painted Stork in the above listed studies are comparable with the data recorded in the current study.

5.3.4. Breeding success

Information on breeding success of select species of colonial nesting birds was gathered from Vedanthangal, Koonthankulam and Vettangudi Bird Sanctuaries. Totally 1583 nests belonging to nine species of birds comprising five families, namely Pelecanidae, Phalacrocoracidae, Ardeidae, Ciconiidae and Threskiornithidae were selected as focal nests. Nesting data were collected throughout the breeding season in all the study sites. The focal nests were observed periodically causing no or the least disturbance to birds and nestlings. The breeding success in terms of percentage was calculated from the total number of fledglings and eggs laid in the focal nests. Breeding success among the years varied in all the species. The number of focal nests among the study sites varied based on the availability and the visibility of active nests. The percentage of breeding success among birds was the highest in Vedanthangal followed by Koonthankulam and Vettangudi.

5.3.4.1 Vedanthangal Bird Sanctuary

In Vedanthangal, nests of nine species of birds, namely Spot-billed Pelican, Darter, Little Cormorant, Grey Heron, Little Egret, Asian Openbill, Painted Stork, Black-headed Ibis and Eurasian Spoonbill were focused and followed up to assess the breeding outcome. Among the birds, Black-headed Ibis and Spot-billed Pelican showed the highest breeding success during 2007- 2008, while the same species had the lowest success during 2009-2010. This could be due to felling of matured *Acacia* trees those had active nests. Between the two species in the family Phalacrocoracidae, the near threatened Darter breed successfully during 2007- 2008 with 94.9% but the same species could not be focused in the subsequent years due to poor accessibility and visibility of their nests. Out of two species in the family Ardeidae, Grey Heron (90.6%) showed the maximum success. In the family Ciconiidae, Asian Openbill (92.1%) recorded the maximum success than Painted Stork. In the family Threskiornithidae, Black-headed Ibis (89.5%) was the successful breeder than Eurasian Spoonbill (table 23).

5.3.4.2. Koonthankulam Bird Sanctuary

Nests of seven species of birds, namely Spot-billed Pelican, Indian Cormorant, Little Cormorant, Little Egret, Intermediate Egret, Painted Stork and Black-headed Ibis were monitored in Koonthankulam Bird Sanctuary. Among the species, Spot-billed Pelican had the highest success (93.3%) during 2009- 2010 followed by Painted Stork (91.3%) during 2007- 2008. The near threatened Black-headed Ibis breed successfully during 2009 - 2010 with 84.4 % and the same species could not be studied during 2007- 2008 and 2008 - 2009 due to poor visibility and accessibility. Families, such as Pelecanidae and Ciconiidae showed the highest breeding success (table 24).

5.3.4.3. Vettangudi Bird Sanctuary

In Vettangudi, only four species of birds, namely Little Cormorant, Intermediate Egret, Asian Openbill and Black-headed Ibis could be studied for assessing breeding success. Among the species, Little Cormorant was the most successful breeder during 2007- 2008 with 94.5% followed by Asian Openbill with 87.7%. During 2009 - 2010, Asian Openbill with 33 active nests, Little Cormorant with 19 nests and Intermediate Egret with three nests settled-into breed. But subsequently, all of them deserted their nests due to inadequate water and disturbance by two Greater Spotted Eagles. Therefore, there was no opportunity to study the nesting success (table 25). Greater Spotted Eagle is one of the winter visitors to the Indian subcontinent. They are known to hunt waterfowls and small birds in well-watered area as documented by Ali and Ripley (1968).

Table 23. Breeding success in select species of colonial nesting birds in Vedanthangal Bird Sanctuary during 2007 – 2010

S. No.	Species	2007-2008		2008-2009		2009-2010	
		N	Breeding Success (%)	N	Breeding Success (%)	N	Breeding Success (%)
1	Spot-billed Pelican	17	100	60	79.7	65	58.5
2	Darter	13	94.9	NS	NS	NS	NS
3	Little Cormorant	16	80.4	20	83.1	35	89.7
4	Grey Heron	14	90.6	20	83.3	20	86.6
5	Little Egret	NS	NS	15	78.2	21	85.3
6	Asian Openbill	21	92.1	70	90.3	65	86.9
7	Painted Stork	34	75.5	50	84.0	50	82.2
8	Black-headed Ibis	16	100	46	85.2	52	89.1
9	Eurasian Spoonbill	15	89.5	20	85.7	20	87.5
Total		146		301		328	

N- Number of focal nests; NS- Not Studied.

Table 24. Breeding success in select species of colonial nesting birds in Koonthankulam Bird Sanctuary during 2007 - 2010

S. No.	Species	2007-2008		2008-2009		2009-2010	
		N	Breeding Success (%)	N	Breeding Success (%)	N	Breeding Success (%)
1	Spot-billed Pelican	28	26.7	60	87.7	66	93.3
2	Indian Cormorant	NS	NS	NS	NS	40	80.9
3	Indian Pond Heron	10	74.1	20	87.9	NS	NS
4	Little Egret	26	88.6	20	78.1	20	80.9
5	Intermediate Egret	10	75.8	20	74.4	20	78.6
6	Painted Stork	76	91.3	85	74.6	65	88.9
7	Black-headed Ibis	NS	NS	NS	NS	45	84.4
Total		150		205		256	

N- Number of focal nests; NS- Not Studied.

Table 25. Breeding success in select species of colonial nesting birds in Vettangudi Bird Sanctuary during 2007 - 2010

S. No.	Species	2007-2008		2008-2009		2009-2010	
		N	Breeding Success (%)	N	Breeding Success (%)	N	Breeding Success (%)
1	Little Cormorant	21	94.5	15	90.0	ND	ND
2	Intermediate Egret	4	50.0	20	65.5	ND	ND
3	Asian Openbill	46	87.7	33	84.0	ND	ND
4	Black-headed Ibis	37	80.0	21	78.6	ND	ND
Total		108		89			

N- Number of focal nests; ND- Nest Deserted.

In India, comprehensive studies pertaining to breeding success of heronry birds are limited except a few. Breeding success of the Little Egret recorded in Vedanthangal (78.1- 80.1%) and Koonthankulam (78.1- 88.6%) Bird Sanctuaries in the present study is similar to what Hilaluddin *et al.* (2003) reported in the same species (78%) in Uttar Pradesh, India.

Breeding success of Little Cormorant studied in Vedanthangal (80.4- 89.9%) and Koonthankulam (90.0- 94.5%) is higher than the success reported by Naheer *et al.* (2009) in Bangladesh (78.76%). Breeding success of Black-headed Ibis in Sakkarbaug Zoo Aviary in Junagadh city, Gujarat, India was reported to be 57% (Devkar *et al.*, 2006). This is much higher than the success found in the present study in Black-headed Ibis in Vedanthangal Bird Sanctuary and Koonthankulam Bird Sanctuary. Breeding success recorded in Asian Openbill and Painted Stork in the present study is higher than the success rate reported by Gopi and Pandav (2007 b) in Asian Openbill ($41.14 \pm 21.43\%$) and Painted Stork ($46.66 \pm 33.54\%$) in Bitarnganika mangrove in Odisha. The breeding success of Darter (94.9%) recorded in Vedanthangal Bird Sanctuary is higher than the success reported in the same species from Gudavi Bird Sanctuary in Western Ghats in Karnataka (Dayananda *et al.* (2008), whereas the breeding success of Little Cormorant (85.3%) in Vedanthangal and Vettangudi Bird Sanctuaries are comparable.

5.3.5. Cause of breeding failure

It appears to be not much of correlation between the water level and the nesting success although water plays a crucial role. Moreover, predation was frequently observed to be a factor in all the three locations studied. The major predators during the egg laying period were the Common Crow, Large-billed Crow and Indian Rat Snake. Domestic Cat, Black Kite and Greater Spotted Eagle disturbed during the nestling period (table 26). In Vedanthangal Bird Sanctuary, crows, kites and Indian Rate Snakes were the major predators which affected the breeding outcome of colonial nesting birds. Among the predators, crows and Indian Rat Snakes were found to be predating only the eggs. Kites and Crow were found to be predating on nestlings, while stray dogs hunted fallen fledglings which were incapable of flying. In Koonthankulam, crows and Indian Rat Snakes were the major egg predators. Kites and domestic cats were the major predators on nestlings. Apart from these predators, 26 fledglings succumbed to electrocution during

their maiden or learning flights. In Vettangudi, Greater Spotter Eagle and crows were the predominant predators (table 26).

Table 26. Causes of breeding failures in the study sites during 2007-2010

S. No.	Location and threats	Predated on					
		Eggs		Nestlings		Fledglings	
		No. of Incidences	%	No. of Incidences	%	No. of Incidences	%
I	Vedanthangal						
1	Crows	26	68	8	73	0	0
2	Kits	0	0	3	27	0	0
3	Indian Rat Snakes	12	32	0	0	0	0
4	Stray dogs	0	0	0	0	8	100
II	Koonthankulam						
1	Crows	58	88	6	19	0	0
2	Kites	0	0	12	37	0	0
3	Indian Rat Snakes	8	12	0	0	0	0
4	Electrocution	0	0	0	0	26	100
5	Domestic Cat	0	0	14	44	0	0
III	Vettangudi						
1	Crows	9	41	0	0	0	0
2	Kites	0	0	4	57	0	0
3	Greater Spotted Eagle	13	59	3	43	0	0

During the incubation period, if disturbed by people, particularly strangers, parent birds were found to desert their nests. Further the eggs from these nests were eaten by crows. However, the parents did not desert their nests once the eggs were hatched as reported by other researchers (Sivasubramanian 1992; Venkatraman 1996 b and, Chinna Sathan and Palpandi 2009). On many occasions nestlings had fallen from the nests due to heavy wind and rain. Sometimes nestlings were found hanging dead on the rim of the nests because of heavy wind and on other times the whole nests were found fallen on the ground due to imperfect positioning or inadequate nesting substrates. Few nestlings were also recorded dead because their tender legs had got trapped in between sticks in the nests. In a few cases, reason for mortality of nestlings could not be ascertained. Stressors associated with agricultural landscapes, such as habitat loss, reduction in prey abundance, changes in cropping patterns and human disturbance could limit avian breeding success (Newton 2004; Radford *et al.*, 2005; Sundar 2009 a , b and Schaub *et al.*, 2010). Similarly, irregular monsoon could alter avian breeding success due to inadequate food availability (Kushlan 1986; Dickey *et al.*, 2008 and Gaston *et al.*, 2009).

5.3.6. Nest-site selection by select species of colonial nesting birds in the study sites

In colonial birds, nest-site selection is an often studied (Birkhead and Furness 1985; Ishtiaq *et al.*, 2004 and Venkatraman 2007) aspect. Social and physiognomic factors have been reported to affect nest-site selection in temperate marshland birds (Burger 1985). Nest-site selection is crucial as secured sites provide protection to young ones from predators and adverse climatic conditions. It is observed that the breeding season is the most vulnerable period in the birds' lifecycle. A very few studies on nest-site selection of birds especially related to heronries are available in India (Singha *et al.*, 2002; Ishtiaq *et al.*, 2004 and Venkatraman 2007).

5.3.6.1. Vedanthangal Bird Sanctuary

A total of 775 nests belonging to twelve species of birds were selected in Vedanthangal Bird Sanctuary to understand the nest-tree preference. Most of the nests were found on *Acacia nilotica* and *Barringtonia acutangula*. Among the birds, comparatively Asian Openbill, Painted Stork, Black-headed Ibis, Grey Heron, Black-crowned Night Heron, Little Egret, Little Cormorant and Eurasian Spoonbill preferred *Barringtonia acutangula*, while Indian Cormorant, Darter and Spot-billed Pelican preferred *Acacia nilotica*. A few White-throated Kingfishers nested in holes on the inside walls of open wells (figures 11-13).

In terms of preference from the nesting trees, the species were grouped and are shown as dendrogram (figure 16). Among 12 species of birds, Indian Pond Heron formed a separate group used only *Prosopis juliflora* those were located outside of the Sanctuary. Group comprising Darter, Little Cormorant, Black-headed Ibis and Spot-billed Pelican used *Acacia nilotica* and *Barringtonia acutangula*, while, group comprising Black-crowned Night Heron, Little Egret, Asian Openbill, Eurasian Openbill and Grey Heron were selective and used only *Barringtonia acutangula* (figure 13).

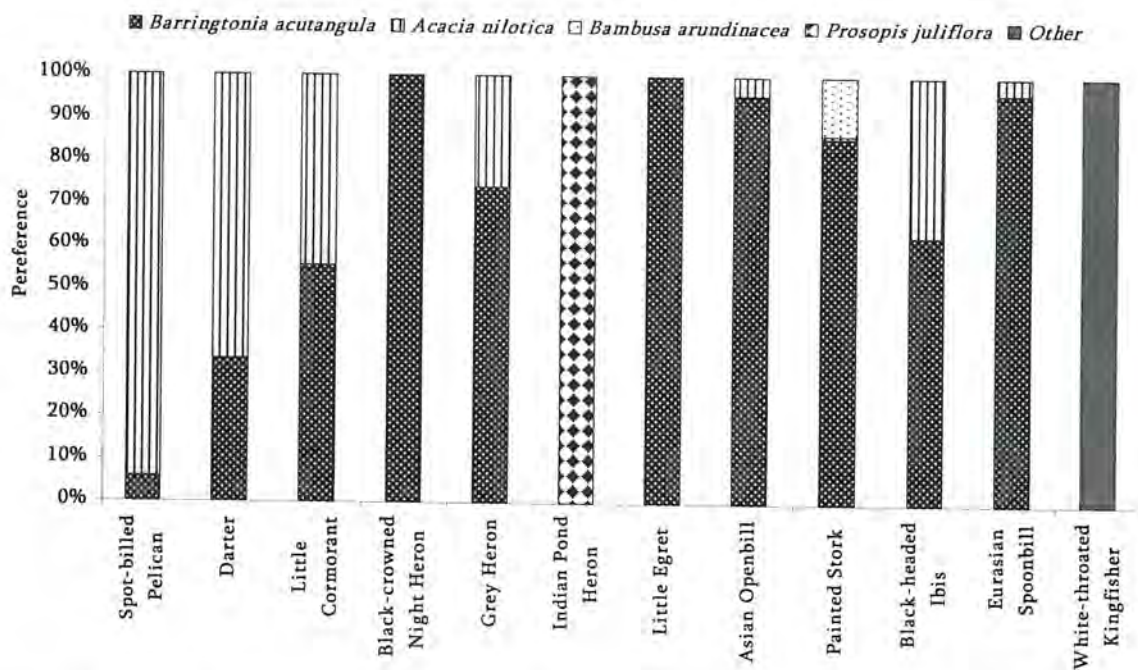


Figure 11. Nest-site selection in birds in Vedanthangal Bird Sanctuary during 2007-2008

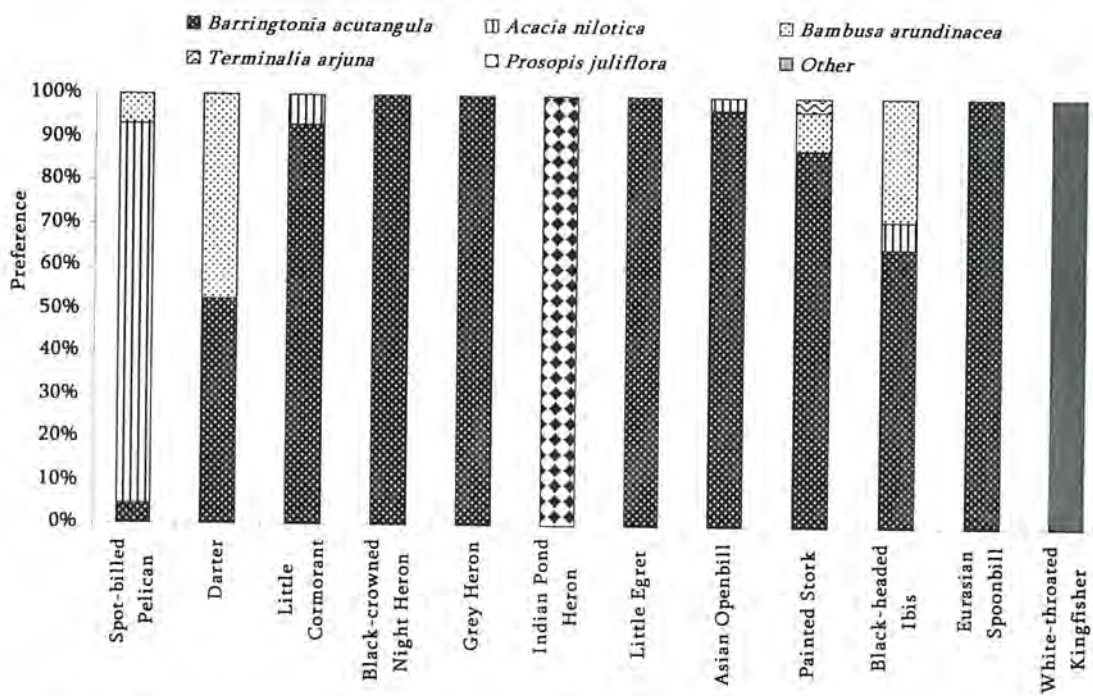


Figure 12. Nest-site selection in birds in Vedanthangal Bird Sanctuary during 2008-2009

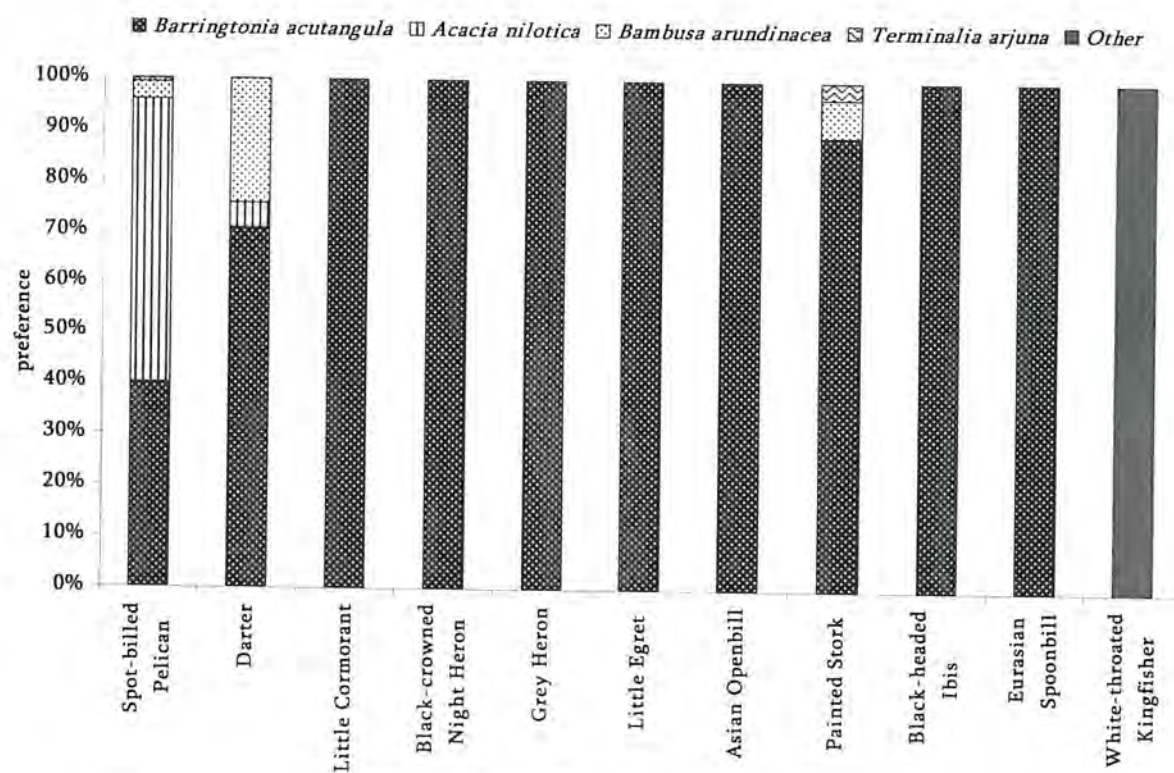


Figure 13. Nest-site selection in birds in Vedanthangal Bird Sanctuary during 2009-2010

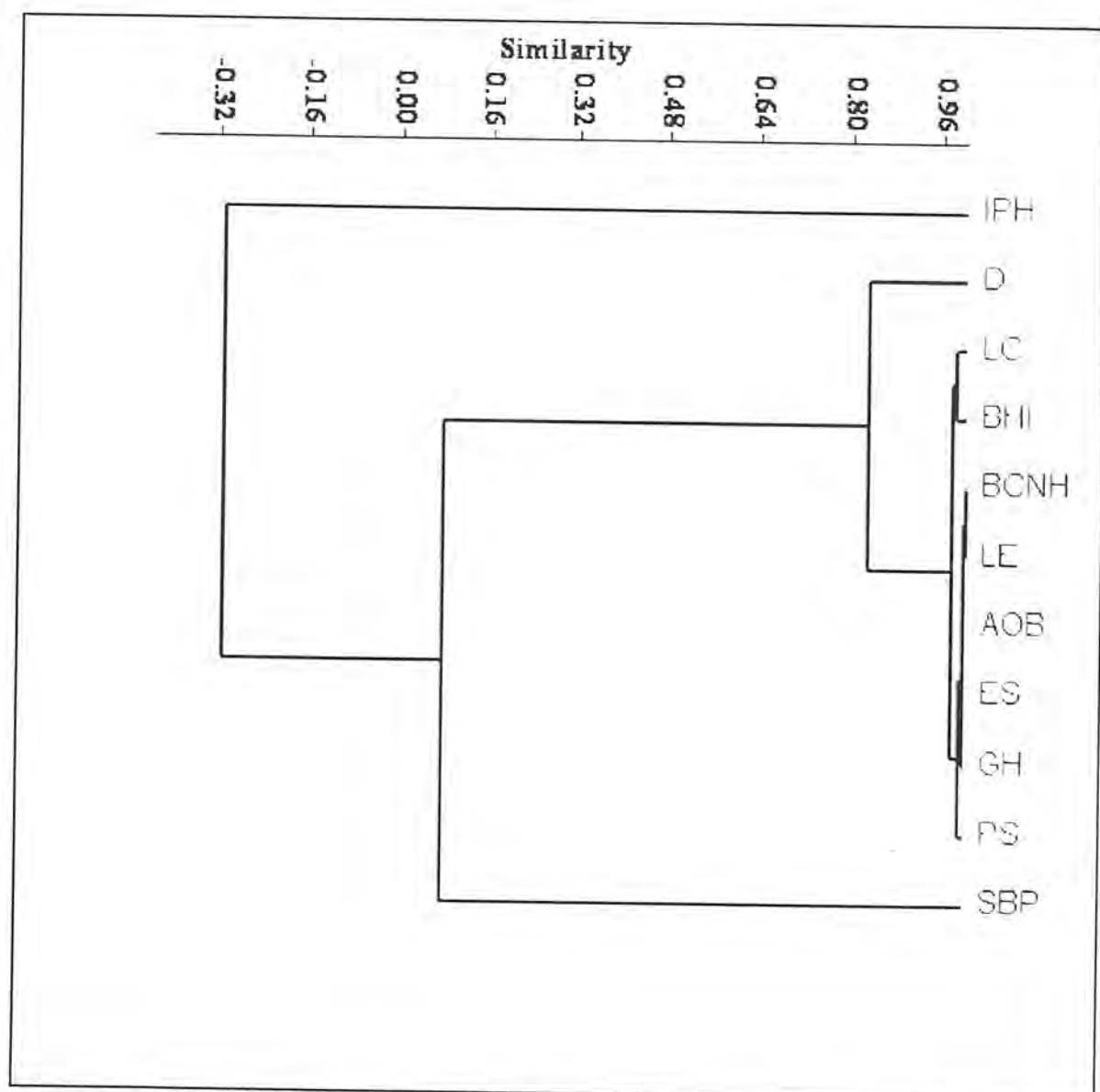


Figure 14. Dendrogram showing the grouping of different species of birds based on their nest-site selection in Vedanthangal during 2007-2010

SBP- Spot-billed Pelican, PS- Painted Stork, GH- Grey Heron, ES- Eurasian Spoonbill, AOB- Asian Openbill, LE- Little Egret, BCHN- Black-crowned Night Heron, BHI- Black-headed Ibis, LC- Little Cormorant, D- Darter and IPH- Indian Pond Heron

Larger birds, namely Spot-billed Pelican, Asian Openbill and Painted Stork tended to nest in upper canopy, medium sized birds such as, Black-headed Ibis, Eurasian Spoonbill and Grey Heron preferred the edge of the canopy and small birds, namely Little Cormorant, Little Egret and Black-crowned Night Heron chose to nest in middle canopy or within the vegetation. Among the birds, comparatively Spot-billed Pelican used taller trees (20.22 ± 4.50 ft), while Black-headed Ibis preferred shorter trees (12.17 ± 1.39 ft) (table 27).

Nests of Grey Heron (5.14 ± 0.09 ft) were found on the trees with taller boles, while the nests of Black-headed Ibis (3.08 ± 0.28 ft) were on trees with shorter boles. Among all the species of birds, Grey Heron preferred younger trees with lowest mean dbh of 112.29 ± 7.03 cm, while Eurasian Spoonbill mostly selected matured trees with the highest mean dbh of 403.07 ± 3.34 cm. In general, Little Cormorant, Grey Heron, Little Egret, Painted Stork and Black-headed Ibis were observed to be nesting nearer to water spread area. Among all the species of birds, Painted Stork was found to build their nests near human settlements, whereas the nests of Spot-billed Pelican were found deep inside the Sanctuary (table 27).

Table 27. Nest-site characteristics of colonial nesting birds in the Vedanthangal Bird Sanctuary (Values are Mean $\pm$ SD)

Nest-site variables	Bird species								F	P
	Spot-billed Pelican	Little Cormorant	Grey Heron	Little Egret	Asian Openbill	Painted Stork	Black-headed Ibis	Eurasian Spoonbill		
Tree height (ft)	20.22 $\pm$ 4.50	14.56 $\pm$ 0.66	14.93 $\pm$ 0.70	16.13 $\pm$ 0.10	17.36 $\pm$ 1.13	15.21 $\pm$ 0.97	12.17 $\pm$ 1.39	15.39 $\pm$ 1.86	42.28	P<0.05
Tree bole height (ft)	3.73 $\pm$ 1.78	4.06 $\pm$ 1.24	5.14 $\pm$ 0.09	3.80 $\pm$ 0.29	3.48 $\pm$ 0.54	3.14 $\pm$ 0.27	3.08 $\pm$ 0.28	4.45 $\pm$ 0.77	15.68	P<0.05
Tree diameter breast height (cm)	146.5 $\pm$ 20.22	118.13 $\pm$ 34.76	112.29 $\pm$ 7.03	268.33 $\pm$ 2.42	228.9 $\pm$ 18.42	313.41 $\pm$ 89.14	134.63 $\pm$ 15.18	403.07 $\pm$ 3.34	103.90	P<0.05
Nest height from the ground (ft)	19.83 $\pm$ 4.45	12.41 $\pm$ 0.93	12.21 $\pm$ 1.17	13.63 $\pm$ 0.19	17.18 $\pm$ 1.21	14.74 $\pm$ 1.09	10.95 $\pm$ 1.13	13.05 $\pm$ 1.91	64.56	P<0.05
Distance to water spread area (m)	5.66 $\pm$ 1.56	1.59 $\pm$ 0.20	1.89 $\pm$ 0.19	2.33 $\pm$ 0.48	5.90 $\pm$ 1.26	2.06 $\pm$ 0.28	3.28 $\pm$ 0.52	5.15 $\pm$ 0.75	128.25	P<0.05
Distance to human habitation (m)	653.53 $\pm$ 20.36	168.28 $\pm$ 9.73	138.50 $\pm$ 12.47	130.50 $\pm$ 2.17	131.26 $\pm$ 26.63	77.83 $\pm$ 15.77	601.37 $\pm$ 5.80	350.25 $\pm$ 0.23	8.24	P<0.05
Tree canopy	Upper	Middle	Edge of the canopy	Middle	Upper	Upper	Edge of the canopy	Edge of the canopy		

P > 0.05 - Not significant; P < 0.05 - Significant

5.3.6.2. Koonthankulam Bird Sanctuary

Babul plantation on 30 ha in Koonthankulam Bird Sanctuary is the main breeding ground for many species of birds. A total of 611 nests belonging seven species of birds were selected in Koonthankulam Bird Sanctuary to understand the nest-site selection. Most of the nests were found either on *Acacia nilotica* or *Prosopis juliflora*. Among the birds, Painted Stork, Little Egret, Intermediate Egret and Indian Pond Heron preferred *Prosopis juliflora* while, Indian Cormorant, Spot-billed Pelican and Darter preferred *Acacia nilotica*. As in other study sites, White-throated Kingfisher was found to prefer the holes on the walls of wells (figures 15 to 17). Larger birds, namely Spot-billed Pelican and Painted Stork were found to nest in upper canopy, the medium sized birds such as, Black-headed Ibis and Eurasian Spoonbill used the edge of the canopy to nest, and small birds, namely Little Cormorant, Indian Cormorant and Little Egret chose to nest in middle canopy or within the vegetation as in Vedanthangal.

In terms of preference of nesting trees all the species of birds were grouped and are shown as dendrogram (figure 18). Among 10 species of birds, Little Cormorant, Darter, Spot-billed Pelican, Black-headed Ibis, Eurasian Spoonbill and Indian Cormorant formed a separate group and they used only *Acacia nilotica* trees which were located inside the Sanctuary. Group comprising Little Egret, Intermediate Egret, Indian Pond Heron, and Painted Stork used six species of nesting trees, namely *Acacia nilotica*, *Prosopis juliflora*, *Tamarindus indica*, *Pongamia pinnata*, *Azadirachta indica* and *Delonix elata* (figure 18). Among all the species, Painted Stork (24.90 ± 7.66 ft) and Little Egret (23.90 ± 3.14 ft) used taller trees, while Spot-billed Pelican preferred shorter trees (13.70 ± 1.29 ft). Nests of Indian Pond Heron (9.53 ± 0.41 ft) were found on trees with taller boles while the nests of Spot-billed Pelican (3.95 ± 1.33 ft) were found on trees with shorter boles. Among the birds, Indian Pond Heron preferred younger trees with lowest mean dbh of 67.58 ± 9.64 cm, while Painted Stork preferred older trees with the highest mean dbh of 153.22 ± 55.21 cm. Black-headed Ibis and Spot-billed Pelican constructed their nests very close to water spread area. Among the birds, Little Egret, Intermediate Egret, Indian Pond Heron and Painted Stork built their nests very close to human settlements, whereas the nests of Spot-billed Pelican and Black-headed Ibis were found far away from the human settlements (table 28).

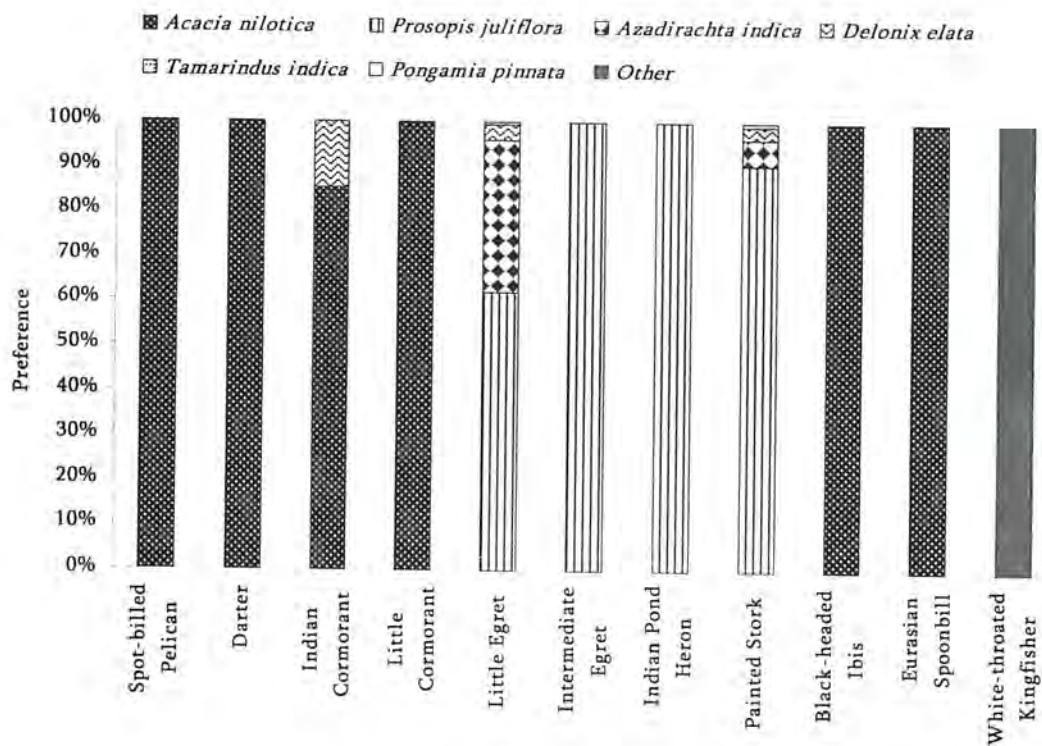


Figure 15. Nest-site selection in birds in Koonthankulam Bird Sanctuary during 2007-2008

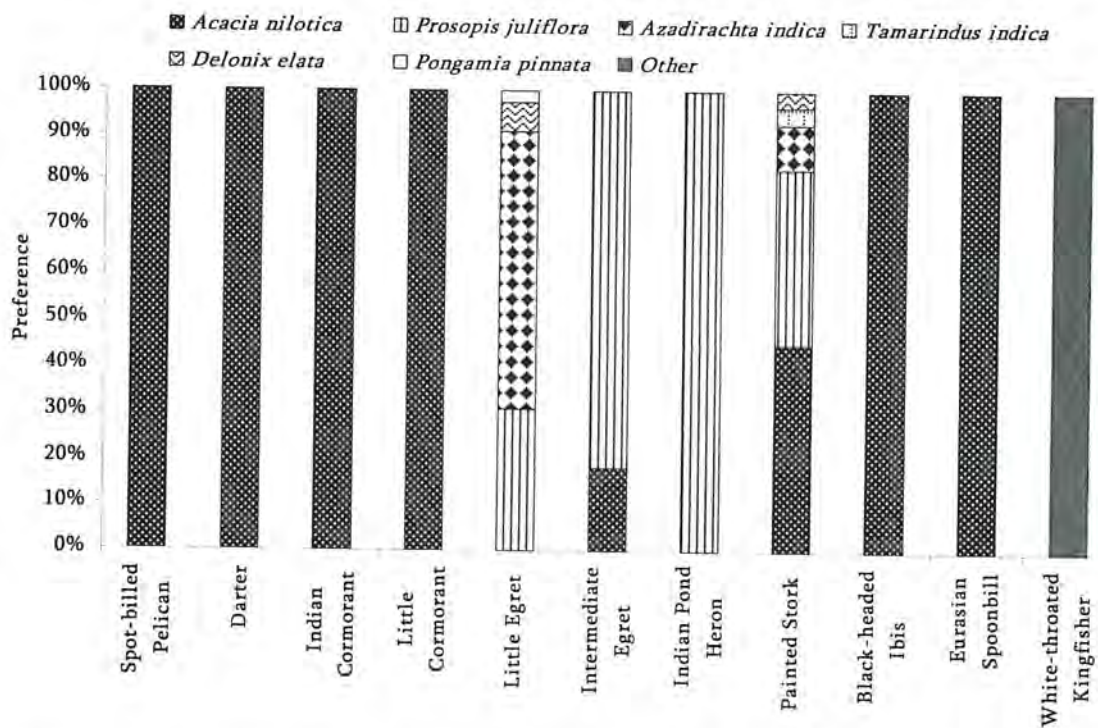


Figure 16. Nest-site selection by birds in Koonthankulam Bird Sanctuary during 2008-2009

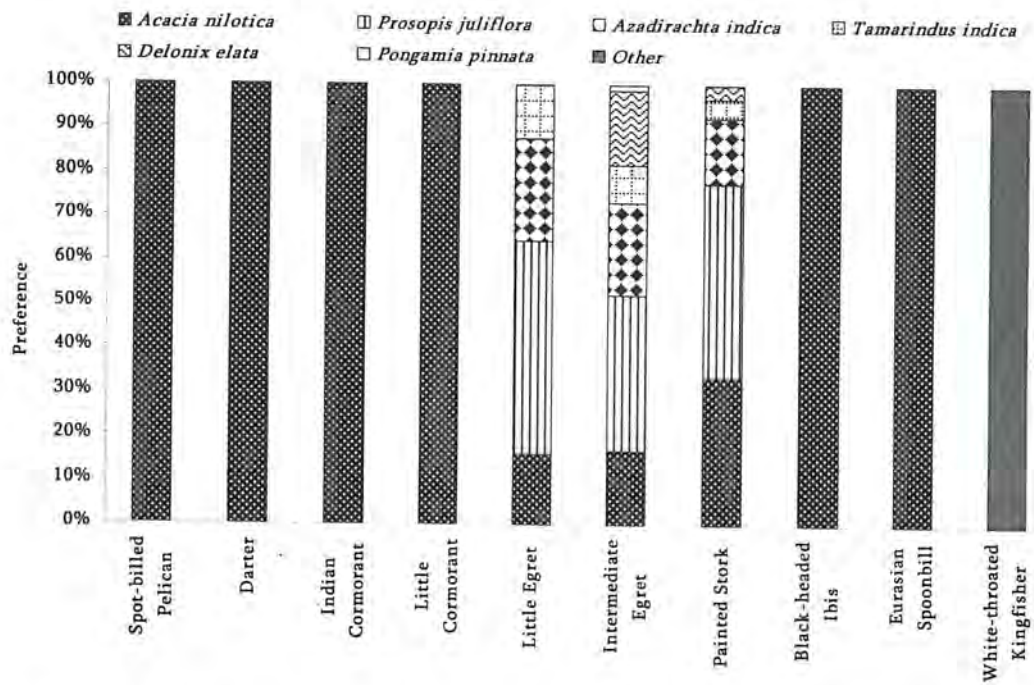


Figure 17. Nest-site selection in birds in Koonthankulam Bird Sanctuary during 2009-2010

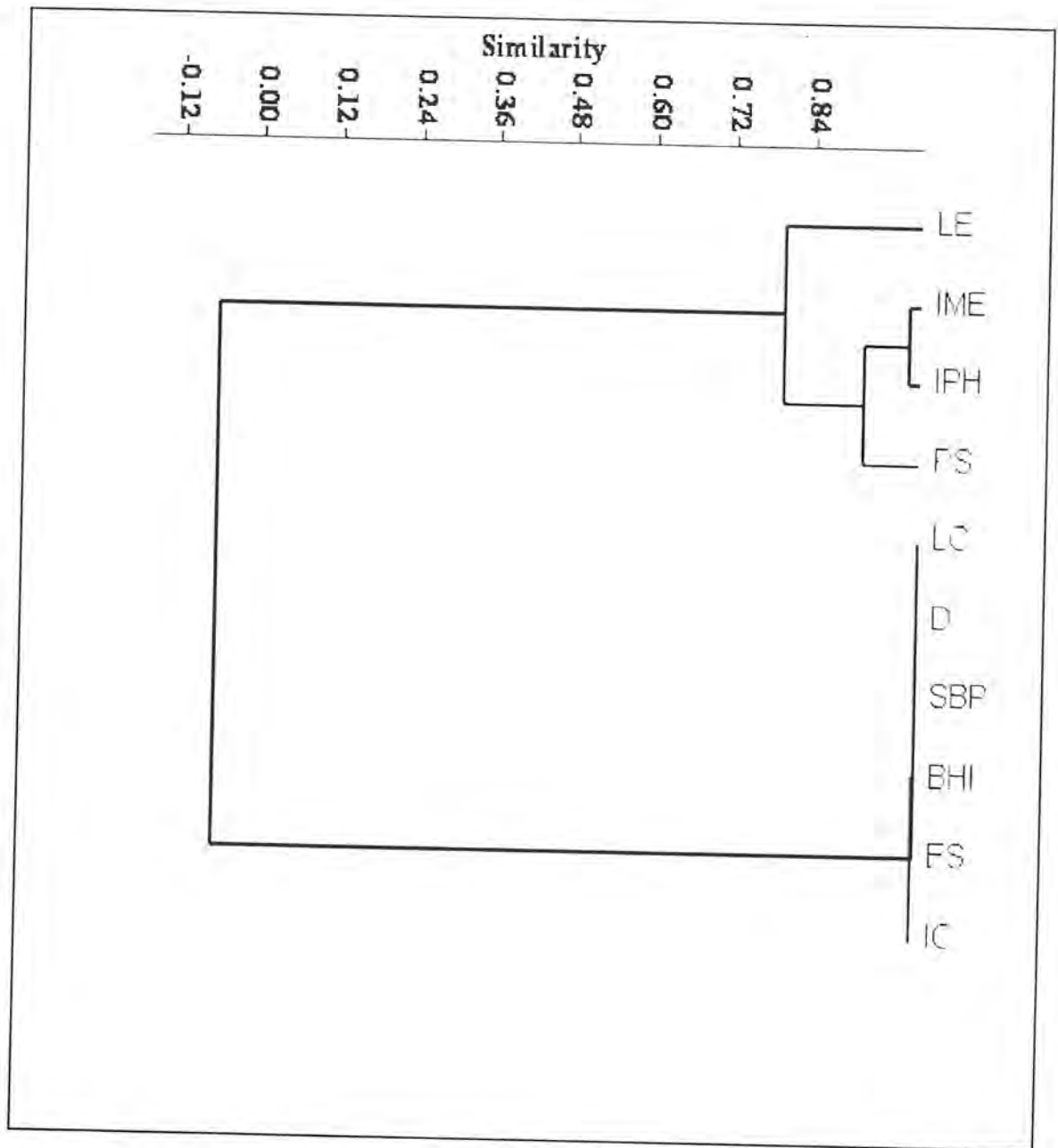


Figure 18. Dendrogram showing the grouping of different species of birds based on their nest-site selection in Koonthankulam during 2007-2010

IC- Indian Cormorant, ES- Eurasian Spoonbill, BHI- Black-headed Ibis, SBP- Spot-billed Pelican, D- Darter, LC- Little Cormorant, PS- Painted Stork, IPH- Indian Pond Heron, IME- Intermediate Egret and LE- Little Egret

Table 28. Nest-site characteristics of colonial nesting birds in the Koonthankulam Bird Sanctuary (Values are Mean $\pm$ SD)

Nest-site variables	Bird species						F	P
	Spot -billed Pelican	Indian Pond Heron	Intermediate Egret	Little Egret	Painted Stork	Black-headed Ibis		
Tree height (ft)	13.70 $\pm$ 1.29	20.18 $\pm$ 0.13	21.50 $\pm$ 1.54	23.90 $\pm$ 3.14	24.90 $\pm$ 7.66	14.18 $\pm$ 1.32	43.92	P<0.05
Tree bole height (ft)	3.95 $\pm$ 1.33	9.53 $\pm$ 0.41	7.48 $\pm$ 0.55	7.71 $\pm$ 0.31	7.75 $\pm$ 1.15	4.81 $\pm$ 1.40	132.39	P<0.05
Tree diameter breast height (cm)	105.44 $\pm$ 26.39	67.58 $\pm$ 9.64	84.08 $\pm$ 2.34	85.66 $\pm$ 3.17	153.22 $\pm$ 55.21	103.80 $\pm$ 31.63	30.91	P<0.05
Nest height from the ground (ft)	13.11 $\pm$ 1.30	17.97 $\pm$ 0.47	20.45 $\pm$ 3.07	20.84 $\pm$ 2.40	24.66 $\pm$ 7.59	13.78 $\pm$ 1.35	43.88	P<0.05
Distance to water spread area (m)	6.58 $\pm$ 2.06	175.80 $\pm$ 21.91	198.20 $\pm$ 15.63	200.20 $\pm$ 13.50	347.08 $\pm$ 272.13	5.96 $\pm$ 1.43	32.97	P<0.05
Distance to human habitation (m)	789.44 $\pm$ 7.66	7.75 $\pm$ 2.55	3.11 $\pm$ 0.18	4.27 $\pm$ 1.77	7.76 $\pm$ 5.39	794.88 $\pm$ 7.62	1.99	P<0.05
Tree canopy	Upper	Middle	Middle	Middle	Upper	Edge of the canopy		

P > 0.05 – Not significant; P < 0.05 – Significant

5.3.6.3. Vettangudi Bird Sanctuary

A total of 197 nests belonging seven species of birds were chosen in Vettangudi Bird Sanctuary for the referred purpose. Most of the nests were found either on *Acacia nilotica* or *Prosopis juliflora*. Among the birds, similar to other two sites, Asian Openbill, Little Cormorant, Black-headed Ibis and Darter largely preferred *Acacia nilotica*. Intermediate Egret and Little Egret used both *Acacia nilotica* and *Prosopis juliflora* trees (figures 19 & 20). Of all the species of birds, Asian Openbill was found to nest in upper canopy. Black-headed Ibis used the edge of the canopy to nest and small birds, namely Little Cormorant and Intermediate Egret preferred middle canopy (table 29). In terms of preference of nesting trees all the species of breeding birds were grouped and are shown as dendrogram (figure 21). Among seven species of birds, Asian Openbill, Little Cormorant, Black-crowned Night Heron, Black-headed Ibis and Darter formed a separate group and used only *Acacia nilotica* trees. Group comprising Little Egret and Intermediate Egret used both *Acacia nilotica* and *Prosopis juliflora* (figure 21).

