Research Articles

Accumulation of Organochlorine Pesticides and Polychlorinated Biphenyls

in Sediments, Aquatic Organisms, Birds, Bird Eggs and Bat Collected from South India

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Abstract. Concentrations of polychlorinated biphenyls (PCBs), DDT and its metabolites (DDTs), HCH isomers (HCHs), chlordane compounds (CHLs) and hexachlorobenzene (HCB) were determined in sediment, soil, whole body homogenates of resident and migratory birds and their prey items (including fish, green mussel, snail, earthworm, crabs, prawn, lizard and frogs), bird eggs and bats collected from southern India during 1995 and 1998. Accumulation pattern of organochlorines (OCs) in biota was, in general, in the order, HCHs > DDTs > PCBs > CHLs=HCB. Magnitude of OC concentrations increased in the order of sediments < green mussel < earthworm < frog < lizard < fish < bird egg < bats < birds tissues. Biomagnification features of OCs were examined in resident and migrant birds to evaluate the exposure levels of these chemicals in wintering grounds of migrant birds. Accumulation of DDTs in migratory birds during wintering in India may be of concern due to the great biomagnification potential of DDTs. Eggs of some resident species contained noticeable concentrations of OCs. Concentrations of OCs in three species of bats analyzed in this study were lower than that found in passerine birds. In addition to OCs, butyltin compounds were also detected at low concentrations in bats.

Keywords: Aquatic biota; bat; biomagnification factor; bird egg; birds; butyltin compounds; crab; earthworm; fish; frog; green mussel; lizard; migrant birds; organochlorine pesticides; PCBs; polychlorinated biphenyls (PCBs); prawn; resident birds; sediments; snail; transformer soil

Introduction

Usage of organochlorine pesticides such as DDT [1,1,1-trichloro-2,2-bis(*p*-chorophenyl) ethane], HCHs (hexachlorocyclohexane isomers), chlordanes (CHLs) in tropical Asian countries has been considered with concern [1-3]. Effects of some of these organochlorines (OCs) on fish-eating water birds and marine mammals have been documented in developed nations in North America and Europe [4-6]. Despite the continuing usage, little is known about the impacts of OCs in bird populations in developing countries. Among those countries that continue to use OCs, India is one of the major producer and consumer in recent years. In view of this, there is likelihood that wild birds in India are exposed to great amounts of OC pesticides [7]. Use of OCs in tropical countries may not only result in exposure to resident birds but also migratory birds when they visit tropical regions in winter. Indian sub-continent is a host to a multitude of birds from western Asia, Europe and Arctic Russia in winter [8]. Hundreds of species of waterfowl including wading birds such as plovers, terns and sandpipers migrate each winter to India covering long distances [9].

Similar to the effects of OC pesticides on bird populations, a few studies have related decline in the populations of bats in various parts of the world to OC exposure [10-16]. The world population of bats was estimated to be 8.7 million during 1936, which declined to approximately 200,000 in 1973 [10] and has recovered slightly to an estimated number of 700,000 in 1991 [10,16]. High tissue concentrations of *p,p'*–DDE have been found in bats in Carlsbad Caverns in Mexico and New Mexico in the USA [10,16]. Occurrence of stillbirths in little brown bats exposed to high concentrations of PCBs, *p,p'*–DDE, and/or oxychlordane has been shown [14,15]. These observations indicate that bats can accumulate high concentrations of OCs and may be affected by their potential toxic effects. The flying fox or the new world fruit bat, short-nosed fruit bat and Indian pipistrelle bat are resident species and are very common in South India. Their habitat is mainly agricultural areas, rock caves, and abandoned houses in domesticated areas. Insects constitute an important diet for many bats, allowing the passage of OCs in their body [17].

Several studies have measured OC pesticides and polychlorinated biphenyls (PCBs) in livers and eggs of birds in developed countries [18-23]. Similarly, several studies have reported OCs in a variety of biota including humans and wildlife from India [24-30]. However, no study has used whole body homogenates of birds, which is important to evaluate biomagnification features and body burdens of OCs [17]. Earlier studies have used specific body tissues to estimate biomagnification of OCs. However, theoretically, estimation of biomagnification factors requires whole body concentrations rather than specific tissue concentrations.

In addition to OCs, butyltins (BTs=MBT+DBT+TBT) are also used in various industrial and household applications and are persistent in the environment. Municipal waste and domestic sewage are a source of BTs in the environment [31-34]. Our earlier study has reported the occurrence of low concentrations of BTs in bird tissues from India [33]. In this study, in addition to OCs, BTs were also measured in bat tissues.

While concentrations OC pesticides in wholebody homogenates of birds have been reported elsewhere [7], concentrations of OCs in prey items and in eggs of Indian birds are not reported. **The objectives** of the present study were,

1) to determine the accumulation of OC pesticides and PCBs in wholebody homogenates of birds and their prey items,
2) to evaluate biomagnification factors (BMFs) using whole body homogenate concentrations of OCs in birds and their major diet,
3) to determine the concentrations of OCs in eggs of resident birds and to calculate transfer rates of OCs through eggs
4) to determine concentrations of BTs and OCs in bats.

In this study, migratory species were grouped into four categories depending on their migratory routes and breeding grounds and are represented by 4 to 13 species with 1 to 6 individuals each. Due to the small number of samples from each species, our comparisons are limited to classes of birds rather than individual species.

1 Materials and Methods

1.1 Samples

All the samples were collected in agricultural areas in south India. Resident and migratory birds (n=92) and 3 species of bat (n=15) were collected from wetland and coastal areas of Porto Novo, Cuddalore, Pudukottai and Mandapam in Tamil Nadu State during November and December 1995 (**Fig. 1**).

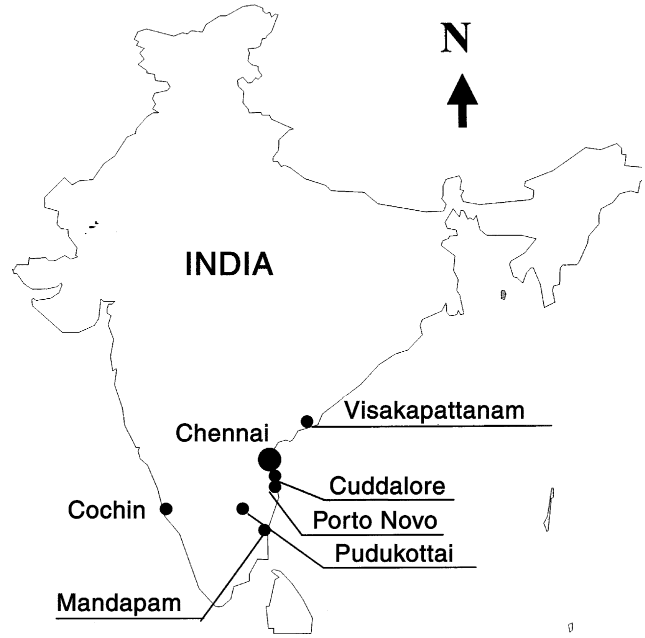

Fig. 1: Map of India showing sampling locations.

A few bats were collected in March 1998 (**Table 1**). The prey items of birds such as, fishes (rainbow sardine, Indian anchovy, round-belly sardine, Java tilapia, swall sp., and mullet), snails (cone and bell snails), green mussel, prawn, earthworm, frog, crabs (black-rice crab and brick red box crab) and lizard were collected from Porto Novo and Cuddalore in March 1998 (**Table 2**). Eggs of some resident birds were obtained in and around Porto Novo during June-August 1997 and March 1998 (**Table 3**). Sediment and soil samples were collected in Ennore (Chennai, Tamil Nadu), Cochin (Kerala) and Visakapattanam (Andra Pradesh) in March 1998 (Fig. 1). Some soils were collected under high voltage electric transformers.