Among the species Intermediate Egret, Asian Openbill and Little Cormorant used taller trees, while Black-headed Ibis preferred shorter trees. Nests of Asian Openbill (14.00 ± 0.00 ft) was found on the trees with taller boles, while the nests of Intermediate Egret (7.00 ± 0.49 ft) was on trees with shorter boles. Among the species, Little Cormorant preferred younger trees with low mean dbh of 53.00 ± 00.00 cm, while Asian Openbill preferred matured trees with the highest mean dbh of 96.50 ± 6.60 cm. In general, nests of Asian Openbill were observed near to water spread area and also human settlements (table 29).

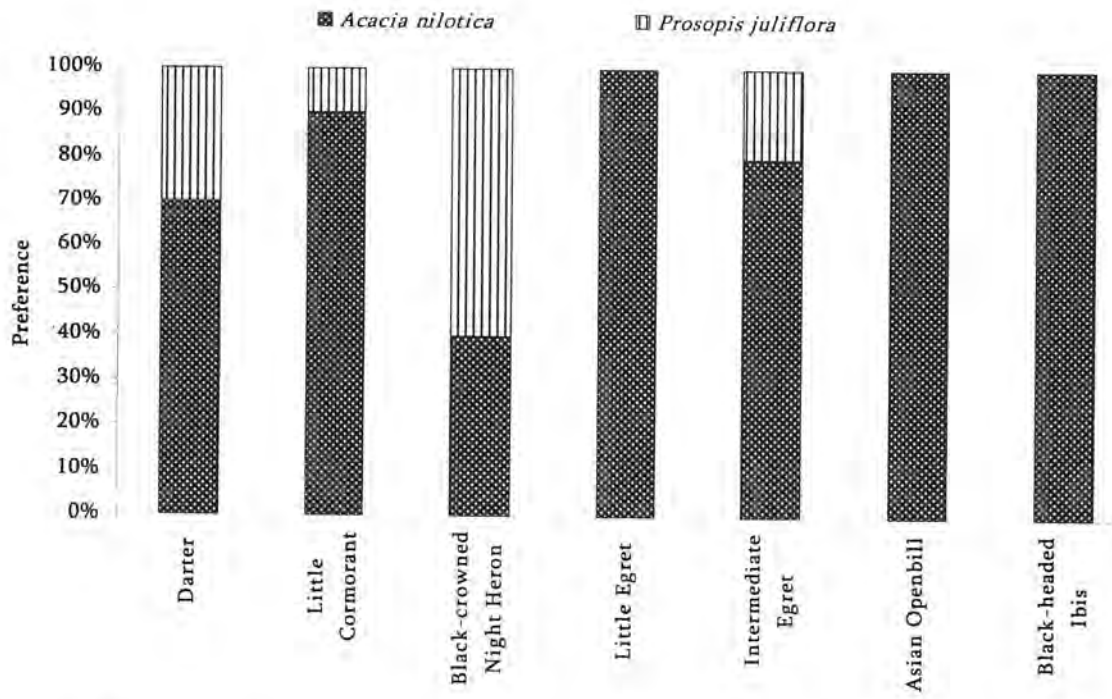


Figure 19. Nest-site selection in birds in Vettangudi Bird Sanctuary during 2007-2008.

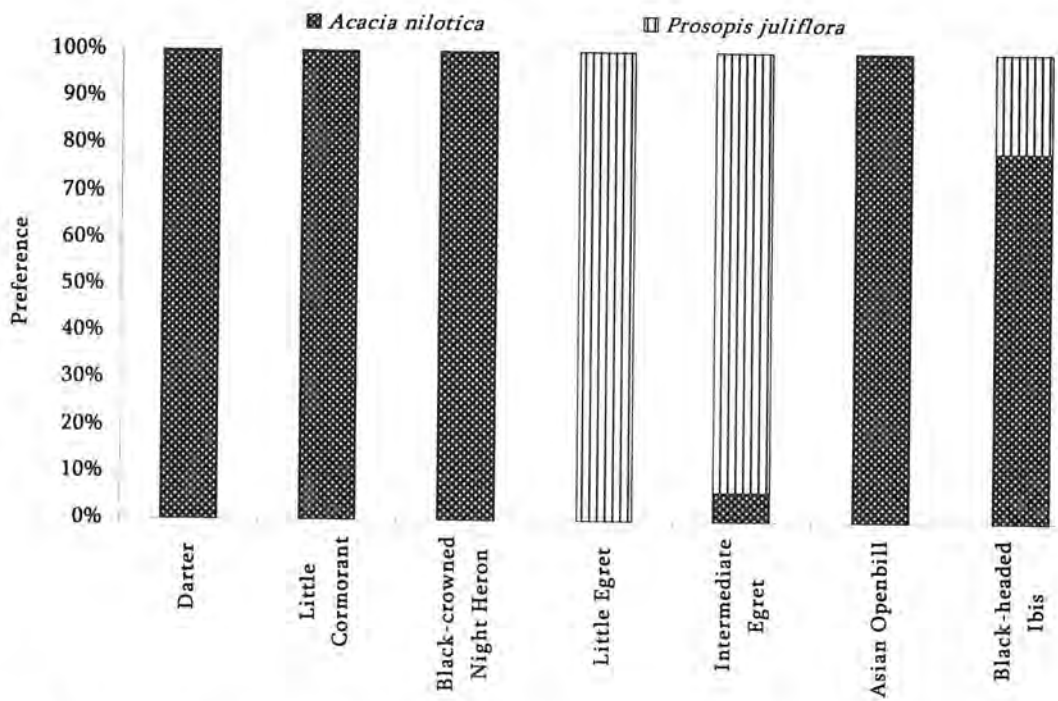


Figure 20. Nest-site selection in by birds in Vettangudi Bird Sanctuary during 2008-2009.

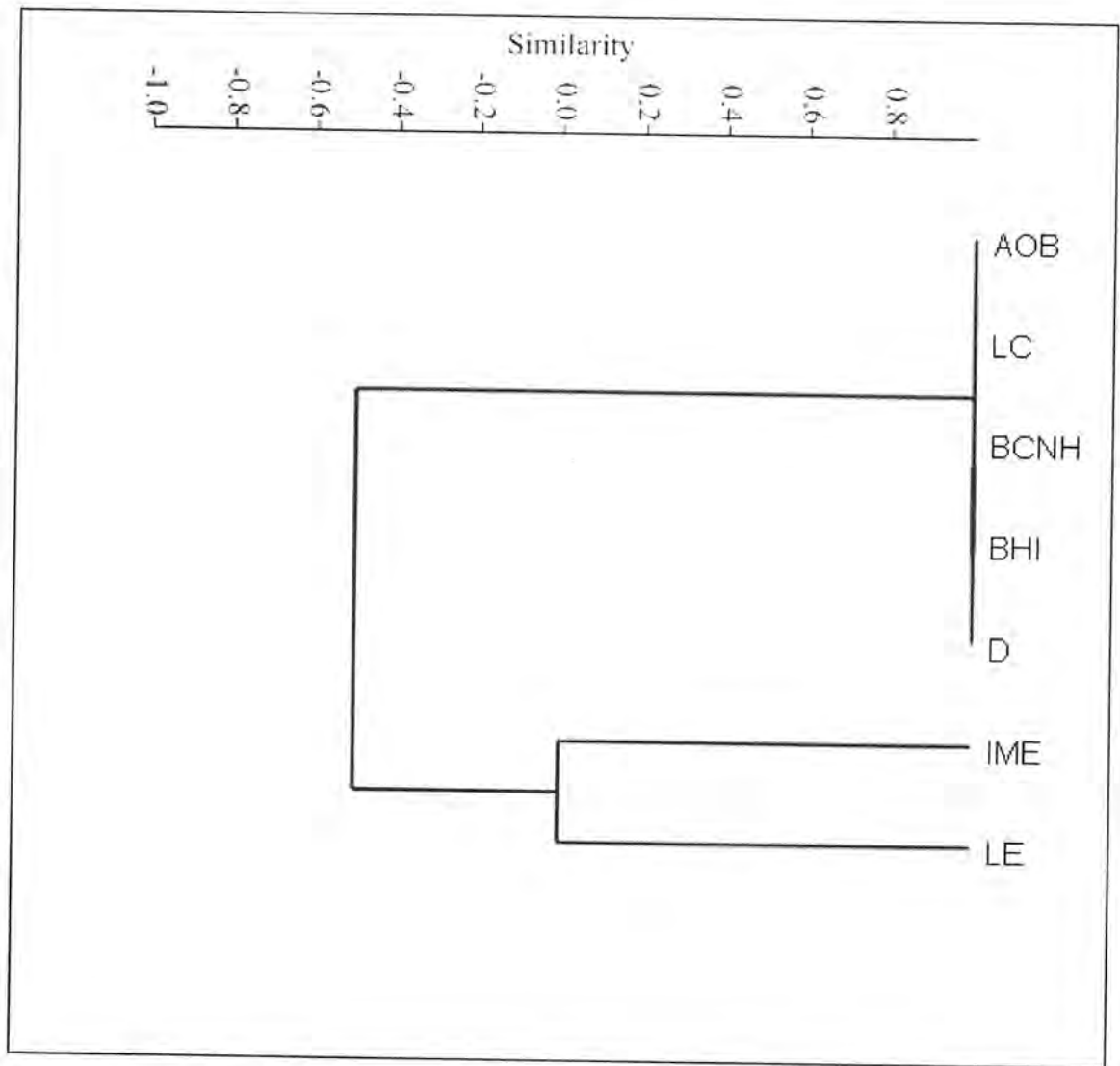


Figure 21. Dendrogram showing the grouping of different species of birds based on their nest-site selection in Vettangudi during 2007-2010

LE- Little egret, IME- Intermediate Egret, D- Darter, BHI- Black-headed Ibis, BCNH- Black-crowned Night Heron, LC- Little Cormorant and ABO- Asian Openbill

Table 29. Nest site characteristics of colonial nesting birds in the Vettangudi Bird Sanctuary (Values are Mean± SD)

Nest-site variables	Bird species				F	P
	Asian Openbill	Black-headed Ibis	Intermediate Egret	Little Cormorant		
Tree height (ft)	25.03 ± 5.56	24.40 ± 1.47	25.10 ± 1.02	25.00 ± 0.38	0.16	P>0.05
Tree bole height (ft)	14.00 ± 0.00	12.25 ± 0.44	7.00 ± 0.49	12.13 ± 0.35	1.82	P<0.05
Tree diameter breast height (cm)	96.50 ± 6.60	63.00 ± 8.50	75.05 ± 14.80	53.00 ± 0.00	109.34	P<0.05
Nest height from the ground (ft)	24.82 ± 5.65	16.93 ± 1.26	20.04 ± 1.23	16.50 ± 0.57	28.7	P<0.05
Distance to water spread area (m)	29.54 ± 0.51	40.50 ± 2.67	29.45 ± 0.51	40.00 ± 2.93	265.31	P<0.05
Distance to human habitation (m)	51.46 ± 0.51	66.00 ± 0.00	65.25 ± 2.45	66.00 ± 0.00	1.02	P<0.05
Tree canopy	Upper	Edge of the canopy	Middle	Middle		

P > 0.05 – Not significant; P < 0.05 – Significant

In general opportunities for foraging, breeding, nesting and successful rising of nestlings were always high in Vedanthangal, Koonthankulam and Vettangudi and thus several species of breeding and non-breeding birds congregate each year in these three Sanctuaries. In the present study, most of the breeding birds selected one of the three species of trees, namely *Acacia nilotica*, *Prosopis juliflora* and *Barringtonia acutangula* for nesting in the study sites. The major determining factor for selecting a nesting site was found to be tree height and canopy level which provided protection from predators as reported in Vedanthangal Bird Sanctuary by Venkatraman (2007). Water level was also found to be a major factor in determining the nest site selection. Most of the birds in Vettangudi Bird Sanctuary and Painted Stork in Koonthankulam Bird Sanctuary were observed attempting to nest in the central part of the lake. As soon as water was drained for agriculture purpose, the birds were found to be abandoning their nests as in Vedanthangal Bird Sanctuary, Tamil Nadu.

According to Venkatraman (2007) and Wiens and Rotenberry (1981), habitat selection appears to be a hierarchical procedure with landscape features playing a crucial role at a regional scale and vegetation quality at the sites. Similarly in the present study also, structural characteristic of nest-tree were found to be the crucial factor in the nest-site selection of birds in Vedanthangal, Koonthankulam and Vettangudi Bird Sanctuaries. In particular, matured trees with thick canopy and high diameter at breast height (dbh) had more number of nests. The matured trees were found to be suitable for nest placement as their size and geometry of branching produce the preferred vertical range to birds to place their nests. Further, matured trees provide greater space and nest site availability to the birds those are colonial in nature. Apart from colonial nesting, too many birds constructing their nests too close on strong trees could be a strategy to reduce their predation as explained by Burger (1981), Brown and Brown (2001) and Urfi (2003a,b).

Martin and Roper (1988) narrated the importance of nesting tree cover in determining nest-site selection in western population of Hermit Thrush. Importance of canopy closeness was reported by Sakai and Noon (1991) in North-western California. Similarly, in the present study also, structural characteristics of nest tree species were found to be crucial in the nest-site selection of colonial nesting birds in all three study sites. In particular, the matured trees with thick canopy and broader girth had attracted more nesting birds. Presence of water around the nesting trees reduced the risk of predation by

ground predators such as mangoes and domestic cats. It also reduces the accessibility of local people. So it may be concluded that nest-site selection of colonial nesting birds is influenced by size of the tree, canopy cover with least disturbance.

Complete protection of nesting habitat with availability of adequate nesting substrate would encourage an increase in the number of species and the total number of nesting birds in a heronry over time (Subramanya 2005). Vedanthangal, which has been in existence for over 200 years (Baker 1935, Krishnan 1960, 1993 b, 2001, Paulraj 1984 and Baskaran 1999), has grown in size both with respect to species and number of birds although it suffered a setback around 35 years ago, due to loss of nesting substrate, the *Barringtonia* trees (Stairmand 1971). But the reasons were not clear subsequently, when the foreshores of the village irrigation tanks were planted with *A. nilotica* under the social forestry programme, species like Glossy Ibis started nesting. Hence, planting of *A. nilotica* had a positive effect on the heronry scenario in Vedanthangal Bird Sanctuary (Subramanya 2005).

Vedanthangal Bird Sanctuary is the only one in this region that provides a compact grove of trees suitable for nesting of the colonial waterbirds (Santharam 2000). This grove, which is more or less centrally located in the Vedanthangal Bird Sanctuary, consists of about 500 *Barringtonia acutangula* trees. This species withstands seasonal water-logging quite well. The trees form a compact grove with an almost contiguous canopy at 15 to 20 ft. high, occupying approximately half of the area of the Sanctuary and offer a suitable nesting site for waterbirds. The waterbirds do not prefer the trees grown along the bund, but these trees protect the Sanctuary from erosion and provide suitable habitat for other species of birds such as mynas and owls.

Animals can use a variety of physical indications to assess environmental suitability (Cody 1985). Colonial nesting birds, such as Gulls and Terns also reported to breed colonially due to similar habitat preferences, better predator avoidance, and the possibility of exchange of information for food acquisition (Rolland *et al.*, 1998). Multiple factors play role in colony site dynamics in waterbirds which depend on habitat quality in and around breeding locations (Erwin *et al.*, 1998). Therefore, the availability of safe breeding and foraging sites directly influences the colony location, colony size and reproductive parameters in colonial birds.

5.4. Pesticide Contamination

Due to indiscriminate use of agricultural and industrial chemicals, and uncontrolled generation of wastes, the entire Indian environment and biota particularly freshwater sources (Pillai 1986; Babu Rajendran and Subramanian 1997), estuaries (Bhattacharya *et al.*, 2003), coastal and offshore areas (Sarkar and Sengupta, 1988 b; Iwata *et al.*, 1993a; Sarkar *et al.*, 1997), inland soils (Babu Rajendran and Subramanian 1999), fishes (Babu Rajendran *et al.*, 1994) Das *et al.*, 2002; Vijayan *et al.*, 2004; Muralidhran *et al.*, 2009; Dhananjayan and Muralidhran 2010; Muralidharan *et al.*, 2013), birds (Tanabe *et al.*, 1998; Muralidharan *et al.*, 2008; Muralidharan and Dhananjayan, 2010; Dhananjayan and Muralidharan, 2010; Dhananjayan *et al.*, 2011; Muralidharan *et al.*, 2012), bird eggs (Muralidharan 2002), bats (Senthilkumar *et al.*, 1999b), river dolphins (Kannan *et al.*, 1993, 1994; Senthilkumar *et al.*, 1999a and Subramanian *et al.*, 1999), food stuff (Kannan *et al.*, 1992), marine mammals (Tanabe *et al.*, 1993 and Tanabe, 2002) and human milk (Tanabe *et al.*, 1990) have been reported to be loaded with mixtures of residues of persistent organochlorine pesticides (POPs).

In Tamil Nadu, large tracks of agricultural land adjoining Sanctuaries or reservoirs offer ideal habitat for birds. As birds use these habitats in addition to protected areas, any contamination in either of these areas is bound to harm the birds. Moreover, in many situations, agricultural runoff brings in chemical residues into the Sanctuaries. There is an urgent need to gather information, conduct research and monitor regularly the impacts of these chemicals on different life forms particularly birds. The present study, therefore studied the impacts of persistent pesticides on fishes and colonial nesting birds in Vedanthangal, Koonthankulam and Vettangudi Bird Sanctuaries in Tamil Nadu. The components studied were fishes, tissues of colonial nesting birds and their eggs.

5.4.1. Organochlorine pesticide residues in fishes

Totally 300 individuals comprising nine species of fishes covering two seasons (breeding and non-breeding season of birds from 2007 to 2010) were collected from the study sites. The list of species and their weight, length and diet are presented in table 30. The results have been compiled in three angles so as to look at site, species and season-wise accumulation pattern.

Table 30. Details of fishes collected from the study sites and their morphometry

S. No.	Common Name	Scientific Name	VBS	KBS	VTBS	Total	Length (cm) (Mean $\pm$ SD)	Weight (g) (Mean $\pm$ SD)	Feeding habit*
1	Rohu	<i>Labeo rohita</i>	NS	14	17	31	12.05 $\pm$ 1.66	76.62 $\pm$ 29.64	Herbivorous
2	Climbing Bass	<i>Anabas testudineus</i>	6	NS	NS	6	11.90 $\pm$ 1.75	36.62 $\pm$ 10.13	Omnivorous
3	White Carp	<i>Cirrhinus mrigala</i>	5	2	5	12	12.23 $\pm$ 1.28	37.35 $\pm$ 8.49	Herbivorous
4	Spotted Snakehead	<i>Channa punctatus</i>	32	17	44	93	12.90 $\pm$ 0.45	29.79 $\pm$ 2.05	Omnivorous
5	Stinging Catfish	<i>Heteropneustes fossilis</i>	28	NS	NS	28	15.37 $\pm$ 0.95	35.12 $\pm$ 6.29	Omnivorous
6	Striped Dwarf Catfish	<i>Mystus vittatus</i>	10	5	10	25	7.92 $\pm$ 0.28	16.94 $\pm$ 1.61	Omnivorous
7	Common Tilapia	<i>Oreochromis mossambicus</i>	24	21	14	59	10.84 $\pm$ 0.43	28.20 $\pm$ 2.98	Omnivorous
8	Cauvery Barb	<i>Puntius dorsalis</i>	15	15	10	40	6.52 $\pm$ 0.22	13.76 $\pm$ 1.29	Omnivorous
9	Long-whiskered Catfish	<i>Aorichthys aor</i>	2	NS	4	6	11.75 $\pm$ 0.25	13.46 $\pm$ 0.66	Omnivorous
Total			122	74	104	300			

VBS- Vedanthangal; KBS- Koonthankulam; VTBS- Vettangudi; NS- Not sampled *Source: Daniels (2002)

5.4.1.1. Organochlorine pesticide residues in fishes from Vedanthangal Bird Sanctuary

Totally 122 fishes comprising eight species, namely *Anabas testudineus*, *Cirrhinus mrigala*, *Channa punctatus*, *Heteropneustes fossilis*, *Mystus vittatus*, *Oreochromis mossambicus*, *Puntius dorsalis* and *Aorichthys aor* were collected during non-breeding and breeding season of birds. Among the organochlorines, residues of total (Σ) HCH was recorded the maximum followed by Σ Endosulfan and Σ DDT, while concentration of Dieldrin was the minimum. The maximum concentration of Σ HCH was recorded in *Anabas testudineus* (128.94 ± 98.36 ng/g) followed by *Oreochromis mossambicus* (93.27 ± 32.13 ng/g) collected from Vedanthangal Bird Sanctuary. The maximum average concentration of Σ Endosulfan, Σ DDT, Σ Heptachlor and Dieldrin were detected in *Heteropneustes fossilis* (59.05 ± 24.02 ng/g), *Oreochromis mossambicus* (41.72 ± 39.49 ng/g), *Anabas testudineus* (22.02 ± 21.34 ng/g) and *Aorichthys aor* (6.08 ± 3.15 ng/g) respectively (figure 22).

Of all the species studied, *Anabas testudineus* recorded the maximum OC residues followed by *Oreochromis mossambicus* and *Heteropneustes fossilis*, while the least was in *Cirrhinus mrigala* and *Aorichthys aor*. Total OCPs in fishes showed variation, but was not significant (ANOVA $F=1.044$; $df=7$; $P>0.05$). The variation in organochlorine pesticides residues in the fishes between seasons was also not significant (ANOVA $F=0.007$; $df=1$; $P>0.05$) (table 31).

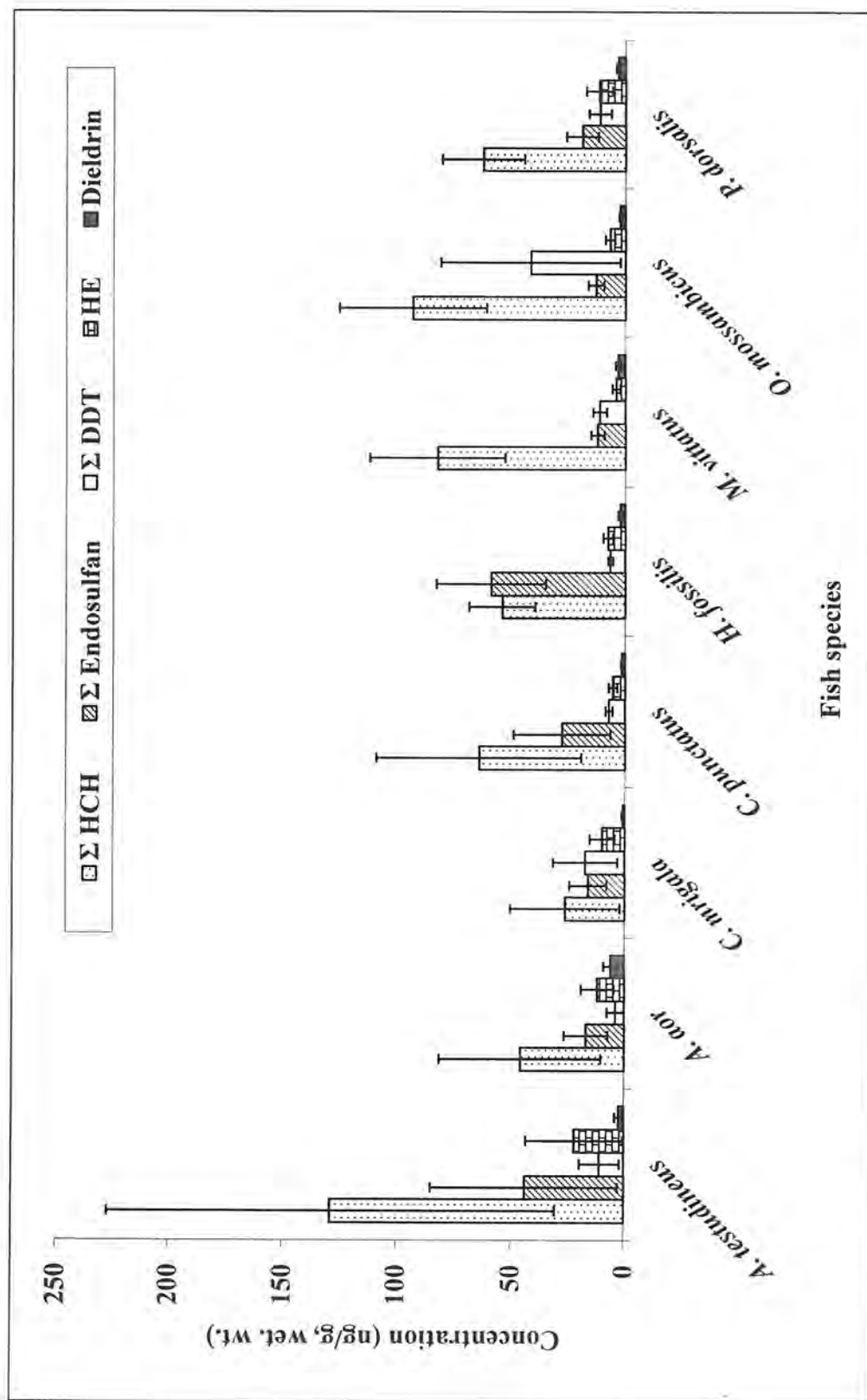


Figure 22. Organochlorine pesticide residues (Mean $\pm$ SE) in the fishes collected from Vedanthangal Bird Sanctuary (2007-10)

5.4.1.2. Organochlorine pesticide residues in fishes from Koonthankulam Bird Sanctuary

Totally 74 fishes comprising six species, namely *Labeo rohita*, *Cirrhinus mrigala*, *Channa punctatus*, *Mystus vittatus*, *Oreochromis mossambicus* and *Puntius dorsalis* were collected during non-breeding and breeding season of birds in Koonthankulam Bird Sanctaury. Among the organochlorine residues analyzed, Σ HCH was the highest in concentration followed by Σ Endosulfan and Σ DDT. The maximum concentration of Σ HCH was recorded in *Mystus vittatus* (54.11 ± 46.19 ng/g) and *Cirrhinus mrigala* (48.80 ± 18.05 ng/g). The maximum average concentration of Σ Endosulfan, Σ DDT, Σ Heptachlor and Dieldrin were in *Channa punctatus* (11.50 ± 6.64 ng/g), *Cirrhinus mrigala* (9.03 ± 2.42 ng/g), *Labeo rohita* (2.75 ± 0.81 ng/g) and *Mystus vittatus* (1.34 ± 0.57 ng/g) respectively (figure 23). Variations in OCP residues among the species were not significant (ANOVA $F=0.659$; $df=6$; $P>0.05$). Among the species, *Mystus vittatus* and *Cirrhinus mrigala* recorded higher load of Σ organochlorine pesticides than the rest of the species studied. *Channa punctatus* and *Labeo rohita* recorded comparatively lower concentrations. The variation in organochlorine pesticide residues in the fishes between seasons was not significant (ANOVA $F=2.316$; $df=1$; $P>0.05$) (table 31).

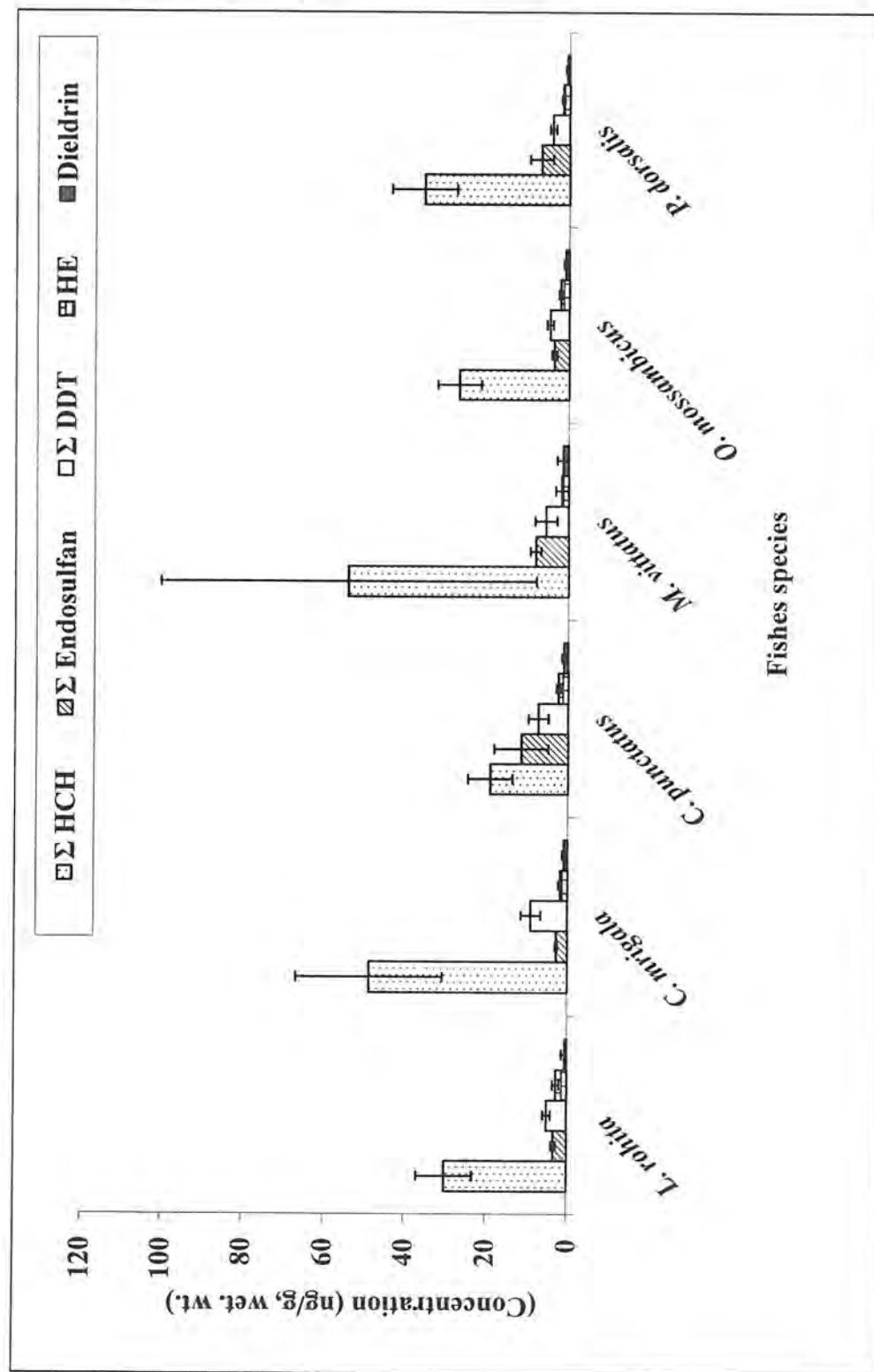


Figure 23. Organochlorine pesticide residues (Mean $\pm$ SE) in the fishes collected from Koonthankulam Bird Sanctuary, (2007-10)

5.4.1.3. Organochlorine pesticide residues in fishes from Vettangudi Bird Sanctuary

Seven species of fishes, namely *Labeo rohita*, *Cirrhinus mrigala*, *Channa punctatus*, *Mystus vittatus*, *Oreochromis mossambicus*, *Puntius dorsalis* and *Aorichthys aor* totaling 104 individuals were collected during non-breeding and breeding season from Vettangudi Bird Sanctuary. Among the OCP residues, Σ HCH was detected the maximum followed by Σ Endosulfan and Σ DDT, while Dieldrin concentration was the minimum. The maximum concentration of Σ HCH was recorded in *Labeo rohita* (91.60 ± 25.88 ng/g) followed by *Oreochromis mossambicus* (73.33 ± 28.56 ng/g) (figure 24). The maximum average concentration of Σ Endosulfan, Σ DDT, Σ Heptachlor and Dieldrin were detected in *Labeo rohita* (figure 24). Levels of total OCP residues among the species showed variation, but not significant (ANOVA $F=1.979$; $df=6$; $P>0.05$). Of all the species analyzed, *Labeo rohita* was the most contaminated species followed by *Oreochromis mossambicus*, while *Puntius dorsalis* was least contaminated. The variation in organochlorine pesticides residues in the fishes between seasons was significant (ANOVA $F=5.104$; $df=1$; $P<0.05$) (table 31).

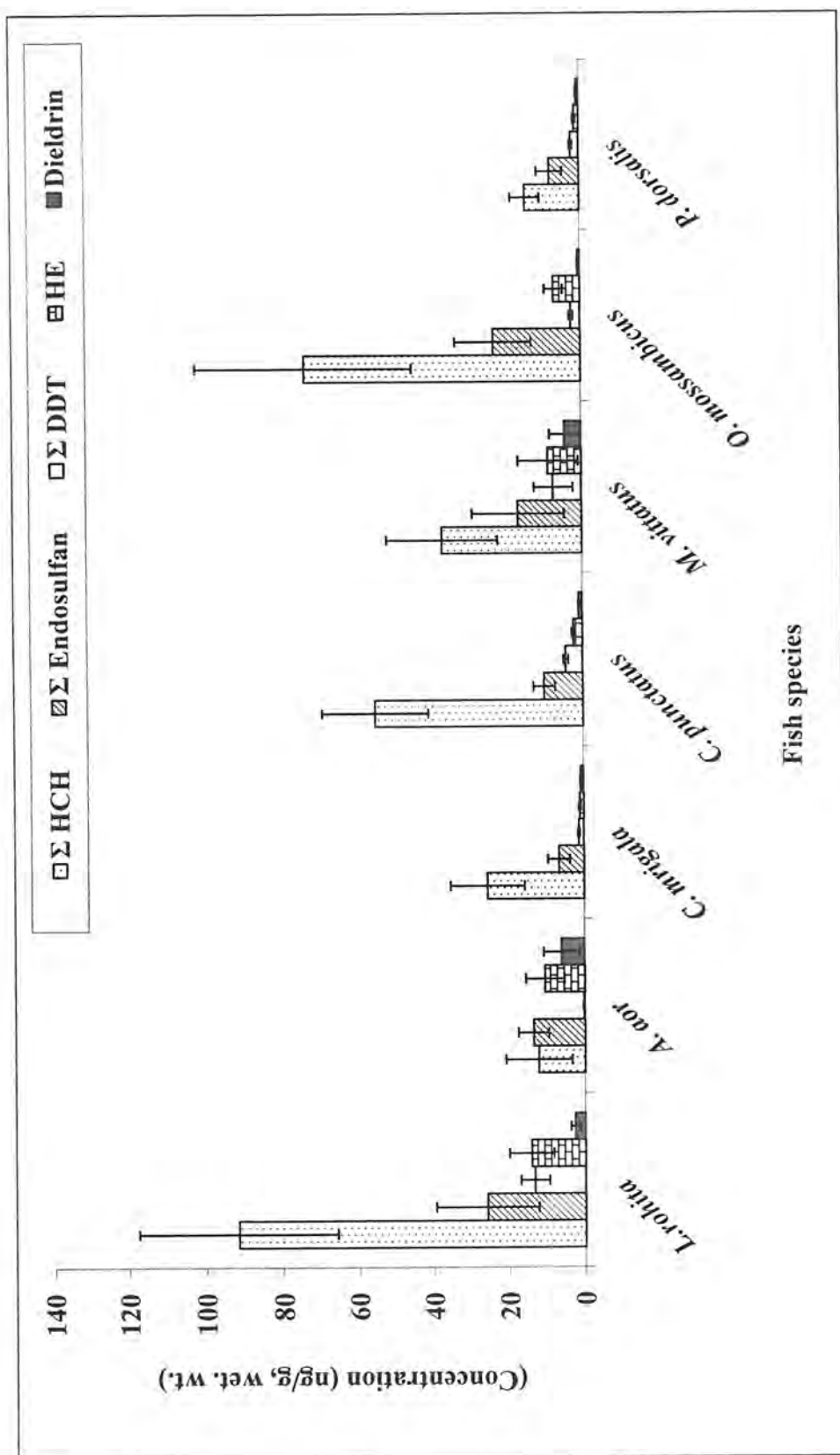


Figure 24. Organochlorine pesticide residues (Mean $\pm$ SE) in the fishes collected from Vettangudi Bird Sanctuary (2007-10).

Table 31. Total organochlorine pesticide residues (ng/g, wet. wt, Mean $\pm$ SE) in various species of fishes collected from the study sites during breeding and non-breeding season of birds (2007-10)

S. No.	Species	Vedanthangal Bird Sanctuary				Koonthankulam Bird Sanctuary				Vettangudi Bird Sanctuary			
		NBS		BS		NBS		BS		NBS		BS	
		N	Mean $\pm$ SE	N	Mean $\pm$ SE	N	Mean $\pm$ SE	N	Mean $\pm$ SE	N	Mean $\pm$ SE	N	Mean $\pm$ SE
1	<i>Labeo rohita</i>	NA	NA	NA	NA	4	24.9 $\pm$ 10.2	10	44.6 $\pm$ 8.2	11	1040 $\pm$ 644	6	134.6 $\pm$ 53.6
2	<i>Anabas testidineus</i>	4	267 $\pm$ 222	2	23.9 $\pm$ 14.3	NA	NA	NA	NA	NA	NA	NA	NA
3	<i>Aorichthys aor</i>	NA	NA	2	72.7 $\pm$ 26.5	NA	NA	NA	NA	NA	NA	4	141.6 $\pm$ 58.9
4	<i>Cirrhinus mirigala</i>	2	3198 $\pm$ 3048	3	60.0 $\pm$ 24.2	NA	NA	2	61.5 $\pm$ 16.4	NA	NA	5	34.0 $\pm$ 9.8
5	<i>Channa punctatus</i>	10	28.0 $\pm$ 12.4	22	133 $\pm$ 98.4	3	19.3 $\pm$ 11.7	14	43.2 $\pm$ 10.1	21	89.5 $\pm$ 22.3	23	53.1 $\pm$ 21.8
6	<i>Heteropneustes fossilis</i>	11	98.5 $\pm$ 24.6	17	136 $\pm$ 50.1	NA	NA	NA	NA	NA	NA	NA	NA
7	<i>Mystus vittatus</i>	NA	NA	10	109 $\pm$ 33.2	NA	NA	5	69.1 $\pm$ 47.8	NA	NA	10	65.4 $\pm$ 24.5
8	<i>Oreochromis mossambica</i>	5	43.2 $\pm$ 15.8	19	809 $\pm$ 633	5	34.8 $\pm$ 15.4	16	36.4 $\pm$ 5.8	NA	NA	14	99.2 $\pm$ 31.5
9	<i>Puntius dorsalis</i>	NA	NA	15	95.9 $\pm$ 22.4	3	29.5 $\pm$ 17.9	NA	NA	NA	NA	10	24.7 $\pm$ 5.9
	F	0.007				2.316				5.104			
	P	P>0.05				P>0.05				P<0.05			

NBS- Non-Breeding Season; BS- Breeding Season; SE- Mean Standard Error; NA- Not Available.

5.4.1.4. Variation in concentration of OCPs in fishes among the locations and species

a) HCH and its isomers

Towards understanding the variation in organochlorine pesticide residues among the study sites, levels in five species of fishes, namely *Cirrhinus mrigala*, *Channa punctatus*, *Mystus vittatus*, *Oreochromis mossambicus* and *Puntius dorsalis* collected from all the three sites were compared. It revealed that fishes from Vedanthangal had varied in load of Σ HCH followed by Koonthankulam. However, the variation was not significant (ANOVA $F=1.688$; $df=2$; $P>0.05$). Further, with reference to the species of fishes, the variation in OC residues among the five species studied was not significant (ANOVA $F=1.337$; $df=4$; $P>0.05$). Of all the five species fishes analyzed for various organochlorine residues, *Oreochromis mossambicus* (93.27 ± 32.13 ng/g) recorded the maximum residues of Σ HCH, while *Puntius dorsalis* (62.59 ± 18.06 ng/g) recorded the minimum (figure 25).

Technical HCH is a broad spectrum OC insecticide that was available for decades and used throughout the world for agricultural and non-agricultural purposes because of its effectiveness and low cost (Li *et al.*, 1998 and Raina *et al.*, 2008). The isomeric forms of HCH are toxic and recalcitrants. They exhibit both acute and chronic toxicity, particularly β isomer acts as an environmental estrogen (Walker *et al.*, 1999). Use of HCH continued unabated until it was banned in 1997 in India, but restricted use of lindane alone (99% γ HCH) was permitted till 2011. However, HCH is totally banned vide Gazette Notification No S.O. 637(E) dated 25/03/2011, for manufacture, import or formulate and use w.e.f. 25th March, 2013 (<http://cibrc.nic.in/> retrieved on 17th April 2013).

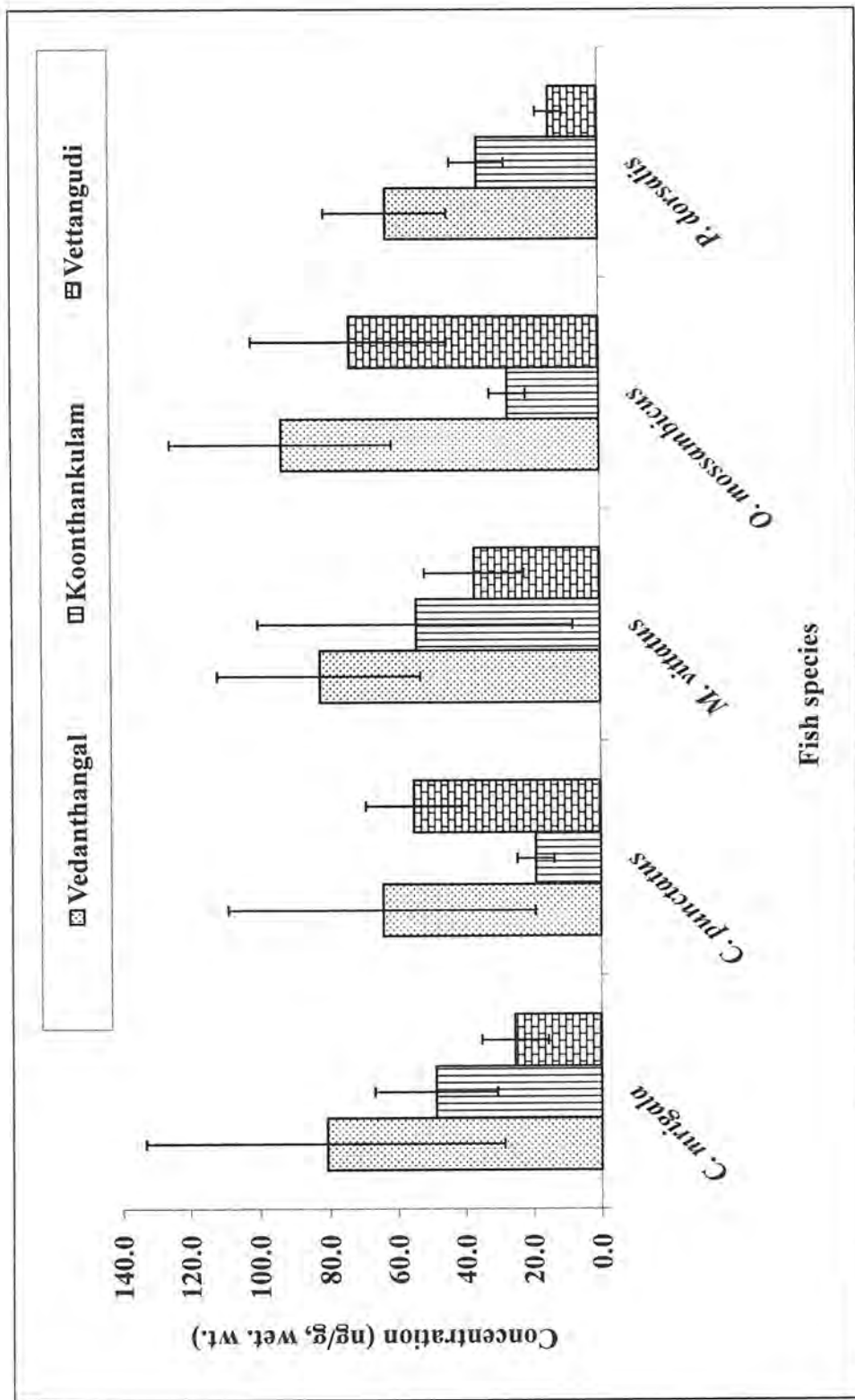


Figure 25. Variation in Σ HCH residues (Mean $\pm$ SE) among select species of fishes collected from the study sites during 2007-2010

The residues of Σ HCH recorded in *A. testudineus*, *C. punctatus*, *H. fossilis*, *M. vittatus*, *O. mossambicus* and *P. dorsalis* in the present study are higher than the levels recorded in nine species of freshwater fishes (51.7 ng/g) from different inland wetlands in Karnataka, while in species, namely *A. aor*, *C. mrigala*, *L. rohita* the levels are lower (Dhananjayan and Muralidharan 2010). The residues of Σ HCH recorded in *A. testudineus* and *M. vittatus* from Vedanthangal Bird Sanctuary and *L. rohita* from Vettangudi Bird Sanctuary are higher than the levels reported in six species of fishes, namely *Cyprinus carpio communis*, *Cyprinus carpio nudus*, *Cyprinus carpio specularis*, *Oreochromis mossambicus* and *Barbus carmuca* from various reservoirs (BDL to 77.68 ng/g), namely Avalanche, Upper Bhavani, Emerald, Kamaraj Sagar, Pykara and Maravakandy, Ooty lake and rivers such as Coonoor and Moyar in Nilgiris district (Vijayan and Muralidharan 1999). Total HCH residues in rest of the fish species from all the three study sites are lower than the levels reported by Vijayan and Muralidharan (1999).

The level of Σ HCH reported in fishes in the present study is higher than the concentrations reported in freshwater fishes of Andhra Pradesh (21 ng/g: Amaraneni and Pillala 2001) and Punjab (7 ng/g: Kaur *et al.*, 2008). Kumari *et al.* (2001) reported high concentration of HCH in fishes (147.6 ng/g) of river Ganga at four sites in Bihar; Buxar, Patna, Mokama and Rajmahal and possibilities of higher dietary intake of pesticides to human beings through consumption of fishes. Total HCH residues recorded in the present study are higher than the levels reported in *Platicephalus* sp. (5.4 ng/g) *Epinephelus* sp. (7.37 ng/g) and *Lutjanus rivulatus* (70.56 ng/g) collected from a few rivers in Calicut, Kerala (Sankar *et al.*, 2006).

Further, the levels of Σ HCH reported in the present study are higher than the levels reported in fish samples collected from Rajasthan (Battu *et al.*, 1984) and Ludhiana, Punjab (Raizada *et al.*, 1989). Species-specific differences in lipid content of the fishes and level of contamination in the water and food will also influence the accumulation pattern of organochlorine residues among the species.

Although a few systematic investigations on long-term basis in fishes have been carried out in India, the available information shows presences of Σ HCH as high as 6300 ng/g in the fishes of village ponds in India (Dua *et al.*, 1996). It was also reported that residues of HCH persist in the environment, concentrate in the crops, and continue to be detected in the food chain (Nigam and Siddiqui 2001). An extensive study on inland wetlands of

India (Vijayan *et al.*, 2004) documented threats and conservation issues in many wetlands across the country. The study pointed out contamination at varying magnitude in fishes. Compounding to the loss of wetlands is that almost all the wetlands studied from 14 states in the country were contaminated at varying levels. About 80% of fishes from the wetlands in the country, even from relatively remote regions had residues of HCH, while Heptachlor epoxide was detected in about 78% and Endosulfan in 66% of the wetlands studied. The most persistent DDT and its homologs (p,p' constituents) were detected in 76% of fishes (Vijayan *et al.*, 2004) examined.

The average concentration of Σ HCH in fishes in the present study are several folds lower than the maximum tolerance level (1000 $\mu\text{g/g}$) suggested by the Ministry of Health, Government of India (Mohindru 2005), and levels are also well below the tolerance limit (200 ng/g) prescribed for fish products (FDA, 2001) for human consumption. But, no guideline is available in terms of impact on birds.

Percentage composition of HCH isomers was also computed among the species. Among the isomers, β HCH was detected the maximum in all the fishes and it contributed more than 50% to the Σ HCH, whereas δ HCH showed the least contribution (figure 26). However, the physicochemical properties of these HCH isomers are different. The β HCH has the lowest water solubility, vapor pressure, and is the most stable and relatively resistant to microbial degradation (Ramesh *et al.*, 1991). Also it should be noted that α HCH gets converted to β HCH in the environment (Wu *et al.*, 1997). Many studies have reported that β HCH was dominant in environmental samples after long-term transformation (Wu *et al.*, 1999). The variation in the level of β HCH in different species of fishes is significant. This could be due to the high persistence and stable nature of β isomer (Ramesh *et al.*, 1991 and Wu *et al.*, 1999).

Sub-lethal concentration of lindane (γ HCH) in Orange Chromide (*Etroplus maculatus*) in India was studied by Bijoy Nandan and Nimila (2012). During the laboratory experiment, the red blood cell count, hemoglobin (Hb), hematocrit (Ht), mean corpuscular hemoglobin (MCH), mean corpuscular volume and mean corpuscular hemoglobin concentration (MCHC) were significantly reduced ($P > 0.0001$) in fishes exposed to the toxicant (lindane; 0.001 - 0.005 $\mu\text{g/g}$) compared to the control groups. Σ HCH and lindane recorded in the fishes collected from all the three study sites are lower than the concentration reported to cause biochemical changes (Bijoy Nandan and Nimila (2012).

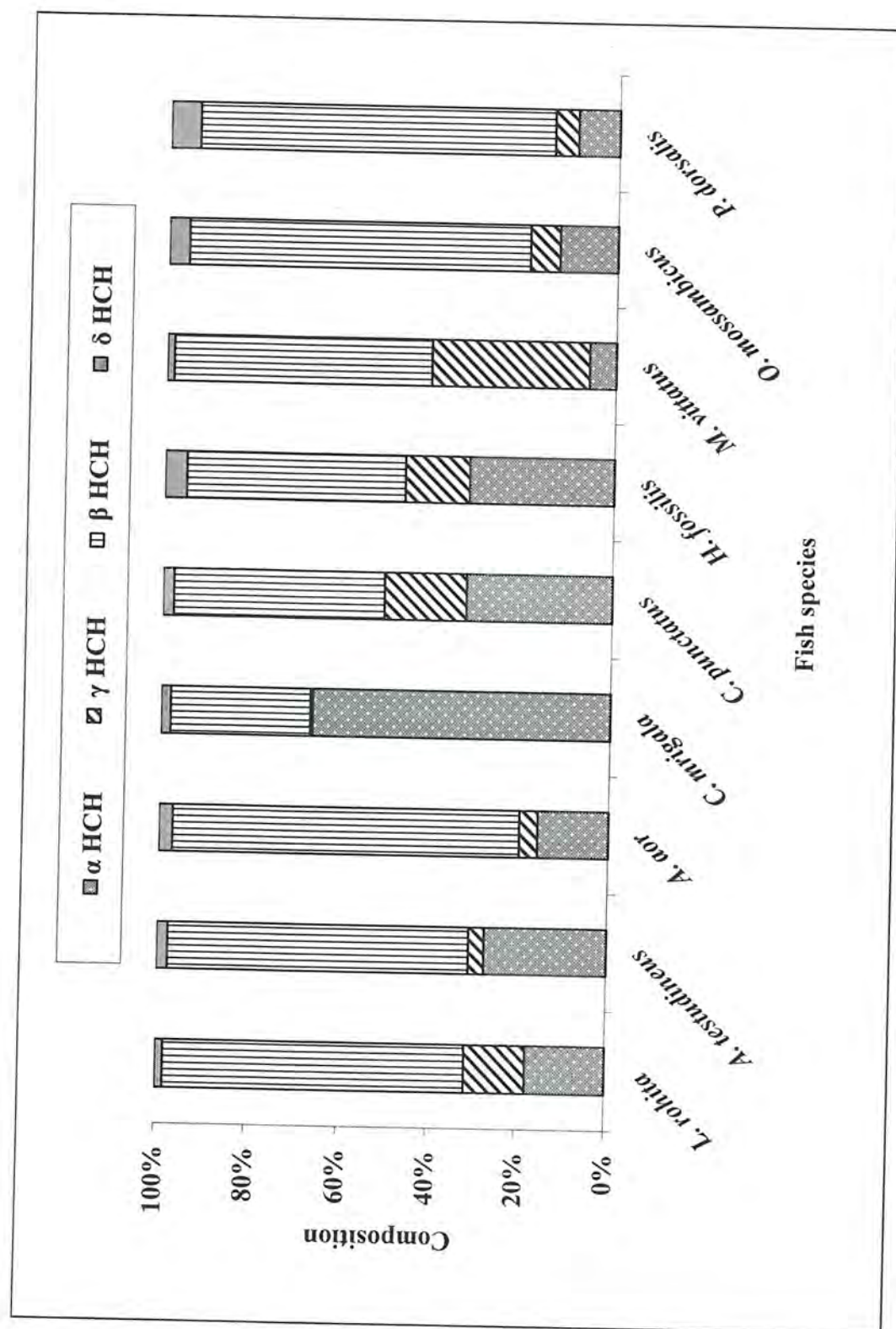


Figure 26. Percentage composition of HCH isomers in the fishes collected from the study sites during 2007-2010

b) DDT and its metabolites

Average concentration of Σ DDT among the species studied showed variation, but was not significant (ANOVA $F=0.788$; $df=4$; $P>0.05$). The maximum level of Σ DDT was detected in the fishes collected from Vedanthangal Bird Sanctuary. Further, the levels were almost similar in the fishes collected from Koonthankulam and Vettangudi. However, the variation was not significant (ANOVA $F=0.979$; $df=2$; $P>0.05$). Among the fishes, *Oreochromis mossambicus* (41.72 ± 25.49 ng/g) had the highest concentration of Σ DDT, while *Channa punctatus* (7.01 ± 1.54 ng/g) had the lowest (figure 27). Among the metabolites, p,p' DDT contributed 50% to the Σ DDT, while p,p' DDD made the least contribution (figure 28).

Concentration of DDE has severe ecological implications as this metabolite is the most persistent and toxic than its parent compound, the DDT. Furthermore, DDE is known to alter metabolic functions in organisms by acting as an antiandrogen, binding to androgen receptors, which causes reproductive abnormalities (WHO 2004). In India, the use of DDT in agriculture was banned in 1989. But a maximum of 10,000 tons of DDT per annum for the control of malaria is being permitted (Dash *et al.*, 2007). DDT can accumulate and biomagnify in organisms (Walker 2001) due to its lipophilicity ($K_{ow} = 5.7 - 6.36$) and persistence ($T_{1/2} = 10 - 15$ years). Their long persistence is the reason that residues of DDT and its metabolites are still being detected in the environment. The degree of persistence of DDE varies considerably, as persistence depends on the medium and many environmental parameters.

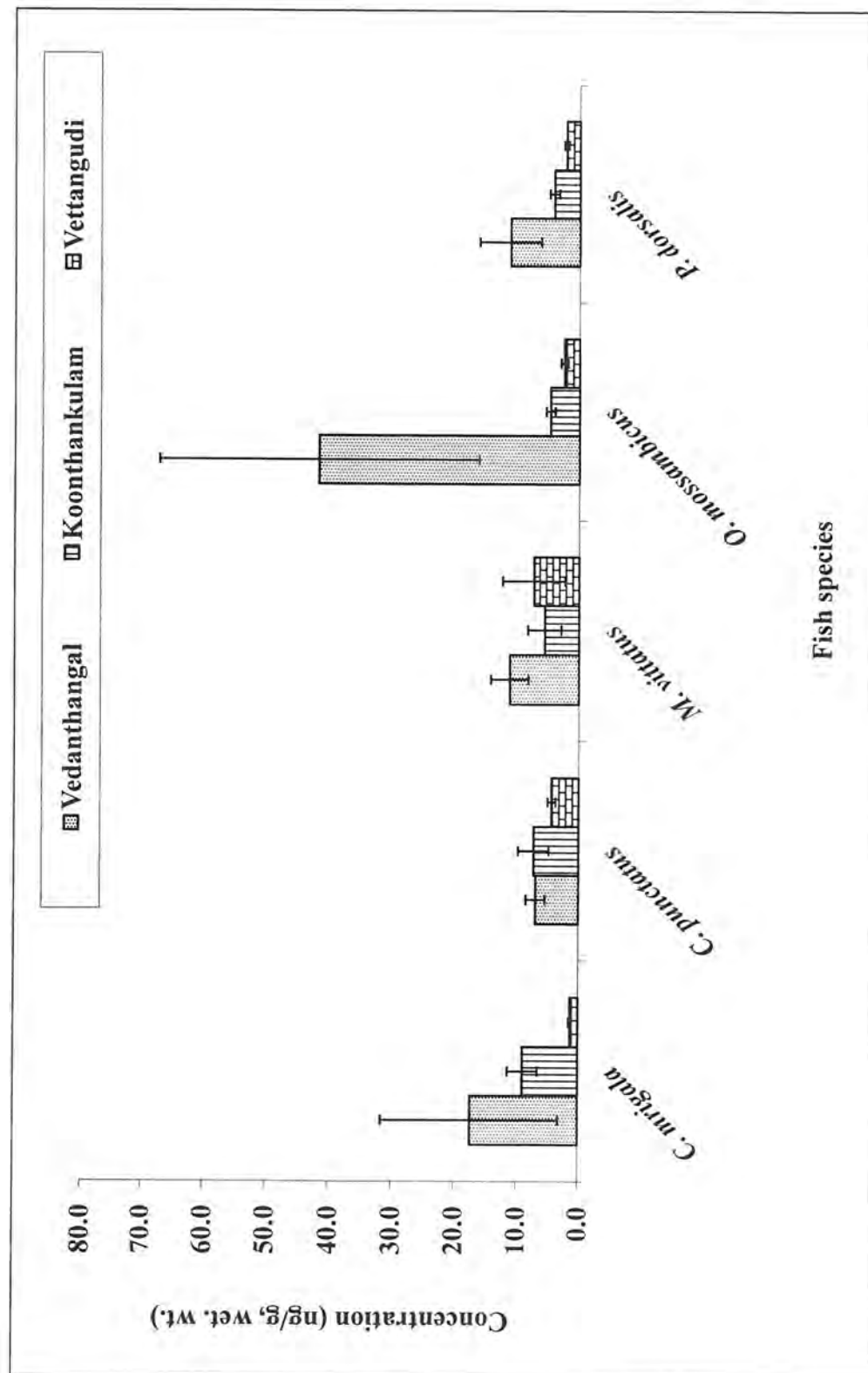


Figure 27. Variation in Σ DDT residues (Mean $\pm$ SE) among select species of fishes collected from the study sites during 2007-2010

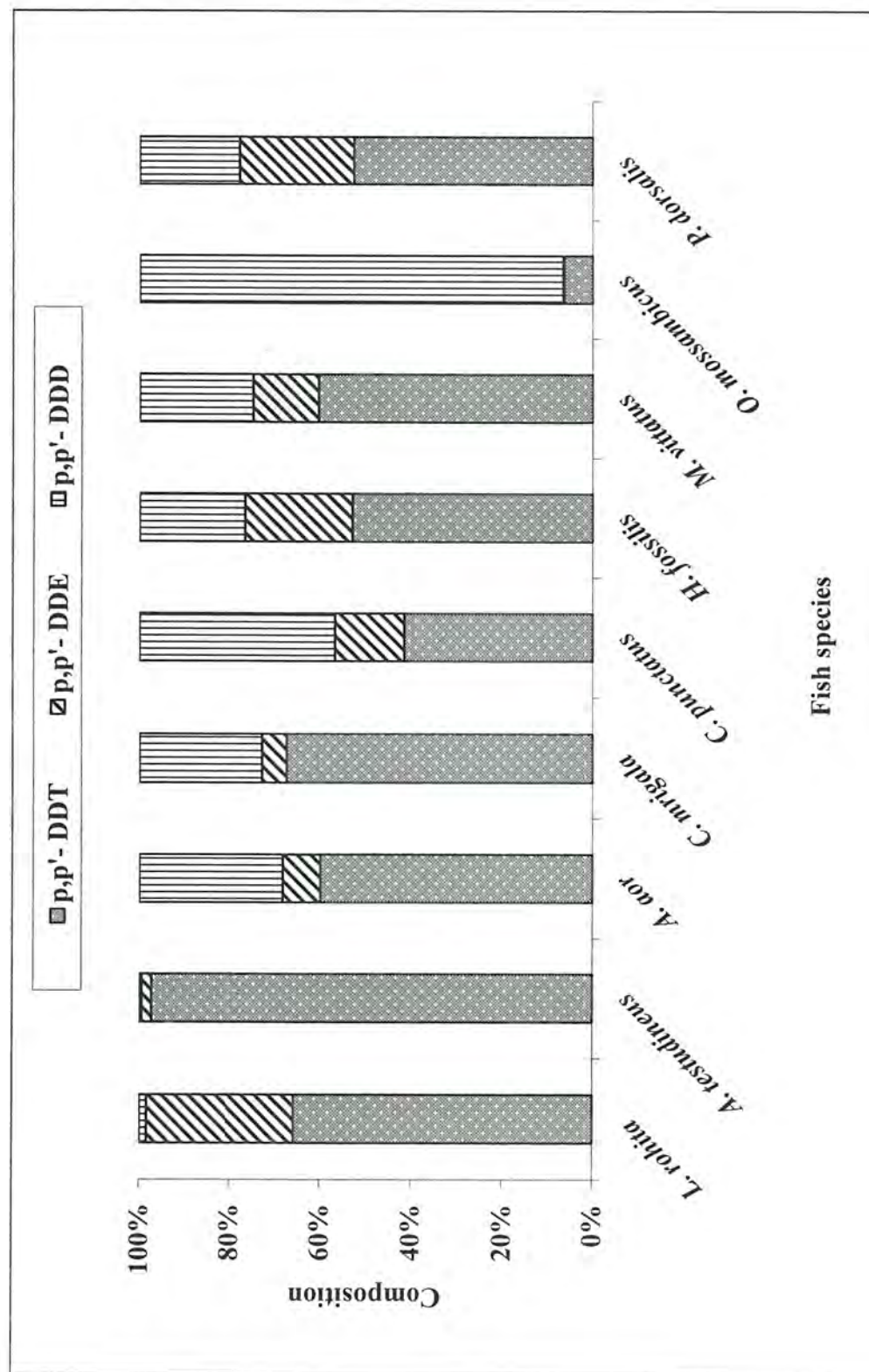


Figure 28. Percentage composition of DDT metabolites in the fishes collected from the study sites during 2007-2010

Levels of Σ DDT recorded in *O. mossambica* from Vedanthangal Bird Sanctuary are higher than the levels reported in 1050 fishes (BDL to 23.72 ng/g) comprising six species of fishes studied from various reservoirs, namely Avalanche, Uppar Bhavani, Emerald, Kamaraj Sagar, Pykara and Maravakandy, Ooty lake and rivers such as Coonoor and Moyar in Nilgiris district. Remaining eight species of fishes had lower concentrations of Σ DDT than the levels reported in the fishes in Nilgiris (Vijayan and Muralidharan, 1999). The levels of Σ DDT in *C. mirigala* and *O. mossambica* from Vedanthangal and *L. rohita* from Vettangudi Bird sanctuary is higher than the levels reported in freshwater fishes (3.4 - 12.3 ng/g) of different inland wetlands in Karnataka (Dhananjayan and Muralidharan, 2010).

Σ DDT reported in this study is higher than the levels (1-2 ng/g) reported in fishes of Ganges Estuary, Bangladesh (Jabber *et al.*, 2001 and Pandit *et al.*, 2006) and in fishes of Nilgiri district (Vijayan and Muralidharan, 1999). Misra (1989) recorded residues of DDT (47.7 ng/g) and DDE (17.09 ng/g) in *Labeo bata* from Mahala reservoirs in Rajasthan, India and Dua *et al.* (1996) reported Σ DDT (7077 ng/g) in the fishes of village ponds in Shajahanpur, Uttar Pradesh, India. It may be noted that the concentrations recorded in the fishes included in the present study are lesser than the concentrations referred above. Further, the Σ DDT detected in the present study is lower than the levels reported in fishes (72.6 - 1666 ng/g) from Ganga River (Kumari *et al.*, 2001) and comparable with the levels reported in freshwater fishes of Punjab (Kaur *et al.*, 2008). DDT residues reported in *A. testidineus*, *C. mirigala*, *M. vitatus*, *O. mossambica*, *P. dorsalis* from Vedanthangal Bird Sanctuary, *L. rohita* from Vettangudi Bird Sanctuary are higher than the levels reported in freshwater fish, *Scatophagus argus* (6.91 ng/g) collected from a few rivers in Calicut, Kerala (Sankar *et al.*, 2006). Further, it is to be noted that p,p' DDT gets converted into p,p' DDE due to the activity of mixed function oxygenase enzyme through metabolic functions.

Impact of environmental concentrations of DDT on gill in *Tilapia Sarotherodon melanotheron* was studied by Riou *et al.* (2012). They reported Σ DDT (15-1500 ng/g dw) to affect the structure of gill epithelium, eventually the gill associated functions. It is noted that the Σ DDT concentrations recorded in two species of fishes, namely *C. mirigala* (17.40 ng/g) and *O. mossambica* (41.72 ng/g) collected from Vedanthangal are closer to the levels responsible for gill damages.

The concentration of DDT recorded in all the species of fishes in the present study is higher than the level prescribed for fish products in India (7 ng/g) (Anonymous 1998) and FAO/ WHO (2.5 ng/g). Newell *et al.* (1987) had reported a guideline value of 200 ng/kg of total DDT in fishes for the protection of colonial nesting birds. The results obtained in this study in fishes were also lower than the recommended tolerance limits (Σ DDT: 1 mg/kg) by the Ministry of Health, Government of India (Mohindru 2005) for human consumption.

Although in none of the fishes included in the present study, DDT exceeded the referred guideline value, we need to be watchful. Because, even though DDT was banned for agriculture in India during 1989, it is continued to be used for public health purpose and still we find unsafe levels of residues in the environment. Moreover, many organochlorine pesticides even in trace levels have been linked to hormonal disturbance and reproductive problems in aquatic animals (Colborn *et al.*, 1993).

Moreover, the levels of presence of DDT compounds in the fishes from the three study sites indicate the availability or use of DDT in the state. Hence, considering the facts that DDT has a high half-life of 10 - 20 years, it degrades to DDE and DDD (Sericano *et al.*, 1990) and the DDE accounts for 50 - 70% of the Σ DDT burden in the environment (Newsome and Andrews, 1993), DDT and its metabolites bio-accumulate and are reported to be probable human carcinogens (Fairey *et al.*, 1997), fresh inputs of DDT into the environment through the usage for public health needs, has to be monitored. In this context it is to be noted that we still have instances of DDT poisoning in birds in India.

c) Cyclodiene insecticides

Fishes of Vedanthangal had the highest residues of Σ Endosulfan, Σ Heptachlor and Dieldrin followed by the fishes of Vettangudi and Koonthankulam (figures 29-31). Among the various cyclodiene insecticides, Σ Endosulfan was the maximum in concentration, and it contributed almost 55% to the Σ cyclodiene insecticides (figure 32). Endosulfan is reported to be more toxic to fishes (the 28-h LC 50= 0.09 - 11.2 ng/ml) than other life forms. However it depends on the species and water temperature. Studies also have shown that Endosulfan although is readily detoxified by fishes, it can be

accumulated while they are exposed. Among the cyclodiene insecticides, residues of Dieldrin were found in all the individual fishes tested in all the three locations. The levels recorded in the present study are higher than the levels (0.03 - 1 ng/g) reported in the fishes collected from Delhi, Calcutta and Punjab in India (Nair *et al.*, 1991; Kole *et al.*, 2001 and Kaur *et al.*, 2008). However levels found in the present study are much below the known toxic levels and also below levels known to be associated with ill effects. Nevertheless, long-term monitoring is needed.

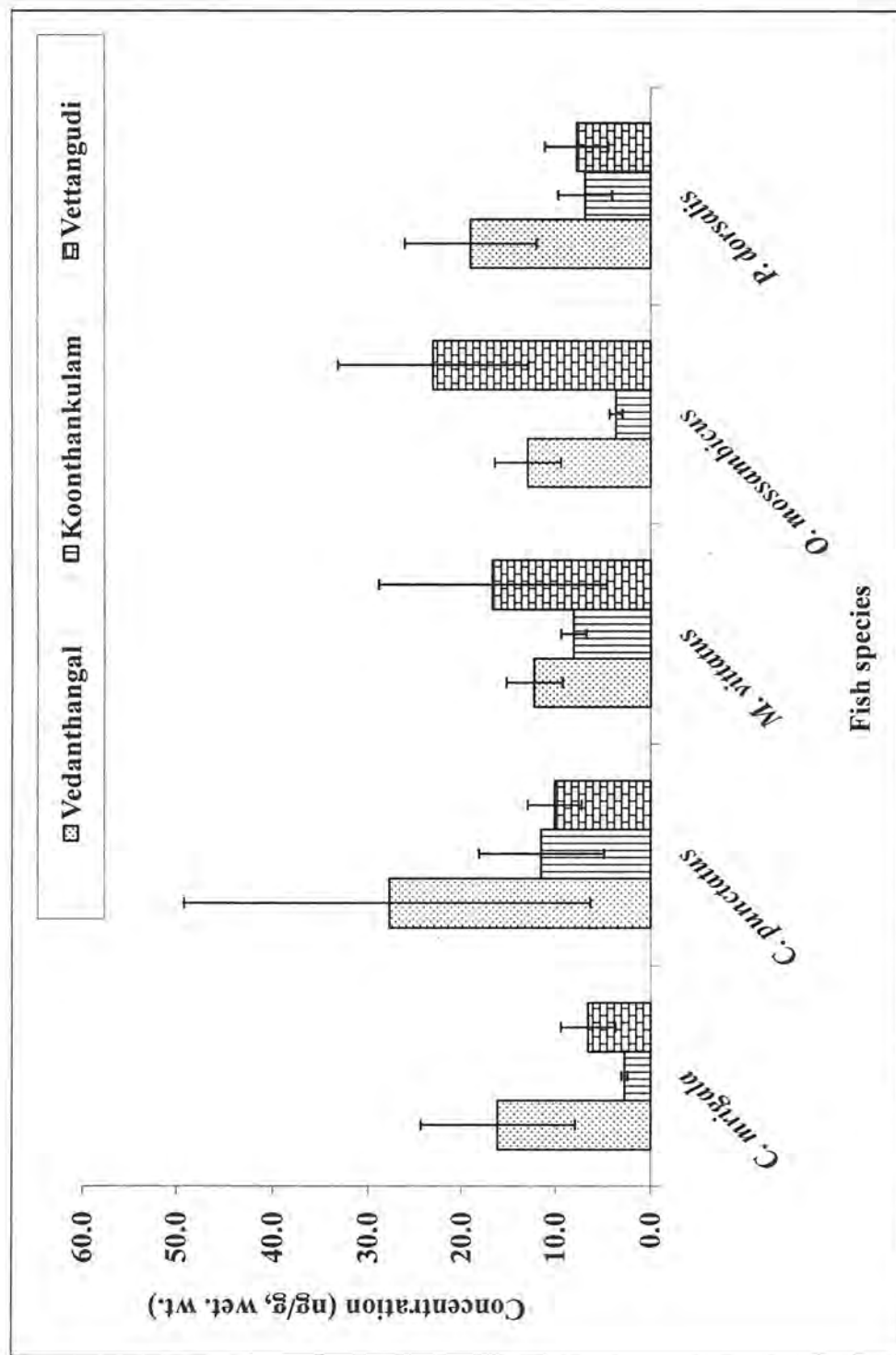


Figure 29. Variation in Σ Endosulfan residues (Mean $\pm$ SE) among select species of fishes collected from the study sites during 2007-2010

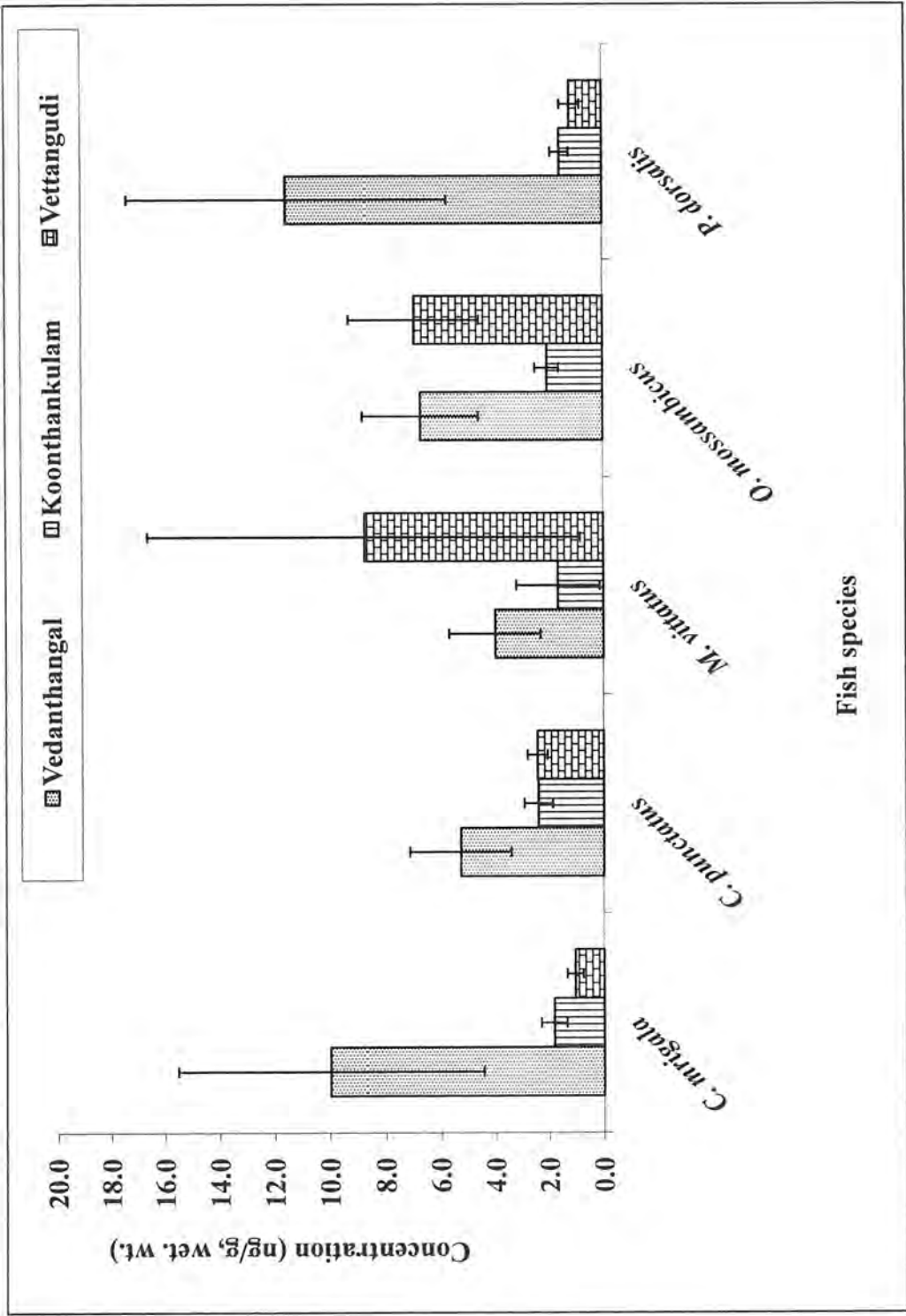


Figure 30. Variation in Heptachlor Epoxide residues (Mean $\pm$ SE) among select species of fishes collected from the intensive study sites during 2007-2010

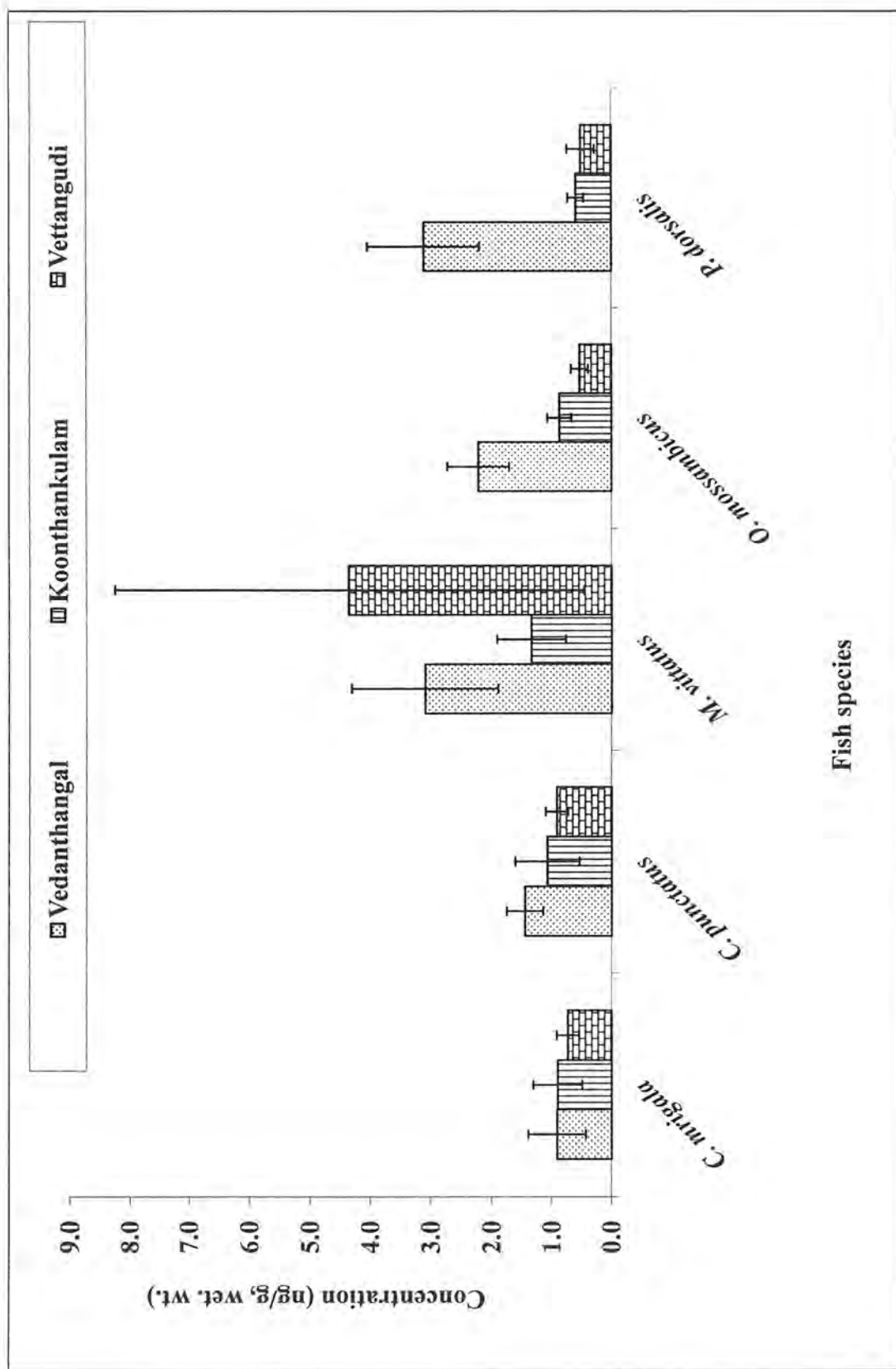


Figure 31. Variation in Dieldrin residues (Mean $\pm$ SE) among select species of fishes collected from the study sites during 2007-2010

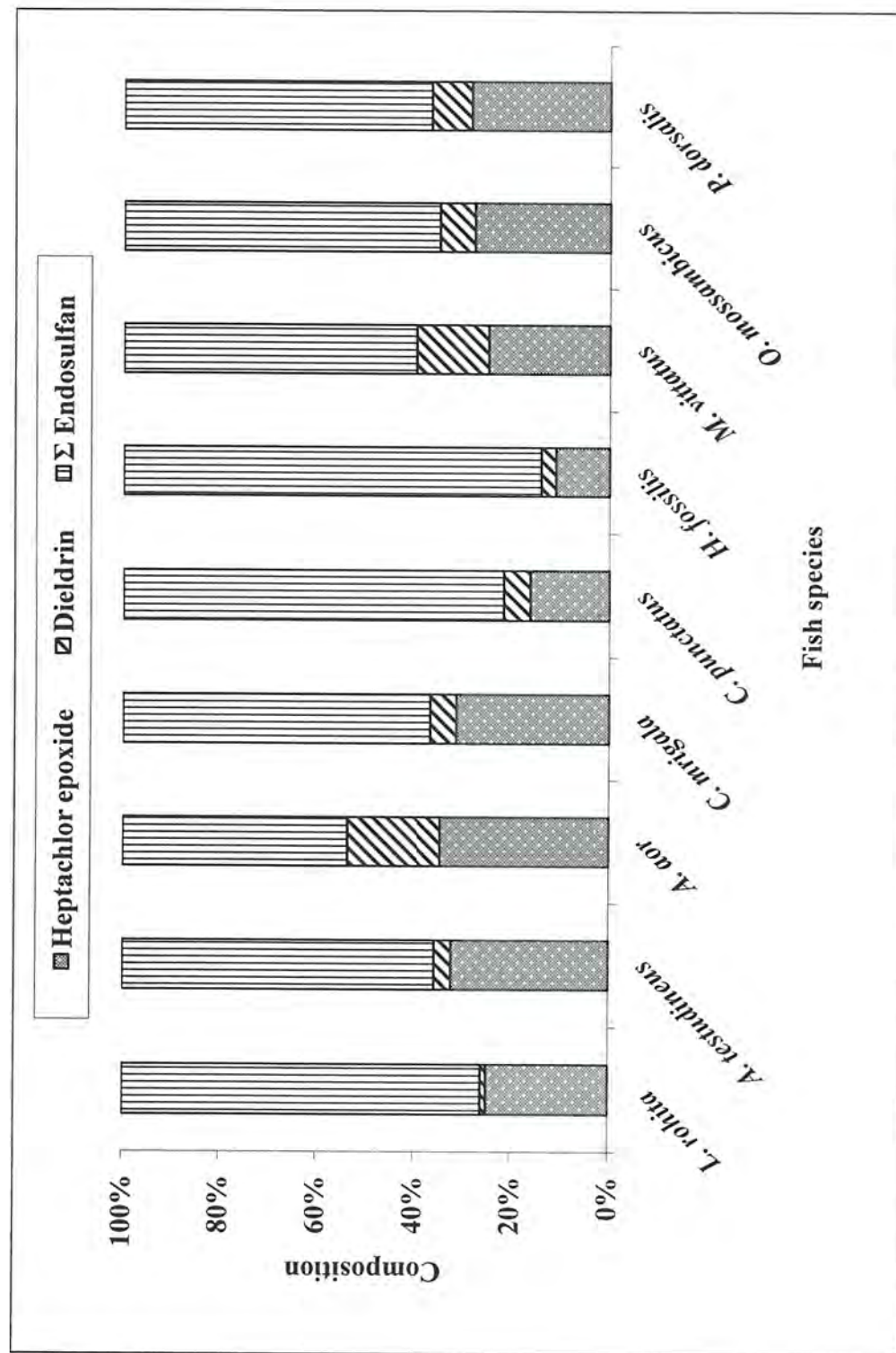


Figure 32. Percentage composition of cyclodiene residues in the fishes collected from the study sites during 2007-2010

Endosulfan is an off-patent organochlorine insecticide and acaricide that is being phased out globally. Endosulfan became a highly controversial agrochemical due to its acute toxicity, potential for bioaccumulation and role in endocrine disruptions (Vinay Malik 2013). Because of its threats to human health and the environment, a global ban on the manufacture and use of Endosulfan was negotiated under the Stockholm Convention in April 2011. It may be noted that Kerala government banned endosulfan way back in 2002 particularly in Kasargod district, Kerala. More than 80 countries, including the European Union, Australia and New Zealand, several West African nations, the United States, Brazil and Canada have already banned it or announced phase-outs by the time the Stockholm Convention's ban was agreed upon. It is still used in China and few other countries. The Supreme Court of India has banned Endosulfan in India with effect from May, 2011, with certain exemptions for five additional years (Vinay Malik 2013). The concentration of Σ Endosulfan recorded in all the fish species from Vedanthangal, Koonthankulam and Vettangudi Bird Sanctuaries in the present study are higher than the levels (BDL- 4.3 ng/g) reported in nine species of fresh water fishes from Karnataka (Dhananjayan and Muralidharan 2010). Concentrations of Σ Heptachlor recorded in the present study are lower than the concentrations reported (110 ng/g) in the fishes of the Ganges Estuary, Bangladesh (Jabber *et al.*, 2001) and in freshwater fishes of Andhra Pradesh (76.5 ng/g; Amaraneni and Pillala, 2001) and fishes of River Ganga at four sites in Bihar: Buxar, Patna, Mokama and Rajmahal (401.7 ng/g; Kaur *et al.*, 2008).