Table 1: Biometric data and ecological characteristics of resident and migratory birds and bats collected from India from November and December, 1995.

Species (Scientific name)	n	TW* (g)	SL* (cm)	Site[$]	Habitat during migration#	Main food during wintering#
Strict Residents						
Black-winged kite (Elanus caeruleus)	1	232	30.1	2	Village, cultivation, jungles	Small birds, mice, lizards, frogs, snails
Brahminy myna (Sturnus pagodarum)	1	50	19	1	Gardens, towns, villages	Berries, pigs, insects
Brain-fever bird (Cuculus varius)	1	103	31.5	2	Scrub jungle, agriculture fields	Insects, worms, nectar, fish
Common swallow (Hirundo rustica)	1	15	14.2	2	Near standing water, thickets	Flies, midges
Cotton teal (Nettapus coromandelianus)	2	318 (301-335)	39 (39)	4	Inland waters, jheels, rain-filled ditches	Crustacean, insects, vegatable matter
Crested kingfisher (Ceryle rudis)	1	79.4	25.3	2	Streams, rivers, ponds	Cheifly fish, tadpoles, water insects
Crimson-crested barbet (Megalaima haemalephala)	1	36	14	2	Light forests, groves, gardens	Fruits, berries, insects
Dabchick (Podiceps ruficollis)	1	163	28.4	4	Marshes, jheels, mudflats	Frogs, crustacean, insects, tadpoles
Indian roller (Coracias benghalensis)	1	126	29.5	2	Open forest, jungles, cultivation	Beetles, insects
Indian tree pie (Dendrocitta vagabunda)	1	95	35	2	Groves, country side, foot hills	Figs, fruits, bats, small birds
Koel (Eudynamys scolopacea)	1	180	35	2	Open forest, scrub jungles, villages	Fruits, berries, insects, catterpillar
Little egret (Egretta garzetta)	1	415	74.3	4	Marshes, jheels, tidal mudflats	Mollucs, frogs, reptiles, snails
Magpie robin (Copsychus saularis)	1	31	17.3	2	Plains, hills, woodlands	Beetles, insects

Table 1: Biometric data and ecological characteristics of resident and migratory birds and bats collected from India from November and December, 1995. (cont'd)

Species (Scientific name)	n	TW* (g)	SL* (cm)	Site$	Habitat during migration#	Main food during wintering#
Pond heron (Ardeola grayii)	2	212 (203-221)	53 (52-53)	1&4	Water, river, well, swamps, mudflats	Frogs, fish, crabs, insects
Spotted owlet (Athene brama)	2	133 (131-135)	20 (19-21)	1	Deciduous forest, coastal areas	Small mammals, fish, frogs, lizards
White-breasted kingfisher (Halcyon symrnensis)	1	77.2	25.7	1	Ponds, puddles, rain-filled ditches	Fish, tadpoles, lizards, insects
White-breasted waterhen (Amaurornis phoenicurus)	1	205	36	4	Moist grounds, tangles, bushes	Molluscs, insects, worms, grains
Local Migrants						
Black-winged stilt (Himantopus himantopus)	1	175	58	4	Marshes, jheels, village salt pans	Molluscs, snails, worms, insects
Kentish plover (Charadrius alexandrinus)	5	31 (28-35)	16 (15-17)	1	Sea coasts, saline lakes, lagoons	Crustaceans, molluscs, insects
Little pranticole (Glareola lactea)	1	44	21	1	Rivers, streams	Beetles, bugs, termites, flies
Little-ringed plover (Charadrius dubius)	5	30 (27-32)	16 (15-17)	1	Coastal areas, seashores, mudflats	Crustaceans, crabs, insects, fish
Short-distance Migrants						
Common greenshank (Tringa nebularia)	2	139 (127-150)	31 (31)	3	Taiga zone, marshes, woody areas	Molluscs, crustaceans, cheifly insects
Common red shank (Tringa totanus)	5	104 (88-118)	30 (28-34)	3	Seashore rocks, water surfaces	Molluscs, insects, worms, grains
Crab plover (Dromas ardeola)	1	237	41	3	Islands, sandy coastlines, lagoons	Crabs, crustaceans, molluscs
Great knot (Calidris tenuirostris)	1	14	38	3	Sandflats, lagoons, harbors, estuaries	Bivalves, annelids, crustaceans
Green sandpiper (Tringa ochropus)	1	19	15	1	Wooded areas, river, swamps	Aquatic and terrestrial insects
Gull-billed tern (Gelochelidon nilotica)	2	171 (156-185)	41 (41)	3	Coastal areas, wet lands	Crustaceans, fish, insects, crab
Long-billed Mongolian plover (Charadrius mongolus)	6	66 (60-69)	20 (19-20)	1	Inland marshes, river, coastal areas	Insects, small crabs, small fish
Pintail snipe (Gallinago stenura)	1	95	29	3	Drier areas, marshes, river	Molluscs, insects, earthworms
Sandwich tern (Thalasseus sandvicensis)	2	210 (205-215)	41 (40-42)	3	Coastal areas, wet lands	Crustaceans, fish, insects, crab
Short-toed lark (Calandriella cinerea)	3	21 (18-23)	15 (15)	1	Villages, marshes, inland rivers	Insects, grains
White-cheeked tern (Sterna repressa)	5	94 (88-108)	37 (35-38)	1&3	Coastal areas, open sea, marshes	Fish, prawn, molluscs, crabs
Whiskered tern (Childonias hybrida)	1	77	28	2	Inland lakes, lagoons, farm lands	Small crabs, frogs, fish, insects
Wood sandpiper (Tringa galreola)	1	113	26	2	Peatlands, open swamps, boreal forest	Molluscs, larvae, worms, insects
Long-distance Migrants						
Bartailed Godwit (Limosa lapponica)	1	237	41	3	River valleys, scrub, tundra	Molluscs, annelids, insects, seeds
Common sandpiper (Actitis hypoleucos)	5	43 (39-45)	19 (18-20)	1	Seashore, river banks, water surfaces	Molluscs, insects, worms
Curlew sandpiper (Calidris ferruginea)	5	51 (44-61)	21 (20-22)	3	Sandy flats, estuaries, lagoons	Molluscs, crustaceans, shrimps, insects
Golden plover (Pluvialis fulva)	1	107	25	2	Coastal areas, salt-marshes, grasslands	Molluscs, worms, crustaceans
Gray plover (Pluvialis sequatarola)	2	203 (200-205)	31 (30-31)	3	Mud-flats, beaches, lakes and pools	Molluscs, crustaceans, shrimps, insects
Lesser-crested tern (Thalasseus benghalensis)	5	189 (177-196)	41 (39-43)	3	Opean sea, shore lines	Fish, prawns
Lesser-golden plover (Pluvialis dominica)	2	119 (115-122)	25 (25)	1	Marshes, grass fields, salty-marshes	Molluscs, worms, crustaceans
Terek sandpiper (Xenus cinereus)	3	51 (51)	25 (23-26)	1&3	Coastal areas, marshes, river banks	Sand insects, tadpoles, crabs, fish
White-winged tern (Chlidonias leucopterus)	5	34 (29-39)	24 (23-25)	1&3	Marshes, coastal wet lands, tidal creeks	Insects, crabs, small fish, tadpoles
Bats						
Flying fox/ New world fruit bat (Pteropus marianus)	1	30	8,0	1	Rice fields, gardens, abandoned houses	Insects, fruits, nectar
Indian pipistrelle bat (Pipistrellus pipistrellus)[!]	11	37 (34-39)	9.8 (9.2-10.5)	1	Rice fields, gardens, abandoned houses	Insects, small fishes, rat, garbage
Short-nose fruit bat** [(UI)]	3	36 (33-39)	8.8 (8.5-9.1)	1	Rice fields, gardens, abandoned houses	Fruits, nectar, plant materials, insects

$ = collection sites 1, 2, 3 and 4 represents, respectively, Porto Novo, Cuddalore, Mandapam and Pudukottai (Figure 1)
* TW and SL denotes total body weight and standard length; # suitable only for short- and long-distant migrants
** = samples were also collected in March 1998. UI = unidentified; Figures in parentheses represent range.