Da Cuna *et al.* (2011) studied acute toxicity, histological and physiological changes in fish *Cichlasoma dimerus* exposed to Endosulfan (0.25 to 16 mg/L for 96 hrs) in laboratory condition. They found decreased erythrocyte, corpuscular volume and corpuscular hemoglobin concentration in the fishes. High concentration of endosulfan (32 μ g/g) caused malformation and larval mortality in Florida Flagfish (*Jordanella floridae*) over complete life cycle (Beyger *et al.*, 2012). However, the levels of Endosulfan detected in the fishes of the current study are lower than the levels reported to cause malformation and mortality.

Heptachlor residues in fishes, namely *A. testidineus*, *A. aor*, and *P. dorsalis* collected from Vedanthangal Bird Sanctuary, *L. rohita* and *A. aor* collected from Vettangudi Bird Sanctuary are higher than the levels (10.8 ng/g) recorded in 156 individuals comprising nine species of fishes collected from ten inland wetlands in Karnataka (Dhananjayan and Muralidharan 2010). Concentrations of Σ Endosulfan and Heptachlor are comparable

with the levels reported by Vijayan and Muralidharan, (1999) in 1050 fishes comprising six species of fishes, namely *Cyprinus carpio communis*, *Cyprinus carpio nudus*, *Cyprinus carpio specularis*, *Oreochromis mossambicus* and *Barbus carmuca* studied from various reservoirs (BDL - 16.24 ng/g), namely Avalanche, Uppar Bhavani, Emerald, Kamaraj Sagar, Pykara and Maravakandy, Ooty lake and rivers such as Coonoor and Moyar in Nilgiris district. When total cyclodiene residues reported in the present study are compared with the levels reported in the fishes of a few Rivers in Calicut, Kerala (Feroke, Korappuzha and Purakkattiri), they are higher than the levels in *Platicephalus* sp. (5.4 ng/g) and, comparable with *Epinephelus* sp. (7.37 ng/g) and *Lutjanus rivulatus* (70.56 ng/g) (Sankar *et al.*, 2006).

In some earlier studies in India, Battu *et al.* (1984) detected OCPs in fresh water fishes in Ludhiana, Punjab. Residues of both DDT and HCH were present in all the samples and the maximum level of DDT was found to be 3.02 µg/g, while Kannan *et al.* (1992) reported mean levels of HCH and DDT to be 0.002 and 0.015 µg/g respectively, in fishes in India. Amaraneni and Pillala (2001) analysed fish samples in Andhra Pradesh, India and the maximum concentration of α , γ HCH and DDT were found to be 123.8, 98.70 and 157.4 µg/g respectively. Anupma *et al.* (2001) detected residue of DDT in fish samples from Ganga River, India in the range of 0.073- 1.67 µg/g. Vijayan *et al.* (2004) documented OCPs in the fresh water fishes of Inland Wetlands of India. The study reported residues of Σ OCPs between BDL- 0.3 µg/g and they also stated that 77% of fishes studied were contaminated with HCH and 66% with DDT.

Higher concentrations of HCH than DDT in the fishes, despite the higher bioaccumulation potential of DDT, might be due to the consumption of HCH and phasing out of DDT in agriculture earlier than HCH. It may further be noted that, although the notorious chemical, namely DDT is banned for agriculture in India, it is still being used for civic health purpose as stated elsewhere in this thesis. As the OCPs have adverse effects not only on the fishes, but also on the colonial nesting birds, their regular monitoring is strongly advised.

5.4.2. Organochlorine pesticide residues in colonial nesting birds.

Seventy six individuals comprising 13 species of colonial nesting birds were examined for organochlorine residues. Name of the species and number of individuals included in the present study are presented in table 32.

Table 32. Details of birds collected dead from the study sites in Tamil Nadu (2008 - 2010)

S. No.	Name of the Bird	Scientific Name	Locations			Total
			Vedanthalangal	Koonthankulam	Vettangudi	
1	Spot-billed Pelican	<i>Pelicanus philippensis</i>	-	10	-	10
2	Little Cormorant	<i>Phalacrocorax niger</i>	4	1	-	5
3	Indian Cormorant	<i>Phalacrocorax fuscicollis</i>	-	21	-	21
4	Black-crowned Night Heron	<i>Nycticorax nycticorax</i>	-	2	-	2
5	Grey Heron	<i>Ardea cinerea</i>	3	9	-	12
6	Intermediate Egret	<i>Mesophoyx intermedia</i>	-	1	-	1
7	Indian Pond Heron	<i>Ardeola grayii</i>	-	3	-	3
8	Little Egret	<i>Egretta garzetta</i>	-	4	-	4
9	Cattle Egret	<i>Bubulcus ibis</i>	-	1	-	1
10	Painted Stork	<i>Mycteria leucocephala</i>	-	7	-	7
11	Glossy Ibis	<i>Plegadis falcinellus</i>	1	-	-	1
12	Black-headed Ibis	<i>Threskiornis melanocephalus</i>	1	3	3	7
13	Eurasian Spoonbill	<i>Platalea leucorodia</i>	1	1	-	2
Total			10	63	3	76

- Not available

5.4.2.1. Organochlorine pesticide residues in birds from Vedanthangal Bird Sanctuary

Ten individuals comprising five species of birds, namely Little Cormorant, Grey Heron, Eurasian Spoonbill, Glossy Ibis and Black-headed Ibis found dead in the Sanctuary were analysed for pesticide residues in various tissues. Among various organochlorine pesticide residues analyzed, Σ HCH was the highest in concentration followed by Σ endosulfan and Σ DDT. Σ HCH ranged between 1 ng/g in brain of Grey Heron and 871.7 ng/g in liver of the same species. Σ Endosulfan, Σ DDT and Σ Heptachlor ranged from BDL to 323.9 ng/g, 3.2 to 208.6 ng/g and BDL to 403.8 ng/g respectively. Comparatively low levels of Dieldrin were also detected in the range of BDL to 58.5 ng/g. p,p' DDE and γ HCH ranged from BDL to 86.6 ng/g and BDL to 98.9 ng/g respectively. On the whole highest levels of organochlorine pesticide residues were detected in the tissues of Grey Heron followed by Little Cormorant and Black-headed Ibis, while tissues of Glossy Ibis had the lowest levels. Among the tissues, maximum was observed in liver followed by muscle, while the minimum concentration was recorded in brain (table 33). Significant differences were observed among tissues (ANOVA $F= 4.404$; $df= 2$; $P<0.05$) in the residue load. Average concentration of Σ OC among the species showed variation, but not statistically significant (ANOVA $F= 0.948$ $df= 4$; $P>0.05$).

5.4.2.2. Organochlorine pesticide residues in birds from Koonthankulam Bird Sanctuary

Totally 63 individuals comprising 12 species of birds, namely Cattle Egret, Indian Cormorant, Little Cormorant, Grey Heron, Spot-billed Pelican, Intermediate Egret, Little Egret, Black-headed Ibis, Black-crowned Night Heron, Painted Stork, Indian Pond Heron and Eurasian Spoonbill found dead in the Sanctuary and around during the study period were analyzed for pesticide residues in various tissues. Among the various organochlorine pesticide residues analyzed, Σ HCH was the highest in concentration and it ranged between BDL in brain of Spot-billed Pelican and 1194 ng/g in liver of Indian Pond Heron. Σ Endosulfan, Σ DDT and Σ Heptachlor ranged from BDL to 637 ng/g, BDL to 198 ng/g and BDL to 963.3 ng/g respectively. Dieldrin levels ranged between BDL and 109.3 ng/g. p,p' DDE and γ HCH ranged from BDL to 63.2 ng/g and BDL to 95.4 ng/g respectively. On the whole higher levels of organochlorine pesticide residues were detected in the tissues of Indian Cormorant followed by Cattle Egret, while tissues of Grey Heron had the lowest levels. Significant differences (ANOVA $F= 11.709$; $df= 2$; $P<0.05$) were observed among tissues in their residue loads. The maximum was observed

in liver followed by muscle tissue, while the minimum concentration was recorded in brain. Significant differences were observed among birds (ANOVA $F=2.560$; $df=11$; $P<0.05$) in the residue load (table 34).

5.4.2.3. Organochlorine pesticide residues in birds from Vettangudi Bird Sanctuary

Three individuals of only Black-headed Ibis found dead during the study period in the Sanctuary were analyzed for OC pesticide residues in various tissues and the levels are presented in table 35. Among various OCP residues analyzed, Σ HCH was the highest and it ranged between BDL in muscle and brain and 236 ng/g in the liver. Σ Endosulfan, Σ DDT and Σ Heptachlor ranged from 1.9 to 31 ng/g, BDL to 167 ng/g and BDL to 18.2 ng/g respectively. Comparatively low levels of Dieldrin were detected in brain. p,p' DDE and gamma HCH ranged from BDL to 15.6 ng/g and BDL to 16.3 ng/g respectively. Total OC residue load among tissues showed variation, but not significant (ANOVA $F= 2.095$; $df=2$; $P>0.05$). While the maximum concentration was observed in liver tissue followed by muscles, the minimum was recorded in brain (table 35).

Table 33. Organochlorine pesticide residues (mean ng/g, wet.wt.) in various tissues of birds collected from Vedanthangal Bird Sanctuary during 2008 - 2010 (Range in parentheses)

S. No.	Name of the bird	N	Organ	Organochlorine pesticide residues						
				Σ HCH	Σ DDT	Σ Endosulfan	HE	Dieldrin	p,p' DDE	γ HCH
1	Glossy Ibis	1	Liver	2.9	8.9	8.1	5.9	4.0	1.0	1.0
			Muscle	4.9	14.0	13.4	6.3	2.9	2.7	1.0
			Liver	871.7	151.2	30.3	118.4	BDL	BDL	44.0
2	Grey Heron	3	Brain	39.1 (1-63.8)	40.0 (2.6-74.7)	51.2 (BDL-131.1)	55.7 (BDL-167.2)	17.4 (BDL-44.1)	2.0 (BDL-7.28)	1.1 (BDL-2.61)
			Muscle	132.4 (3.9-260.8)	106.0 (3.4-208.6)	166.9 (9.9-323.9)	94.90 (14.4-175.3)	32.0 (5.5-58.5)	45.0 (3.4-86.6)	23.9 (3.94-43.85)
			Liver	241.8	77.7	76.8	280.9	33.6	BDL	52.9
3	Little Cormorant	4	Brain	89.9 (24.1-163.6)	67.7 (18.3-120.9)	64.2 (37.6-111.5)	124.4 (7.3-403.8)	34.1 (6.4-48.9)	8.5 (BDL-28.0)	29.0 (7.7-85.8)
			Muscle	84.14 (2.3-180.3)	72.9 (15.6-133.0)	104.4 (30.9-191.1)	98.7 (14.8-224.2)	26.5 (3.8-46.2)	31.1 (BDL-80.0)	35.7 (BDL-98.9)
			Liver	28.0	9.2	6.0	4.5	3.7	2.9	19.9
4	Eurasian Spoonbill	1	Muscle	1.9	3.2	1.7	1.9	0.7	0.3	1.7
			Brain	38.2	26.7	209.4	100.3	75.8	13.2	5.0
			Muscle	2.3	3.2	BDL	BDL	BDL	BDL	2.3
Total		10								

HE- Heptachlor Epoxide; BDL- Below Detection Limit

Table 34. Organochlorine pesticide residues (mean ng/g, wet.wt.) in various tissues of birds collected from Koonthankulam Bird Sanctuary during 2008 - 2010 (Range in parentheses)

S. No.	Name of the bird	N	Organ	Organochlorine pesticide residues						
				Σ HCH	Σ DDT	Σ Endosulfan	HE	Dieldrin	DDE	γ HCH
1	Cattle Egret	1	Liver	156.8	17.6	409.9	33.8	19.0	BDL	BDL
			Brain	25.5	48.3	35.3	9.0	13.8	48.3	BDL
			Muscle	969.5	42.9	125.3	12.4	16.8	42.9	1.7
2	Indian Cormorant	21	Liver	147.8 (29.1-397.7)	73.3 (BDL-198)	143.4 (4.8-539.9)	68.5 (BDL-963)	14.7 (BDL-62.2)	2.4 (BDL-26.2)	17.5 (BDL-76.6)
			Brain	23.9 (2.7-99.1)	15.1 (BDL-70.4)	15.9 (BDL-80.8)	3.5 (BDL-52.0)	8.8 (BDL-57.1)	6.6 (BDL-32.8)	3.5 (BDL-21.4)
			Muscle	94.2 (3.5-981.1)	15.3 (BDL-66.1)	40.0 (2.3-271.7)	24.9 (BDL-489.0)	4.2 (BDL-22.8)	5.4 (BDL-58.8)	3.1 (BDL-21.8)
			Liver	85.3 (1.6-154.1)	12.5 (BDL-30.1)	32.6 (7.0-64.9)	5.0 (BDL-13.0)	5.4 (BDL-16.3)	BDL	7.3 (BDL-21.9)
			Brain	15.8 (5.7-28.8)	13.9 (7.2-24.3)	12.3 (5.2-27.0)	2.7 (BDL-5.5)	20.1 (BDL-64.7)	2.9 (BDL-8.6)	5.1 (0.3-16.0)
3	Grey Heron	9	Muscle	37.0 (0.3-76.3)	5.8 (2.0-11.5)	9.8 (1.5-19.0)	1.6 (0.6-2.6)	0.5 (BDL-1.2)	4.5 (BDL-8.4)	0.1 (BDL-0.3)
			Liver	81.3 (1.2-198.3)	44.6 (BDL-176.5)	29.4 (3.2-75.3)	29.5 (BDL-265.8)	2.6 (BDL-14.9)	7.1 (BDL-37.2)	4.4 (BDL-11.8)
			Brain	6.7 (BDL-15.4)	6.2 (BDL-22.4)	10.2 (BDL-61.6)	0.9 (BDL-5.4)	0.5 (BDL-3.3)	1.6 (BDL-13.6)	0.8 (BDL-2.8)
			Muscle	33.6 (BDL-184.7)	5.7 (BDL-23.1)	14.6 (0.9-69.7)	0.8 (BDL-3.1)	1.9 (BDL-10.8)	1.4 (BDL-5.0)	1.0 (BDL-3.9)
5	Intermediate Egret	1	Brain	292.6	32.9	42.7	10.8	6.1	17.3	BDL
			Muscle	6.4	3.7	6.3	3.4	0.8	0.6	1.1
6	Little Cormorant	1	Brain	17.0	15.6	107.8	BDL	BDL	BDL	BDL
			Liver	57.7 (28.2-87.3)	33.7 (BDL-67.4)	16.8 (11.8-21.8)	0.9 (BDL-1.8)	0.5 (BDL-1.1)	28.0 (BDL-56.0)	0.5 (BDL-1.0)
			Muscle	5.7	5.2	8.8	0.6	BDL	2.7	0.6
7	Little Egret	4	Liver	400.7 (34.0-708.4)	49.9 (BDL-141.7)	46.4 (BDL-140.8)	100.8 (BDL-399.5)	8.5 (BDL-25.8)	14.2 (BDL-56.7)	21.0 (3.5-46.6)
			Brain	54.9 (2.5-101.9)	37.8 (4.4-88.7)	29.1 (0.6-47.8)	36.3 (BDL-103.7)	7.1 (BDL-19.4)	5.5 (BDL-22.0)	24.6 (2.2-84.7)
			Muscle	134.2 (5.9-409.0)	6.3 (BDL-19.7)	49.7 (0.6-110.9)	12.4 (BDL-49.6)	6.8 (BDL-21.7)	1.7 (BDL-4.1)	22.4 (BDL-82.2)

Table 34. Continued ...

S. No.	Name of the bird	N	Organ	Organochlorine pesticide residues						
				Σ HCH	Σ DDT	Σ Endosulfan	HE	Dieldrin	p,p' DDE	γ HCH
8	Black-crowned Night Heron	2	Liver	253.5 (231.2-275.8)	72.3 (7.0-137.6)	329.4 (21.7-637)	40.4 (15.1-65.6)	30.2 (14.0-46.5)	3.5 (BDL-7.0)	42.9 (BDL-85.9)
			Brain	12.0	1.9	17.5	3.6	5.6	0.9	2.0
			Muscle	129.3 (119.9-138.7)	8.9 (5.6-12.2)	9.4 (7.8-11.1)	3.3 (2.2-4.3)	1.4 (1.1-1.7)	8.1 (5.6-10.6)	0.3 (0.3-0.3)
9	Painted Stork	7	Liver	74.4 (8.0-217.8)	29.7 (BDL-114.6)	73.6 (BDL-181.6)	10.2 (BDL-36.1)	3.9 (BDL-12.6)	5.8 (BDL-31.7)	21.2 (BDL-95.4)
			Brain	19.7 (2.3-60.2)	11.8 (2.2-28.1)	6.7 (1.5-12.9)	4.4 (BDL-23.3)	0.9 (BDL-3.1)	3.2 (BDL-15.7)	2.5 (BDL-7.1)
			Muscle	13.6 (2.6-48.8)	10.8 (BDL-53.3)	99.4 (0.3-556.0)	3.0 (BDL-13.1)	1.9 (BDL-4.4)	2.0 (BDL-11.7)	1.0 (BDL-3.1)
10	Indian Pond Heron	3	Liver	454.7 (63.1-1194)	88.1 (23.3-193.1)	300.0 (128.5-390.5)	20.3 (BDL-50.9)	36.4 (BDL-109.3)	37.0 (BDL-63.2)	15.0 (13.1-18.4)
			Brain	207.5 (38.7-516.7)	9.5 (BDL-23.4)	102.4 (53.2-175.3)	8.6 (4.0-11.7)	39.3 (2.9-96.7)	BDL	12.6 (0.9-31.3)
			Muscle	23.4 (4.5-53.1)	14.3 (4.0-29.5)	10.3 (7.2-14.8)	1.6 (BDL-4.2)	3.4 (BDL-9.0)	0.2 (BDL-0.5)	1.3 (0.5-2.1)
11	Eurasian Spoonbill	1	Brain	768.1	BDL	307.1	17.7	30.8	BDL	9.0
			Liver	10.6	7.1	27.9	24.2	19.7	0.6	0.8
12	Black-headed Ibis	3	Liver	451.6 (82.5-1071.4)	84.1 (32.3-157.5)	75.2 (28.6-132.6)	17.8 (BDL-32.7)	19.6 (10.2-29.6)	5.6 (BDL-16.7)	15.0 (9.8-24.8)
			Brain	76.3 (5.2-167.7)	23.2 (4.4-55.6)	13.7 (0.4-27.7)	2.5 (BDL-7.6)	4.2 (BDL-10.9)	3.7 (BDL-9.6)	2.2 (BDL-5.2)
			Muscle	17.5 (2.5-33.2)	14.4 (1.3-36.4)	19.3 (5.3-44.1)	2.2 (BDL-3.6)	1.2 (0.6-2.1)	3.8 (BDL-10.9)	0.8 (BDL-2.1)
Total		63								

HE- Heptachlor Epoxide; BDL- Below Detection Limit.

Table 35. Organochlorine pesticide residues (mean ng/g, wet.wt.) in various tissues of Black-headed Ibis collected from Vettangudi Bird Sanctuary during 2008-2010 (Range in parentheses)

S. No.	Name of the bird	N	Organ	Organochlorine pesticide residues						
				Σ HCH	Σ DDT	Σ Endosulfan	HE	Dieldrin	p,p' DDE	γ HCH
1	Black-headed Ibis	3	Liver	159.9 (83.7-236)	97.5 (27.8-167)	19.5 (14.8-24.20)	13.2 (12.2-14.30)	BDL	7.8 (BDL-15.6)	BDL
			Brain	6.7 (BDL-13.3)	4.2 (2.2-6.1)	1.1 (BDL-2.1)	1.5 (BDL-2.9)	8.6 (BDL-17.3)	2.6 (2.2-2.9)	BDL
			Muscle	56.1 (BDL-112.3)	2.1 (BDL-4.2)	16.5 (1.9-31)	9.1 (BDL-18.2)	BDL	2.1 (BDL-4.2)	8.2 (BDL-16.3)

HE- Heptachlor epoxide; BDL- Below Detection Limit



5.4.2.4. Variation in OCP residues among species

a) HCH and its isomers

Maximum load of HCH was recorded in Herons and Egrets, while the minimum was observed in Pelicans and Cormorants. Species, namely Cattle Egret, Indian Pond Heron and Black-crowned Night Heron recorded the maximum concentrations of HCH 645, 440 and 359 ng/g respectively. Significant variations in HCH residues were observed among various species of birds studied (ANOVA $F= 1.913$; $df=12$; $P< 0.05$). Comparatively higher load of $\sum$ HCH (> 200 ng/g) was recorded in Cattle Egret, Indian Pond Heron and Eurasian Spoonbill (figures 33-35). Of all the HCH isomers, β HCH was the highest in concentration and it contributed more than 50% to the $\sum$ HCH, while γ HCH made the least contribution (figure 36).

The high frequency of occurrence of HCH in the samples analyzed could reflect the recent use of HCH in the study sites. Total HCH residues among the species are almost comparable with the concentration reported by Vijayan and Muralidharan (1999) in various species of birds collected from Nilgiri district. There is not much of information available on the mortality of birds due to HCH poisoning in the wild in India and elsewhere. However, some data generated in the laboratory give some basic information about HCH and its toxicity. Rock doves (*Columba livia*) when treated with 72 $\mu\text{g/g}$ of γ HCH, one bird that died on the 7th day had 31.6 $\mu\text{g/g}$ in liver. While not diagnostic, these residues can be related to dangerous exposure to the toxicant (Hill *et al.*, 1975). The levels recorded in the current study are lower than the LD_{50} values reported from the dietary toxicity study for Bobwhite (882 $\mu\text{g/g}$), Japanese Quail (425 $\mu\text{g/g}$), Ring-necked Pheasant (561 $\mu\text{g/g}$) and Mallard (1500 $\mu\text{g/g}$) (Hill *et al.*, 1975). The HCH concentrations reported in the tissues of birds included in the present study do not fall within toxic range, but very much indicative of exposure.

Total HCH concentration recorded in the present study is lower than the concentration reported in six species of colonial nesting birds, namely Pond Heron (8800 ng/g), Little Egret (73000 ng/g), White-breasted Kingfisher (4200 ng/g), Black-caped Kingfisher (310 ng/g) and Common Kingfisher (110 ng/g) collected from India and Vietnam (Kunisue *et al.*, 2003). The levels are similar to the results reported in select species of colonial nesting birds from Gujarat and Tamil Nadu (Vijayan and Muralidharan 1999;

Senthilkumar *et al.*, 2005; and Dhananjayan 2009). HCH was reported as one of the most common residues in Waterfowl from Mexico, although at low levels (Mora *et al.*, 1987). It is also reported that India is the greatest consumer of HCHs in the world (Kumari *et al.*, 2001) with approximately 36 million kg/ year for agricultural purpose till 1990 (Ramesh *et al.*, 1992). It was largely being used against sucking and biting pests and as fogging agent for control of pests in grain stores (Mathur *et al.*, 2005).

Accumulation pattern of persistent pesticides in resident birds in India was reported by Kunisue *et al.* (2003). They reported high levels of Σ HCH in the whole body of Little Egret (73,000 ng/g) and Indian Pond Heron (8800 ng/g) in India. However, HCH recorded in the same species from the study sites are lower than the level reported by Kunisue *et al.* (2003). Σ HCH concentrations recorded in the present study are lower than the concentrations reported in Large Cormorant (0.47 to 4.6 $\mu\text{g/g}$), Little Egret (0.02 to 9.41 $\mu\text{g/g}$), Cattle Egret (0.005 to 0.42 $\mu\text{g/g}$) and Indian Pond Heron (2.04 - 4.76 $\mu\text{g/g}$) collected from Nilgiris, Tamil Nadu (Vijayan and Muralidharan 1999). However, concentrations of HCH reported in birds in the present study are several times higher than the concentrations reported in the birds of Oxbow lakes of Northeastern Louisiana (Niethammer *et al.*, 1984). Further, it is noted that HCH is also one of the most common residues observed in birds as reported by Mora *et al.* (1987).

Sakellarides *et al.* (2006) documented the accumulation profile of Σ HCH residues in the liver tissue of many species of waterbirds, namely Grey Heron (ND -10 ng/g), Black-crowned Night Heron (ND - 20 ng/g), Little Egret (ND - 40.7 ng/g), Little Bittern (ND- 415 ng/g), Bittern (ND - 38.9 ng/g), White Stork (ND - 219 ng/g), Pygmy Cormorant (ND - 72.9 ng/g) and Dalmatian Pelican (ND -12.0 ng/g) in Greece. When compared with these levels, concentrations of Σ HCH recorded in Cattle Egret, Intermediate Egret, Little Egret, Grey Heron, Black-Crowned Night Heron, Indian Pond Heron, Black-headed Ibis and Eurasian Spoonbill in the present study are higher and comparable with the levels in Painted Stork, Asian Openbill, Little Cormorant and Spot-billed Pelican.

Among the isomers of HCH detected in the tissues of birds, β HCH was the most predominant. This is due to isomerization of δ HCH and γ HCH in to β HCH and also its persistent nature (Jensen 1983 and Burke *et al.*, 2003). The low levels of γ HCH may be due to its rapid disappearance in the tissues of birds after death (French and Jefferies

1968). Further, it is also reported that β HCH will accumulate 10 to 30 times more in fatty tissues than lindane (Heeschen 1980). Although technical HCH is mainly composed of α HCH (65-70 %), β HCH (7-10 %), γ HCH (14-15%) and δ HCH (approximately 7 %), the Σ HCH was dominated completely by β HCH. The strong persistency of β HCH can be attributed to its slow rate of degradation in contrast to other isomers (WHO 1992).

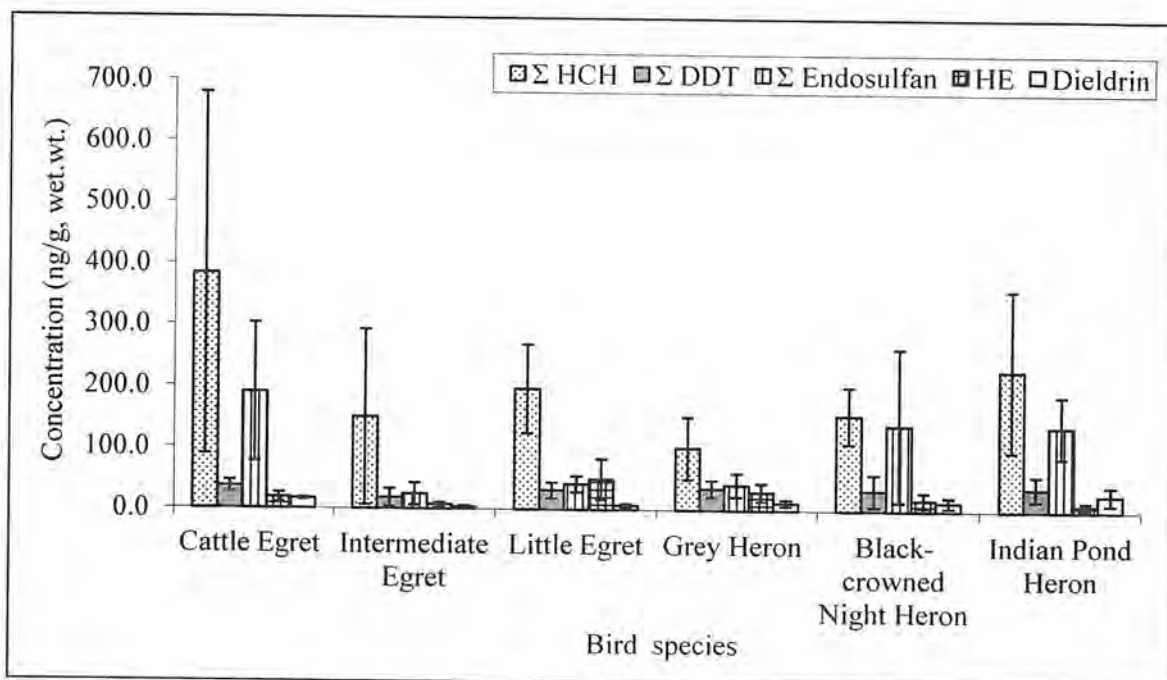


Figure 33. Organochlorine pesticide residues (Mean $\pm$ SE) in herons and egrets collected from the study sites during 2008-2010

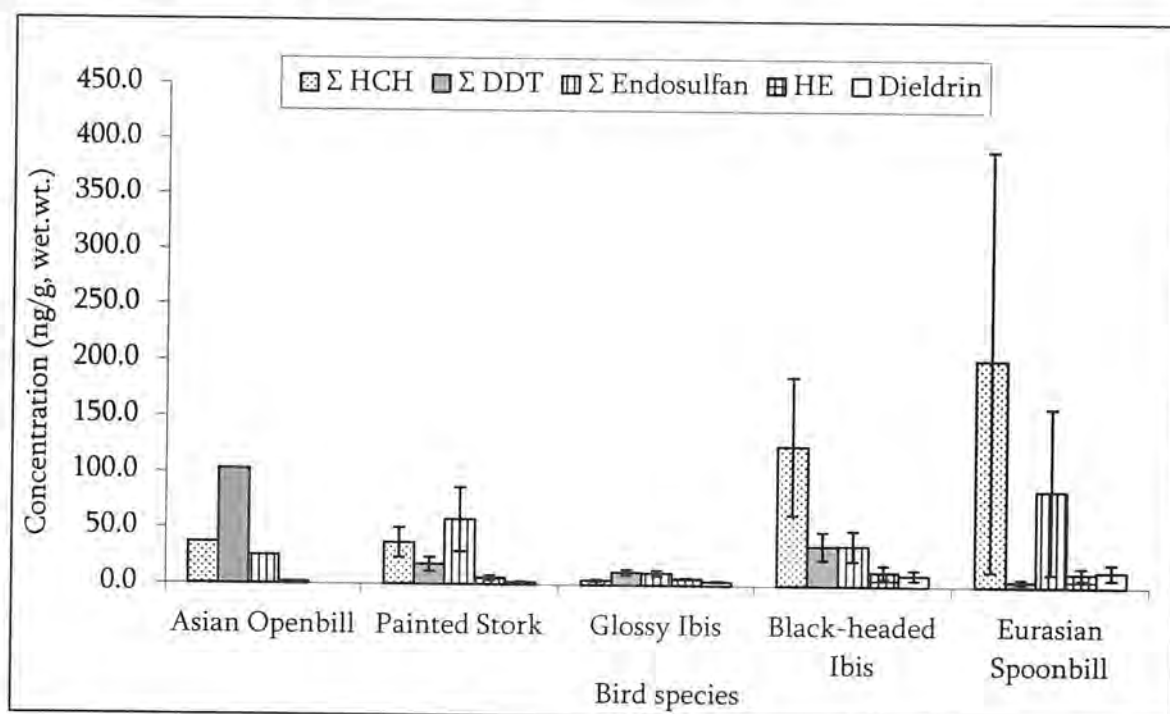


Figure 34. Organochlorine pesticide residues (Mean $\pm$ SE) in storks, ibises and spoonbill collected from the study sites during 2008-2010

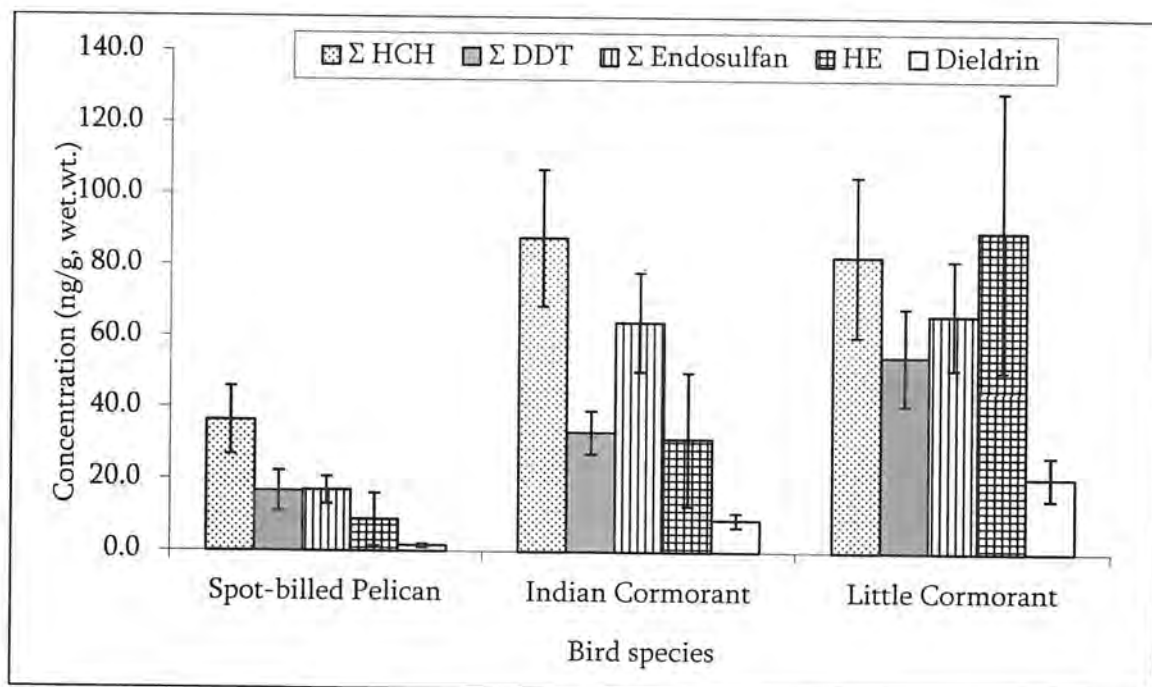


Figure 35. Organochlorine pesticide residues (Mean $\pm$ SE) in pelican and cormorants collected from the study sites during 2008-2010

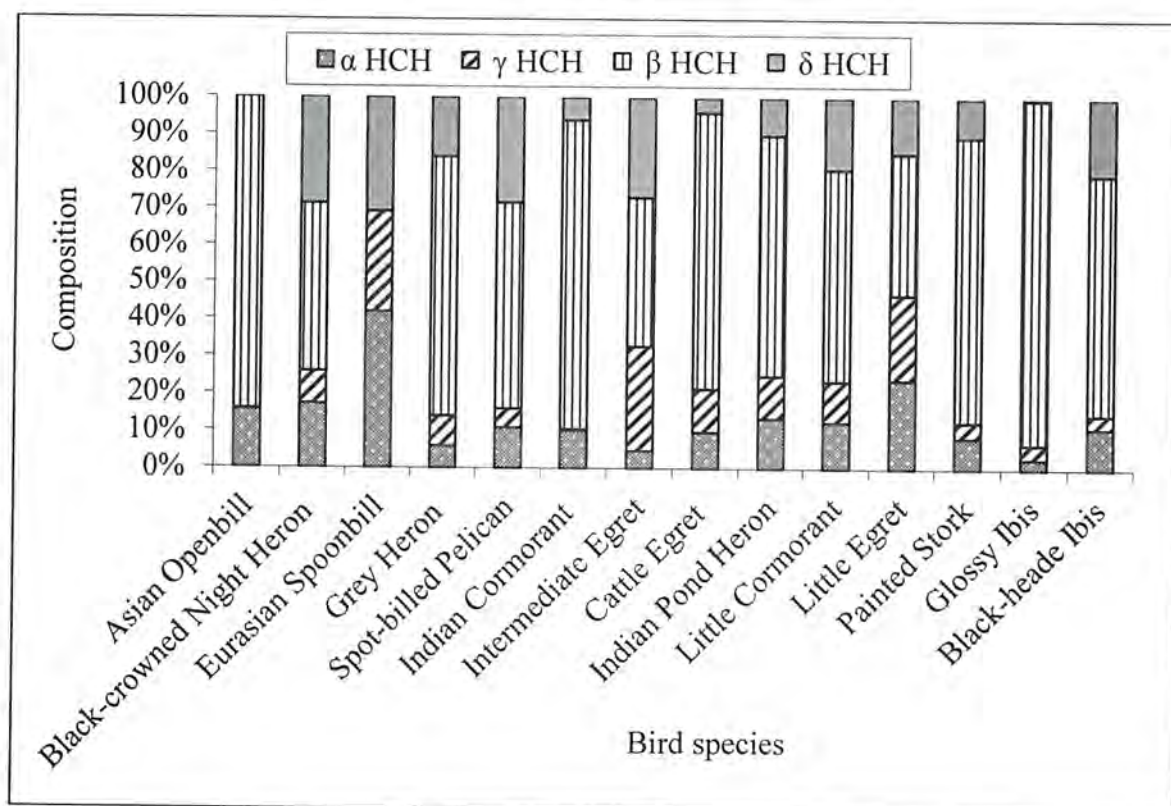


Figure 36. Percentage composition of HCH isomers in the birds collected from study sites

The toxicity of lindane to birds was demonstrated in Canada when nearly half of a flock of domestic pigeons died several days after receiving a diet (seeds) that was inadvertently contaminated with very high levels of lindane (2100 mg/kg) (Blakely 1982). The birds included in this current study had less than those levels reported in the study sites above. However, great variation in sensitivity of species to contaminants is known to exist.

b) DDT and its metabolites

Maximum load of $\sum$ DDT was recorded in Asian Openbill (102.8 ± 0 ng/g) followed by Little Cormorant (54.7 ± 13.7 ng/g). Of the various metabolites detected, p, p' DDE was the highest in concentration and it ranged from BDL to 80.0 ng/g among the species of birds studied. $\sum$ DDT concentration was around 35 ng/g in Asian Openbill, Grey Heron, Indian Pond Heron, Little Cormorant and Black-headed Ibis (figure 33-35). Among the metabolites, p,p' DDE contributed more than 50% to the $\sum$ DDT, whereas p,p' DDD contributed the least (figure 37). Levels of $\sum$ DDT in birds showed variation, but not significant (ANOVA $F=1.084$; $df=12$; $P>0.05$). $\sum$ DDT levels recorded in the birds included in the present study are lower than the earlier study in resident and migratory birds (DDTs 0.3 to 3,660 ng/g) from South India (Tanabe *et al.*, 1998).

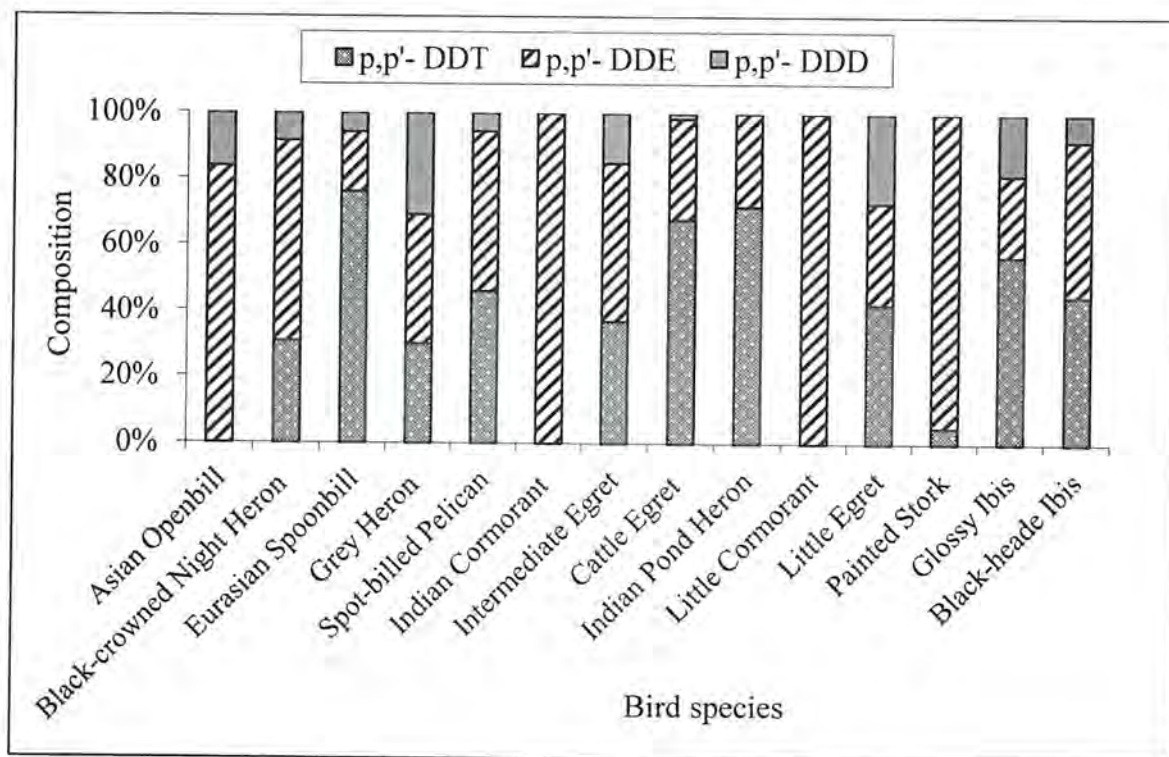


Figure 37. Percentage composition of DDT metabolites in the birds collected from study sites

Studies have demonstrated behavioral effects due to DDE in Ring Doves *Streptopelia risoria* (Haeghele and Hudson, 1977). Courtship behavior was shown to be affected by 10 µg/g DDE in the diet administered over a period of 63 days. Further this also leads to accumulation of DDE in the brain. It was also reported that a steep decline in number of birds was observed after single DDT treatment in areas compared to unsprayed areas (Douthwaite 1992). As no mortality of birds was reported in the treated areas, it could be interpreted that the birds avoided the area. The Σ DDT levels detected in brain samples of colonial nesting birds in the present study are lower than the concentration reported to cause courtship behavior. Further it is also lower than the concentration (> 30 µg/g) reported to be lethal to birds (Stickel and Stickel 1969). In experimental studies, DDE levels in brain tissue of birds those associated with mortality were found in the range of 200 - 500 µg/g (Blus 1996).

Total DDT concentrations recorded in birds in the present study are lower than the concentration reported in Large Cormorant (0.04 to 43.35 µg/g), Little Egret (0.11 to 99.5 µg/g), Cattle Egret (0.007 to 0.4 µg/g) and Indian Pond Heron (0.006 - 4.47 µg/g) collected from Nilgiri, Tamil Nadu (Vijayan and Muralidharan 1999) and in resident and migratory birds (0.3 to 3,660 ng/g) from India and Vietnam (Tanabe *et al.*, 1998; Kunisue *et al.*, 2003; Senthilkumar *et al.*, 2005 and Dhananjayan 2009). An earlier study on organochlorine residues in some Indian birds by Kaphalia *et al.* (1981) showed that the mean concentrations of p,p' DDE, p,p' DDT in brain tissues of Cattle Egret were 0.028 and 4.976 µg/g respectively which are lesser than the concentration recorded in the current study. Recent studies on fishes, soil and water collected from various locations in Indian regions have revealed varying concentrations of DDT and its derivatives, suggesting continued entry of DDT into the environment (Shankar *et al.*, 2006; Sumbramanian and Tanabe 2007; Muralidharan *et al.*, 2008; Dhananjayan and Muralidharan 2010 and Dhananjayan *et al.*, 2010). As referred earlier in the thesis, India banned DDT for agricultural use in 1989, but it is still being used for malaria control.

a) Cyclodiene insecticides

Among the cyclodiene group of pesticides tested, Endosulfan showed higher accumulation than Heptachlor Epoxide and Dieldrin. Cyclodiene insecticide residues were higher in many species of birds, namely Cattle Egret, Little Egret, Indian Pond

Heron and Little Cormorant. Dieldrin was above 20 ng/g in Indian Pond Heron and Little Cormorant currently studied (figure 33-35). Σ Endosulfan contributed more than 50% to total cyclodiene insecticides, whereas Dieldrin contributed the least (figure 38). Significant differences were observed for Endosulfan (ANOVA $F=1.811$; $df=12$; $P<0.05$) and dieldrin (ANOVA $F=2.301$; $df=12$; $P<0.05$) residues among the various species of birds. Level of cyclodiene insecticides recorded in various species of herons, egrets, cormorant and pelicans in the present study are comparable with the levels in birds belonging to the same family of birds (Sakellarides *et al.*, 2006) in Greece.

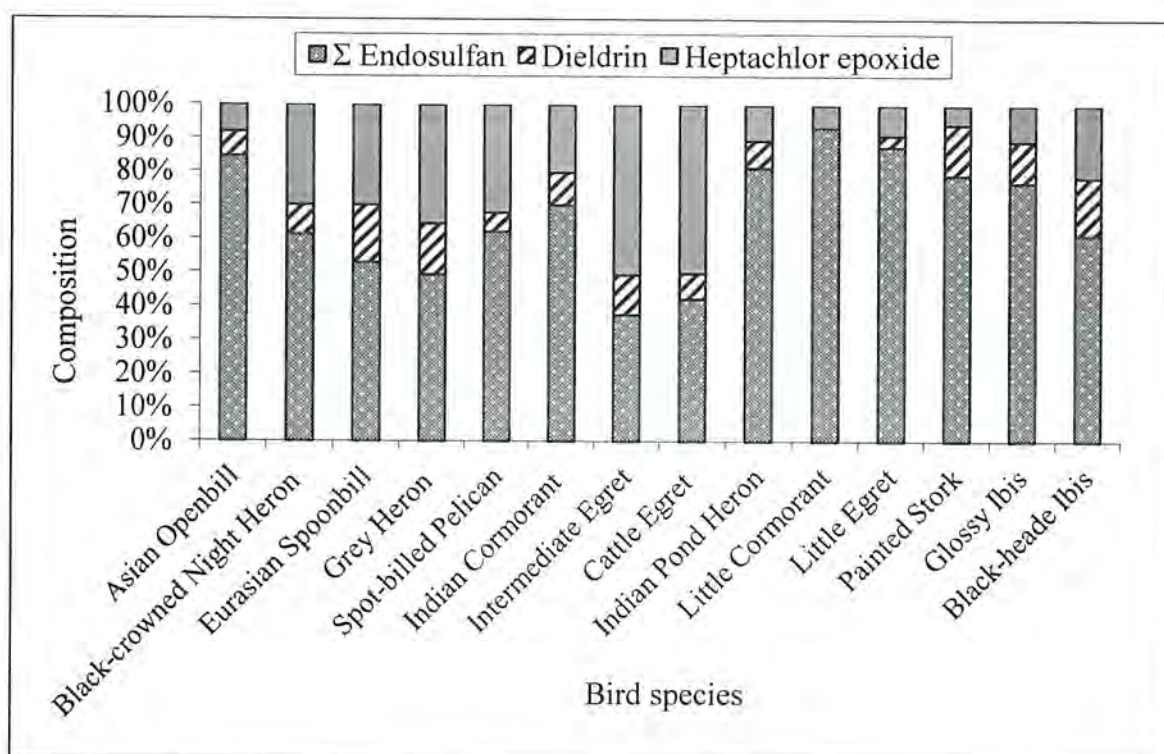


Figure 38. Percentage composition of cyclodiene residues in the birds collected from intensive study sites.

Vijayan and Muralidharan (1999) reported various cyclodiene insecticides in resident birds, namely Large Cormorant, Little Egret, Cattle Egret and Indian Pond Heron in Nilgiris. Average concentration of Endosulfan recorded in the birds in the present study is lower than the levels reported in Large Cormorant (2.74 - 33.98 $\mu\text{g/g}$), Little Egret (0.11- 63.9 $\mu\text{g/g}$), Cattle Egret (2.79 - 4.43 $\mu\text{g/g}$) and Indian Pond Heron (BDL - 8.87 $\mu\text{g/g}$). Similarly, concentrations of Heptachlor Epoxide (0.001-16.48 $\mu\text{g/g}$) and Dieldrin (BDL- 0.12 $\mu\text{g/g}$) recorded in birds are also lower than the levels reported in various bird species in Nilgiris.

Cyclodiene insecticide residue levels recorded in birds in the present study do not appear to pose any threat to birds when compared with published information (Rudd and Genelly 1956; Robinson *et al.*, 1967; Heinz and Johnson 1982; Tanabe *et al.*, 1998; Muralidharan 1993 and 2002; Muralidharan and Murugavel 2001; Senthilkumar *et al.*, 1999 and 2001; Muralidharan *et al.*, 2008; Dhananjayan and Muralidharan 2010 and Dhananjayan *et al.*, 2010). Dieldrin, one of the highly toxic OC pesticides, was the least detected among the cyclodiene pesticides in the present investigation. Dieldrin has been labeled as a commonly detected environmental contaminant, due to its stability (Santerre *et al.*, 1997). Dieldrin residue levels associated with mortality in birds are reported to be 5-10 µg/g in the brain (Rudd and Genelly 1956; Robinson *et al.*, 1967; Heinz and Johnson 1982; and Peakall 1996). Aldrin in the gastrointestinal tract (89.75 µg/g) and Dieldrin in the brain (4-5 µg/g) (after being metabolized from aldrin) was reported to be responsible for the death of many Sarus Cranes and granivores birds in Bharatpur in India (Muralidharan 1993). The residue levels in the current study are lower than the lethal level. However, continued exposure may cause ill effects (Rudd and Genelly 1956; Robinson *et al.*, 1967; and, Heinz and Johnson 1982).

Environmental contamination by Dieldrin might be mainly from the agricultural use of Aldrin years back and to a lesser extent from the use of Dieldrin itself. Many species of birds had died as a result of eating food contaminated with Aldrin and Dieldrin (Fuchs 1967; Reichel *et al.*, 1974; Jones *et al.*, 1978; Newton *et al.*, 1991 and Muralidharan, 1993). It was reported that about 1 µg/g or more of Dieldrin in the brain on a wet weight basis may pose hazard to many species of birds (Heinz and Johnson 1982). Behavioral disturbances were observed in Bobwhite Quail with 4 µg/g of Dieldrin in Brain (Peakall, 1985). Most of the birds studied showed comparatively less Dieldrin burden and are well below the levels expected to create harmful effects to avian population (Heinz and Johnson 1981). However, it may be noted that the Long and Margan “Effects Range-Low” (ER-L) value (i.e., the contamination level above which adverse biological effects are occasionally observed), is listed as 0.02 µg/kg for dieldrin (Long *et al.*, 1995). Heptachlor is readily metabolized to Heptachlor Epoxide, which is lipid soluble and readily stored in body fat (Burrage and Saha 1972). Heptachlor Epoxide is reported to pose greater risks to birds if residues levels exceed 4 µg/g in their brain (Blus *et al.*, 1984; and, Peakall 1996). Residues of Heptachlor Epoxide in many of the individuals included in the present study are lesser than the reported risk levels.

Although the toxic effects of Endosulfan in birds are not extensively documented, studies have indicated that young birds are more sensitive than adults (DeWitt 1963 and Hudson *et al.*, 1972). The lowest reported dietary toxicity of Endosulfan is 805 $\mu\text{g/g}$ to birds (Hill *et al.*, 1975). However, the experimental study by Henny *et al.* (1983) concluded that residues greater than 1.5 $\mu\text{g/g}$ were most definitely associated with decreased reproduction rates in avian species. Heptachlor is readily metabolized to Heptachlor Epoxide, which is lipid soluble and readily stored in body fat (Burrage and Saha 1972). Residues of Heptachlor Epoxide in many of the individuals in the present study are to be viewed with concern as Heptachlor Epoxide seems to pose a greater risk to birds if the residues levels exceed 1 $\mu\text{g/g}$ (Blus *et al.*, 1984).

Variations in OCP residues among the organs and different species of birds clearly indicate the difference in accumulation capacity among the species. Among the various tissues, the maximum load was observed in liver in all the species of birds studied. This is due to the high lipid content in liver and hydrophobic nature of OCs (Mackay *et al.*, 1999). Moreover, the presence of persistent pesticide residues in liver and brain of birds also indicates that they are still being introduced in to the higher levels of the food chain (Krol *et al.*, 2002).

5.4.2.4. Variation in OCP residues among locations and tissues

Comparison of OCP residues among the locations is presented in figure 39. For this purpose, residue levels in all the species of birds with respect to locations were pooled. Residues of all the pesticides tested showed higher level of accumulation in the birds of Vedanthangal than those in Koonthankulam and Vettangudi Bird Sanctuaries. However, it was not significant (ANOVA $F=2.346$; $df=2$; $P>0.05$). Σ DDT and Heptachlor Epoxide and Dieldrin residues showed significant variation ($P<0.05$). The levels of HCH recorded in various tissues of birds were almost similar in all the locations (figure 39). The higher load of OCP accumulation in birds of Vedanthangal can be explained by intensive agricultural activities in the vicinity or catchment areas now and also in the past with high chemical inputs. Although there are no industrial discharges into the Sanctuaries studied, there is considerable agricultural drainage from nearby agricultural lands. Moreover birds do visit adjoining agricultural fields to meet their requirements.

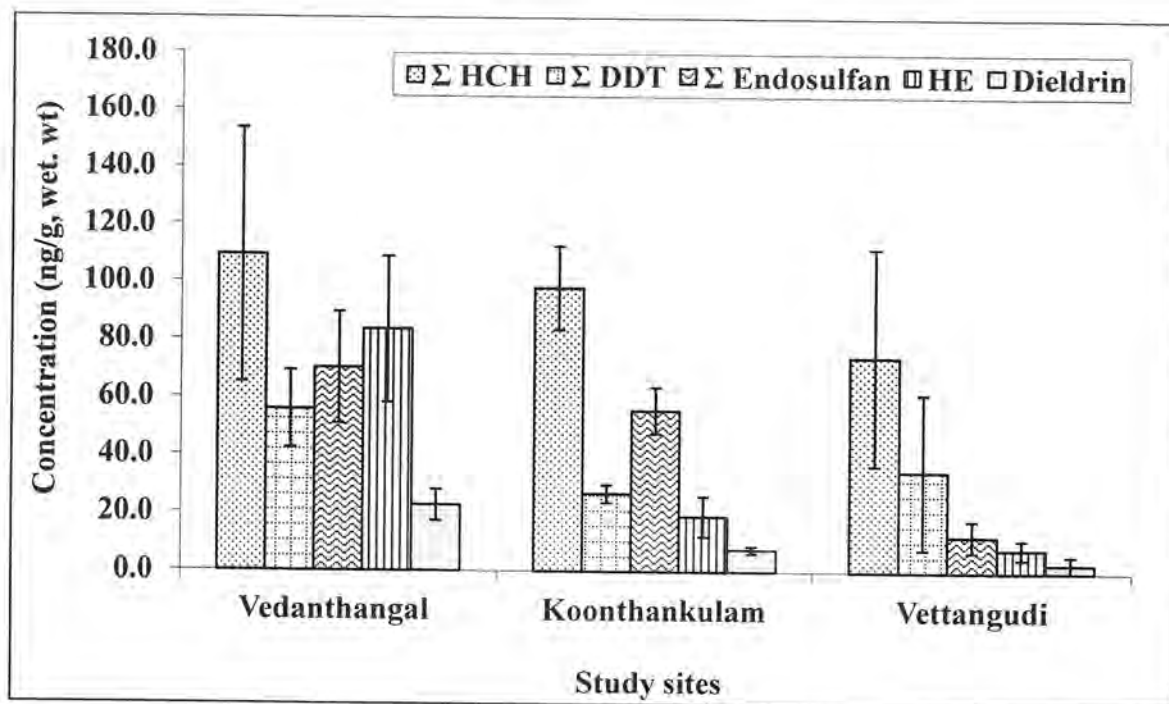


Figure 39. Variation in organochlorine pesticide residues (Mean $\pm$ SE) in birds among the study sites

Although present levels of OCP residues in birds mostly correspond to their agricultural use in the past, concern on current inputs should also persist. The present research is the maiden one which determined the levels of OC pesticide residues in birds in three different Sanctuaries in Tamil Nadu. While, all the wild birds are exposed to pollutants in their habitats, top consumers of aquatic environments such as the colonial nesting birds are specially affected (Hela *et al.*, 2006 and Sakellarides *et al.*, 2006). Level of Σ HCH recorded in the colonial nesting birds in the present study are higher than the levels (47 ng/g dw) reported in Great Cormorant *Phalacrocorax carbo sinensis* in the Axios and Evros Deltas, Messolonghi Lagoon, and Amvrakikos Gulf (Goutner *et al.*, 2011).

Significant difference was observed among tissues in their residue loads. Maximum was observed in liver than other tissues in all the species of birds studied. This is due to high lipid content and hydrophobic nature of OCs (Mackay *et al.*, 1999). However, the differences observed in OCs among the tissues are due to combination of tissue specific retention and solubility in lipids. Changes in feeding behavior of birds can also bring in differences in OCP concentrations among tissues. It was reported that birds readily biotransform both α and γ HCH (Moisey *et al.*, 2001).

Overall, contamination in birds of Vedanthangal, Koonthankulam and Vettangudi Bird Sanctuaries appeared to be within sub-lethal ranges. Sub-lethal physiologic response may occur at some of the concentrations observed in this study but applicable threshold values were lacking in the literature. Significant relationship was observed among residues of different pesticides in birds from all the three study sites. This is due to one set of chemicals can enhance the accumulation of another set. This was demonstrated in dietary dosage study on accumulation of lindane and enhanced storage of DDT (Ritchey *et al.*, 1967) in chicken tissues. The data suggest that the increased concentration of some OCs during recent years, particularly in colonial nesting birds may be an important factor in the accumulation of pesticides.

DDT and HCH, the two OC insecticides are of primary concern, because of their use for agriculture and public health purposes respectively in India. No historical data on OC pesticide residues in colonial nesting birds are available in India. Although the varying levels of DDT, HCH, Endosulfan and Dieldrin residues among other organochlorines detected in various species of birds in the current investigation are indicative of food chain accumulation, they do not appear to be responsible for any population decline in any of the species in the study sites. Hence, monitoring on the use, accumulation and effects of some potentially dangerous pesticides in the protected areas is recommended. Another important gap is the lack of information on integrated approach evaluating direct and indirect effects on wildlife on the use of pesticides.

5.4.3. Organochlorine pesticide residues in eggs of colonial nesting birds

Totally 97 eggs comprising 12 species of birds collected from three study sites (table 36) between 2008 and 2010 were analyzed for organochlorine residues.

Table 36. Details of eggs of colonial nesting birds collected from the study sites in Tamil Nadu (2008-2010)

S. No.	Name of the Bird	Scientific Name	No. of eggs collected			Total
			Vedanthalangal	Koonthankulam	Vettangudi	
1	Spot-billed Pelican	<i>Pelicanus philippensis</i>	-	11	-	11
2	Little Cormorant	<i>Phalacrocorax niger</i>	3	-	1	4
3	Indian Cormorant	<i>Phalacrocorax fuscicollis</i>	-	4	-	4
4	Black-crowned Night Heron	<i>Nycticorax nycticorax</i>	5	-	-	5
5	Grey Heron	<i>Ardea cinerea</i>	5	-	-	5
6	Indian Pond Heron	<i>Ardeola grayii</i>	-	1	-	1
7	Little Egret	<i>Egretta garzetta</i>	-	4	-	4
8	Intermediate Egret	<i>Mesophoyx intermedia</i>	-	1	2	3
9	Asian Openbill	<i>Anastomus oscitans</i>	8	3	8	19
10	Painted Stork	<i>Mycteria leucocephala</i>	7	17	-	24
11	Black-headed Ibis	<i>Threskiornis melanoleuca</i>	6	9	-	15
12	Eurasian Spoonbill	<i>Platalea leucorodia</i>	-	2	-	2
Total			34	52	11	97

- Not collected

5.4.3.1 Organochlorine pesticide residues in eggs of birds from Vedanthangal Bird Sanctuary

A total of 34 eggs comprising six species of birds, namely Asian Openbill, Black-crowned Night Heron, Grey Heron, Little Cormorant, Painted Stork and Black-headed Ibis were collected and analyzed for pesticide residues. Among various OC residues analyzed, Σ HCH was the highest in concentration followed by Σ DDT and Σ Endosulfan. Total HCH in eggs ranged between 1.39 ng/g in Painted Stork and 241.58 ng/g in Asian Openbill. Total DDT, Σ Endosulfan and Σ Heptachlor ranged from BDL to 228.89 ng/g, BDL to 48.21 ng/g and BDL to 8.95 ng/g respectively. Residues of Dieldrin was the maximum (5.96 ng/g) in the eggs of Asian Openbill while it was below detection limit in Grey Heron. p,p' DDE, one of the metabolites of DDT was frequently detected in most of the eggs and it ranged between BDL in Black-headed Ibis and 228.06 ng/g in Painted Stork. On the whole, the highest level of organochlorine pesticide residues was detected in the eggs of Grey Heron followed by Little Cormorant, while eggs of Black-crowned Night Heron had the lowest (table 37).

5.4.3.2. Organochlorine pesticide residues in eggs of birds from Koonthankulam Bird Sanctuary

Fifty two eggs comprising nine species of birds as listed in table 36 were analyzed for pesticide residues. Among various OC pesticide residues analyzed, Σ HCH was the highest in concentration. It ranged between BDL in the eggs of Asian Openbill and 67.11 ng/g in Painted Stork. Σ Endosulfan, Σ DDT and Heptachlor ranged from BDL to 15.10 ng/g, BDL to 40.17 ng/g and BDL to 5.84 ng/g respectively. Dieldrin and p,p' DDE ranged between BDL to 19.03 ng/g and BDL to 34.17 ng/g respectively. On the whole the highest levels of OC pesticide residues were detected in the eggs of Intermediate Egret, while eggs of Eurasian Spoonbill had the lowest levels (table 38).

5.4.3.3. Organochlorine pesticide residues in eggs of birds from Vettangudi Bird Sanctuary

Eleven eggs comprising three species of birds, namely Asian Openbill, Intermediate Egret and Little Cormorant were analyzed for pesticide residues, and levels are presented in table 39. Among the OCP residues analyzed, Σ HCH was the highest in concentration and it ranged between BDL in Asian Openbill and 695.68 ng/g in Little Cormorant. Σ DDT,

Σ Endosulfan and Σ Heptachlor ranged from 2.32 to 220.15 ng/g, BDL to 84.36 ng/g and BDL to 36.45 ng/g respectively. Comparatively low levels of Dieldrin were recorded in the eggs of all the three species of birds. p,p' DDE, the most stable metabolite of DDT, ranged between BDL in the eggs of Asian Openbill and 158.07 ng/g in Intermediate Egret.

5.4.3.4. Variation in OCP residues in eggs among species

To understand the variation in contamination among the species, the data were pooled, species wise irrespective of sites. Levels of Σ HCH, Heptachlor Epoxide and Σ DDT varied significantly ($P < 0.05$) in the eggs of birds studied. Dieldrin and p,p' DDE did not vary in their residue levels significantly ($P > 0.05$) among species. On the whole, the level of Σ OC residues in the eggs of Little Cormorant, Intermediate Egret and Grey Heron were significantly higher than other species of birds. In India there have been studies carried out in birds and their eggs for contaminants (Regupatthy and Kuttalam 1990; Muralidharan *et al.*, 1992 and Ranapratap, 2004). The present study is the first to use eggs of colonial nesting birds to assess the impact of pesticides on colonial nesting birds in Vedanthangal, Koonthankulam and Vettangudi Bird Sanctuaries in Tamil Nadu.

Table 37. Mean organochlorine pesticide residues (ng/g, wet wt.) in the eggs of birds collected from Vedanthangal Birds Sanctuary, (Range in parentheses)

S. No.	Name of the Bird	N	Organochlorine pesticide residues					
			p,p' DDE	Σ DDT	Σ HCH	HE	Σ Endosulfan	Dieldrin
1	Asian Openbill	8	4.47 (BDL-10.77)	7.94 (BDL-20.42)	53.48 (7.87-241.58)	0.43 (BDL-1.92)	4.33 (1.38-10.60)	1.16 (BDL-5.96)
2	Black-crowned Night Heron	5	0.86 (BDL-1.32)	1.50 (BDL-2.11)	26.80 (4.00-57.42)	BDL	3.63 (BDL-9.59)	0.92 (BDL-4.60)
3	Grey Heron	5	2.11 (BDL-5.38)	10.12 (4.27-19.64)	81.47 (4.16-205.96)	0.14 (BDL-0.69)	11.90 (BDL-48.21)	(BDL)
4	Little Cormorant	3	3.18 (BDL-7.79)	7.44 (1.77-13.68)	53.16 (10.86-126.09)	0.38 (BDL-1.13)	5.66 (1.29-8.07)	0.83 (BDL-1.47)
5	Painted Stork	7	34.56 (BDL-228.06)	36.11 (BDL-228.89)	41.85 (1.39-162.68)	0.78 (BDL-3.65)	2.61 (1.27-4.23)	0.71 (BDL- 2.43)
6	Black-headed Ibis	6	13.30 (BDL-72.74)	14.06 (BDL-72.74)	51.73 (2.35-189.33)	1.49 (BDL-8.95)	5.69 (BDL- 22.97)	0.39 (BDL-1.57)
Total		34						

BDL - Below Detection Limit

Table 38. Mean organochlorine pesticide residues (ng/g, wet wt.) in the eggs of birds collected from Koonthankulam Birds Sanctuary, (Range in parentheses)

S. No.	Name of the Bird	N	Organochlorine pesticide residues				
			p,p' DDE	Σ DDT	Σ HCH	HE	Σ Endosulfan
1	Asian Openbill	3	5.38 (BDL-11.73)	8.97 (3.42-15.83)	11.75 (BDL-22.36)	2.33 (BDL-5.24)	3.78 (1.54-6.95)
2	Eurasian Spoonbill	2	0.72 (BDL-1.45)	4.18 (3.70-4.65)	6.34 (3.61-9.08)	BDL	1.29 (BDL-1.66)
3	Spot-billed Pelican	11	4.23 (BDL-34.17)	8.05 (1.60-40.17)	17.88 (2.67-58.01)	0.61 (BDL-5.84)	2.17 (BDL-4.70)
4	Indian Cormorant	4	4.89 (BDL-16.60)	5.50 (BDL-16.60)	26.81 (8.37-63.83)	BDL	1.47 (BDL-2.29)
5	Intermediate Egret	1	BDL	3.31	63.20	BDL	BDL
6	Indian Pond Heron	1	4.93	9.08	9.25	1.11	2.56
7	Little Egret	4	2.24 (BDL-4.84)	2.95 (1.37-6.47)	19.40 (3.33-31.82)	BDL	5.13 (1.30-15.10)
8	Painted Stork	17	4.09 (BDL-26.21)	6.06 (BDL-27.15)	20.97 (BDL-67.11)	0.22 (BDL-1.94)	2.19 (BDL-5.83)
9	Black-headed Ibis	9	2.24 (BDL-14.24)	2.88 (BDL-14.24)	12.76 (3.92-26.59)	0.24 (BDL-1.23)	3.33 (1.25-13.65)
Total		52					

BDL - Below Detection Limit

Table 39. Mean organochlorine pesticide residues (ng/g, wet wt.) in the eggs of birds collected from Vettangudi Birds Sanctuary, (Range in parentheses)

S. No	Name of the Birds	N	Organochlorine pesticide residues					
			p,p' DDE	Σ DDT	Σ HCH	HE	Σ Endosulfan	Dieldrin
1	Asian Openbill	8	2.50 (BDL-15.65)	6.20 (2.32-22.13)	51.70 (BDL-212.19)	0.20 (BDL-1.03)	3.51 (BDL-8.87)	3.33 (BDL-23.00)
2	Intermediate Egret	2	87.08 (16.10-158.07)	137.75 (55.35-220.15)	132.44 (36.22-228.67)	21.86 (7.27-36.45)	44.98 (5.60-84.36)	4.01 (3.62-4.41)
3	Little Cormorant	1	BDL	32.50	695.68	5.03	28.56	BDL
Total		11						

BDL - Below Detection Limit

The chemical pesticides considered in this study are toxic, persistent, and they biomagnify in lipid-rich tissues throughout the food chain (Moriarty 1990 and Furness 1993). Furthermore, they can negatively influence the birds' health, survival and reproduction (Ohlendorf *et al.*, 1978; Scheuhammer 1987; Walker 1994 and Grassman *et al.*, 1998). In order to estimate the potential risk for birds, the threshold levels known and available in the literature were considered carefully, although threshold levels vary among chemical compounds, bird species, and other environmental factors. Additionally, low concentrations of individual toxicants could damage organisms by possible interactions and synergistic effects (Wachs 1994 and Busch 1996).

a) HCH and its isomers

The variation in HCH levels in eggs of birds was highly significant (ANOVA $F= 2.367$; $df= 11$; $P< 0.05$). Σ HCH level was the highest and it ranged between 9.25 ng/g in the eggs of Indian Pond Heron and 214 ng/g in eggs of Little Cormorant. Eggs of four species of birds, namely Grey Heron, Asian Openbill, Intermediate Egret and Little Cormorant exceeded 40 ng/g (table 40). Among the isomers, β HCH was the highest in almost all the birds studied and it constituted more than 65% of the Σ HCH, while δ HCH made the least contribution (figure 40).

The presence of β HCH and lindane may indicate its recent use in this region. Lindane is moderately harmful to birds, in contrast to Heptachlor and especially its metabolite Heptachlor Epoxide which is lethal for birds in concentration $\geq 9 \mu\text{g/g}$ (Blus *et al.*, 1985). Although use of HCH in agriculture has been banned, it was used on many crops including paddy and pulse until 2012 (<http://cibrc.nic.in/> retrieved on 17th April 2013).

Table 40. Mean organochlorine pesticides residues (ng/g, wet. wt. mean $\pm$ SE) in the eggs of select species of colonial water birds in the study sites (irrespective of location)

S. No.	Name of the Birds	Organochlorine pesticides						
		N	p,p' DDE	Σ DDT	Σ HCH	HE	Σ Endosulfan	Dieldrin
1	Asian Openbill	19	3.79 $\pm$ 1.15	7.37 $\pm$ 1.46	46.1 $\pm$ 15.7	BDL	3.90 $\pm$ 0.77	1.95 $\pm$ 1.21
2	Black-crowned Night Heron	5	BDL	1.50 $\pm$ 0.26	26.8 $\pm$ 9.17	BDL	3.63 $\pm$ 1.57	BDL
3	Eurasian Spoonbill	2	BDL	4.18 $\pm$ 0.48	6.34 $\pm$ 2.74	BDL	1.29 $\pm$ 0.37	BDL
4	Grey Heron	5	2.52 $\pm$ 0.91	9.76 $\pm$ 2.39	68.0 $\pm$ 33.8	BDL	10.2 $\pm$ 7.67	BDL
5	Spot-billed Pelican	11	4.23 $\pm$ 3.03	8.05 $\pm$ 3.42	17.8 $\pm$ 4.80	BDL	2.17 $\pm$ 0.43	BDL
6	Indian Cormorant	4	4.89 $\pm$ 3.93	5.50 $\pm$ 3.72	26.8 $\pm$ 12.6	BDL	1.47 $\pm$ 0.35	BDL
7	Intermediate Egret	3	58.1 $\pm$ 50.2	92.9 $\pm$ 65.3	109 $\pm$ 60.2	14.6 $\pm$ 11.1	30.2 $\pm$ 27.1	2.68 $\pm$ 1.36
8	Indian Pond Heron	1	4.93 $\pm$ 0.00	9.08 $\pm$ 0.00	9.25 $\pm$ 0.00	1.11 $\pm$ 0.00	2.56 $\pm$ 0.00	1.57 $\pm$ 0.00
9	Little Cormorant	4	2.39 $\pm$ 1.85	13.7 $\pm$ 6.72	214 $\pm$ 163	1.54 $\pm$ 1.19	11.2 $\pm$ 5.93	BDL
10	Little Egret	4	2.24 $\pm$ 0.92	2.95 $\pm$ 1.18	19.4 $\pm$ 6.56	BDL	5.13 $\pm$ 3.34	BDL
11	Painted Stork	24	13.0 $\pm$ 9.43	14.8 $\pm$ 9.38	27.1 $\pm$ 7.25	BDL	2.31 $\pm$ 0.28	BDL
12	Black-headed Ibis	15	6.67 $\pm$ 4.81	7.36 $\pm$ 4.76	28.4 $\pm$ 11.1	BDL	4.27 $\pm$ 1.57	2.09 $\pm$ 1.23
ANOVA		97	P > 0.05	P < 0.05	P < 0.05	P < 0.05	P < 0.05	P > 0.05

HE-Heptochlor Epoxide; P>0.05 Not Significant; P<0.05 Significant

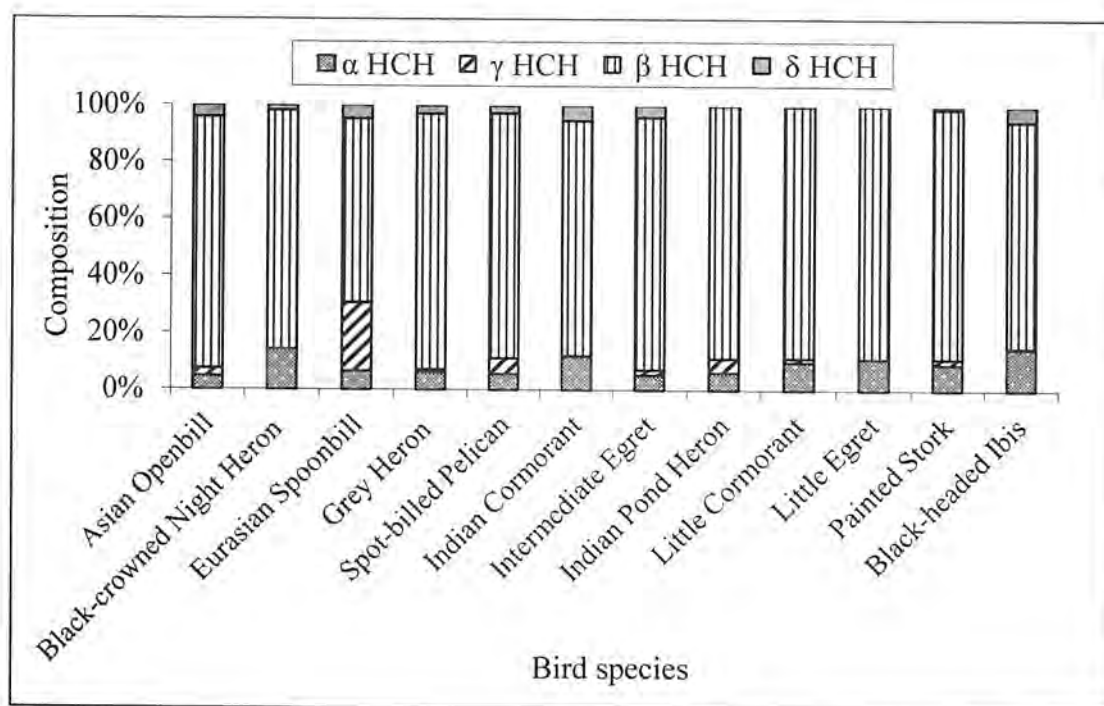


Figure 40. Percentage composition of HCH isomers in the eggs of birds collected from study sites

The level of HCH reported in the present study are lower than the levels (BDL - 0.86 $\mu\text{g/g}$) reported in the eggs of select colonial water birds in Keoladeo National Park, Bharatpur, India (Muralidharan *et al.*, 1992) and higher than the levels (220 ng/g) reported in a few species of colonial nesting birds in America and Japan (Somers *et al.*, 1993 and Senthilkumar *et al.*, 2005). Furthermore, the Σ HCH levels reported in the present study are comparable with the levels reported in Black-crowned Night Heron (Ohlendorf *et al.*, 1978). Bouwman *et al.* (2008), reported the level of Σ HCH in eggs of water birds, such as Cattle Egret (0.8 ng/g), Reed Cormorant (3.4 ng/g), Kelp Gull (1.3 ng/g), White-fronted Plover (1.7 ng/g), Crowned Plover (4.2 ng/g), Little Grebe (0.8 ng/g) and African Sacred Ibis (2.3 ng/g). The level of Σ HCH recorded in eggs of birds in the present study are higher than the levels reported in South Africa (Bouwman *et al.*, 2008).

Concentration of Σ HCH recorded in the eggs of colonial nesting birds is comparable with levels reported in Cattle Egret (38 ng/g) in Egypt (Mullie *et al.*, 1992), Grey Heron (92 ng/g) in France (De Cruz *et al.*, 1997), Black-headed Heron (100 ng/g) in Zimbabwe (Whitwell *et al.*, 1974), while the levels of Σ HCH recorded in the present study are lower than the levels reported in Shag (3000 ng/g) in Finmark, Norway (Barret *et al.*,

1996), Herring Gull (5100 ng/g) in Finmark, Norway (Barret *et al.*, 1996) and African Darter (99 ng/g) in South Africa (Bouwman *et al.*, 2008).

Pol *et al.* (2012) reported various organochlorine residues in eggs of endangered Brown Pelican in USA and Mexico. The levels of Σ HCH in eggs of Brown Pelican ranged from 0.5 to 36.7 ng/g. The level of Σ HCH in eggs of colonial nesting birds, namely Asian Openbill, Grey Heron, Little Cormorant, Painted Stork, Spot-billed Pelican, Intermediate Egret and Black-headed Ibis collected from three study sites are higher than the levels of Σ HCH reported in the studies cited above.

The most predominant occurrence of β HCH in eggs reflects its stable nature than the other isomers, namely α , γ and δ . Some of the eggs showed higher proportion of α and γ HCH suggesting recent exposure to technical HCH mixture (70% α , 15 % γ , 6% β and 9% δ HCH) used in India (Tanabe *et al.*, 1998). Similarly, Nygard (1999) noticed the presence of elevated proportion of p,p' DDE and β HCH in Merlin eggs in Norway. As reported by Goutner *et al.* (1997), lindane has not received much attention as far its effects on eggs of birds are concerned. Although varying levels of HCH and its isomers are recorded in many species of birds world over, their effects on reproductive success are not clear.

b) DDT and its metabolites

Inter specific differences in DDT levels were significant among all the species tested (ANOVA $F= 2.096$; $df= 11$; $P>0.05$). Intermediate Egret (92.9 ± 65.3) recorded the maximum concentration of Σ DDT followed by Painted Stork (14.8 ± 9.38 ng/g). The lowest level was detected in the eggs of the Black-crowned Night Heron (1.50 ± 0.26 ng/g). p,p' DDE ranged between 0.72 ng/g in Eurasian Spoonbill and 58.1 ng/g in Intermediate Egret. Of all the DDT metabolites, p,p' DDE was present at the highest concentration and contributed more than 50% to the total DDT, while p,p' DDD made the least contribution. Among all the birds, the highest concentration of p,p' DDE was recorded in Painted Stork and Black-headed Ibis (figure 41).