Table 2: Biometrical data of bird diet samples collected from south India in 1995 and 1998.

Sample (Scientific name)	n	TW[1] (g)	SL[2] (cm)
Rainbow sardine (Dussumieria elopoides)	5	17.5 (10.2-20.9)	12.8 (10.9-14.3)
Indian anchovy (Stolephorus indicus)	4	14.20 (13.6-15.0)	12.6 (12.1-13.1)
Round-belly sardine (Amblygaster clupeoides)	3	38 (20-57)	15.9 (12.1-19.8)
Java thilapia (Thilapia mossambica)	4	21.9 (10.5-35.9)	10.4 (8.7-12.5)
Dwarf prawn (Macrobrachium equidens)	25	8.3 (4.1-12.3)	1.56 (0.9-2.7)
Brick red box crab (Calappa philagrius)	5	13.1 (5.8-27.7)	6.5 (4.3-8.5)
Black-rice crab (Somanniathelpusa sp.)[4]	26	1.8 (1.4-2.5)	1.24 (0.33-1.77)
Cone snail (Augur territella)	25	2.4 (1.1-3.8)	0.51 (0.31-0.69)
Bell (apple) snail (Pila ampullacea)	11	4.14 (1.63-16.3)	2.1 (1.1-4.1)
Tiger frog (Rana tigrina)	3	16.2 (8.3-23)	11.5 (10.8-11.9)
Calotus (Lizard)[3]	4	23.6 (17.1-28.4)	26.1 (18-36.1)
Earthworm[3,4]	NM	NM	NM
Green mussel (Perna viridis)[4]	12	13 (5.5-26.9)	4.2 (3.3-4.8)
Fish pool (Swall, mullet, sardine, anchovy pool)[4]	17	9.8 (5.5-15)	7.8 (5.6-10)

[1] and [2] total weight and standard length, respectively; values in brackets denote range.
n = number of individuals pooled and homogenized
[3] = unidentified; NM = not measured; [4] indicates samples collected in March 1998.

Table 3: Details of bird egg samples collected from India during July-August, 1997 and March, 1998.

Bird egg (Scientific name)	n	Egg weight (g)	Shell weight (g)	Egg length (cm)	Egg width (cm)	Total egg weight (g)
House crow	2	7.6	1.56	3.76	2.56	9.45
(Corvus splendens)		(7.58-7.62)	(1.50-1.61)	(3.56-3.95)	(2.54-2.57)	(9.29-9.60)
House crow 1998*	2	7.09	1.8	3.99	2.42	9.03
(Corvus splendens)		(6.99-7.18)	(1.71-1.89)	(3.93-3.99)	(2.36-2.48)	(8.90-9.15)
Red jungle fowl	2	42.2	6.52	5.59	4.18	48.9
(Gallus gallus)		(42.2-42.2)	(6.23-6.80)	(5.59-5.59)	(4.17-4.18)	(48.7-49.2)
Turkey	2	45.2	6.36	5.87	4.25	53.2
UI		(44.7-45.7)	(6.18-6.53)	(5.75-5.98)	(4.25-4.25)	(51.3-55.1)
Spotted dove	1	7.17	1.19	3.13	2.45	8.94
(Streptopelia chinensis)						
Spotted dove 1998*	2	7.68	1.27	3.84	2.2	8.8
(Streptopelia chinensis)		(7.51-7.85)	(1.21-1.33)	(3.69-3.78)	(2.13-2.26)	(8.68-8.91)
Collard dove	2	2.94	0.47	2.24	1.95	3.47
(Streptopelia decaoto)		(2.7-3.2)	(0.43-0.50)	(2.23-2.25)	(1.95-1.95)	(3.19-3.74)
Blue rock pegion	3	3.48	1.05	2.48	2	4.6
(Columbia livia)		(2.91-4.46)	(0.81-1.36)	(2.44-2.56)	(1.95-2.08)	(3.84-5.43)
Baya weaver	10	0.99	0.41	2	1.43	1.7
(Ploceus philippinus)		(0.44-1.54)	(0.20-0.60)	(1.64-2.30)	(1.27-1.58)	(1.18-2.03)
Sparrow	13	1.19	0.34	2.03	1.44	1.83
(Passer domesticus)		(0.85-1.64)	(0.19-0.63)	(1.92-2.20)	(1.39-1.49)	(1.45-2.55)
White wagtail	1	1.94	0.61	2.1	1.19	2.88
UI						

* denotes samples collected in March 1998
UI = unidentified; Values in parentheses indicates range

1.2 Sampling

Sediments were sampled by a grab sampler and stored in clean polyethylene bags until freeze-dried for analysis. Fresh fishes, prawn, crab, snails and green mussel were obtained from local fishermen. Lizard and frogs were collected from nomadic tribes. Earthworm and a species of crab were collected from paddy fields. Most birds were trapped by mist net, while few of them were obtained from nomadic tribes. Bat samples were collected using nets at abandoned houses located in and around Porto Novo. Egg samples were collected randomly in selected nests of passerine species that are abundant in the region. Immediately after collection, samples were iced, transported to laboratory and shipped to Japan in frozen condition. The biometric data (ecology, standard length and weight) of the samples were recorded prior to analysis. Birds were feathered and wholebody was homogenized using a homogenizer. All the samples were stored at -20°C until analyzed. For eggs, only yolk was used for analysis after measuring shell weight, shell width and length.

1.3 Classification of birds based on migratory routes

Bird species analyzed in this study were grouped into four categories, based on their migratory behavior, [35] for further discussions;

(1) *strict residents*; living in the same region all year for their entire life span,
(2) *local migrants*; which migrate only between Himalaya and south Indian regions,
(3) *short-distant migrants*; those breeding in central Asia (e.g., common green shank, green sandpiper, whiskered tern), central Russia (pintail snipe), southern Russia (sandwich tern), central China (common redshank, short-toed lark), Gulf of Oman (crab plover), eastern Russia (great knot, long-billed Mongolian plover), southern Europe (wood sandpiper) and middle east (gull-billed tern, white-cheeked tern),
(4) *long-distant migrants*; which have their breeding grounds in northern Europe (e.g., bar-tailed godwit, golden plover, lesser-golden plover), eastern to southeastern Russia (white-winged tern and terek sandpiper), western Europe to eastern Russia (common sandpiper), Arctic Russia (curlew sandpiper, gray plover) and Middle east, Papua New Guinea and Australia (lesser-crested tern).