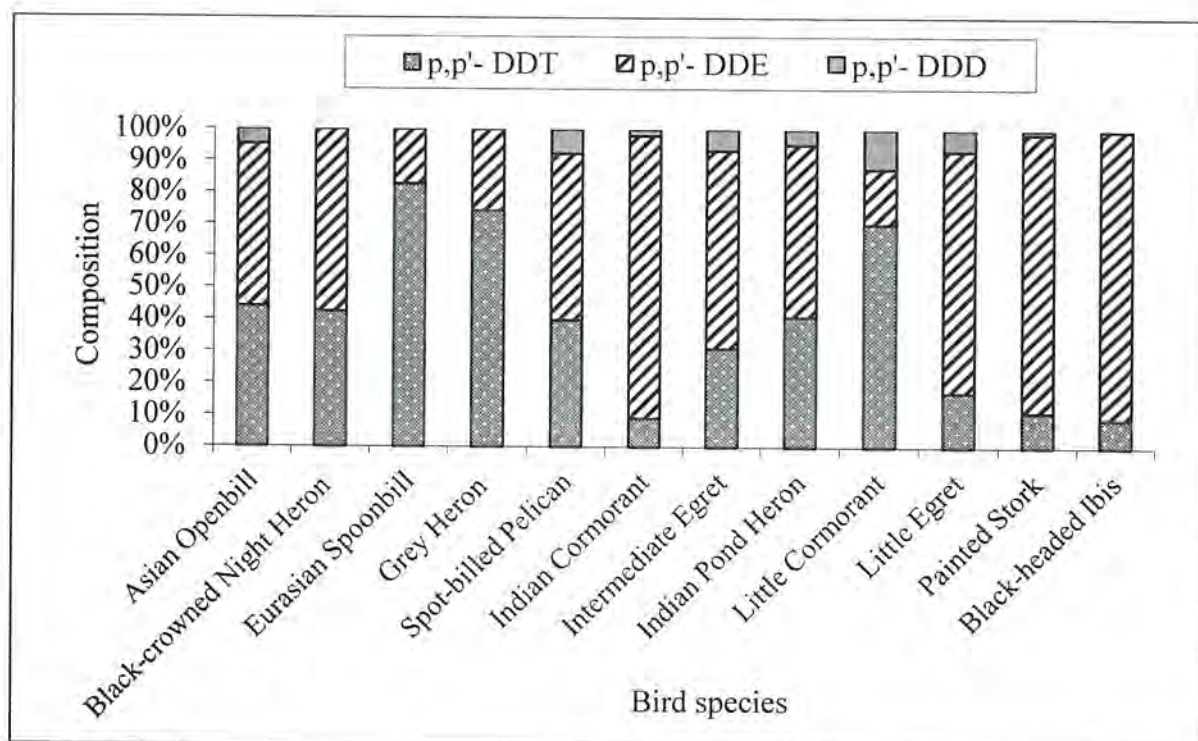


Figure 41. Percentage composition of DDT metabolites in the eggs of birds collected from study sites

Many studies have reported association between high concentration of DDT (between 500 ng/g and 6000 ng/g) specifically p,p' DDE in bird eggs and impaired reproduction (Castillo *et al.*, 1994) and eggshell thickness with organochlorine contaminants (Blus *et al.*, 1974 and Nygard 1999). The levels found in the present study are below the threshold levels (0.5 µg/g) (Fox 1976; Hall *et al.*, 1989 and Castillo *et al.*, 1994). Relatively, larger portion of p,p' DDE, which is the major constituent of the technical mixture of DDT suggests recent exposure of these species to DDT in the study sites. HCH and DDT have been reported as the predominant OC pesticides in resident and local migratory birds in South India (Tanabe *et al.*, 1998) which is quite similar to the levels reported in the eggs of birds from other countries (Custer *et al.*, 1999 and Nygard 1999). Concentration of p,p' DDE residues in eggs of Little Egret studied currently are lower than the level of p,p' DDE (33.4 to 116. 0 ng/g) in yolk of the same species reported from Thailand by Keithmaleesatti *et al.* (2007).

Frequency of occurrence of p,p' DDE was the highest (50%) of all the pesticides tested. This confirms the continued presence of DDE in the environment. This could be largely due to the chemical's persistence and also its use in malaria control. The relationship

between DDE concentration and eggshell thinning have been reported in many species of birds, namely Dalmatian Pelican *Pelicanus crispus* (6.91 µg/g; Crivelli *et al.*, 1989), Night Heron (3.3 µg/g; Fasola *et al.*, 1987) and Great-crested Grebe (10 µg/g; Galassi *et al.*, 2002). The concentrations recorded in the present study are lower than the DDE concentration (5.6 µg/g), which was responsible for 10.5% eggshell thinning in the eggs of Merlin in Norway. Regarding p,p' DDT and p,p' DDD the concentrations recorded in the present study were below the levels which created reproductive failure in wild birds (Fox, 1976; Hall *et al.*, 1989 and Castillo *et al.*, 1994) elsewhere.

Soon after the publication of the classic paper by Ratcliffe (1967) describing eggshell thinning in eggs of Peregrine falcon, Hickey and Anderson (1968) documented decreases in the mean eggshell thinning due to DDE residues in raptorial and colonial nesting birds. There are also a few experimental studies that reported eggshell thinning related to DDE residues in eggs (Wiemeyer and Porter 1970; Longcore *et al.*, 1971). Longcore *et al.*, (1971) reported 18% eggshell thinning in Black Duck when it was experimentally exposed to DDE that ranged from 34 to 63 µg/g wet wt. According to Wiemeyer and Porter (1970), the levels (4 to 44 µg/g wet wt) of DDE reduced 10% thickness in American Kestrel. However, in the present study, the levels of DDE are lower than the levels reported to cause eggshell thinning.

Bouwman *et al.* (2008), reported the level of Σ DDT in eggs of water birds, such as Cattle Egret (24 ng/g), Reed Cormorant (300 ng/g), Kelp Gull (88 ng/g), White-fronted Plover (43 ng/g), Crowned Plover (23 ng/g), Little Grebe (46 ng/g) and African Sacred Ibis (68 ng/g). Concentration of Σ DDT recorded in the eggs of colonial nesting birds in the current study are lower than levels reported in Cattle Egret (3200 ng/g) in Egypt (Mullie *et al.*, 1992), Grey Heron (470 ng/g) in France (De Cruz *et al.*, 1997), Black-headed Heron (5100 ng/g) in Zimbabwe (Whitwell *et al.*, 1974), Shag (180 ng/g) in Finmark, Norway (Barret *et al.*, 1996), Herring Gull (260 ng/g) in Finmark, Norway Barret *et al.* (1996), African Darter (3400 ng/g) in South Africa (Bouwman *et al.*, 2008) and in Brown Pelican (53-1210 ng/g) in USA and Mexico (Pol *et al.*, 2012).

The contamination status of the marine environment in Hong Kong was studied by measuring concentrations of DDT in the eggs of selected waterbirds, such as Little Egret, Chinese Pond Heron, Great Egret, Black-crowned Night Heron, and Chinese Pond Heron.

Concentration of Σ DDT ranged between 1270 - 5330 ng/g (Wang *et al.*, 2011). The levels reported in the current study are lower than these levels. In India, Tanabe *et al.* (1998) documented the contaminants in the eggs of inland and coastal fish-eating birds from South India. The study suggested that the Pond Heron is under risk due to DDT burdens. However, residues of DDT recorded in the same species from Koonthankulam Bird Sanctuary in the present study are lower.

The levels of DDE in the current study is lower than the levels reported to be associated with eggshell thinning (2-32 $\mu\text{g/g}$ wet wt) in many species of birds by various researchers (Cooke *et al.*, 1976; Henny *et al.*, 1985 and Fitzner *et al.*, 1988) in several countries. Although DDT is banned India, still environmental residue levels of its metabolites are at detectable levels. Level of DDE at 1973 $\mu\text{g/g}$ in an egg of Himalayan Grey-headed Fishing Eagle at Corbett National Park is an extreme example (Naoroji, 1997). Therefore, the continuous monitoring of DDE in eggs not only in colonial nesting birds but also other indicator species is very essential.

The levels of Σ DDT detected in the present study are lower than the levels (0.05-0.80 $\mu\text{g/g}$) reported in selected colonial water birds in Keoladeo National Park in Bharatpur, India (Muralidharan *et al.*, 1992) and also in Great Cormorants in Japan (Senthilkumar *et al.*, 2005). In contrast to many studies in various countries on the levels of DDE, in the egg of many species of birds, the levels reported in Indian birds are low. It may be noted that in India we do not have historic information on the eggshell thickness and residue levels of persistent pesticides. Hence, it is difficult to understand the trends.

c) Cyclodiene insecticides

Among the cyclodiene group of pesticides, concentration of Heptachlor Epoxide and Σ Endosulfan showed significant differences among species. Heptachlor Epoxide was the maximum in the eggs of Intermediate Egret (14.6 ± 11.1 ng/g) and below detection limit in Little Egret and Black-crowned Night Heron (BDL). The Σ Endosulfan in the eggs of Intermediate Egret, Little Cormorant and Grey Heron, was 30.2 ± 27.1 , 11.2 ± 5.93 ng/g and 10.2 ± 7.67 ng/g respectively. Dieldrin levels did not vary significantly among species ($P > 0.05$). The maximum concentration of Dieldrin was recorded in Intermediate Egret (2.68 ± 1.36 ng/g) (table 40). Among the cyclodiene insecticides, Σ Endosulfan

contributed more than 50% to the Σ cyclodiene insecticides, while Heptachlor Epoxide contributed the least (figure 42).

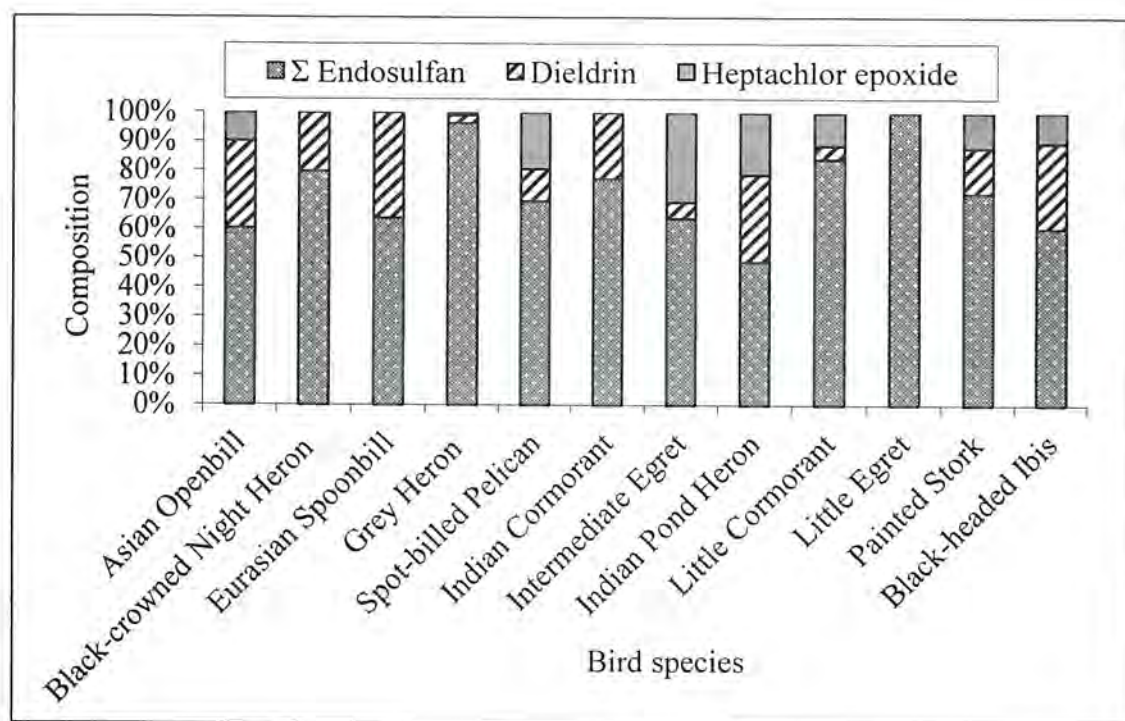


Figure 42. Percentage composition of cyclodiene residues in the eggs of birds collected from study sites (2008-10)

The levels of Dieldrin in the eggs of colonial nesting birds included in the current study are lower than levels (0.86 to 5.78 $\mu\text{g/g}$) reported in eggs of the select species of colonial water birds at Keoladeo National Park, Bharatpur, India (Muralidharan *et al.*, 1992). All the species in the present study recorded less than 1 $\mu\text{g/g}$ of Dieldrin, which is not expected to create any ill effects to the bird populations (Stickel 1973). King *et al.* (1978) while summarizing the effects of Dieldrin on various species of birds, reported considerable variation in the residues. They proposed that amounts greater than 1 $\mu\text{g/g}$ must be viewed as hazardous. Hence, Dieldrin levels found in this study are not expected to harm the birds. More over chances for fresh input of Aldrin and Dieldrin in to the environment is less. However it is necessary to keep track of the environmental residue levels.

5.4.3.5. Relation between eggshell thickness and organochlorine residues

Egg measurements and eggshell parameters of all the 12 species of birds are tabulated in table 41. The variation in eggshell thickness and shell index was significant among the species (ANOVA $F=13.417$; $df=11$; $P<0.05$). Quantitative relationship among organochlorine residue levels in various species of colonial nesting birds is described in a correlation matrix (table 42). Concentration of p,p' DDE in the eggs of many species of birds were negatively correlated with eggshell thickness, but not significant. Although, there was no strong correlation between other organochlorines and eggshell thickness, the negative influence on the eggshell thickness is evident.

Table 41. Eggshell measurement and eggshell parameters in various species of birds in the study sites in Tamil Nadu.

S.No.	Eggshell Parameters →		Shell Thickness (mm)		Shell Weight (mg)		Egg Length (mm)		Egg Breadth (mm)		Shell Index (mg/mm ²)	
	Species ↓		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1	Asian Open-bill Stork		0.35	0.02	367.41	31.46	58.03	1.39	40.61	0.78	0.15	0.01
2	Black-crowned Night Heron		0.20	0.00	213.47	43.39	48.13	0.56	34.58	0.10	0.13	0.03
3	Eurasian Spoonbill		0.37	0.02	331.70	5.10	66.35	0.05	38.85	2.05	0.13	0.01
4	Grey Heron		0.28	0.01	207.56	52.64	50.50	1.46	35.72	2.19	0.11	0.02
5	Spot-billed Pelican		0.48	0.03	978.44	44.86	76.81	0.89	52.11	0.45	0.24	0.01
6	Indian Shag		0.18	0.05	163.95	6.02	44.37	1.08	28.73	0.42	0.13	0.00
7	Median Egret		0.24	0.01	137.77	65.85	47.93	1.59	31.27	2.08	0.09	0.04
8	Indian Pond Heron		0.20	-	155.80	-	39.00	-	30.00	-	0.13	-
9	Little Cormorant		0.23	0.01	84.97	21.10	40.30	2.06	27.33	1.07	0.08	0.01
10	Little Egret		0.22	0.00	228.40	5.41	41.81	0.40	32.05	0.28	0.17	0.00
11	Painted Stork		0.44	0.02	715.46	30.16	67.46	0.55	46.45	0.32	0.23	0.01
12	Oriental White Ibis		0.32	0.03	511.09	17.08	64.82	0.61	42.59	0.41	0.19	0.00
ANOVA F			7.133		40.243		66.319		65.461		13.417	
			P<0.05		P<0.05		P<0.05		P<0.05		P<0.05	

- Not applicable; SE- Standard Error

Table 42. Correlation between eggshell thickness and organochlorine residues in the eggs of select species of colonial nesting birds collected from study sites (2008- 10)

S. No	Name of the Bird	N	Organochlorine Pesticide residues			
				p,p' DDE	Dieldrin	HE
1	Asian Openbill	19	r	-0.12	-0.16	0.09
			P value	0.61	0.53	0.70
2	Black-crowned Night Heron	5	r	-0.68	0.55	-
			P value	0.21	0.34	-
3	Grey Heron	5	r	-0.71	0.25	0.22
			P value	0.18	0.68	0.72
4	Grey Pelican	10	r	-0.20	-0.12	0.11
			P value	0.59	0.75	0.75
5	Indian Cormorant	4	r	-0.22	-0.48	-
			P value	0.78	0.52	-
6	Little Egret	4	r	-0.01	-	-
			P value	0.99	-	-
7	Painted Stork	22	r	-0.02	0.10	0.03
			P value	0.93	0.66	0.88
8	Black-headed Ibis	15	r	-0.24	0.07	0.25
			P value	0.39	0.79	0.37

HE- Heptachlor Epoxide; - Not tested; Not Significant ($P > 0.05$), Significant ($P < 0.05$)

Birds in experiments on dietary dosage of DDE laid eggs that had considerably thinner shell than did birds on clean diet without the compound (Wiemeyer and Porter 1970 and Longcore *et al.*, 1971). Various studies on DDE levels and their relation to eggshell thickness in wild birds indicated extreme inter-specific differences in sensitivity. Brown Pelican in California displayed 44% eggshell thinning when eggs contained 59 $\mu\text{g/g}$ (wet wt) of DDE (Risebrough 1972). American White Pelican, a fish-eating bird exhibited 15% reduction when eggs contained 2 $\mu\text{g/g}$ wet wt (Blus *et al.*, 1974). Great Blue Heron, Double-crested Cormorant, Snowy Egret, White-faced Ibis, Black-crowned Night Heron and Grey Heron displayed 10%, 11%, 12%, 12%, 9% and 12% eggshell thinning when eggs contained 4 $\mu\text{g/g}$, 32 $\mu\text{g/g}$, 2 $\mu\text{g/g}$, 2 $\mu\text{g/g}$, 4 $\mu\text{g/g}$ and 6 $\mu\text{g/g}$ respectively (Cooke *et al.*, 1976; Henny *et al.*, 1985 and Fitzner *et al.*, 1988). However, the levels of p,p' DDE recorded in the eggs of colonial nesting birds from the study sites are lower than the levels reported above.

Winn (1973) demonstrated the effect of Dieldrin on reproduction in Mallard through experimental studies. The result revealed that 4 µg/g of Dieldrin decreased 24% of eggshell thickness. He also reported that dosage of 4 - 10 µg/g and 4 - 30 µg/g caused impaired fertility and chick mortality respectively. However, it must be noted that it differed from the works reported by others. Lehner and Egbert (1969) reported a much smaller reduction in eggshell thickness of 4% with a dietary level of 10 µg/g of Dieldrin in pheasants (Dahlgren and Linder 1970) and Japanese Quail (Hill *et al.* 1975). These studies also did not record any significant thinning. The level of Dieldrin recorded in the eggs of birds in the present study is many folds lower than the levels discussed above.

Thinning eggshells are not the only risk associated with increased pollutant burden in birds. Subtle changes in behavior also have been seen and associated with pollution in many terrestrial birds. No such studies have been done on colonial nesters or fish-eating birds. Increased exposure can affect behavioural aspects such as courtship, incubation, nest attentiveness (Bustnes *et al.*, 2001), and feeding the nestlings (WHO and IPCS 2002). It has been reported that nests of Great Black-backed Gulls (*Larus marinus*) with higher blood levels of PCBs, DDE, β HCH and oxy-chlordane were more prone to be predated by ravens and crows, when compared with birds that had lower levels, and these birds also had smaller eggs (Helberg *et al.*, 2005). Abnormal reproductive behaviour, skewed sex ratios, differential gender related mortalities and feminization of the male embryos are other potential effects (Blus and Henny, 1997; WHO and IPCS 2002) associated with exposure, but none of these have yet been studied on colonial nesting birds. Effects on immune function (Bustnes *et al.*, 2004), proneness to disease (Hario *et al.*, 2004), skeletal deformities (Giesy *et al.*, 1994; Thomson *et al.*, 2006), and wing feather asymmetry (Bustnes *et al.*, 2002) are some of the sub-lethal effects reported which may eventually affect the reproduction of the individuals, their communities, and their ecological role.

5.4.3.6. Relation between levels of DDT and reproductive success

DDT concentration and its correlation with breeding success in various species of birds have been reported worldwide. Hence, in the present study reproductive success of select colonial nesting birds was compared with the concentration of DDT residues in their respective eggs. To understand the relation between concentration of DDT and

reproductive success, a random sample egg was collected from the marked nests and residue levels were measured. The fate of the remaining eggs through incubation, hatching and fledging of nestlings monitored and breeding success was calculated. Relationship among DDT residue levels in all the species of colonial nesting birds studied is described in table 43.

DDT, primarily through its major metabolite DDE affects the reproductive success of birds. Eggshell thinning is an important, but not exclusive factor related to reproductive problem (Blus 1984). Unfortunately most studies on the reproductive effects of DDE or DDT on wild birds were experimental and might not fit in field conditions. This was a lacuna for interpreting the effects of residues in eggs on reproductive success in birds in wild condition. Therefore, in the current study we followed sample eggs technique, an established method that gives more insights into the effects of residues on reproductive success. In this technique, one egg was collected safely from the nest when first eggs soon after laying and analyzed for pesticide residues, the nest was marked, fate of the remaining eggs monitored through periodic visits, and the residues in the egg were related to nest success which is similar to what Blus (1984) had reported in Long-billed Curlews in Oregon.

Table 43. Comparison between reproductive success and DDT concentration in select species of colonial nesting birds in the study sites

S. No.	Study sites and Species	N	Concentration in Range (ng/g)		Success (%) *		Remarks
			p'p' DDE	p'p' DDT	Hatching Success	Fledging Success	
I	Vedanthangal Bird Sanctuary						
1	Black-crowned Night Heron	3	1.07-1.32	0.66-0.82	100	100	-
2	Black-headed Ibis	6	BDL-72.74	BDL-1.80	100	91.6	Chick was found dead in the nest
3	Asian Openbill	4	BDL-10.77	BDL-1.00	100	100	-
4	Painted Stork	5	BDL-228.06	BDL-1.31	100	87.5	Chick was found dead in the nest
II	Koonthankulam Bird Sanctuary						
1	Spot-billed Pelican	4	BDL	BDL-1.28	100	100	-
2	Black-headed Ibis	9	BDL-14.24	BDL-1.97	100	100	
3	Little Egret	4	BDL-4.84	BDL	100	100	-
4	Indian Cormorant	4	BDL-16.60	BDL-2.00	100	100	-
5	Painted Stork	15	BDL-26.2	BDL-3.4	100	92.2	Chick predated by cat
III	Vettangudi Bird Sanctuary						
1	Asian Openbill	5	BDL-2.31	2.32-3.58	100	93.3	Chick was found missing
Total		59					

*excluded the eggs collected for contamination analysis

Longcore *et al.* (1971) stated with evidence that Black Duck receiving dietary dosage of 10- 30 $\mu\text{g/g}$ of DDE had significantly reduced the survival rate of hatchlings. They reported that DDE levels ranged between 12 and 144 $\mu\text{g/g}$ in eggs of treated birds. Barn Owls on a diet containing 3 $\mu\text{g/g}$ of DDE had reduced 75% of hatching and fledgling success when eggs contained average of 12- 41 $\mu\text{g/g}$ (Mendenhall *et al.*, 1983). However, the levels of DDE residues recorded in the eggs of present study are many folds lower than the levels which cause reproductive failures in birds. The levels of DDE and $\sum$ DDT recorded in the eggs of colonial nesting birds in the present study are lower than the levels reported to reduce the productivity in Brown Pelican (≤ 1.5 $\mu\text{g/g}$ wet wt) in South Carolina, Bald Eagle (≤ 2.2 $\mu\text{g/g}$ wet wt), Black-crowned Night Heron (≤ 1 $\mu\text{g/g}$ wet wt), Snowy Egrets (≤ 1 $\mu\text{g/g}$ wet wt) in various regions within the US and White-faced Ibis (≤ 1 $\mu\text{g/g}$ wet wt) in Nevada (Blus, 1982; Henny *et al.*, 1984; Henny and Herron 1989 and Wiemeyer *et al.*, 1993).

Residues of $\sum$ DDT recorded in the eggs of present study is lower than the levels (200 - 1700 ng/g) reported in the eggs of Little Egret and Black-Crowned Night Heron (Connel *et al.*, 2003). Moreover, the concentrations recorded in all the species birds in the study sites are well below the level (1000 $\mu\text{g/g}$) which causes significant reduction in reproduction (Connel *et al.*, 2003). Henny and Herron (1989) reported that the levels of DDE at 4- 8 $\mu\text{g/g}$ in the White-face Ibis reduced reproductive success. He reported that no young ones were produced when sampled eggs contained DDE at ≥ 15 $\mu\text{g/g}$ in the Bald Eagle. However, the levels DDT recorded in the eggs of present study are much lower than the levels reported to reduce reproductive success.

The levels of *p,p'* DDE detected in the eggs of birds currently studied are well below the threshold levels (4 - 8 $\mu\text{g/g}$ wet wt) associated with impaired reproduction as reported by (Custer *et al.*, 1983 and Henny *et al.*, 1984). However, DDE concentration in eggs of Painted Stork (228.06 ng/g) and Black-headed Ibis (72.74 ng/g) may be associated with effects on survival rate of young ones of these species when it continuously exposed to such pesticides.

p,p' DDE concentration in eggs of colonial nesting birds in this study is lower than the levels those are correlated with decreased reproduction in Double-crested Cormorant (>1 ng/g; Custer *et al.*, 1999), (>4 ng/g in White-faced Ibis; Henny and Herron 1989) (>3 ng/g in Brown Pelican; Blus *et al.*, 1974), >8 ng/g in Black-crowned Night Heron, >5 ng/g in Green Heron and >5 ng/g in Snowy Egret (Henny *et al.*, 1985).

Experimental studies on the effect of Dieldrin on bird reproduction are limited (Walker *et al.*, 1969 and Mendenhall *et al.*, 1983). The limited data on birds suggest that the reproductive process of birds is not particularly sensitive to Dieldrin. Field studies on the effect of Dieldrin on the Purple and Common Gullinules failed to show any significant effect on either the percentage of egg hatched or on survival of young ones (Fowler *et al.*, 1971). The levels of Dieldrin detected in the eggs of colonial nesting birds are not alarming, but can be treated with concerns when concentrations increase further through food chain.

It does not appear that the organochlorine contaminants detected in these individuals are likely to have an impact on the demographic performance of these species as a whole. However, residues may reach high levels causing decreased reproductive or survival in some years, particularly when combined with other non-anthropogenic stressors such as predations. The present study showed wide range of pesticide contamination and food chain accumulation of persistent organochlorine pollutants. Invariably, eggs of all the species collected from study sites were contaminated with pesticide residues, but not alarming. Although, the concentration of organochlorine residues in eggs of some species seem to be lower than the levels documented elsewhere, it is of concern as even low levels of contamination if continued, it can pose serious ill effects. Hence, the study recommends continuous monitoring of pesticide residues in the environment and their impact on the avian populations.

RECOMMENDATIONS

6. RECOMMENDATIONS

Colonial nesting birds such as egrets, herons and storks are associated with the agricultural ecosystems. In Tamil Nadu although there are breeding colonies within protected areas, their major feeding habitats are smaller ponds and lakes located within agricultural ecosystems and human settlements. While it may be a general presumption that the population of these colonial nesting birds is on the decline, there is very little structured information collected on long-term basis available on the population status and breeding success of these birds in Tamil Nadu. Further the present study is a maiden study in Tamil Nadu to assess the residues of pesticides in various biological components along with ecological studies. The study encompassed two major components, namely 1) bird studies (population, distribution, breeding ecology and habitat use) and 2) levels of pesticide contamination in fishes, dead birds and eggs of colonial nesting birds collected from select bird Sanctuaries in Tamil Nadu. Summary of the findings and recommendations are given below.

6.1. Vedanthangal Bird Sanctuary

- Rainwater and water depth are the lifeline of Vedanthangal Bird Sanctuary, which is one of the crucial factors for the arrival of migratory and breeding resident birds.
- Vedanthangal Bird Sanctuary depends on Valayaputhur tank from where the excess water flows into the Sanctuary. Unfortunately water outflow from Valayaputhur tank is being blocked by Valayaputhur villagers for irrigating their agricultural crops. Thus there is competition for water between birds and farmers. Hence, an effective mechanism for sharing of water is very much necessary. Although it is a sensitive issue, since the farmers seem to understand the benefits of birds, it may be feasible to implement.
- Although the Sanctuary has official boundary, physical demarcation is missing. There is no earthen dyke on northern and eastern side of the Sanctuary. During monsoon, runoff not only floods the cultivable areas nearby and the Sanctuary, but also brings in residues of pesticides and fertilizers from the agricultural lands. Hence, earthen bunds need to be built to avoid agricultural runoff entering the

Sanctuary and also help hold sufficient amount of water for breeding birds. It may be meaningful to store water in Valayaputhur tank and draw subsequently to the Sanctuary based on need.

- Spot-billed Pelican, a near threatened species nests largely on *A. nilotica*. During 2009-10, they could not breed successfully because old *A. nilotica* trees were cut down leading to shortage of nesting trees in the Sanctuary. Further, competition was noticed between Pelican and Painted Stork for nesting trees. Hence, it is recommended to plant more *A. nilotica* saplings. Construction of artificial nesting sites as a stop gap measure might also help the birds to an extent.
- Stinging Catfish (*Heteropneustes fossilis*) is one among the dominant fishes in Vedanthangal. Present study showed that this species did eat and hinder the growth of other species of fishes. As long as *H. fossilis* remains in the wetland in large numbers, it is difficult for others species to establish a viable population. Hence, *H. fossilis* need to be periodically harvested so as to enable colonization of other species of fishes. This may be done by extensive gill netting during non-breeding season. Professional expertise may also be sought for selective fishing.
- Many migratory ducks (e.g. Northern Pintail, Northern Shoveler, Common Teal, and Garganey) and resident ducks (e.g. Spot-billed Duck) need mounds with adequate vegetation cover for resting and nesting. At present, Vedanthangal Bird Sanctuary does not have such mounds unlike Koonthankulam Bird Sanctuary. Hence, a few mounds approximately 2-4 m height with 20 m radius may be constructed.
- Many species of birds, namely Spot-billed Pelican, Asian Openbill, Painted Stork, Little Cormorant, Darter and Black-headed Ibis breeding in Vedanthangal were found to be feeding in nearby wetlands, particularly Madhuranthagam Tank. Therefore protecting and maintaining nearby wetlands are also very essential.
- Vedanthangal attracts lot of tourists. Hence, problem associated with tourism have to be efficiently addressed.

6.2. Koonthankulam Bird Sanctuary

- Similar to Vedanthangal, Koonthankulam also does not have dykes on northern and western side of the Sanctuary. During monsoon and post monsoon, runoffs not only flood the cultivable areas (paddy field) around the Sanctuary but also enter the Sanctuary and bring in residues of chemical pesticides and fertilizers into the Sanctuary. Hence, earthen bunds with sluice gates could regulate water for the benefit of breeding birds.
- In the present study, Spot-billed Ducks were found to eat paddy grains in nearby cultivable lands. In order to protect the crops, farmers were found killing the birds and also destroying their nests. Setting fire to nesting trees with active nests destroyed eggs and nestlings of Painted Stork and Ibises. Hence, a programme to create awareness among farmers needs to be initiated. This could reduce the bird-human conflict around the Sanctuary.
- Waterfowls, such as Northern Pintail, Common Teal, Gargany and Spot-billed Duck depend on submerged hydrophytes for food. Since, availability of such aquatic vegetation in Koonthankulam is scanty; a few common hydrophytes such as *Nymphaea* and *Hydrilla* sp. may be introduced.
- A few species of colonial nesting birds, namely Painted Stork, Intermediate Egret and Little Egret were found to breed on trees located in the village. During the study, a few local people cut down nesting trees present in their land. Cutting down of potential nesting trees causes serious damage to nesting birds' habitats. Development of community based conservation programmes might help solve these issues. In Kokkare Bellur, Karnataka such efforts have been largely successful in Spot-billed Pelican conservation.
- High voltage electric lines from Koodankulam to Thirunelveli pass through nesting areas in the Sanctuary. Mortality of Painted Storks and Spot-billed Pelicans due to electrocution were noticed during the study. Hence, realignment of the electrical lines away from the nesting areas is recommended.

- Firewood collection, illegal fishing by local people and cattle grazing are the other issues in this Sanctuary which require attention.

6.3. Vettangudi Bird Sanctuary

- Existing earthen bund needs to be strengthened to avoid any breach during the monsoon. Certainly, it would also help store more water in the Sanctuary for the benefits of birds and farmers as well.
- State Forest Department has plans to plant more trees including *Barringtonia acutangula*. Plantation of such trees needs to be done soon to provide more potential habitats to water birds for roosting and nesting.
- Owing to siltation, the depth of the tank is decreasing over the years. Periodic slit removal is necessary. Farmers' cooperation can be sought as they need water for cultivation.
- Department could allow the villagers to collect bird guano during summer to be used as manure for their crops. Perhaps this would help the farmers to have better understanding of birds.
- As this Sanctuary is close to human settlements, anthropogenic pressure increases particularly during festivals. Birds, namely Asian Openbill, Little Cormorant, Black-headed Ibis start breeding from October and nestlings emerge by November. Playing loud music and busting crackers during the breeding period should be regulated or banned. This could be done through creation of environmental awareness among the villagers.
- Water should not be drained beyond a point for irrigation. Breeding seasonality/status is to be taken in to consideration as complete draining may force birds to desert nesting.

6.4. Pesticides contamination

- Based on the information that we have gathered, it can be inferred that the levels of Σ DDT, HCH and cyclodiene insecticide residues in fishes, tissues, and eggs of colonial nesting birds is indicative of exposure. However, not alarming.
- If accumulation of organochlorine residues continues unchecked, colonial nesting birds will certainly be affected. Hence, regular monitoring of persistent chemicals, especially in breeding colonies of birds is recommended.
- Apart from persistent chemicals, organophosphate and carbamate group of chemicals are being used by farmers around the Sanctuaries. Such chemicals are expected to cause impact among the birds. Hence, monitoring the impacts of such chemicals is necessary for the conservation of birds, particularly colonial nesting birds.
- It is important to note that legislation on the use of pesticides alone is unlikely to help conserve birds and the environment. Hence, the following is recommended with respect to use of chemicals for crop protection.
 1. Create awareness among farmers with support and training in Integrated Pest Management (IPM) and Good Agricultural Practices (GAP).
 2. Allocate subsidies for the purchase of minimum-risk inputs.
 3. Regulate use of pesticides based on impact on the environment.
 4. Continuous monitoring of pesticide residues in select biota, particularly birds is necessary.
 5. Restrict pesticide usage around the protected areas and bird Sanctuaries at least during migratory and breeding seasons of birds.
 6. Encourage eco-friendly cultivation practices and eventually organic farming.

SUMMARY



7. SUMMARY

Colonial water birds are one of the major vital components of a wetland ecosystem. They serve as an excellent indicator of wetland health. In India, destruction of fresh water wetlands and entry of contaminants pose significant threats to the long-term stability of the population of colonial water birds and their habitats.

Enormous quantities of man-made chemicals are used in modern agriculture. Despite obvious benefits, their indiscriminate use has resulted in accumulation of residues in food and animal tissues causing environmental and ecological impact. Presence of pesticide residues, particularly persistent organochlorines in different biological and non-biological components has raised concern about their long-term accumulation and effects. Birds occupy different trophic levels in different food chains and hence are exposed to different concentrations of contaminants through their food.

Ill effects of pesticides on wildlife, especially raptors, waterfowl and fish-eating birds have been extensively studied around the world. But, in India such information on birds, particularly fish-eating birds (colonial birds) is limited. Although, some information is available on the residue levels of pesticides present in eggs of fish-eating and insectivorous birds in India, they fail to bring out the exact scenario of pesticide usage in agricultural areas and residue levels in eggs, and the consequent impact on breeding outcome. Further, there are no studies which have reported the residue levels in eggs and simultaneously monitored the population of birds over a period of time in India. The present work was conducted in select heronries in Tamil Nadu with the following objectives; identify the heronries in Tamil Nadu, monitor the population and study breeding ecology of colonial nesting birds in select locations, document the residue levels of organochlorine pesticides in fishes, eggs and tissues of colonial nesting birds and assess the impacts.

Survey was conducted to identify the heronries in the state. Local people were enquired to get details on the nesting locations and breeding history of colonial nesting birds. Direct count method was followed to estimate the number of species and individuals. Breeding ecology of select colonial nesting birds were studied using focal animal sampling

technique. Agricultural practices, land-use pattern, threats and disturbances were also recorded. Samples, namely fishes, dead birds and eggs were collected as per standard operating protocols. Soxhlet extraction method was followed with suitable solvents and cleaned up for estimating organochlorine pesticide residues using Gas Chromatograph equipped with electron capture detector.

Field surveys in 41 heronries in 14 districts were conducted between March and September 2007. The distribution showed that not all the districts in Tamil Nadu have ideal breeding locations for the colonial nesting birds. Number of heronries located in Tirunelveli (8), Kanyakumari (7) and Ramanathapuram (6) were relatively more. The remaining districts had between one and three sites. With respect to species distribution, Little Egret, Little Cormorant and Indian Pond Heron were found in nearly twenty heronries in Tamil Nadu. Black Ibis and Woolly-necked Stork were found only in two locations. Heronries, namely Vedanthangal Bird Sanctuary, Vettangudi Bird Sanctuary and Koonthankulam Bird Sanctuary were selected for further studies.

During the period of study (Oct '07 - March '10), 18 species of fish-eating birds were observed in Vedanthangal Bird Sanctuary. Total population was the maximum (30,551) during March 2010 and minimum (118) during September 2009. Of which Cattle Egret, Glossy Ibis, Painted Stork, Spot-billed Pelican, Indian Cormorant and Little Cormorant were the predominant species. White-throated Kingfisher and Pied Kingfisher were only a few in numbers. Out of the 18 species found in the sanctuary, 12 species were observed breeding. However, we monitored eight species, namely Spot-billed Pelican, Asian Openbill, Black-headed Ibis, Painted Stork, Grey Heron, Little Cormorant, Little Egret and Eurasian Spoonbill. On the whole, the total number of nests recorded was the maximum (3,185) during 2009-10 and the minimum (2,819) during 2007-08. Among the species the maximum number of nests was of Spot-billed Pelican (887) followed by Painted Stork (576) and Asian Openbill (570). Nests of Darter and White-throated Kingfisher were only a few.

Between October 2007 and March 2010, 21 species of fish-eating birds were observed in Koonthankulam Bird Sanctuary. Total population was the maximum (28,190) during March 2010 and minimum (52) during October 2009. Of all the species, Cattle Egret, Glossy Ibis, Painted Stork, Spot-billed Pelican, Indian Cormorant and Black-headed Ibis

were the predominant species. White-throated Kingfisher and Pied Kingfisher were only a few. Out of 21 species found in this sanctuary, 11 species were observed breeding. However, we monitored six species, namely Spot-billed Pelican, Black-headed Ibis, Painted Stork, Little Egret, Intermediate Egret and Indian Cormorant. Maximum number of nests (3,650) was recorded during 2009 - 2010 and the minimum (2,169) during 2007-08. Among the breeding birds, Painted Stork (1,861) was predominant followed by Spot-billed Pelican (877).

The population and number of species in Vettangudi Bird Sanctuary were relatively lower than in Vedanthangal and Koonthankulam. Total population was the maximum (3989) during December 2008 and minimum (17) during March 2010. Among the species, Cattle Egret, Little Egret, Asian Openbill and Black-headed Ibis were more in number and White-throated Kingfisher was less. Species, namely Asian Openbill, Black-headed Ibis, Little Cormorant, Black-crowned Night Heron, Intermediate Egret, Little Egret and Darter nested in the sanctuary. However, we monitored species, namely Asian Openbill, Black-headed Ibis, Little Cormorant and Intermediate Egret. Among all the species, Asian Openbill (326) was the most predominant. During 2009, seven species of birds settled into begin nesting in December, but due to inadequate water and disturbance by Greater Spotted Eagle, all of them deserted the Sanctuary soon. Density was calculated to examine the variation in population of colonial nesting birds among study sites, species, and families. There was a significant difference in the density of colonial nesting birds among the study sites, species, families, and between seasons ($P < 0.05$).

In Vedanthangal Bird Sanctuary, most of the nests were found on *Acacia nilotica* and *Barringtonia acutangula*. Among the birds, Asian Openbill, Painted Stork, Black-headed Ibis, Grey Heron, Eurasian Spoonbill and Little Egret predominantly used *Barringtonia acutangula*. Indian Cormorant, Spot-billed Pelican and Darter mostly preferred *Acacia nilotica*. In Koonthankulam Bird Sanctuary, Painted Stork, Little Egret, Intermediate Egret and Indian Pond Heron preferred *Prosopis juliflora*, while Indian Cormorant, Spot-billed Pelican and Darter used *Acacia nilotica*. Many of the birds breeding in Vettangudi Bird Sanctuary preferred *Acacia nilotica*. Nest-site characteristics, such as tree diameter at breast height, canopy level, tree and nest height, nest distance from water spread area and human settlement were also gathered and discussed.

Data on breeding success of select species of colonial nesting birds were gathered in Vedanthangal, Koonthankulam and Vettangudi Bird Sanctuaries. Totally 1583 nests belonging to five families, namely *Ardeidae*, *Pelecanidae*, *Ciconiidae*, *Phalacrocoracidae* and *Threskiornithidae* were focused. In Vedanthangal, Black-headed Ibis and Spot-billed Pelican showed the highest breeding success during 2007-08, while the same species had the least success during 2009-10. In Koonthankulam, Spot-billed Pelican and Painted Stork had the highest success rate, while Intermediate Egret had the least. Among the four species of birds studied in Vettangudi Bird Sanctuary, Little Cormorant was the most successful breeder.

Towards assessing pesticide contamination, three hundred individuals comprising nine species of fishes covering two seasons, namely breeding (October to March) and non-breeding season (April to September) of birds were collected from the study sites. Among the organochlorines analyzed, HCH was most frequently detected followed by Heptachlor epoxide, Endosulfan and DDT. Σ OCPs in fishes showed variation, but was not significant ($P>0.05$). Among the isomers, β -HCH contributed more than 50% to the Σ HCH. Among DDT metabolites, p,p' DDT had high percentage of occurrence. Among the cyclodiene insecticide residues, Endosulfan was detected in more than 60% of the fishes. Variations in organochlorine residue levels among the locations and between seasons were not significant ($P>0.05$).

Totally 76 individuals belonging to 14 species of birds found dead during the study period were analyzed for pesticide residues in various tissues. Among various organochlorine pesticide residues analyzed, levels of HCH were the maximum. Σ HCH ranged between BDL in muscle of Spot-billed Pelican and 981 ppb in muscle of Indian Cormorant. Heptachlor epoxide, Σ Endosulfan and Σ DDT ranged from BDL to 963 ppb, BDL to 637 ppb and BDL to 208.6 ppb respectively. Comparatively, low levels of Dieldrin ranging between BDL and 109.3 ppb in the tissues were recorded. Concentration of Σ DDT, Dieldrin and heptachlor epoxide significantly ($P<0.05$) varied among the locations while Σ HCH, Σ Endosulfan and Dieldrin significantly ($P<0.05$) varied among the species. On the whole, levels of organochlorine residues detected were higher in the tissues of wading birds such as Cattle Egret, Little Egret and Grey Heron than in swimming birds, namely Little Cormorant and Indian Cormorant. Higher accumulation of p,p' DDT, β -HCH and Σ Endosulfan in the tissues indicate continued exposure to these chemicals. The residue

levels of DDT, HCH, Dieldrin, Heptachlor epoxide and Endosulfan in all the birds studied, did not indicate any poisoning. However, HCH, the most predominantly detected contaminant in all the birds can be expected to create harm, if the birds are continuously exposed. Similarly, DDT and its metabolites are also capable of creating certain abnormalities, especially reproductive failures, if exposure continues to exist.