1.4 Organochlorine analysis

For birds, whole body homogenates were used. For bat, fishes, prawn, earthworm, frog and lizard, whole body was used. For crab, green mussel and snail, edible tissues (after shelling) were used. Details of OC analysis in biological samples have been described elsewhere [36]. Sediment and soil samples were analyzed following the method described previously [37]. Tissues were homogenized with anhydrous sodium sulphate and Soxhlet extracted with a mixture of 300 mL diethyl ether and 100 mL hexane for 7 h. After Kuderna-Danish (K-D) concentration, 1 mL of the aliquot was dried at 80°C to determine lipid content. The remaining extract was transferred to a 20 g Florisil (Floridin Co. USA) packed dry column (15 mm i.d. X 26 mm), and the solvents were dried by a gentle flow of nitrogen. OCs absorbed on Florisil were eluted with a mixture of 120 mL acetonitrile and 30 mL water, transferring the elute to a separatory funnel containing 600 mL of water and 100 mL of hexane. After partitioning, hexane layer was concentrated to 6 mL and then cleaned with equal volume of concentrated sulphuric acid. The cleaned extract was fractionated by passing through a 12 g of wet Florisil column eluting with hexane (90 mL; first fraction) and then with 20% dichloromethane in hexane (150 mL; second fraction). The first fraction contained PCBs, HCB, *p,p'*-DDE and *trans*-nonachlor while second fraction contained *p,p'*-DDT, *p,p'*-DDD, HCH isomers (α-,β-,γ- and δ-), *cis*-nonachlor, *cis*-chlordane, *trans*-chlordane and oxychlordane. Each fraction was concentrated and injected into a gas chromatograph equipped with a ^{63}Ni electron capture detector (GC-ECD) for the identification of OCs.

Soil and sediment samples were ground and passed through a 500 µm sieve. Twenty gram of soil or sediment was mixed with 20 mL of water (hexane-washed) in a 250 mL Erlenmeyer flask and allowed to soak for 30 min. The samples were extracted with 200 mL of acetone by shaking for 1 hr. The supernatant was decanted into a 1 L separatory funnel containing 100 mL of hexane and 600 mL of water. The separatory funnel was shaken and the hexane layer was concentrated using a K-D concentrator. The K-D extracts were cleaned with concentrated sulphuric acid and subjected to silica gel (Wako gel S-1) column chromatography. The fractionation step described above was followed for sediments and soil. Activated copper chips were used to remove sulphur in sediment and soil extracts.

Identification and quantification of OCs were performed by injecting an aliquot of the final extract into a GC-ECD (Hewlet-Packard 5890 series II with a moving needle-type injection system). The capillary column consisted of (30 m X 0.25 mm i.d.), DB-1 (100% dimethyl polysiloxane) stationary phase (J&W Scientific Co., USA) at 0.25 µm thickness. The oven temperature was programmed from 60°C (1 min hold) to 160°C (10 min hold) at a rate of 20°C/min and then to 270°C (15 min hold) at a rate of 2°C/min. Injector and detector temperatures were kept at 250°C and 300°C, respectively. Helium was used as a carrier gas while nitrogen was the make-up gas. An equivalent mixture of Kanechlors 300, 400, 500 and 600 with known PCB composition and content was used as a standard. Concentrations of individually resolved peaks of PCB isomers and congeners were summed to obtain total PCB concentrations. OC pesticides were quantified by comparing individual peak area of the sample to the corresponding peak area of the standard.

Recoveries of OC pesticides and PCBs in fortified samples were between 90 and 110% (n=3). Procedural blanks were analyzed with every set of 5 samples to check for cross contamination and to correct sample values, if needed. The detection limit was 0.1 ng/g for OC pesticides and 1 ng/g for total PCBs. The concentrations of OCs and PCBs in tissues are expressed on a wet wt basis, whereas in soil and sediment on a dry wt basis. Concentrations in egg yolk are on a lipid weight basis. DDTs represent the sum of *p,p'*-DDE, *p,p'*-DDD and *p,p'*-DDT while CHLs include *cis*-chlordane, *trans*-chlordane, *cis*-nonachlor, *trans*-nonachlor and oxychlordane. HCHs include α-,β-,γ- and δ- isomers.

1.5 Butyltin analysis

Butyltin compounds were analyzed in whole body homogenates of bats following the method described elsewhere [33]. Approximately 2 g of homogenized whole body soft tissue was extracted twice with 70 mL of 0.1% tropolone-acetone and 5 mL of 2N HCl. The extract was then transferred to 0.1% tropolone-benzene, and the moisture in the solvent was removed with anhydrous Na_2SO_4. BTs were propylated by adding *n*-propylmagnesium bromide as a Grignard reagent. After breaking the excess of Grignard reagent with 2N H_2SO_4, BTs were transferred to 10% benzene/hexane and subjected to a dry Florisil column. BTs adsorbed on the Florisil were eluted with 20% water/acetonitrile to remove lipid. The elute was then subjected to a wet Florisil column for further purification.

Samples were analyzed for MBT, DBT and TBT using a gas chromatograph equipped with a flame photometric detector (GC-FPD). Chromatographic separation was performed on a Hewlett-Packard 5890 series II gas chromatograph with a 30 m X 0.25 mm (i.d.) DB-1 capillary column coated at 0.25 µm film thickness. Butyltin trichloride, dibutyltin dichloride and tributyltin chloride of known amount (0.1 µg each) spiked into Minke whale liver were concurrently run through the whole analytical procedure and the propylated mixture was used as an external standard. Concentrations were quantified by comparing peak heights of BTs in samples with those in the external standards. The detection limits of MBT, DBT and TBT in tissues were 3.0, 2.0 and 1.0 ng/g wet wt, respectively. The recovery rates (n=4) for MBT, DBT and TBT were 99±17, 119± 9 and 92± 9%, respectively. All results refer to butyltin species as cations and they were corrected for the recovery of the internal standard.

1.6 Biomagnification Factor (BMF)

Biomagnification factor (BMF) of OCs in birds was calculated using the following formula:

$$\text{BMF} = \frac{\text{Concentrations of OCs in wholebody homogenates of birds}}{\text{Concentrations of OCs in wholebody of the prey items of birds}}$$

For this calculation, it was assumed that the analyzed prey items contributed to 100% of the diet of birds. The major prey items of each bird species are shown in **Table 1**. In order to reduce uncertainties, BMF was calculated only for the birds collected from Porto Novo and Cuddalore since the availability of the prey items was limited to the these locations.

2 Results and Discussion

2.1 Concentrations of OCs

2.1.1 Soil, sediment and prey items of birds

Concentrations of PCBs, HCHs and DDTs were in the ranges of <1-120, <0.1-4.8, <0.1-35 ng/g, dry wt, respectively (**Table 4**). High concentrations (120 ng/g) of PCBs were found in soils collected under the transformer. A few earlier studies have reported [37-39] similar concentrations of OC pesticides and PCBs in soils collected in South India. Earthworm is an indicator of soil pollution by OC pesticides. Earthworms collected in rice fields in Porto Novo contained all analyzed OCs at less than 10 ng/g.

Concentration of OC pesticides and PCBs in green mussels and cone snails were relatively low (Table 4). However, bell snails contained the highest concentrations of HCHs (4100 ng/g wet wt) than in any other biological samples analyzed

Table 4: Concentrations of PCBs and organochlorines pesticides in sediment, earthworm, aquatic biota and lizard collected from south India.

Sample name	Fat (%)	PCBs	HCHs	DDTs	CHLs	HCB
Sediments and soil			ng/g dry wt			
Chennai (Kasimedu)		ND	0.1	<0.1	<0.04	ND
Chennai (Ennore)		2.0	2.1	35	0.8	<0.05
Cochin		2.0	4.8	3.8	0.37	<0.01
Visakapattanam		1.8	0.21	<0.1	ND	0.2
Transformer soil*		120	1.6	<0.1	0.5	0.12
Aquatic biota			ng/g wet wt			
Rainbow sardine	7.71	12	41	12	0.31	0.1
Indian anchovy	2.52	7.8	6.4	43	0.2	<0.01
Round-belly sardine	9.59	17	68	14	0.3	0.1
Java thilapia	9.89	17	2000	18	1.31	<0.03
Dwarf prawn	0.82	11	20	0.9	<0.03	<0.03
Brick red box crab	3.8	17	300	42	3.7	0.21
Black-rice crab*	2.81	3.3	4.8	6.3	0.41	0.24
Cone snail	0.42	12	25	1.1	0.5	ND
Bell (apple) snail	0.73	4.8	4100	1.1	1.51	0.22
Tiger frog	1.74	4.3	17	0.8	ND	ND
Calotus (Lizard)	2.1	7.9	28	0.7	0.11	0.1
Earthworm*	2.86	9.5	7.5	6.3	0.43	0.2
Green mussel*	1.21	1	6.6	15	0.52	0.18
Fish pool*	1.71	1.7	6.7	1.5	ND	<0.01

* indicates sample collected in 1998; ND = not detected

in this study. A study conducted in Florida, USA, reported undetectable concentrations of several OC pesticides in snails [40]. Consistent with great concentrations of HCHs in bell snails, little egret and black-winged stilt, which feed on bell snail contained greater concentrations of HCHs.