Totally 97 eggs of 12 species of birds were analyzed for organochlorine pesticide residues. Among the species studied, Painted Stork, Spot-billed Pelican and Black-headed Ibis were the near threatened birds. Egg measurement and eggshell parameters including shell index of all the species of birds were calculated. Thickness showed negative correlation with organochlorine residues. Among various organochlorine pesticide residues analyzed, isomers of HCH were the maximum followed by Σ DDT, Heptachlor epoxide and Σ endosulfan. Among the isomers, γ -HCH contributed more than 50% of the Σ HCH. Among the metabolites, p,p' DDE had higher accumulation in all species studied. Among the cyclodiene insecticides, Σ endosulfan contributed more than 50%. Concentration of Σ DDT, HCH, heptachlor epoxide and endosulfan in the eggs significantly ($P < 0.05$) varied among the species. Levels of Σ organochlorine residues detected were the highest in the eggs of Little Cormorant followed by Intermediate Egret and Grey Heron, while eggs of Eurasian Spoonbill had the lowest. The levels of OC residues detected in the eggs of birds currently studied are well below the threshold levels (4 - 8 $\mu\text{g/g}$ wet wt) associated with impaired reproduction. However, DDE concentration in eggs of Painted Stork (228.06 ng/g) and Black-headed Ibis (72.74 ng/g) may be associated with effects on survival rate of young ones of these species when it continuously exposed to such pesticides

Although all the sanctuaries have official boundary, physical demarcation is missing and there is no proper earthen dyke in Vedanthangal and Koonthankulam Bird Sanctuaries. During monsoon, runoff not only floods the cultivable areas nearby and the Sanctuaries, but also brings in residues of pesticides and fertilizers from the agricultural lands. Hence, earthen bunds need to be built to avoid agricultural runoff entering the Sanctuary and help hold sufficient amount of water for breeding birds. It is recommended to plant more new saplings to augment nesting tree availability. Construction of artificial nesting sites as a stopgap measure might also help the birds to an extent. Firewood collection, illegal fishing by local people and cattle grazing are the other issues in all the study sites which

require attention. Development of community based conservation programmes might help solve these issues. As legislation on the use of pesticides alone is unlikely to help conserve birds and the environment, it is recommended to resort to eco-friendly cultivation methods, and eventually organic farming.

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PUBLICATIONS

STATUS OF PESTICIDE CONTAMINATION IN BIRDS IN INDIA

WITH SPECIAL REFERENCE TO THREATENED SPECIES

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INTRODUCTION

Declining population of birds breeding at regular sites and infrequent sightings or total absence of insectivorous birds, such as drongos and bee-eaters in the agricultural fields in various parts of India are being reported. The population of Spot-billed Pelican *Pelecanus philippensis* which plummeted from 2000 to 330 within a span of 30 years in Karnataka (Kannan & Manakadan 2005); declining breeding population of Sarus Crane *Grus antigone*, from 27 pairs during 1973 (Walkinshaw 1973) to six pairs during 1990 (Vijayan 1991) in Keoladeo National Park, Bharatpur; report on the presence of residues of a few organochlorine pesticides in the tissues of c. 100 species of birds (Dhananjayan 2009) and eggs of eight species of fish-eating birds, in Keoladeo National Park (Muralidharan *et al.*, 1992); unsuccessful breeding of Himalayan Grey-headed Fish-eagle *Ichthyophaga nana* at Corbett National Park in Uttar Pradesh (Naoroji 1997); higher accumulation of organochlorine pesticides in resident and migratory birds from south India (Tanabe *et al.* 1998); population decline upto 99.9% in vultures in the entire country (Prakash *et al.* 2003, 2007) and fast disappearing common bird House Sparrow in India (Vijayan 2003, Dandapat *et al.* 2010, Ghosh *et al.* 2010) give credence to the concern of ornithologists. In the case of Sarus Crane in Bharatpur, it was confirmed that the decline in population was mainly due to application of aldrin in the agricultural fields around the Park: 18 Sarus Crane were found dead inside the Park within a span of three years due to aldrin poisoning (Muralidharan 1993). Even after the ban on aldrin, death of 15 Sarus due to monocrotophos poisoning was reported (Pain *et al.* 2004).

Unfortunately, mortality of Sarus Crane in its entire range of distribution has become rampant these days. Although such definite information is not available for many species of birds in India, studies conducted elsewhere give definite proof of the deleterious effects of pesticides on avifauna and the ecosystem.

Following the success of DDT in World War II, several organochlorine pesticides (OCPs) were discovered for the control of crop pests and vector-borne diseases, and the use of pesticides in agriculture commenced in India around 1948-1949 (Gupta 1986). It increased manifold with the green revolution starting in the early 1970s. Today, India is the second largest manufacturer of pesticides in Asia and the third largest consumer in the world. Estimated usage of pesticides in India was 72,130 metric tons (mt) during 1991-1992. In recent years, the consumption has come down. While it was 41,020 mt during 2003-2004, it increased slightly to c. 43,860 mt during 2008-2009 (<http://www.indiastat.com/agriculture/2/consumptionofpesticides/206872/stats.aspx>). The continued dependence clearly shows that pesticides, regardless of the long-term consequences, have become a major tool in today's agriculture, even as alternatives to pesticides are being tried and talked about.

Although India is in the process of phasing out persistent organochlorine group of pesticides, many are still being used in substantial quantity either for agriculture or civic health. For example, DDT which has been banned for agriculture (Ministry of Agriculture, Govt. of India notification dated May 26, 1989), is still being used, more than 12 years later, in public health programmes, especially in malaria

eradication. However, it has been limited to an annual ceiling of 10,000 mt till an acceptable substitute is identified (Source: Ministry of Agriculture, Govt. of India). DDT continues to pose problems to the environment. Similarly, notwithstanding the recommendation of the expert committee, chlordane and gamma HCH are still being used. Even though endosulfan is a known neurotoxin and endocrine disruptor, the industry is unwilling to accept the ban on it.

Pesticide use in India averages 600 gm per hectare, compared to 10 kg per hectare in developed countries. Insecticides (73%) dominate the market, followed by herbicides (14%) and fungicides (11%). The demand of cotton, rice and wheat-growers is almost 70% of the total pesticide consumption, and the states consuming most are Andhra Pradesh, Punjab, Karnataka and Gujarat. About 231 pesticides are registered for use in India (Pesticide Registration Information for India, 2010). Presently 44 types of pesticides are manufactured in India and approximately 59 million kg are used in the agricultural sector annually (Menon 2006, *see also* <http://www.pollutionissues.com/A-Bo/Agriculture.html>). Almost all pesticides, especially organochlorine compounds, have a very slow decomposition rate and long half-life, thereby they remain as residues in the ecosystem for years and continue to exert deleterious effects on birds and other wildlife more subtly than by outright killing.

Replacement of organochlorine (OC) insecticides with short-lived chemicals such as organophosphates (OP), carbamate and other compounds appeared to alleviate many problems of persistence and bioaccumulation (Blus 1982, Wiemeyer *et al.* 1984). However, further studies reveal that serious effects are also associated with the use of these newer compounds, particularly from a short-term perspective, where acute or subacute toxicity (Grue *et al.* 1983, Henny *et al.* 1985) and reduction in the food base are major concerns (Rands 1985, Potts 1986). It has been demonstrated that some OP compounds can also have temporary effects on shell quality: parathion was shown to reduce eggshell thickness of the Common Quail *Coturnix coturnix* (Haegele & Tucker 1974) and methyl parathion did so in Northern Bobwhite *Colinus virginianus*.

The US Environmental Protection Agency (US-EPA 1980) tests chemicals for avian reproduction hazards and also requires shell thickness measurements as part of the registration process. Therefore, measuring eggshell quality remains a valuable tool for testing or monitoring a variety of contemporary environmental hazards.

Field biologists in India are not equipped to handle dead birds in large numbers if they come across such phenomena. Many instances go unrecorded unless they attract media and public attention. Classic examples are the death of large numbers of Peafowl in Madhya Pradesh during July 2000, many species of



ANANT ZANJALE

Dramatic decline of Gyps species of vultures in south Asia due to the veterinary drug (not a pesticide) highlights the dangers of releasing new chemicals in the environment without testing on non-target species



K. K. SINGH

There have been many cases of death of Sarus Cranes after eating pesticide-laden seeds

ducks in Chilika Lake during January 2006 and in Okhla Bird Sanctuary, Uttar Pradesh during February 2006. India does not have a structured programme whereby the residue levels of many harmful pesticides could be monitored and instances of mass mortality among birds brought on record.

LITERATURE REVIEW

While the information available on pesticide contamination in the Indian context is very little, it is appreciable in Western countries (Custer *et al.* 1990, Mora *et al.* 1993, Olsen *et al.* 1993, Guitart *et al.* 1994, Fossi *et al.* 1995, Bustnes *et al.* 2001, Minh *et al.* 2002, Gomara *et al.* 2004, Mora 2008, Mora *et al.* 2008, Chen *et al.* 2009). An attempt has been made to compile all that is available in Indian literature and relevant references from western literature. DDT and its breakdown product DDE gained notoriety about 50 years back in North America. While it was Rachel Carson whose book *Silent Spring* brought to light the ill effects of DDT on the environment, Ratcliffe (1967) investigating the Peregrine Falcon (*Falco peregrinus*) and Sparrow-hawk (*Accipiter nisus*) in Britain, was the first to note a correlation between the magnitude of decrease in eggshell weight, decrease in breeding populations and the exposure of populations of these species to persistent organic pesticides. Heath *et al.* (1969) showed experimentally that DDE impaired reproductive performance. Later it was proved responsible for eggshell thinning that led to population crashes and reproductive impairment in many species of birds in North America (King *et al.* 1978, Fleming *et al.* 1984).

Organophosphosphates are also very toxic, particularly to birds, although they remain in the environment for shorter periods than organochlorines. They act on living organisms by

reducing the activity of cholinesterase (ChE) in the blood and acetylcholinesterase (AChE) in the brain. Accumulation of acetylcholine in nerve tissues causes a change in the transmission of nerve impulses across synapses (Stone 1979). This leads to paralysis of the respiratory muscles and depression and paralysis of the respiratory centre (Murphy 1986). Following acute oral exposure to an organophosphate



SHYAM GHATE

The disappearance of Pallas's Fish-eagle from Keoladeo National Park and many other wetlands could be due to extensive use of pesticides in the catchment areas



ASAD R. RAHMAN

High levels of DDT in fat deposits of Crow, Kite and Vulture have been reported from Lucknow. Decline of Egyptian Vulture needs to be investigated considering that it eats all types of food found around human habitation

pesticide, inhibition in the order of 80% of AChE activity causes death. In the case of continued exposure, inhibition in the order of 40-50% in brain AChE activity is enough to cause death (Eisler 1986, Grue *et al.* 1991).

A number of effects on bird behaviour were linked to exposure to organophosphate compounds; important among them were reduction in singing (Grue & Shipley 1981), decreased vigilance (Levin & Rodnitzky 1976), disturbed nesting behaviour (Grue *et al.* 1982) and feeding behaviour (Adams 1977).

The declining population of the Swainson's Hawk was attributed to the use of monocrotophos on Sunflower to protect it from grasshoppers, accounting for more than 5% of the Hawk population. Although it has not been used in the US for the last 10 years because of its dangerous toxicity, its use in Argentina (wintering ground) has caused poisoning of several Swainson's Hawk (Di Silvestro 1996). Needless to say, pesticide use affects not only the local population of birds but also migrants. Thus, even if a state or country protects its wildlife and birds, the very purpose is defeated if the entire distribution range, including migratory grounds of the species, is not equally protected.

In North America, the use of carbofuran has declined markedly over the course of the last decade. Because of huge bird mortality attributed to this chemical, it has now been withdrawn from the US for all but a few minor uses (US-EPA 1991). Carbofuran products are currently banned in Canada for the

same reasons (US-EPA 2008), but in India they are still being used.

The effects of pesticides on wildlife, especially raptors, waterfowl and fish-eating birds, have been extensively studied in North America (Stickel *et al.* 1969, Ambrose *et al.* 1988, Fleming *et al.* 1984, Custer *et al.* 1990). In India, although the available information is less, there have been a few studies in recent years (Tanabe *et al.* 1998, Muralidharan 1993, 2002, Muralidharan & Murugavel 2001, Senthilkumar *et al.* 1999, 2001, Muralidharan *et al.* 2008, Dhananjayan & Muralidharan 2010, Muralidharan & Dhananjayan 2010, Dhananjayan *et al.* 2010).

Kaphalia *et al.* (1981) reported high levels of DDT in fat deposits of crow, kite and vulture collected from Lucknow. Misra (1989) studied the levels of organochlorine in a few biological and non-biological samples, including six species of birds in Mehala water reservoir in Rajasthan. Muralidharan (1993) attributed the mortality of 18 Sarus Crane and a few granivorous birds in Keoladeo National Park, Bharatpur to aldrin. Pain *et al.* (2004) found monocrotophos to be the culprit in the death of 15 Sarus, again in Bharatpur. Unsuccessful breeding of Himalayan Grey-headed Fish-eagle at Corbett National Park in Uttar Pradesh was reported by Naoroji (1997). Increased accumulation of organochlorine in resident and migratory birds from South India was documented by Tanabe *et al.* (1998). Senthilkumar *et al.* (1999, 2001) measured levels of pesticides, dioxins and polychlorinated biphenyls (PCBs) in a few species of

birds in South India. Information is also available on the residue levels of various organochlorine pesticides (OCPs) in tissue and plasma of many species of birds in India (Muralidharan *et al.* 2008, Dhananjayan & Muralidharan 2010, Dhananjayan *et al.* 2010). Reports on the indirect impact of agrochemicals on avifauna associated with agro-ecosystem are also available (Rajendren 2003, Muralidharan *et al.* 2004). Death of 58 aquatic birds of six species was reported in Okhla Bird Sanctuary, Uttar Pradesh (Gopi Sundar 2006). Residue levels of organochlorines in the eggs of a few species of terrestrial birds were reported by Regupathy & Kuttalam (1990), Muralidharan *et al.* (1992) and Ranapratap (2004).

AIM OF THE PRESENT STUDY

There are hundreds of potentially harmful chemicals to monitor in the environment. However, this study narrowed its scope to pesticides which are the most persistent and known to bioaccumulate in birds and cause deleterious effects.

MATERIAL AND METHODS

Sample Collection and Transportation

Samples of dead birds were collected from different parts of the country opportunistically. Field biologists, forest officials, private estate managers and farmers were requested to send samples whenever they came across any dead birds. In the event of mass mortality of birds, exclusive visits were made to investigate the incident. Proper protocol was followed to preserve and transport samples

without delay to the laboratory at SACON, Coimbatore.

Sample Processing

All the birds received were subjected to post-mortem examination. Tissues, blood plasma and eggs were preserved in deep freeze for analysis. Samples of 2-10 gm of the tissue were ground with sodium sulphate and the mixture was packed in Whatman thimbles and desiccated overnight. The desiccated thimble was Soxhlet-extracted with pesticide grade hexane for 6 hrs. The extract was condensed in a rotary flask evaporator to a specific aliquot and placed on a Florisil-packed glass column for cleanup. The eluate was condensed in a rotary flask evaporator and stored in a deep freeze at -20 °C until analysis by gas chromatography. Extracts with high fat content were subjected to acid digestion. Sulphuric acid was added drop by drop, and the sample washed with 20-30 ml of aqueous sodium bicarbonate solution. This procedure was repeated until the extract become colourless with neutral pH. Blood plasma samples were processed adapting standard operating protocol (US-EPA 1980, Bhatnagar *et al.* 1992, 2004). The extract was filtered, and the filtrate was evaporated with rotary flask evaporator to near dryness. Residues of organochlorine pesticides thus extracted were reconstituted with 1 ml hexane and stored for analysis.

Chemical Analysis

Quantification of organochlorine pesticides in all samples was done with Hewlett-Packard 5890 Series



II Gas Chromatograph equipped with Ni^{63} Electron Capture Detector (ECD) and DB-608 fused silica capillary column (30 m x 0.32 mm x 0.5 μm) coated with 35% phenyl methyl polysiloxane. Chromatographic conditions were as follows: detector 300 $^{\circ}\text{C}$; injector 250 $^{\circ}\text{C}$; oven temperature programmed as 180 $^{\circ}\text{C}$ -3 min; 4 $^{\circ}\text{C}/\text{min}$ -260 $^{\circ}\text{C}$ -15 min. All the samples were analysed for alpha-hexachlorocyclohexane (α -HCH), beta-hexachlorocyclohexane (β -HCH), delta-hexachlorocyclohexane (δ -HCH), gamma-hexachlorocyclohexane or lindane (γ -HCH), heptachlor epoxide (HE), dieldrin, *p,p'*-DDT, *p,p'*-DDE, *p,p'*-DDD, a-endosulfan, b-endosulfan and endosulfan sulphate. An equivalent mixture manufactured by Dr. Ehrenstorfer Laboratories (Germany) was used as standard. Concentrations of individual compounds were quantified from the peak area of the sample to that of the corresponding external standard for calibration. Recoveries of the compounds from fortified samples (50 ppb) ranged from 91 to 102% and the results were not corrected for per cent recovery, and expressed in wet weight basis. Analyses were

run in batches of 10 samples plus four quality controls (QCs), namely reagent blank, matrix blank, QC check sample and random sample in duplicate. The minimum detection limit for all the compounds analysed was 1 ppb.

RESULTS AND DISCUSSION

Between 2002 and 2010, about 1500 dead individuals comprising 60 species of birds were received from different parts of the country. However, in this article, organochlorine pesticide residue levels in 534 individuals comprising 56 species of birds are presented (Table 1). Additionally, information on 300 eggs of 37 species, and 140 blood plasma samples from 16 species, is discussed. Further, residue levels in tissues, plasma and eggs of threatened birds are discussed in detail (Table 2). There was a constant increase in the number of birds we received dead at the laboratory between 2002 and 2010 (Figs. 1&2). Nevertheless this is certainly an underestimation, as the sampling is mainly opportunistic and only proportionate to effort invested. Dead birds received



Being at the apex of the food chain, raptors are the worst victims of pesticide biomagnification in their bodies

Table 1. Dead birds received for organochlorine residues analysis during 2003-2005

S. No.	Common Name	Scientific Name	Food habits	N
1	Asian Openbill	<i>Anastomus oscitans</i>	Carnivorous	1
2	Barn Owl	<i>Tyto alba</i>	Carnivorous	6
3	Black Ibis	<i>Pseudibis papillosa</i>	Carnivorous	2
4	Collared Scops Owl	<i>Otus bakkamoena</i>	Carnivorous	2
5	Greater Coucal	<i>Centropus sinensis</i>	Carnivorous	11
6	Little Egret	<i>Egretta garzetta</i>	Carnivorous	10
7	Intermediate Egret	<i>Mesophoyx intermedia</i>	Carnivorous	1
8	Black-crowned Night Heron	<i>Nycticorax nycticorax</i>	Carnivorous	1
9	Shikra	<i>Accipiter badius</i>	Carnivorous	10
10	Besra	<i>Accipiter virgatus</i>	Carnivorous	8
11	White-rumped Vulture	<i>Gyps bengalensis</i>	Carnivorous	18
12	White-bellied Drongo	<i>Dicrurus caeruleus</i>	Carnivorous	1
13	Great Indian Bustard	<i>Ardeotis nigriceps</i>	Omnivorous	1
14	Asian Koel	<i>Eudynamis scolopacea</i>	Frugivorous	22
15	Red-vented Bulbul	<i>Pycnonotus cafer</i>	Frugivorous	10
16	Red-whiskered Bulbul	<i>Pycnonotus jocosus</i>	Frugivorous	6
17	Rose-ringed Parakeet	<i>Psittacula krameri</i>	Frugivorous	7
18	White-eared Bulbul	<i>Pycnonotus luteolus</i>	Frugivorous	2
19	Baya Weaver	<i>Ploceus philippinus</i>	Granivorous	2
20	Rock Pigeon	<i>Columba livia</i>	Granivorous	80
21	Grey Francolin	<i>Francolinus pondicerianus</i>	Granivorous	11
22	House Sparrow	<i>Passer domesticus</i>	Granivorous	13
23	Laughing Dove	<i>Streptopelia senegalensis</i>	Granivorous	1
24	Nilgiri Wood Pigeon	<i>Columba elphinstonii</i>	Frugivorous	1
25	Eurasian Collared Dove	<i>Streptopelia decaocto</i>	Granivorous	8
26	Spotted Dove	<i>Streptopelia chinensis</i>	Granivorous	8
27	Scaly-breasted Munia	<i>Lonchura punctulata</i>	Granivorous	6
28	Bar-headed Goose	<i>Anser indicus</i>	Herbivorous	1
29	Common Coot	<i>Fulica atra</i>	Herbivorous	2
30	Blyth's Reed Warbler	<i>Acrocephalus dumetorum</i>	Insectivorous	2
31	Cattle Egret	<i>Bubulcus ibis</i>	Insectivorous	9
32	Indian Nightjar	<i>Caprimulgus asiaticus</i>	Insectivorous	2
33	Green-billed Malkoha	<i>Phaenicophaeus tristis</i>	Insectivorous	16
34	Indian Pitta	<i>Pitta brachyura</i>	Insectivorous	5
35	Indian Robin	<i>Saxicoloides fulicata</i>	Insectivorous	6
36	Indian Roller	<i>Coracias benghalensis</i>	Insectivorous	4
37	Kestrel	<i>Falco tinnunculus</i>	Insectivorous	1
38	Large-tailed Nightjar	<i>Caprimulgus macrurus</i>	Insectivorous	1
39	Oriental Magpie Robin	<i>Copsychus saularis</i>	Insectivorous	4
40	Nilgiri Pipit	<i>Anthus nilghiriensis</i>	Insectivorous	1
41	Indian Pond Heron	<i>Ardeola grayii</i>	Insectivorous	12
42	Spotted Owlet	<i>Athene brama</i>	Insectivorous	7
43	Yellow-billed Babbler	<i>Turdoides affinis</i>	Insectivorous	28
44	Common Quail	<i>Coturnix coturnix</i>	Omnivorous	6
45	Common Myna	<i>Acridotheres tristis</i>	Omnivorous	18
46	House Crow	<i>Corvus splendens</i>	Omnivorous	27
47	Indian Peafowl	<i>Pavo cristatus</i>	Omnivorous	18
48	Large-billed Crow	<i>Corvus macrorhynchos</i>	Omnivorous	11
49	Black Kite	<i>Milvus migrans</i>	Omnivorous	66
50	Sarus Crane	<i>Grus antigone</i>	Omnivorous	1
51	Grey Heron	<i>Ardea cinerea</i>	Piscivorous	1
52	Little Cormorant	<i>Phalacrocorax niger</i>	Piscivorous	8
53	Painted Stork	<i>Mycteria leucocephala</i>	Piscivorous	8
54	Black-headed Ibis	<i>Threskiornis melanocephalus</i>	Piscivorous	8
55	White-throated Kingfisher	<i>Halcyon smyrnensis</i>	Piscivorous	2
56	Spot-billed Pelican	<i>Pelecanus philippensis</i>	Piscivorous	10

were categorised into five groups based on their feeding habits, namely insectivorous (36.8%), omnivorous (31.6%), piscivorous (12.3%), carnivorous (8.8%) and herbivorous (10.5%).

Among the various organochlorines tested, isomers of HCH and metabolites of DDT contributed more to the total OCPs followed by heptachlor epoxide. Among the isomers of HCH, $\hat{\alpha}$ -HCH accounted for 44% of total HCH, while $\hat{\alpha}$ -, $\hat{\alpha}$ - and $\hat{\alpha}$ -HCH accounted for 29%, 17% and 10% respectively. Of all the metabolites of DDT, p,p' -DDE contributed the maximum (63%) to the total DDT residue, indicating its higher persistence in bird tissue. The maximum accumulation of organochlorine residues was in fat and liver tissue of birds and the minimum in food content. Although, the differences were not significant among tissues and between sexes (ANOVA, $P>0.05$), significant differences were observed in organochlorine levels among the various species of birds studied. Further, when all the birds were grouped based on their food habits (frugivorous, granivorous, insectivorous, carnivorous, omnivorous and piscivorous) significantly higher load of pesticide residues was recorded in carnivorous birds (ANOVA, $P<0.05$). Total organochlorine pesticide load was in the following order: carnivores> insectivores> piscivores> frugivores> omnivores> granivores (Fig. 3). Comparisons among species indicated significant differences in frequency of detection of some OCPs (Dhananjayan 2009).

Carnivorous species, namely Besra Sparrow-hawk, Collared Scops-owl, Barn Owl, White-rumped Vulture and Spotted Owlet recorded 8,623, 4,258, 1,370, 1,295



GOBIND SAGAR BHARDWAJ

Even forest birds such as the Nilgiri Flycatcher suffer from pesticide poisoning, either directly or indirectly due to the loss of insect population that is their food

Table 2. List of threatened birds included in the study

S. No.	Common Name	Scientific Name	Number of samples analysed			Status	Food habit
			Dead birds	Blood plasma	Eggs		
1	White-rumped Vulture	<i>Gyps bengalensis</i>	18	17	2	Critically Endangered	Carnivore
2	Egyptian Vulture	<i>Neophron percnopterus</i>	-	6	-	Endangered	Carnivore
3	Great Indian Bustard	<i>Ardeotis nigriceps</i>	1	-	-	Critically Endangered	Omnivore
4	Sarus Crane	<i>Grus antigone</i>	1	4	-	Vulnerable	Omnivore
5	Nilgiri Wood-pigeon	<i>Columba elphinstonii</i>	1	-	-	Vulnerable	Frugivore
6	Black-headed Ibis	<i>Threskiornis melanocephalus</i>	7	1	15	Near Threatened	Piscivore
7	Spot-billed Pelican	<i>Pelecanus philippensis</i>	10	-	11	Near Threatened	Piscivore
8	Painted Stork	<i>Mycteria leucocephala</i>	7	3	24	Near Threatened	Piscivore
9	Nilgiri Flycatcher	<i>Eumyias albicaudata</i>	-	-	3	Near Threatened	Insectivore
10	Nilgiri Pipit	<i>Anthus nilghiriensis</i>	1	-	-	Near Threatened	Insectivore
Total			47	31	55		



BHASKAR MEHTA

Wetland birds such as the Black-headed Ibis face food shortage in many intensive agriculture areas as run-off pesticides kill their prey

and 502 ppb of total OCPs respectively. Minimum contamination was observed in granivorous species, namely Rock Pigeon (707 ppb), Baya Weaver (385 ppb), Grey Francolin (252 ppb) and Laughing Dove (34 ppb).

Where individual pesticides are concerned, significant variation was observed in HCH residues among various species of birds studied ($P < 0.05$). Comparatively higher load of total HCH (>2000 ppb) was recorded in Blyth's Reed-warbler, Collared Scops-owl, Indian Peafowl, Nilgiri Wood-pigeon, Shikra, Spotted Owlet and Yellow-billed Babbler. DDE had the highest concentration among all the OCPs detected.

It ranged from below detectable levels upto 7,114 ppb among the bird species studied. Individual levels from Asian Koel, Cattle Egret, Common Myna, Green-billed Malkoha, Indian Peafowl, Black Kite, Ring Dove, Shikra, White-rumped Vulture and Yellow-billed Babbler tested had more than 500 ppb of p,p' -DDE.

Among the cyclodiene pesticides tested, heptachlor epoxide showed the highest accumulation, followed by endosulfan and dieldrin. Similar to HCH and DDE, cyclodiene insecticide residues were also higher in many individuals of Asian Koel, Blyth's Reed-warbler, Cattle Egret, Common Myna, House Crow, Indian Peafowl, Black Kite, White-rumped Vulture and Yellow-billed Babbler. In many of

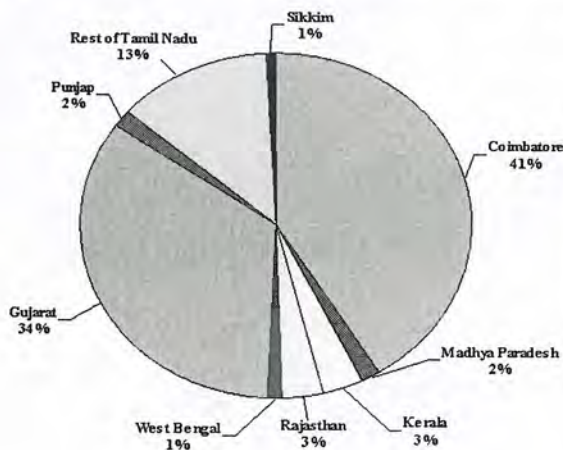


Fig. 1: Dead birds received from various places in India during 2002-2010

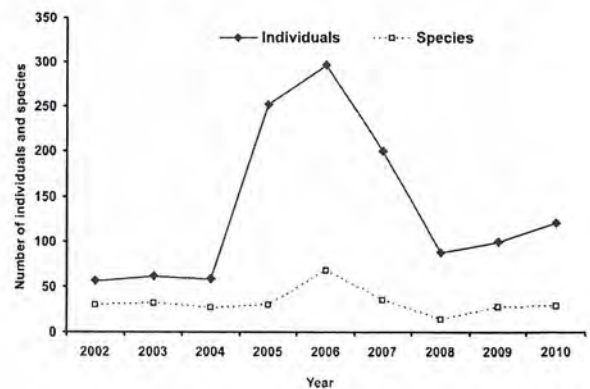


Fig. 2: Number of individuals and species received dead between 2002 and 2010 in India

the bird tissue samples, organochlorines tested were found in appreciable concentrations. Further, DDE and isomers of HCH were detected in most or all individuals. Total DDT and HCH levels were high in many individuals and may warrant attention. The results clearly indicate that OCPs, namely DDT and HCH, remain widely persistent in birds all over India.

During the last two decades, the impact of pesticides on many species of birds has become abundantly clear. Between 1987 and 1990, 18 Sarus Crane and more than 50 Collared Dove fell victim to aldrin and monocrotophos in and around Keoladeo National Park, Bharatpur (Muralidharan 1993, Pain *et al.* 2004). Mass mortality of Peafowl occurred in Madhya Pradesh and some parts of western India in 1999 (Muralidharan 2002). This was clearly a case of misuse of pesticides. Although Peafowl were also killed for illegal trade of feathers at the same time, the impact of pesticides on their mortality was quite evident. Recently (in January 2011) 19 Peafowl died after consuming pesticide-treated seeds in agricultural fields near Gandhinagar and Vadodara in Gujarat (Patel 2011), in yet another instance of negligence by farmers.

During 2004-2007 we have records of more than 32 Peafowl deaths in the country. Among other reasons, death due to pesticide poisoning has become a cause for concern. The frequency of occurrence of HCH,



ATANU AND SHUKLA

Not much information is available on the impact of pesticides on frugivorous forest birds such as the Nilgiri Wood-pigeon. Are they safe from these chemicals?



GARIWA BHATTA

The Nilgiri Pipit is endemic to high altitude grasslands of the Western Ghats where its habitat is mostly surrounded by tea plantations where pesticides are extensively used. There is a need to study the impact of pesticides on the insects on which this bird feeds



BHASKAR MEHTA

It will be interesting to know the pesticide load of Painted Stork which feeds on fish, frogs, and insects in all types of polluted wetlands

heptachlor epoxide, total DDT, total endosulfan and dieldrin in the tissues of various birds was 100, 98, 92, 85 and 45 per cent, respectively.

Though all the birds received dead at the laboratory were not victims of pesticide poisoning, the presence of residues clearly indicates that the birds had imbibed these pesticides from the environment. Continuous exposure to some of the chemicals may turn out to be dangerous and reflect on the population sooner than later. Although no conclusive evidence is available regarding the ill effects of DDT on any avian species in this country, its presence at varying levels in the tissues and eggs of many species (Kaphalia *et al.* 1981, Misra 1989, Muralidharan 1993, Muralidharan *et al.* 1992, Muralidharan & Murugavel 2001, Muralidharan *et al.* 2008, Dhananjayan 2009) clearly indicates that DDT is still present in the environment. This is because of its continued use for disease control and its prolonged residual effect. Unless there is a complete ban on its use, DDT residue levels cannot be brought down in the environment. This is applicable not only to DDT, but also to all persistent pollutants such as PCBs. Although we suspect that pesticides might be the reason for population decline or mass mortality observed in many species of birds in India, concrete evidence is available only for a few species.

In addition to organochlorines, residues of

chlorpyrifos, the most common organophosphate, have also been detected in the stomach contents of Asian Koel collected from an agriculture field near Coimbatore, confirming the cause of its death. Hence it is clear that even chemicals with a very short half-life, such as chlorpyrifos, pose a threat to birds if the exposure levels are high.

Pesticide contamination in threatened birds HCH and its Isomers

Pesticide concentrations measured in select species of threatened birds are given in Table 3. Among 10 species of threatened birds studied, the

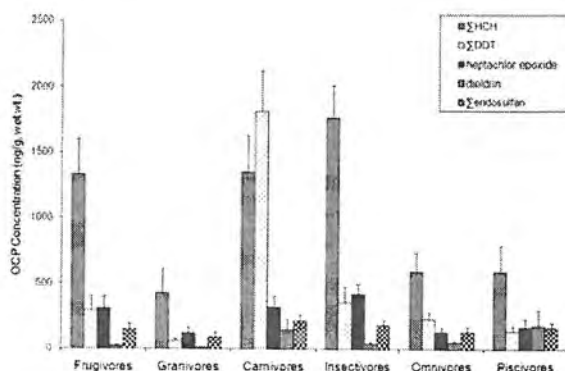


Fig. 3: Variation in total organochlorine residues among various groups of birds collected from India

Table 3. Organochlorine pesticide residues (ng/g, wet wt) in tissues of threatened birds.

Species	N	Total HCH	Total DDT	Total Endosulfan	Heptachlor epoxide	Dieldrin
White-rumped Vulture ^a	18	(BDL-1920)	(BDL-11630)	(BDL-270)	(BDL-3050)	(BDL-130)
Painted Stork	7	228.5 (23.4-454.7)	37.3 (9.5-88.1)	137.6 (10.3-300.0)	10.2 (1.6-20.3)	26.4 (3.4-39.3)
Spot-billed Pelican	10	40.5 (6.7-81.3)	18.8 (5.7-44.6)	18.1 (10.2-29.4)	10.4 (BDL-29.5)	1.7 (BDL-2.6)
Black-headed Ibis	7	101.1 (2.3-451.6)	31.9 (2.1-97.5)	44.4 (BDL-209.4)	20.4 (1.5-100.3)	21.9 (1.5-75.8)
Nilgiri Wood Pigeon	1	6006	142	722	1729	63
Nilgiri Pipit	1	713	BDL	BDL	BDL	BDL
Sarus Crane	3	286 (56-944)	21.4 (5.5-148)	45.4 (11-92)	53.8 (BDL-10)	5.7
Total	47					

Source: ^aMuralidharan *et al.* (2008), BDL: Below Detection Limits.

maximum level of total HCH was recorded in Nilgiri Wood-pigeon (6,006 ppb) followed by White-rumped Vulture (1,920 ppb) while the minimum was in Spot-billed Pelican (40.5 ppb). Total HCH levels in the present study are much higher than the levels reported in White-rumped Vulture (106 ppb) collected from urban Lucknow, India during 1980 (Kaphalia *et al.* 1981). Previous studies on Indian biota have also reported high levels of HCH (Tanabe *et al.* 1998, Senthilkumar *et al.* 1998, 2001, Vijayan *et al.* 2004, Muralidharan *et al.* 2008). While none of the vulture tissues received from Delhi had detectable HCH residues, the muscle and liver tissues of this species from Mudumalai had 0.11 and 1.03 µg/g respectively (Muralidharan *et al.* 2008). Although these levels are not indicative of toxic effects, they are higher than the levels reported in South African Vulture (van Wyk *et al.* 2001).

Technical HCH is one of the most widely distributed organochlorines in the world. Although technical HCH is mainly composed of α -HCH (65-70%), β -HCH (7-10%), γ -HCH (14-15%) and δ -HCH (approximately 7%), the total concentration (total HCH) is controlled completely by β -HCH. The strong persistence of β HCH can be attributed to its slow rate of degradation as proved in broilers (δ -HCH > γ -HCH > β -HCH) (WHO-IPCS 1992).

In blood plasma, the load of total HCH was the highest in Sarus Crane (286 ppb), followed by White-rumped Vulture (136 ppb), while the lowest was in Black-headed Ibis (11.4 ppb) (Table 4). Total HCH levels in the present study are almost two to four times as high as the levels reported in Rock Pigeon (48 ppb),

House Crow (30 ppb) and Black Kite (60 ppb) collected from urban Lucknow, India during 1980 (Kaphalia *et al.* 1981). There is also substantial use of α -HCH in India for agricultural purpose, which might be a contributing factor.

In eggs, the concentration of total HCH ranged between 17.9 ppb in Painted Stork and 347 ppb in Nilgiri Flycatcher (Table 5). Relatively high levels of HCH in the eggs of Nilgiri Flycatcher and Black-headed Ibis may be through constant consumption of contaminated food due to their association with agricultural ecosystems. Total HCH levels recorded in the present study are lower than the levels (total HCH: ND-0.99 ppm) reported in select colonial waterbirds in Keoladeo National Park, Bharatpur (Muralidharan 1992), and many species of fish-eating birds in America and Japan (Somers *et al.* 1993, Senthilkumar *et al.* 2005). The most predominant occurrence of α -HCH in eggs reflects its stable nature compared to the other isomers, namely β -, γ - and δ -HCH. Some of the eggs showed higher proportion of α - and β -HCH, suggesting recent exposure to technical HCH mixture (containing 70% α -, 15% β -, 6% γ - and 9% δ -HCH) used in India (Tanabe *et al.* 1998).

HCH has been restricted in India for agricultural use. But a possible source of these compounds might be related to the use of gamma-HCH, which is commercially available as lindane in India. Lindane has not received much attention in terms of its effects on eggs of birds (Goutner *et al.* 1997). However, several studies have been carried out on the contamination levels of this pesticide (King *et al.* 1978,



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Thanks to the protection provided by the forest department and local people, the population of Spot-billed Pelican has increased, but is it safe from the increasing use of pesticides and other chemicals which it may accumulate through its food?

Becker *et al.* 1993). Its use as a heptachlor substitute for seed treatment is considered safer to wild birds (Blus *et al.* 1985). However, varying levels of contamination by lindane and its metabolites in eggs of birds have been reported (Becker *et al.* 1993).

Although there is not much information available on HCH poisoning in India and elsewhere, data generated in the laboratory gives some basic information about its toxicity. The levels recorded in the present study are lower than the LC_{50} values reported from the dietary toxicity for Bobwhite (882 mg/kg), Japanese Quail (425 mg/kg), Ring-necked Pheasant (561 mg/kg) and Mallard (1500 mg/kg) (Hill *et al.* 1975). HCH concentrations reported in the birds in the present study do not fall within toxic level, but are indicative of exposure. It is also to be noted that India is the greatest consumer of HCH in the world (Kumari *et al.* 2001).

DDT and its Metabolites

The mean concentration of total DDT in tissues of the threatened birds considered in this study ranged from levels below detection limits in Nilgiri Pipit to 142 ppb in Nilgiri Wood-pigeon (Table 3). DDT and its metabolites were also high in the tissues of the White-rumped Vulture. Below detectable level (BDL) of DDT and its metabolites were reported in many species of birds studied in India (Muralidharan *et al.* 2008). Although the levels of DDT detected in the present study are well below the levels (brain: >30 ppm) reported to be responsible for mortality of birds (Stickel *et al.* 1969, Stickel *et al.* 1970), they are higher

than the levels reported in South African Vulture (van Wyk *et al.* 2001). The differences in concentration of DDT and its metabolites detected among the threatened species studied here could be related to the level of contamination of their habitats.

In blood plasma, the mean concentration of total DDT among species ranged from 8.8 ppb in Egyptian Vulture to 147 ppb in Painted Stork (Table 4). Total DDT concentration documented in blood plasma of Indian White-rumped Vulture and Egyptian Vulture was two to four times higher than the levels measured in blood samples of African White-rumped Vulture (3.44 ng/ml) (van Wyk *et al.* 2001) and Egyptian Vulture (0.82-6.0 ng/ml) reported from different localities in Spain (Gomara *et al.* 2004). It is interesting to note that the DDT metabolites detected in blood samples of White-rumped Vulture in the present study are several times lower than the values reported in the same species in Lucknow, India (Kaphalia *et al.* 1981).

In eggs, the maximum level of total DDT was recorded in White-rumped Vulture (6,160 ppb) followed by Nilgiri Flycatcher (236 ppb) and the minimum in Black-headed Ibis (7.36 ppb) (Table 5). These levels are also far below the concentrations in eggs which were correlated with toxic effects (5 $\mu\text{g/g}$ wet wt) and impaired reproduction (0.5 $\mu\text{g/g}$ wet wt) in different bird species (Hall *et al.* 1989, Hoffman *et al.* 1998). According to the results obtained by Iseki *et al.* (2001), the concentration of POPs in eggs is similar to that found in blood samples. It is well known that *p,p'*-DDE is commonly associated with eggshell thinning in many birds (Dirksen *et al.*

Table 4. Organochlorine pesticide residues (ng/g, wet wt) in blood plasma of threatened birds

Species	N	Total HCH	Total DDT	Total Endosulfan	Heptachlor epoxide	Dieldrin
White-rumped Vulture ^b	17	136 (BDL-770)	64.8 (BDL-455)	31.7 (BDL-104)	23.9 (BDL-73.4)	6.5 (BDL-73.4)
Egyptian Vulture ^b	6	76.6 (BDL-215)	8.8 (BDL-25.6)	26.2 (BDL-33.1)	14.4 (BDL-17.9)	4.8 (BDL-7.3)
Painted Stork ^c	4	78.2 (45.6-131)	147 (13.6-333)	41.1 (BDL -70)	296 (4.5-808)	10.5 (6.2-19)
Black-headed Ibis ^c	1	11.4	27.5	66	28.9	BDL
Sarus Crane ^c	4	286 (56-944)	21.4 (8.8-43)	45.4 (5.5-148)	53.8 (11.0-92)	5.7 (BDL-10)
Total	32					

Source: ^b Dhananjayan *et al.* (2010), ^c Dhananjayan and Muralidharan (2010), BDL: Below Detection Limits.