Brick red box crab contained relatively higher concentrations of OC pesticides and PCBs than in black-rice crab, prawn and frog (Table 4). Concentrations in these organisms that are often associated with sediments were higher than in bell snails and green mussels. The concentrations of OCs in crabs were 2 to 3-fold higher than those reported in our earlier studies for the samples collected during 1987-90 [26,29].

The concentrations of OCs in fishes were comparable or higher than those found in sediments, green mussel, snails, crabs, prawn, frog and lizard (Table 4). Elevated concentrations of OCs were noticed in Java tilapia. The concentrations of HCHs in tilapia were 20-30 times higher than that found in several species of birds, but 2-fold less than in bell snail. Similar to that in crabs, concentrations of HCHs in fishes were greater than those reported earlier for the samples collected during 1987-91 [26-29]. These results imply continuing usage of HCH in Indian agriculture. The concentrations of OCs in lizard were similar to that found in cone snail and prawn [26].

2.1.2 Bat

Organochlorine pesticides and PCBs were found in bats collected in 1995 and 1998 (**Table 5**). OC contamination pattern varied slightly among the 3 species. HCHs or DDTs were the predominant contaminants in bats and PCBs were the third most abundant in all the bats. Concentrations of CHLs and HCB were minimal. The observed variations in OC contamination pattern among the 3 species may be due to the differences in age or sex or habitat. In general, Indian pipistrelle bat contained higher concentrations of OCs than short-nosed fruit bat and flying fox. Greater concentrations of OCs in Indian pipistrelle bat can be explained by its habitat dominated by agricultural fields, aquatic bodies and domestic areas where the application of DDTs or HCHs for agricultural and vector control purposes are common. In addition, Indian pipistrelle bat feeds on insects, domestic wastes and fish, while flying fox and short-nosed fruit bat feed mainly nectar, plant materials, insects and fruits. Similar concentrations of HCHs and DDTs but greater concentrations of PCBs have been reported in bats from Spain [41,42] (**Fig. 2**). Indian pipistrelle bat also contained noticeable concentrations of PCBs, which were greater than those observed in resident birds. The concentrations of OCs in bats collected in 1998 were greater than those collected in 1995.

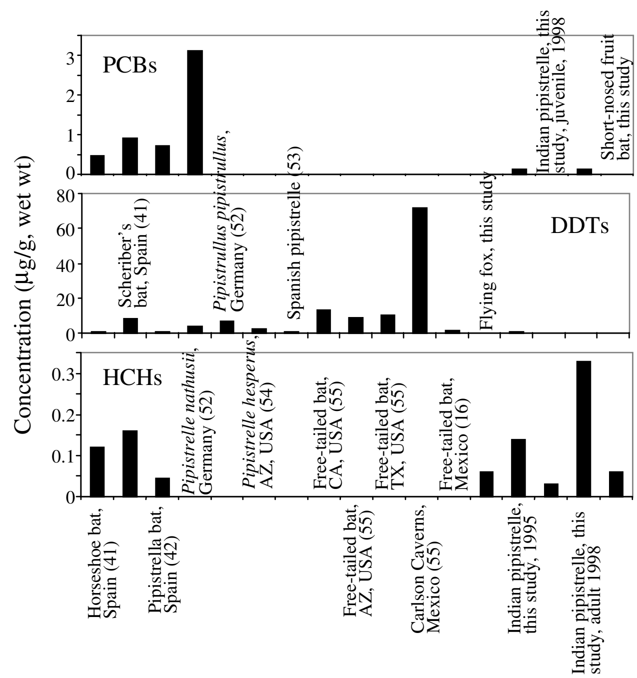

Fig. 2: Comparison of concentrations of PCBs, DDTs and HCHs found in bats from different countries. *The numbers in parentheses correspond to respective literature.

Concentrations of HCHs and DDTs observed in bats, in general, indicate considerable exposure to these compounds. Cumulatively, India is the largest producer and consumer of HCHs in the world [30,43,44]. Under the National Malaria Eradication Program of India, 85% of the DDT produced in this country is used for the vector control while a major proportion of HCHs is used in agriculture [45].

Concentrations of BTs in bats were in the range of 12-36 ng/g, wet wt (Table 5). BT compounds were not detected in immature pipistrelle bats collected in 1998. Flying fox and short-nosed fruit bat contained lower, but similar concentrations (18 ng/g). The major source of BTs in bats could be from household articles and domestic wastes that contain butyltins as heat or light stabilizers or biocides in a variety of appliances [46].

Table 5: Concentrations of PCBs and organochlorine pesticides and butyltin compounds in bats collected from India.

Sample name	n	Fat (%)	PCBs	HCHs	DDTs	CHLs ng/g wet wet	HCB	BTs*
Flying fox or new world fruit bat	1	7.91	8.3	58	24	0.1	0.4	18
Indian pipistrelle bat 1995	4	7.86	130	140	390	1.4	3.4	20
		(5.05-11.3)	(27-230)	(120-150)	(78-670)	(0.9-2.1)	(0.1-5.6)	(12-28)
Indian pipistrelle bat, 1998	5	3.56	5.3	29	16	<0.03	<0.05	ND
New born (juvenile)		(2.23-4.93)	(3.8-6.1)	(24-38)	(10-21)	(<0.01-<0.05)	(<0.03-<0.05)	
Indian pipistrelle bat, 1998	2	10	130	330	30	0.8	0.5	33
adult		(9.7-10.3)	(44-210)	(280-370)	(14-45)	(0.3-1.3)	(0.5-0.5)	(29-36)
Short-nosed fruit bat	3	4.51	19	62	3.7	0.2	0.13	18
		(4.34-4.63)	(6.8-33)	(18-150)	(0.4-10)	(0.1-0.3)	(0.1-0.2)	(15-21)

* BTs = MBT+DBT+TBT

ND = not detected; values in parentheses indicate range.

2.1.3 Birds

OC pesticides and PCBs were detected in all wholebody homogenates of resident, local migrant, short- and long-distance migrant birds (**Table 6**). Residue pattern of OCs in most resident birds followed the order, HCHs>DDTs>PCBs>CHLs=HCB. Concentrations of HCHs in resident birds were in the range of 21-8800 ng/g whereas those of DDTs ranged from 0.8-3400 ng/g. This feature is similar to that reported earlier [7,24-30,47] and is reflective of the concentrations found in prey items of birds. PCB concentrations in spotted owlet, a

Table 6: Concentrations of PCBs and organochlorine pesticides (ng/g wet wt) in resident and migratory birds collected from south India.

Species	n	Fat (%)	PCBs	HCHs	DDTs	CHLs	HCB
Strict Residents							
Black-winged kite	1	11.2	29	1900	640	0.6	4
Brahminy myna	1	4.8	63	43	7.5	<0.1	0.3
Brain-fever bird	1	20	14	43	150	0.43	0.39
Common swallow	1	8.06	82	440	100	0.4	0.4
Cotton teal	2	11.6 (11.4-11.7)	20 (20)	120 (72-160)	67 (48-85)	<0.1 (<0.1)	0.2 (0.2)
Crested kingfisher	1	8.5	160	310	290	<0.1	0.3
Crimson-crested barbet	1	6.09	35	21	0.8	<0.1	<0.1
Dabchick	1	5.1	36	210	83	0.2	<0.1
Indian roller	1	7.6	24	720	89	<0.1	0.4
Indian tree pie	1	9.9	27	230	61	<0.1	0.2
Koel	1	5.9	6.5	26	1.3	ND	<0.1
Little egret	1	12	33	8800	970	0.3	1.2
Magpie robin	1	2.9	44	390	41	<0.1	<0.1
Pond heron	2	13.1 (10.2-16.3)	44 (22-65)	1100 (1100)	3400 (3100-3600)	2.9 (1.5-4.3)	1.0 (0.9-1.1)
Spotted owlet	2	5.9 (4.3-7.5)	870 (790-940)	1200 (1100-1200)	390 (360-420)	8.8 (5.5-12)	0.2 (0.1-0.2)
White-breasted kingfisher	1	9.9	40	420	410	0.4	0.3
White-breasted waterhen	1	5.2	23	840	170	ND	0.2
Local Migrants							
Black-winged stilt	1	15.9	30	4100	510	0.6	2
Kentish plover	5	9.1 (7.6-11)	150 (69-300)	450 (280-590)	210 (67-330)	1.0 (0.6-1.3)	<0.8 (<0.1-1.4)
Little pranticole	1	12.3	150	160	350	1.5	0.7
Little-ringed plover	5	7.6 (7.3-8.9)	210 (40-640)	1000 (390-1400)	4400 (760-13000)	1.4 (0.8-2.3)	0.4 (0.3-0.5)
Short-distant Migrants							
Common greenshank	2	12.2 (9.4-15)	57 (18-94)	92 (23-160)	130 (75-190)	<0.2 (ND-0.4)	2.4 (0.1-4.7)
Common red shank	5	10.9 (9.2-12.8)	90 (40-210)	54 (19-89)	600 (160-1100)	1.4 (0.9-3.0)	1.5 (0.9-3.4)
Crab plover	1	9	67	73	770	0.6	1.8
Great knot	1	4.1	26	94	90	ND	<0.1
Green sandpiper	1	13.4	66	12	17	<0.1	<0.05
Gull-billed tern	2	8.6 (7.7-9.4)	360 (160-550)	550 (160-930)	1100 (1000-1200)	2.9 (0.3-5.2)	4.0 (0.2-7.8)
Long-billed Mongolian plover	6	7.6 (6.1-9.9)	250 (130-420)	310 (62-480)	260 (120-620)	12 (1.7-24)	3.4 (1.6-4.6)
Pintail snipe	1	7.64	99	7400	230	1.1	3.7
Sandwich tern	2	6.7 (6.5-6.9)	250 (110-390)	3900 (450-7000)	230 (230)	1.0 (0.8-1.1)	2.1 (0.5-3.7)
Short-toed lark	3	5.0 (4.1-6.6)	20 (20)	1100 (120-3000)	110 (19-200)	0.2 (0.1-0.2)	1.0 (0.3-2.0)
White-cheeked tern	5	6.7 (5.2-8.9)	2700 (430-4400)	84 (15-200)	1000 (220-1800)	2.6 (0.5-3.7)	1.8 (0.8-4.0)
Whiskered tern	1	11.6	51	1000	440	0.2	0.6
Wood sandpiper	1	2.39	53	50	29	<0.1	1.5
Long-distant Migrants							
Bartailed Godwit	1	6.8	28	92	110	1.1	0.9
Common sandpiper	5	7.4 (4.9-10.9)	120 (70-170)	230 (82-380)	620 (140-1900)	0.5 (0.3-0.7)	0.6 (0.3-1.6)
Curlew sandpiper	5	12.7 (10.2-16.1)	36 (27-48)	54 (40-82)	11 (9.2-16)	1.1 (0.5-2.6)	0.4 (0.2-0.6)
Golden plover	1	4.8	76	380	84	1	0.6
Gray plover	2	8.7 (8.5-8.9)	25 (23-26)	35 (31-38)	14 (10-17)	1.0 (0.4-1.5)	0.2 (0.2)
Lesser-crested tern	5	11.9 (7.2-16.6)	320 (170-520)	32 (19-47)	92 (52-170)	2.0 (0.8-3.4)	0.9 (0.7-1.3)
Lesser-golden plover	2	6.9 (4.4-9.3)	62 (34-89)	210 (140-280)	86 (42-130)	0.7 (0.4-0.9)	0.6 (0.4-0.7)
Terek sandpiper	3	5.6 (4.4-7.4)	550 (37-1400)	750 (140-5500)	1200 (180-3300)	2.4 (1.0-4.8)	0.8 (0.5-1.2)
White-winged tern	5	12.2 (11.1-13.6)	550 (210-850)	360 (36-710)	1300 (850-1700)	5.7 (3.9-10)	1.4 (1.1-1.8)

Figures in parentheses indicate range; ND = not detected resident bird, were in the range of 790-940 ng/g (mean: 870 ng/g) which is similar to that found in some migrant birds analyzed. This may be due to the predatory nature of spotted owlet, which feeds on small migratory birds such as terns and small mammals, frogs, fish and lizard. Mean concentrations of HCHs and DDTs in spotted owlet were also considerable at 1200 and 390 ng/g, respectively. Among residents, koel (cuckoo bird) recorded the lowest concentrations of PCBs (6.5 ng/g), and HCHs (26 ng/g) which was one to three orders of magnitude lower than those found in other birds. Crimson-crested barbet recorded the least DDT concentrations of 0.8 ng/g wet wt. Concentrations of CHLs and HCB were low in all the resident birds (<5.0 ng/g).

Among four species of local migrants, the black-winged stilt (*n*=1) contained the highest HCHs concentration of 4100 ng/g (Table 6). Concentrations of PCBs in all local migrants (30-210 ng/g), except spotted owlet, were slightly higher than in strict residents (6.5-160 ng/g). Little pranticole, contained concentrations of PCBs and DDTs similar to those found in other local migrants but concentrations of HCHs were lower.

PCB concentrations in short-distant migrants were relatively higher than those in resident or local migrants and ranged from 26 to 2700 ng/g. White-cheeked terns recorded the highest PCB concentrations (Table 6). HCHs concentrations in short-distant migrants were also considerable and ranged from12 to 7400 ng/g. The highest HCH concentrations were found in pintail snipe. This may be explained by the earlier wintering arrival of pintail snipe from central Asia to India than the other species such as green sandpiper, which arrives from Russia. In addition, pintail snipe feeds on molluscs, earthworms and insects in agricultural fields. Green sandpiper, which contained the lowest HCH concentrations among the short-distant migrants, feeds on aquatic and terrestrial insects. DDT concentrations varied between 17 and 1100 ng/g. The four species of short-distant migrating terns contained different patterns of contamination. Gull-billed terns contained great concentrations of DDTs while sandwich tern and whiskered tern contained high concentrations of HCHs. White-cheeked tern had elevated concentrations of PCBs relative to DDTs and HCHs. The breeding grounds of white-cheeked tern and gull-billed tern are Middle Eastern countries. The differences in migratory route and feeding habit are the explanations for varying OC contamination pattern.