1995, Konstantinou *et al.* 2000). The *p,p'*-DDT and *p,p'*-DDD are less frequent in plasma samples of vulture, and *p,p'*-DDD is the lesser detected of the two most common persistent metabolites of DDT (DDD and DDE) in wildlife and environment (Jiminez-Castro *et al.* 1995). Between the two species of vultures studied, the White-rumped had a higher organochlorine burden. The average total burden of DDT (eDDT) in many species of birds studied reveal that the Indian environment is contaminated with DDT. As DDT and its derivatives are quite stable and are resistant even to enzyme action (Kaphalia *et al.* 1981), their residual effect in biological tissues remains even after exposure ceases.

Cyclodiene Insecticides

The levels of cyclodiene compounds, namely heptachlor epoxide, dieldrin and total endosulfan were the maximum in Nilgiri Wood-pigeon, being 1,729 ppb, 63 ppb and 722 ppb respectively, while they were below detection limit in Nilgiri Pipit (Table 3). While Peakall (1996) reported 5-10 ppm of dieldrin in the brain of birds to be lethal, Muralidharan (1993) documented 4-5 ppm in the brain of Sarus Crane which died due to dieldrin poisoning in Keoladeo National Park, Bharatpur. Concentration of dieldrin recorded in the present study is well below the levels expected to harm the avian population as reported by Heinz & Johnson (1981).

However, it may be noted that the Long and Morgan “Effects Range-Low” (ER-L) value (i.e., the contamination level above which adverse biological effects are occasionally observed), is reported as 0.02 µg/kg for dieldrin (Long *et al.* 1995). Another cyclodiene pesticide heptachlor epoxide, a

metabolite of heptachlor, was detected in the tissues of all the birds studied, except the White-rumped Vulture received from Delhi. Maximum levels were recorded in the brain (3.05 µg/g) and liver (2.32 µg/g) tissues of White-rumped Vulture received from Ahmedabad (Muralidharan *et al.* 2008). The experimental study by Henny *et al.* (1983) concluded that residues greater than 1.5 ppm in the brain were most definitely associated with decreased reproduction rates in avian species. Many birds included in the current study had high residues of heptachlor epoxide in one or more tissues, and are to be viewed with concern.

In blood plasma of threatened birds, heptachlor epoxide ranged between 14.4 ppb in Egyptian Vulture and 296 ppb in Painted Stork (Table 4). While dieldrin levels ranged from below detection limit in Black-headed Ibis to 10.5 ppb in Painted Stork, total endosulfan ranged from 26 ppb in Egyptian Vulture to 66 ppb in Black-headed Ibis. The mean heptachlor epoxide levels determined in blood plasma of the present study were similar to the levels reported in whole blood of African White-rumped Vulture (10.5-25 ng/ml), Cape Griffon *Gyps coprotheres* (11.34-16.07 ng/ml) and Lappet-faced Vulture (<nd-5.81 ng/ml) (Van Wyk *et al.* 2001). The concentrations of dieldrin detected in the present study are comparable with levels reported in blood plasma of Bald Eagle (10 ppb) and Caspian Tern (7-15 ppb) (Henny *et al.* 1981, Mora *et al.* 1993).

Detectable levels of total endosulfan were found in 75% of the samples tested. Limited information seems to exist regarding residue levels of this metabolite in avian species, and wildlife in general. It was proposed that endosulfan, in contrast to the

Table 5. Organochlorine pesticide residues (ng/g, wet wt) in eggs of threatened birds

Species	N	Total HCH	Total DDT	Total Endosulfan	Heptachlor epoxide	Dieldrin
White-rumped Vulture ^a	2	NA	6160 (5110-7210)	NA	NA	9 (3-15)
Painted Stork	24	17.9 (2.67-58)	8.1 (1.6-40.2)	2.17 (0.43-4.70)	0.61 (BDL-5.84)	0.34 (BDL-1.11)
Spot-billed Pelican	11	27.1 (0.54-163)	14.8 (0.54-229)	2.31 (0.44-5.83)	0.38 (BDL-3.65)	0.50 (BDL-2.43)
Black-headed Ibis	15	28.35 (2.35-189)	7.36 (BDL-72.7)	4.27 (BDL-22.9)	0.74 (BDL-8.95)	2.09 (BDL-19)
Nilgiri Flycatcher	3	347 (48.2-640)	236 (224-146)	263 (BDL-479)	22.1 (11.4-28.8)	7.73 (BDL-22.2)
Total		55				

Source: ^a Muralidharan *et al.* (2008), NA: Not Analysed, BDL: Below Detection Limits.

other organochlorine insecticides, is not very persistent in the environment and has a half-life in water between 3 and 7 days (Eichelberger & Lichtenberg 1971). It was reported that birds that feed primarily on fish and other aquatic organisms have detectable levels of endosulfan, rather than birds with other food habits (i.e., granivores, insectivores and scavengers) (Van Wyk *et al.* 2001). Aggarwal *et al.* (2008) reported that subchronic concurrent exposure to arsenic and endosulfan at environmentally relevant concentrations significantly altered the functional immunological parameters tested in birds. The movement of endosulfan into the environment adjacent to the site of application was noted as of particular concern, especially to fish (Antonious & Byers 1997). On the contrary, in the present study piscivorous birds had less endosulfan burden. This might be due to small sample size and lack of information on usage pattern.

In eggs, the mean concentration of total endosulfan, heptachlor epoxide and dieldrin were in the range of 2.17-263 ppb, 0.38-22.1 ppb, and 0.34-9.0 ppb respectively (Table 5). Heptachlor epoxide levels in the present study were lower than the levels reported in the eggs of various species of colonial waterbirds (Muralidharan 1993) and terrestrial birds (Dhananjayan 2009) in India. Not much information is available on endosulfan for comparison. All the species in the present study recorded less than 1 ppm of dieldrin, which is not expected to create any ill effects to birds (Stickel 1973). King *et al.* (1978) while summarizing the effects of dieldrin on various species of birds, reported considerable variation. They proposed that levels higher than 1 ppm must be viewed as hazardous. Dieldrin levels found in the present study pose no hazard to the birds, unless exposure level increases.

Of all the ten species of threatened birds sampled, there was clear evidence to prove the cause of death in Great Indian Bustard and Sarus Crane. Reduced brain AChE activity supported by the presence of residues of methyl parathion confirmed that methyl parathion was responsible for the death of Great Indian Bustard received from Pune. It is beyond doubt that the population of this species is on the decline for more than three decades now. Although the circumstantial evidence for the decline of this typical grassland bird points towards hazardous agricultural practices, no other confirmed report of pesticide poisoning is available to date. This is mainly because toxicological investigations were not carried out even on the Great Indian Bustard. This is applicable to many species of birds in India.

CONCLUSION AND RECOMMENDATIONS

The present study on organochlorine pesticide residues in 56 species of birds including 10 threatened species in India indicates varying levels of contamination. The residue levels may increase further in birds due to continued use of pesticides both for agriculture or public health and also through biomagnification in the food chain. Increased build-up of toxicants as a result of prolonged exposure may not only affect resident wild birds but also migratory ones when they visit India. Continued studies are necessary in order to monitor populations of birds and to evaluate spatio-temporal variations in contamination levels in the country. This will also help assess effectiveness of Government policies on chemical usage in the country.

India is now both the largest manufacturer and consumer of pesticides in South Asia. Despite the proliferation of different types of new generation pesticides, organochlorines are sure to be of concern

for many more years to come. Based on the information that we have of the last two decades, the impacts of pesticides on birds, including many threatened species, are abundantly clear. We have proof beyond doubt for a few species of birds, and there are indications of toxic effects in other cases. If the present trend of pesticide usage continues unchecked, birds will certainly be one of the worst affected non-target organisms. Since agriculture has a place of prime importance in India's economy, large scale and unscrupulous use of chemical pesticides in this sector is likely to continue, which might lead to many adverse effects not only on birds, but also on man. Although it is essential to bring in effective legislation, this alone is insufficient to control contamination. Hence, an environmentally sustainable approach is imperative. Government should consider adopting policies and strategies such as training and

demonstrations in integrated pest management (IPM) techniques for farmers, good agricultural practice and eventually advocacy of organic farming.

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ORGANOCHLORINE PESTICIDE CONTAMINATION IN THE FOOD ITEMS OF FISH-EATING BIRDS—: A CASE STUDY FROM KOONTHANKULAM BIRD SANCTUARY, SOUTHERN INDIA

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ABSTRACT

Indiscriminate use of chemical pesticides to enhance food production has contaminated every ecosystem components in this country. Piscivorous birds by the virtue of their top most position in food chain serve as the best indicator of pesticide contamination in aquatic ecosystem. Regurgitated food items of fish-eating birds collected from Koonthankulam Bird Sanctuary were analysed to examine the level of organochlorine pesticide residues. Among various organochlorine pesticide residues analyzed, isomers of HCH were the maximum followed by DDT and endosulfan. Total HCH ranged between 33 ppb and 190 ppb. Total DDT, total endosulfan, heptachlor epoxide ranged from BDL to 4.7 ppb, BDL to 96.8 ppb and BDL to 5 ppb respectively. Comparatively, low levels of dieldrin ranging between BDL and 3.17 ppb among the foods of birds were recorded. Concentration of total endosulfan and dieldrin varied significantly (ANOVA, $P < 0.05$; $df = 39$; $F = 5.274$) among the species. On the whole, levels of organochlorine residues detected were higher in the regurgitated food of wading birds such as Little Egret and Intermediate Egret than in swimming bird, namely Spot-billed Pelican. Higher accumulation of p, p'-DDT, HCH and total endosulfan in the food indicate continued usage of these pesticides in the adjoining agricultural fields. HCH, the commonly detected contaminant in all the foods, can be expected to create harm to chicks, if they are continuously exposed. The finding of the present investigation could serve as baseline information for future references.

Keywords: Koonthankulam, Regurgitated food, Fish-eating birds, Organochlorine, Pesticides

INTRODUCTION

Indiscriminate use of chemical pesticides to enhance food production has contaminated every ecosystem in this country. As a consequence, birds, fish and other wild animals are placed in intimate contact with the toxic materials or may ingest them with their food (DeWitt et al., 1960). Fish-eating birds by the virtue of their top most position in food chain they exposed to these contaminant at higher proportion. The effects of pesticides on wildlife, especially waterfowl and fish-eating birds have been extensively studied in North America (Custer et al., 1990). In India, although the information are available on various species of birds, in recent years (Dhananjayan et al., 2011a, 2011b, 2011c; Jayakumar et al., 2011), there is a few studies on fish-eating birds and no studies carried out on the level of organochlorine pesticide residues in the regurgitated food items of birds. The present study reports the level of organochlorine pesticide residues in the food of fish-eating birds in Koonthankulam Bird Sanctuary in Southern India.

MATERIALS AND METHODS

Regurgitated food items of fish-eating birds collected from the nests were brought over ice to SACON laboratory, Coimbatore and stored in deep freezer till the time of processing. About 10g of the food was ground with anhydrous sodium sulphate and the mixture was packed in a thimble, which was desiccated overnight prior to extraction. The thimble was extracted with 250 ml of pesticide grade hexane in a soxhlet extractor for 6 h. The extract was condensed in a rotary flask evaporator to a specific aliquot. The condensed aliquot was placed on a column packed with silica gel (60–120 mesh) and eluted with 250 ml of hex-

ane. The collected eluant was again condensed in a rotary flask evaporator and stored in deep freezer at -20°C till gas chromatography analysis. The extract was filtered through sodium sulfate and evaporated with rotary flask evaporator to near dryness and residues of OCPs were reconstituted in 2 ml of hexane.

Processed samples were injected into a Hewlett Packard 5890 Series II gas chromatograph equipped with Ni63 electron capture detector (ECD). A fused silica capillary column (30 X 0.32 mm X 0.5 lm) DB-608 was used for quantification. Chromatographic conditions were as follow; detector 300°C ; injector 250°C ; oven temperature was programmed as $180^{\circ}\text{C} - 3 \text{ min}$; $4^{\circ}\text{C/min} - 260^{\circ}\text{C} - 15 \text{ min}$. All the samples were analysed for alpha-hexachlorocyclohexane (α -HCH), β -HCH, δ -HCH, lindane, heptachlor epoxide, dieldrin, p,p'-DDT, p,p'-DDE, p,p'-DDD, α -endosulfan, β -endosulfan and endosulfan sulfate. Spiked and duplicate samples were also analysed. Pesticide residues were analysed and quantified from individually resolved peak areas with the corresponding peak areas of standard.

RESULTS AND DISCUSSION

Regurgitated food items of Spot-billed Pelican (*Pelicanus philippensis*), Painted Stork (*Mycteria leucocephala*), Little Egret (*Egretta garzetta*) and Intermediate Egret (*Mesophoyx intermedia*) collected from Koonthankulam Bird Sanctuary were analysed for organochlorine pesticide residues. Among the species studied, Painted Stork and Spot-billed Pelican are notable and near threatened (IUCN, 2011).

Among various organochlorine pesticide residues analyzed, isomers of HCH were the maximum followed by

DDT and endosulfan. Total HCH ranged between 33 ppb in Spot-billed Pelican and 190 ppb in Little Egret. Total DDT, total endosulfan, heptachlor epoxide ranged from BDL to 4.7 ppb, BDL to 96.8 ppb and BDL to 5 ppb respectively. Comparatively, low levels of dieldrin ranging between BDL and 3.17 ppb were recorded in the food items of birds. Concentration of total endosulfan and dieldrin varied significantly ($p < 0.05$; df 39; F 5.274) among the species. On the whole, levels of organochlorine residues detected were higher in the regurgitated food items of wading birds such as Little Egret and Intermediate Egret than in swimming bird, namely Spot-billed Pelican. Higher accumulation of p , p' -DDT, HCH and total endosulfan in the food items indicate continued usage of these pesticides in the adjoining agricultural fields.

As there is no studies available on pesticide residues in regurgitate food items of fish-eating birds in India, the levels detected in the present study are compared with levels of fishes which are the major diet of fish-eating birds. The average concentration of total HCH in the regurgitated food of birds are several folds lower than the maximum tolerance level (1000 $\mu\text{g/g}$) reported by Mohindru (2005). The levels also well below the tolerance limit (200 ng/g) prescribed for fish products (FAO/WHO, 1989). The levels of total DDT recorded in this study are higher than the levels (1-2 ppb) reported in fishes of Ganges Estuary, Bangladesh (Jebber et al., 2001) and in fishes of Nilgiri district (Vijayan and Muralidharan, 1999). Newell et al., (1987) had reported a guideline value of 200 ng/kg of total DDT in fishes for the protection of fish-eating birds. However, the levels detected in the present study are less than the level reported by Dhananjayan and Muralidharan (2010) in the inland wetland fishes of Karnataka. Cyclodiene insecticide residue levels recorded in the regurgitated food items of present study are at very low. Such levels may not pose any threat to birds. Dieldrin, one of the highly toxic organochlorine pesticide, was least detected among the cyclodiene groups. Endosulfan, a less persistent OC in bird was less than that of HCH and DDT. Although the toxic level for endosulfan for birds is unknown, studies have indicated that young birds are more sensitive than adults (DeWitt, 1963).

CONCLUSION

The residue levels of DDT, HCH, dieldrin, heptachlor epoxide and endosulfan detected in all the regurgitated food items of fish-eating birds in the present study do not indicate any poisoning. However, the higher frequency detection of HCH in all the food items might be expected to create harm to chicks, if they are continuously exposed. The detection of DDT and its metabolites are capable of creating reproductive abnormalities if they continue to expose to these same levels when complain with other toxic pollutant with varying environmental conditions. The finding of the present investigation could also serve as baseline information for future references. As the OCPs have adverse effects not only on the fishes but also on the fish-birds, their regular monitoring is strongly advised.

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PESTICIDE CONTAMINATION - A MAJOR BUGBEAR TO BIRDS IN INDIA

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INTRODUCTION

Population decline in many species of birds and its relation to environmental contamination is a point that enjoys consensus among ornithologists the world over. In India, several species of birds, especially in agricultural landscapes have either disappeared in totality or their population has plummeted drastically (Dhananjayan 2009; Muralidharan et al., 2008, 2010; Dhananjayan et al., 2011a; Jayakumar et al., 2011). Sarus Crane that is largely associated with agro-ecosystems has been a victim for many years (Vijayan 1991, Muralidharan 1993; Pain et al., 2004). Peacock, Spot-billed Pelican and Grey-headed Fish Eagle are the other notable species, which are suspected to suffer due to contaminants. Higher accumulation of organochlorine in resident and migratory birds from south India (Tanabe et al., 1998), population decline up to 99.9 % in vultures in the entire country (Prakash et al., 2003; 2007) and fast disappearing common bird 'House Sparrow' in India (Vijayan 2003; Ghosh et al., 2010; Dhananjayan et al., 2011b) give credence to the concern of Indian ornithologists. There are many cases of pesticide poisoning in birds, but such incidents largely go unrecorded. Therefore, there is a strong felt need to monitor the impact of pesticides on Indian avifauna through surveillance and monitoring.

MATERIALS AND METHODS

The approach followed to collect samples of dead birds from different parts of the country was largely opportunistic. Cooperation of field biologists, forest officials, private estate managers, farmers were sought to send samples whenever they came across any dead birds. In the event of any mass mortality of birds, exclusive visits were made to investigate the same. Proper protocol to preserve and transport samples was followed to reach them without delay to the laboratory at SACON, Coimbatore.

Birds received were subjected to post-mortem examination. Tissues were preserved in deep freezer for analysis. About 2-10 g of the tissue samples were ground with sodium sulphate and the mixture was packed in a whatman thimble and desiccated over night. The desiccated thimble was Soxhlet extracted with pesticide grade hexane for 6 hrs. The extract was condensed in a rotary flask evaporator to a specific aliquot and placed on a florisil packed glass column for cleanup. The eluate was condensed in a rotary flask evaporator and stored in deep freezer at -200C until analysis in gas chromatograph.

Quantification of organochlorine pesticides in all samples was made with Hewlett-Packard 5890 Series II Gas Chromatograph equipped with Ni63 Electron Capture Detector (ECD) and DB-608 fused silica capillary column. Chromatographic conditions were as follow: detector

300oC; injector 250oC; oven temperature was programmed as 180oC-3min; 4oC/min-260oC-15 min. All the samples were analysed for alpha-hexachlorocyclohexane (α -HCH), beta-hexachlorocyclohexane (β -HCH), delta-hexachlorocyclohexane (δ -HCH), gamma-hexachlorocyclohexane or lindane (γ -HCH), heptachlor epoxide (HE), dieldrin, p,p'-DDT, p,p'-DDE, p,p'-DDD, α -endosulfan, β -endosulfan and endosulfan sulfate.

RESULTS AND DISCUSSION

Data collected over the years have confirmed several instances of pesticide poisoning and documented varying magnitude of contamination in more than 100 species of birds. Sarus Crane (Muralidharan, 1993), Peacock, Great Indian Bustard, are a few notable victims (Muralidharan and Dhananjayan, 2010) to pesticides while White-rumped Vulture to Diclofenac (Oaks et al., 2004).

Among various organochlorine pesticides (OCP) tested in several species of birds, isomers of HCH and metabolites of DDT contributed more to the total OCPs followed by heptachlor epoxide. Among the isomers of HCH, β -HCH accounted for 44 % of total HCH while γ , α and δ -HCH accounted 29%, 17% and 10 % respectively. Of all the metabolites of DDT, p,p'-DDE contributed the maximum (63%) to the total DDT indicating its higher persistence in tissues of birds. The maximum accumulation of organochlorine residues was in fat and liver tissues of birds and the minimum in food content. Further when all the birds were grouped based on their food habits (frugivorous, granivorous, insectivorous, carnivorous, omnivorous and piscivorous) significantly higher load of pesticide residues were recorded in carnivorous birds. Despite the ban on many persistent pesticides, residue levels of certain pesticides in many species of birds are of concern. Fast degrading pesticides, namely methyl parathion and chlorpyrifos also have proved to be fatal to a few species of birds.

Pesticides regrettably have become an indispensable tool for the Indian agriculture and public health departments for many decades now. Population of even so-called common birds such Drongos, Bee-eater, House Sparrow, Indian Roller has been of concern of late. Hence, SACON has made a beginning in this direction to address the issues on a national as well as local scale.

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Assessment of Exposure to and Effect of Organochlorine Pesticides on Birds in India

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Abstract

Effects of pesticides on birds have been well documented in many European and North American countries. Although we have some information on the levels of persistent environmental contaminants in many species of birds in India, but due to lack of adequate data, we are unable to make any direct correlation with the reported population decline. Of all the birds, levels of DDT, HCH and dieldrin recorded in some of the species were indicative of poisoning. Although varying levels of many persistent pesticides have been documented, the levels were not indicative of either food chain build up or poisoning. However, the residue levels recorded were higher than the concentration reported in some other parts of the world. Further, even though very high level of lead indicative of poisoning was observed, it cannot account for the massive reduction that the species have witnessed. However, such levels have to be viewed with concern. In India, unfortunately, no historical data on the levels of organochlorine pesticides are available in any species of birds. Birds, by virtue of their position in the food chain, serve as an excellent indicator of the environmental problem in a better fashion than the other components of the ecosystem. It is needless to say that birds are one of the worst affected non-target organisms. Hence, continual monitoring of persistent chemicals is very essential.

Keywords: Birds, organochlorine pesticides, impact on birds, India

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1. INTRODUCTION

Birds are a visible and important part of the world we share and they appear to be a major target of pesticide pollution because they occupy a wide range of trophic levels in different food chains and are thereby exposed to pollutants through their food [1]. Birds have been widely used as bioindicators for environmental pollution, particularly for persistent organochlorines, which have been considered as potential endocrine-disrupting chemicals in wildlife [2].

Among the innumerable chemicals introduced into the environment, pesticides have been posing serious problems. Organochlorine pesticides and certain

other persistent toxic chemicals are widely disposed in the environment and are commonly found in tissues and eggs of wild birds from the Arctic to the Antarctic. The organochlorine due to their persistent nature remains stored in the body fat and largely disturbs calcium metabolism and thereby reduces eggshell thinning over a period of time eventually leading to population decline [3]. Some organochlorine chemicals are highly toxic and can cause mortality directly, whereas others reduce reproductive success or cause subtle effects on the ecosystem [4].

Birds, fish and other wild animals are placed in intimate contact with the toxic materials or may ingest them with their food [5]. The effects of pesticide on

wildlife, especially raptors, waterfowls and fish-eating birds have been extensively studied around the world [6–14]. Although food abundance and quality greatly impact reproductive effort and success in many predatory birds [15], there has been an increasing concern about the potential deleterious effects of organochlorine and other pesticides on the population of many species of birds [16, 17]. Chlorinated pesticides have been shown to give rise to estrogen-dependent reproductive effects in several avian species [18]; further, DDT and its metabolites have also been shown to cause obstruction of Ca^{2+} metabolism in birds [19]. However, for the clarification of the toxic effects of OCs, basic information such as the distribution of OCs among organs (or tissues) is still insufficient [20].

India is now both the largest manufacturer and consumer of pesticides in South Asia. Despite proliferation of different types of pesticides, organochlorines such as HCH and DDT still account for two thirds of the total consumption in the country for agriculture and public health purposes [21]. Studies on common resident birds like Partridges [22], Passerine birds [23], and Kingfisher [2] are present worldwide, while it is lacking in India.

2. PESTICIDES ON BIRDS IN INDIA

There is little information available on the presence of few organochlorine pesticide residues in the tissues of a few species of birds and the higher accumulation of organochlorine in resident and migratory birds from South India [3]. Declining population of birds breeding at regular sites and infrequent sightings or total absence of insectivorous birds, such as drongos and bee-eaters in the agricultural fields in various parts of India, are being reported. Declining breeding population of Sarus Crane *Grus antigone*, [24–27] in Keoladeo National Park, Bharatpur,

reports on the unsuccessful breeding of Himalayan Grey-headed Fish Eagle *Ichthyophaga nana* at Corbett National Park in Uttar Pradesh [28], fast disappearing common bird House Sparrow in India [29–31] give credence to the concern of ornithologists. In the case of Sarus Crane in Bharatpur, it was inferred that the decline in population was mainly due to application of aldrin in the agricultural fields around the park; 18 Sarus Cranes were found dead inside the park within a span of three years due to aldrin [32]. Even after the ban on aldrin, death of 15 Sarus Cranes due to monocrotophos poisoning was reported [27]. Unfortunately, mortality of Sarus Crane has become rather frequent. Although such definite information is not available for many species of birds in India, studies conducted elsewhere give definite proof for the deleterious effects of pesticides on avifauna and the ecosystem.

In India, although we keep guessing that pesticide could be the reason for the decreasing population trend in many insectivorous and piscivorous birds, nothing has been proved till date [32]. Except a very few studies on the problems of pesticide contamination in Indian wildlife and birds especially resident birds [33–36], not much of research has been carried out to bring out the exact picture of pesticide contamination in a specific region. In India, unfortunately systematic monitoring has never been done to evaluate levels of residues and their biological effects. Limited surveys carried out by various authors have been mainly confined to very small number of individuals to a particular place and periods. The results of scattered studies in the Indian environment are briefly discussed below.

HCH and DDT residues of the internal body organs, depot fat and blood plasma of a few species of Indian wild birds from

Lucknow, were estimated by Kaphalia et al. [37]. High levels of DDT were detected in depot fat of crow, kite and vulture (50.8, 67.0, and 95.3 ppm respectively). Total HCH detected in depot fat of crow was 29.7 ppm, lesser amounts were found in vulture, kite and cattle egret, respectively. A single specimen of pigeon ovary examined contained 1.21 ppm total HCH and 0.31 lindane. Within the same food habit group, smaller individuals are likely to ingest larger amounts of pesticide residues. The study also clearly indicates that HCH level in liver, lung and kidney were generally high in pigeon and crow and in the breast muscles and spleen of vulture. Total HCH and γ -HCH (lindane) levels were high in breast muscle, liver, and heart and lung tissues of pigeon, crow and vulture, compared with the respective tissues of chicken, cattle egret, and kite. More lindane and total HCH was found in tissues of vulture compared with other species. Total HCH detected in depot fat of crow was 29.7 ppm. Avian species thus reflect biological magnification of HCH and DDT residues, presumably due to their food habits.

A study by Misra [38] in monitoring and surveillance of pesticide pollution of Mahala water reservoir with reference to its avifauna reported relatively high levels of total organochlorine pesticide residues in Flamingo and Red-wattled Lapwing brain, as compared with other tissues. Flamingo contained 7.39 $\mu\text{g/g}$ beta HCH and 7.46 $\mu\text{g/g}$ *p,p'*-DDE in brain while Red-wattled Lapwing had 3.45 $\mu\text{g/g}$ alpha HCH, 5.82 $\mu\text{g/g}$ gamma HCH and 3.66 $\mu\text{g/g}$ aldrin in brain. Large-pied Wagtail had 5.42 $\mu\text{g/g}$ *p,p'*-DDE in the brain which are many times higher than the concentrations present in other species of birds studied. Total DDT concentrations were 2.0, 5.42 and 6.34 $\mu\text{g/g}$ in brain of Black-winged Stilt, Large-pied Wagtail and Flamingo respectively. In other tissues, total residues of DDT generally

occurred in the following order: Large-pied Wagtail > Flamingo > Black-winged Stilt > Indian Sandgrouse > Red-wattled Lapwing. Snipe had no detectable total DDT residues. Total DDT detected was 3.73, 10.53, 0.56, 0.15 and 5.05 $\mu\text{g/g}$ in liver of Black-winged Stilt, Large-pied Wagtail, Indian sandgrouse, Red-wattled Lapwing and Flamingo, respectively. The study found high correlations of organochlorine pesticides (OCPs) between breast muscle (a major component) and body tissue when the data from all the individual birds (six species) were compared and subjected to a correlation test. The total organochlorine residues levels in brain, alimentary canal, kidney, liver and ovary correlate at the 0.01 $\mu\text{g/g}$ significant levels. Brain, alimentary canal and kidney rank one, of which alimentary canal and kidney are in highest correlation.

A study on organochlorine residues in the eggs of selected colonial water birds breeding at Keoladeo National Park, Bharatpur, India [39] recorded higher concentration of dieldrin in eggs of Large Cormorant (1.54 ppm), Indian Shag (2.94 ppm), Darter (1.52 ppm), Grey Heron (5.95 ppm), Cattle Egret (2.52 ppm), Painted Stork (5.78 ppm) and Spoon Bill (1.3 ppm). As the concentration in all the eggs was higher than 1 ppm, it was suggested that the concentration would have been associated with reproductive impairment [40].

The breeding population of Sarus Crane in Keoladeo National Park, Bharatpur, has come down to six pairs as against 27 pairs in 1973 [24]. As diagnostic and circumstantial evidences prove, the cause of death of 18 Sarus Cranes between 1987 and 1988 and 1989 and 1990 to be aldrin poisoning [26], the reason for the decline in the breeding population become obvious. Brain tissue of Sarus Cranes, Collared Doves and Blue Rock Pigeons collected from Keoladeo National Park,

Bharatpur, showed an average of 19.33, 15.19 and 20.42 ppm of dieldrin respectively. Dieldrin in other tissues ranged from 0.78 ppm to 92.26 ppm in Sarus Cranes 3.44 ppm to 66.17 ppm, in Collared Doves and 16.92 ppm to 20.99 ppm in Blue Rock Pigeons. Very high residues of aldrin in the gastrointestinal tract (89.75 ppm) and dieldrin at much higher quantities in the brain than the lethal level (4–5 ppm) clearly indicate that dieldrin after being metabolized from aldrin was responsible for the death of many Sarus Cranes in Bharatpur. Himalayan Grey-headed Fishing Eagle *Ichthyophaga nana* an endangered species has been breeding unsuccessfully for the last five years in Corbet National Park in Uttar Pradesh [41]. Detection of high levels of organochlorine pesticides in the unhatched egg makes the reason all the most strong.

Higher accumulation of organochlorine in resident and migratory birds from South India was documented by Tanabe et al. [3]. Senthilkumar et al. [33, 42] measured levels of pesticides, dioxins and polychlorinated biphenyls (PCBs) in a few species of birds. Tanabe et al. [3] refers that generally the organochlorine contamination levels in individual species of birds may vary with feeding habits and the residue pattern of organochlorine in most species of resident birds analyzed followed the order of HCHs > DDTs > PCBs. He also reported that the concentrations of HCHs in resident birds of South India were in the range of 14 to 8,800 ng/g followed by DDTs ranging in concentrations from 0.3 to 3, 600 ng/g. Global comparison of organochlorine concentrations indicated that resident birds in India had the highest residues of HCHs and moderate to high residues of DDTs.

The postmortem reports of five desi birds showed that they died because of

organophosphorus insecticide poisoning [43]. On post mortem examination, slight ascites could be noticed. Hemorrhages on pericardial fat were observed. Lungs were edematous and revealed a few hemorrhages. Livers appeared congested and slightly harder in consistency. Ovarian follicles revealed moderate to severe congestion. Mucosa of proventricular and intestine were congested and revealed hemorrhages.

Death of 58 aquatic birds comprising six species has been recently reported in Okhla Bird Sanctuary, Uttar Pradesh [44] but the reason was not confirmed. Muralidharan et al. [34] reported the levels of persistent organochlorine pesticide residues in tissues of White-backed Vulture from different locations in India. The levels of DDT, HCH and dieldrin residues among other organochlorine have been detected in the tissues and eggs; none of them was indicative of either food chain buildup or poisoning leading to population decline.

A comprehensive study by Dhananjayan [35] between 2004 and 2009 reported 12% of birds studied exceeded organochlorine, PCBs and PAHs levels which are reported to be the cause of risk to birds, or to wildlife. Overall, the OCPs, PCBs and PAHs levels were ranged between below detectable limits and levels that could pose threat to birds or to animals that consume them. The highest concentrations of most of the contaminants were found in those species which are relatively higher in the food chain as vultures, kites and crows.

Dhananjayan et al. [36] reported the presence of persistent organochlorine pesticides and polychlorinated biphenyls in blood plasma of White-backed Vulture *Gyps bengalensis*, Egyptian Vulture *Neophron percnopterus* and Griffon Vulture *Gyps fulvus* collected from Ahmedabad, India. All the samples had

varying levels of organochlorine pesticides and PCBs. Statistically significant ($P < 0.05$) differences among species were detected for β -HCH, Σ HCH and Σ DDT. The mean concentration of Σ HCH, Σ DDT and total PCBs among plasma ranged from 43.7 to 136 ng/ml, 8.75 to 64.83 ng/ml and 225.5 to 585 ng/ml respectively. Among the various OCPs analyzed *p,p'*-DDE was detected most frequently. The concentrations of cyclodiene insecticides detected were less than the other organochlorine residues.

Dhananjayan and Muralidharan [45] measured the concentrations of OCPs in blood plasma of 13 species of birds collected from Ahmedabad, India. Among the various OCPs determined, HCH and its isomers had higher contribution to the total OCPs. Concentration of Σ HCHs varied from 11.4 ng/ml in White Ibis *Threskiornis melanocephalus* to 286 ng/ml in Sarus Crane *Grus antigone*, while Σ DDT ranged between 19 ng/ml in Black Ibis *Pseudibis papillosa* and 147 ng/ml in Painted Stork *Mycteria leucocephala*. *p,p'*-DDE was accounted for more than 50% of total DDT in many of the samples analyzed. However, a *p,p'*-DDT to *p,p'*-DDE ratio higher than one obtained for many species of birds indicates the recent use of DDT in this study region. The concentrations of cyclodiene insecticides, heptachlor epoxide, dieldrin and total endosulfan ranged from 12.9 to 296.2 ng/ml, below detectable level to 10.5 ng/ml and 26.2 to 153.2 ng/ml respectively. The pattern of total OC load generally occurred in the following order: granivores < insectivores < omnivores < piscivores < carnivores.

Although reductions in population of many species of birds have been reported in India, no study has attempted to figure out if pesticides were responsible. However, circumstantial evidences could point towards pesticides. Systematic studies on

the impact of pesticides on any species of bird are absent.

3. CONCLUSION

Based on the information that we have, it can be inferred that pesticides have been creating problem to various species of birds in this country. While we have proof beyond doubt for a few species of birds, there are indications in a few other cases. If the present trend continues unchecked, birds will certainly be one of the worst affected non-target organisms to pesticides. It is perhaps needless to say that agriculture occupies a place of prime importance in the economy of the entire country. However, large scale and unscrupulous use of chemical pesticides in agriculture has lead to many problems like health hazards, pollution of environment, adverse effects on non-target organisms, insecticide resistance in insects and unsustainable farming systems. The present investigation looked at the contamination levels of only the persistent organochlorines. However, there are a number of organophosphorous and carbamate pesticides being used in considerable quantum. Although these chemicals do not stay in the system for a long time, they are capable of creating ecological imbalance at various levels. It is imperative to implement stricter environmental controls in the country in order to minimize potential risk to birds, other wildlife and also to human beings.

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Status of Indian Birds and their Conservation



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Impact of Pesticides on Fish-eating Birds in Tamil Nadu

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Indiscriminate use of pesticides in modern agriculture has resulted in the presence of their residues in soil, water, air, plants and animals. Birds, due to their position in a wide range of trophic levels in different food chains, are the most affected non-targeted organisms. Effects of pesticides on wildlife, especially raptors, waterfowl and fish-eating birds have been extensively studied in European and North American countries (Chen et al. 2009). But in India, information on birds particularly fish-eating bird is very limited (Dhananjayan et al. 2011). Although, there are information available on the residue levels of pesticide residues in eggs of fish-eating and insectivorous birds in India, they fail to bring out the consequent impact on breeding success. Further, there are no studies available which investigated the residue levels in eggs and simultaneously monitored the population of birds over a period of time. Impact of pesticides on the population status and breeding success of fish-eating birds in Tamil Nadu is described.

Dead were subjected to postmortem examination at the site of collection and tissues, namely brain, liver, kidney and muscle were brought over ice to SACON and stored in deep freezer till the time of processing. About 10 g of the tissue was ground with anhydrous sodium sulphate and the mixture was packed in a thimble (Whatman), which was desiccated overnight prior to extraction to remove moisture. The desiccated thimble was extracted with 250 ml of pesticide grade hexane (Merck) in a soxhlet extractor for 6 h. The extract was condensed in a rotary flask evaporator to a specific aliquot (5 ml). The condensed aliquot was placed on a column packed with silica gel (60–120 mesh) and eluted with 250 ml of hexane. The collected elutant was again condensed in a rotary flask evaporator and stored in deep freezer at -20°C till gas chromatography analysis. Extracts with high fat contents were subjected to sulphuric acid digestion. The digested extract was filtered through sodium sulfate and evaporated with rotary flask evaporator to near dryness and residues of OCPs were reconstituted in 2 ml of hexane.

Eggs contents were weighed and placed in well cleaned and hexane-rinsed glass jars. Samples were stored in deep freezer (-20°C) until analysis. A known quantity of egg content was mixed with required amount of anhydrous sodium sulphate and ground with the help of pestle and mortar. Subsequently, celite 545 and deactivated (5% water) aluminum oxide (1:1) were added and mixed thoroughly. The resultant powder was loaded in a clean glass column (30 x 1.5 cm) for extraction and clean up. The column was eluted with 250 ml of hexane. The extract was evaporated with rotary flask evaporator to near dryness and residues of OCPs were reconstituted in 2 ml of hexane. Processed samples were stored in deep freezer (-20°C) until analysis in gas chromatograph. Samples were injected into a Hewlett Packard 5890 Series II gas chromatograph equipped with Ni63 electron capture detector (ECD). A fused silica capillary column (30 X 0.32 mm X 0.5 μ m) DB-608 (5% diphenyl and 95% dimethyl polysiloxane) was used for quantification. Chromatographic conditions were as follow; detector 300°C; injector 250°C; oven temperature was programmed as 180°C – 3 min; 4°C/min – 260°C – 15 min. All the samples were analysed for alpha-hexachlorocyclohexane (a-HCH), b-HCH, d-HCH, lindane, heptachlor epoxide (HE), dieldrin, p,p'-DDT, p,p'-DDE, p,p'-DDD, a-endosulfan, b-endosulfan and endosulfan sulfare. Spiked and duplicate samples were also analysed. Pesticide residues were analysed and quantified from individually resolved peak areas with the corresponding peak areas of standard.

Among various organochlorine pesticide residues analyzed, isomers of HCH were the maximum. Total HCH ranged between BDL in muscle of Spot-billed Pelican and 981 ppb in muscle of Indian Cormorant. Heptachlor epoxide, total endosulfan and total DDT ranged from BDL to 963 ppb, BDL to 963.3 ppb and BDL to 208.6 ppb respectively. Comparatively, low levels of

dieldrin ranging between BDL and 109.3 ppb among the tissues of birds were recorded. Concentration of total HCH, total endosulfan and dieldrin significantly ($P < 0.05$) varied among the species and location. On the whole, levels of organochlorine residues detected were higher in the tissues of wading birds such as, Cattle Egret, Little Egret, and Grey Heron than in swimming birds, namely Little Cormorant and Indian Cormorant. Higher accumulation of *p,p'*-DDT, β -HCH and total endosulfan in the tissues warrant attention. The residue levels of DDT, HCH, dieldrin, heptachlor epoxide and endosulfan in all the birds studied do not indicate any poisoning. However, while DDT and its metabolites are capable of creating reproductive abnormalities, HCH, the most predominantly detected contaminant in all the birds can be expected to create harm if the exposure level continues.

Ninety seven eggs comprising 12 species of birds including near threatened species such as Painted Stork, Spot-billed Pelican, and Black-headed Ibis were analyzed for persistent chemicals. Egg and eggshell parameters including shell index of all the species were calculated. Thickness showed negative correlation with organochlorine residues. Among various organochlorine pesticide residues analyzed, isomers of HCH were the maximum followed by total DDT, Heptachlor epoxide and total endosulfan. Total HCH ranged between 0.53 ppb in the eggs of Spot-billed Pelican and 696.6 ppb in the eggs of Little Cormorant. Among the isomers, γ -HCH contributed more than 50% of the total HCH. Total endosulfan and total DDT ranged from BDL to 84.36 ppb, 1 to 228.8 ppb respectively. Among the metabolites, *p,p'*-DDE had higher accumulation among the species. Among the cyclodiene insecticides, total endosulfan contributed more than 50%. Concentration of total DDT, HCH and endosulfan in the eggs significantly ($P < 0.05$) varied among the species and locations. Among the birds, levels of total organochlorine residues detected were high in the eggs of Little Cormorant followed by Intermediate Egret and Grey Heron, while eggs of Eurasian Spoonbill had low levels. Levels detected in these species are almost comparable with the levels reported in the eggs of select colonial water birds breeding at Keoladeo National Park, Bharatpur, India (Muralidharan et al. 1992).

To study the relation between contaminant concentration and reproductive success, a random sample egg was collected from the marked nests. The fate of the remaining eggs through incubation, hatching and the fledging of nestlings were monitored and breeding success obtained. The levels of *p,p'*-DDE detected in the current study are well below the 4–8 $\mu\text{g/g}$ thresholds associated with impaired reproduction (Henny et al. 1984). However, DDE concentration in eggs of Painted Stork and Black-headed Ibis may affect survival rate of young ones. Although the levels of DDT, HCH, Heptachlor epoxide, endosulfan and dieldrin detected in the all the species presently investigated are not capable of indicating chronic effects, may lead to several physical and physiological problems, if the exposure level increases or even remains the same. The findings of the present investigation could serve as baseline information for future research.

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