Concentration pattern of OC pesticides and PCBs in long-distance migrants varied among the 9 species analyzed (Table 6). The bar-tailed godwit, curlew sandpiper, golden plover, gray plover and lesser-golden plover contained high HCH concentrations. Common sandpiper, terek sandpiper and white-winged tern contained higher DDT concentrations than those of PCBs and HCHs. Lesser-crested tern contained higher PCB concentration than those of DDTs and HCHs. As mentioned above, the differences in contamination pattern of OCs among long-distant migrants may be due to the differences in their habitat and migratory route.

In general, contamination pattern observed in birds indicates that exposure to HCHs and DDTs occurs in India as evidenced from their predominance in Indian biota (**Tables 4** and 5). Low concentrations of PCBs in Indian birds (strict residents and local migrants) suggest that its contamination is lower than those of DDTs and HCHs in India. However, spotted owlet, contained considerable concentrations of PCBs. Therefore, further studies on OC contamination are needed, with special reference to raptorial birds. Some migrant birds had comparable concentrations of DDTs and

Table 7: Concentrations (ng/g fat wt) of organochlorine pesticides and PCBs in egg yolks from India in 1997 and 1998.

Bird	n	Fat (%)	PCBs	HCHs	DDTs	CHLs	HCB
House crow	2	5.93	1200	49000	3400	<17	13
		(5.56-6.30)	(1100-1300)	(48000-50000)	(3000-3700)	(<4.5-30)	(12-14)
House crow 1998*	1	7.31	1700	67000	4100	<23	19
Red jungle fowl	2	11.8	930	4100	430	<2.7	<1.8
		(10.6-13)	(760-1100)	(3400-3700)	(340-520)	(<2.0-<3.3)	(<1.5-<2.0)
Turkey	2	12.7	530	350	34	<1.6	<0.9
		(12-13.3)	(500-560)	(310-380)	(33-34)	(<0.8-<2.4)	(<0.8-<1.1)
Spotted dove	2	15.7	800	1800	740	<30	<10
		(14.1-17.3)	(790-810)	(1800-1800)	(710-770)	(<30)	(<10)
Spotted dove 1998*	1	10.1	660	1500	400	<20	<10
Collard dove	2	18.7	750	3900	780	<19	<11
		(18.3-19.1)	(670-830)	(3700-4100)	(670-880)	(<18-<20)	(<10-<12)
Blue rock pegion	3	7.37	350	3000	110	<33	<5.9
		(3.37-12.4)	(56-710)	(1600-5000)	(10-280)	(<3.9-78)	(<1.4-11)
Baya weaver	3	9.8	440	1400	660	<16	<15
		(9.1-11.1)	(330-500)	(1100-1700)	(610-700)	(<10-<21)	(<10-<18)
Sparrow	3	12.3	1500	9700	7900	43	28
		(10.9-14.8)	(1300-1700)	(8300-11000)	(6900-8700)	(40-45)	(21-33)
White wagtail*	1	19.9	660	2100	880	<10	<10

Figures in parentheses indicate range
* sample collected in 1998.

HCHs with those of resident Indian birds. This may have an implication on the sampling period of the migratory birds. Migratory birds in this study were collected during early winter (November and December), which is the beginning of the wintering period. Therefore, samples collected in the later part of the wintering period (March to April) may give a clear evidence of accumulation of OC pesticides, which are still being used in India.

2.1.4 Bird eggs

House crow yolk collected in 1998 recorded the highest concentrations of PCBs, HCHs and DDTs followed by sparrow, red jungle fowl, spotted dove, collard dove, white wagtail, turkey, baya weaver and blue rock pigeon (**Table 7**). Concentrations of PCBs and HCHs in house crow yolk were 1700 and 67,000 ng/g fat wt, respectively. Sparrow accumulated the highest concentrations of DDT (mean: 7900 ng/g fat wt, range: 6900-8700). The results indicate that in granivorous or passerine birds, the accumulation of OCs in eggs were less than that could be expected in omnivorous birds like house crow and sparrow. Even the concentrations of OCs in eggs of omnivorous birds were less than those were reported in fish-eating or raptorial birds [6]. Terns collected from France and USA contained elevated concentrations of PCBs (3600-22000 ng/g wet wt) and DDTs (1000-1800 ng/g wet wt) [21,48-51].

Since the concentrations of OCs measured in the wholebody homogenates of birds provided a best estimate of total body burdens of these compounds, it was possible to evaluate the transfer rates of OCs via eggs based on the information of egg weight or the concentrations in egg. In our earlier study, we assumed that the transfer rate would be about 20% [7]. To examine if the 20% transfer rate was meaningful, we estimated the egg concentrations of OCs in some Indian birds using the following formula.

$$H\,egg = \frac{\text{Body burden (ug) X Transfer rate (\%)}}{\text{Egg weight (g)}}$$

Where,

H*egg* =	Concentration of OC contaminant in the egg (µg/g, wet wt)
Body burden =	Contaminant burden, obtained by multiplying wholebody concentration and body weight (µg)
Transfer rate =	Transfer rate in % (proportion transferred from wholebody to eggs)
Egg weight =	weight of the eggs per clutch (g)

According to our earlier studies, estimated value of egg concentrations from wholebody concentrations of *p,p'*-DDE in spotted dove was 20 ng/g, wet wt. The measured concentration of *p,p'*-DDE in spotted dove egg yolk collected in 1998 in this study was 8.2 ng/g, wet wt. The observed concentration of *p,p'*-DDE in eggs of spotted dove was approximately 2-fold less than the predicted estimate. This can be explained by the clutch size, which contains 2-3 eggs and the contaminants would have been distributed among the 2-3 eggs (8,9). Likewise, we estimated the wholebody concentration of *p,p'*-DDE in house crow based on the concentrations in egg yolk, which was 170 ng/g wet wt. If the transfer rate from the body were assumed to be 20%, then the wholebody concentration would be approximately 850 ng/g, wet wt. However, our earlier analysis has shown that the *p,p'*-DDE concentration in crow was 120 ng/g, wet wt. This implies that the transfer rate of *p,p'*-DDE in house crow would be more than 20%. However, several factors such as number of eggs per clutch, sex, age and health condition would confound such estimates of transfer rates of OCs to eggs. Nevertheless, this is a preliminary attempt to evaluate the relevance of wholebody homogenate analyses in hazard assessment.

2.2 Composition of HCHs, DDTs and BTs

Among HCH isomers, β-HCH was the most predominant in sediment and soil (75.3%). In green mussel and fishes like rainbow sardine, Indian anchovy, round-belly sardine and cone snail, α-HCH predominated (65-96%) in total HCH concentrations. Earthworm, crabs, prawn, frog, Java tilapia, bell snail and lizard contained greater proportions of β-HCH in total HCH concentrations.

Among DDTs, *p,p'*-DDE accounted for 69-90% of the total DDT concentrations in almost all the samples except in round-belly sardine, brick red box crab, lizard and sediments, in which the proportions of *p,p'*-DDT and *p,p'*-DDD were greater than that of *p,p'*-DDE.

Among BTs, MBT accounted for higher composition (45-69%) in all the 3 species of bats followed by DBT and TBT. Greater metabolic capacity may be an explanation for the observed pattern of BTs in bats [33]. In addition, exposure to BT sources predominated by MBT or DBT can contribute to the pattern observed in bats. Our previous study has also reported the presence of low, but detectable concentrations of BTs in birds [33].

Among HCH isomers, β-HCH was the most predominant isomer found in bats and birds suggesting more stable nature of this isomer to enzymatic degradation than α- and γ-isomers. Notably, flying fox, Indian pipistrelle bat, short-nosed fruit bat, resident and migrant birds like crimson-crested barbet, brain fever bird, koel, gull-billed tern and whiskered tern comprised relatively larger proportions of α- and γ-isomers than those in other birds and bat, suggesting recent exposure to technical HCH mixture containing 70% α, 15% γ, 6% β and 9% δ-HCH used in India.

p,p'-DDE was the most abundant of various DDT compounds measured in bats and birds. In most of the samples *p,p'*-DDE contributed to more than 90% of the total DDT concentrations. Higher compositions of *p,p'*-DDE in bats and birds clearly suggest their greater ability to transform *p,p'*-DDT to *p,p'*-DDE. Similarly, our recent study has showed the presence of elevated proportions of *p,p'*-DDE in Ganges River dolphins and fishes from India [47]. Relatively, larger proportions of *p,p'*-DDT, which is the major constituent (80%) of the technical mixture of DDT in flying fox, crimson-crested barbet and Indian tree pie suggest recent exposure to DDT.

2.3 Biomagnification features

Biomagnification factors (BMFs) of OCs were calculated using the concentrations in wholebody homogenates of birds and their major prey items analyzed in this study. Information presented in Table 1 was used to select appropriate prey items for each species. Among resident birds, spotted owlet showed the highest BMF for PCBs and DDTs (**Table 8**). Spotted owlets ingest considerable percent of fish as well as small migrant birds like white-winged tern. This is the reason for high BMF for PCBs in this resident species. Similarly, a few terns showed high BMF for PCBs (**Table 9**). Relatively less BMFs for HCHs and DDTs in migratory birds could be due to that the concentrations in prey items analyzed in India may not represent 100% of the exposures.

Among various OCs, BMFs for HCHs were less than one in most bird species, in spite of the elevated exposures in In-

Table 8: Biomagnification factors (BMFs) of organochlorines (PCBs, HCHs and DDTs) in resident and local migrant birds.

	Concentration in birds			Concentration in diet			Biomagnificatio factor		
Bird	**PCBs**	**HCHs**	**DDTs**	**PCBs**	**HCHs**	**DDTs**	**PCBs**	**HCHs**	**DDTs**
Strict Residents									
Black-winged kite	29	1900	640	68	2100	10	0.43	0.9	7.1
Cotton teal	20	120	67	49	4500	66	0.41	0.03	1.0
Crested kingfisher	160	310	290	56	2100	89	2.9	0.15	3.3
Dabchick	36	210	83	22	4100	18	1.6	0.05	4.6
Little egret	33	8800	970	140	6600	160	0.24	1.3	6.1
Pond heron	44	1100	3400	85	2400	140	0.52	0.46	24
Spotted owlet	870	1200	390	68	2200	90	13	0.55	4.3
White-breasted kingfisher	40	420	410	63	2200	89	0.63	0.19	14
White-breasted waterhen	23	840	170	27	4100	24	0.85	0.2	7.1
Local Migrants									
Black-winged stilt	30	4100	510	27	4100	24	1.11	1.0	21
Kentish plover	150	450	210	49	4500	66	3.11	0.1	3.1
Little-ringed plover	210	1000	4400	67	2100	89	3.1	0.47	49

Table 9: Biomagnification factors (BMFs) of organochlorines (PCBs, HCHs and DDTs) in short- and long-distant migrant birds.

	Concentration in birds			Concentration in diet			Biomagnification factor		
Bird	**PCBs**	**HCHs**	**DDTs**	**PCBs**	**HCHs**	**DDTs**	**PCBs**	**HCHs**	**DDTs**
Short-distant Migrants									
Common green shank	57	92	130	49	4500	66	1.1	0.02	2.0
Common red shank	90	54	600	27	4100	24	3.3	0.01	25
Crab plover	67	73	770	49	4500	66	1.4	0.01	12
Great knot	26	94	90	67	2100	89	0.4	0.04	1.0
Gull-billed tern	360	550	1100	87	2400	140	4.1	0.2	7.9
Long-billed Mongolian plover	250	310	260	76	2400	140	3.2	0.1	1.9
Pintail snipe	99	7400	230	27	4100	24	3.6	1.8	9.6
Sandwich tern	250	3900	230	87	2400	140	2.9	1.6	1.6
White-cheeked tern	2700	84	1000	100	6700	160	27	0.01	6.3
Whiskered tern	51	1000	440	80	2400	140	0.6	0.4	3.1
Wood sandpiper	53	50	29	27	4100	24	2.0	0.01	1.2
Long-distant Migrants									
Bartailed godwit	28	92	110	18	4100	17	1.6	0.02	6.4
Common sandpiper	120	230	620	27	4100	24	4.4	0.05	26
Curlew sandpiper	36	54	11	29	4200	18	1.2	0.01	0.6
Golden plover	76	380	84	38	4200	24	2.0	0.09	3.5
Gray plover	25	35	14	38	4200	24	0.7	0.01	0.6
Lesser-crested tern	320	32	92	67	2100	90	4.8	0.01	1.0
Lesser-golden plover	62	210	86	38	4200	24	1.6	0.05	3.6
Terek sandpiper	550	750	1200	76	2400	14	7.2	0.30	8.6
White-winged tern	550	360	1300	76	2400	14	7.2	0.15	9.3

Values are rounded

dia. Highest BMF for HCHs was noticed in little egret and black-winged stilt. This could be explained by the feeding habit, as these species feed on bell snails, which contained the highest concentrations of HCHs (Table 4). Greater BMFs for DDTs (1-49) were observed in most birds. Especially, pond heron, white-breasted kingfisher and little-ringed plover biomagnified DDTs considerably. Our earlier study has also reported that pond heron and little-ringed plover are at great risk from DDTs pollution in India [7].

Among migrant birds, common red shank, gull-billed tern, long-billed Mongolian plover, pintail snipe, sandwich tern, white-cheeked tern, common sandpiper and white-winged tern showed higher BMFs for PCBs (Table 9). It is noteworthy that most tern species biomagnified PCBs at a greater levels than DDTs and HCHs. This is in accordance with a few studies, which have reported greater accumulation of PCBs [48-52].

Similar to those observed for strict resident and local migrants, short- and long-distance migrants showed greater BMFs of DDTs than PCBs and HCHs. Common red shank, crab plover, pintail snipe, common sandpiper, terek sandpiper and white-winged tern showed BMFs of DDTs greater than 8. Our previous study [7] has also documented that terek sandpiper is at risk from DDTs due to their elevated accumulation. On the whole, DDT accumulation is of great concern in birds migrating to India.

2.4 Global comparison of OCs in bats

Concentrations of PCBs, DDTs and HCHs measured in Indian bats were compared with those reported in other parts of the world (**Fig. 2**). The concentrations of PCBs in Indian bats were less than those reported from other regions (Fig. 2). Concentrations of DDTs in Indian bats were lower than that of bats from Mexico and Spain. Elevated concentrations of *p,p'*-DDE in the range of 10-100 µg/g was observed in juvenile bats from Mexico and USA (Fig. 2). Recent concentrations of HCHs recorded in Indian bats reflect continuing usage of HCHs for agricultural purpose.

3 Conclusions

Concentrations of OCs in sediments, soil, earthworm, green mussel, snails, prawn, crabs, frog and lizard suggested continuing usage of DDTs and HCHs in India. For the first time, concentrations of OCs in three species of bats collected from India are reported. Concentrations of PCBs were lower in bats from India than those reported from other locations. However, higher levels of HCHs were found in Indian bats when compared with those reported for the other parts of the world. This study also reports for the first time the concentrations of OCs in several species of birds and egg yolks of birds from India. Most of the egg yolks analyzed in this study were from passerine or omnivorous birds from rural areas and that the concentrations of OCs were relatively low. Further studies are needed to monitor OCs in raptors from India. DDTs showed the greatest BMFs in most birds and exposure to DDT is considered with concern in birds migrating from remote areas.

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