Chinese Science Bulletin 2005 Vol. 50 No. 20 2257—2266

Progress in study on endocrine disrupting pesticides (EDPs) in aquatic environment

XUE Nandong[1, 2], WANG Hongbo[2] & XU Xiaobai[1]

1. State Key Laboratory of Environmental Chemistry and Ecotoxicology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China;
2. Department of Environmental Sciences and Engineering, Hunan Agricultural University, Changsha 410128, China

Correspondence should be addressed to Xu Xiaobai (email: xuxb@public.bta.net.cn)

Abstract **Background on the generation of the problems of endocrine disrupting pesticides (EDPs) in aquatic environment, characteristics of EDPs, adverse effects and their effect mechanism of EDPs on human and wildlife, the transportation and degradation pathways of EDPs in water and analysis methods of EDPs in water were reviewed. The importance of EDPs in water should be attached to adverse effects on wildlife and human health. It was advised to establish research programs on EDPs in aquatic environment especially in water supply source.**

Keywords: endocrine disrupting pesticides (EDPs), aquatic environment.

DOI: 10.1360/982005-348

The book entitled "Our Stolen Future" by Colborn et al.[1] published in March 1996 highlighted the effects of endocrine disrupting chemicals (EDCs) on human and the environment and was instrumental in raising public awareness and scientific researches on EDCs. In recent years, the adverse effects of environmental EDCs on wildlife and human health have already become an international research focal point[2]. United State Environmental Protection Agency (USEPA) announced 67 EDCs, which were screened from 8600 commercials and chemicals and posed adverse effects on human and wildlife, in August 1998. Those chemicals have significantly different natures. Some of them (such as chlorinated dioxins, po1ychrollnated biphenyls (PCBs), organochlorinated pesticides (OCPs) and phthalate) are difficult to degrade; others are much easier to degrade such as some polar herdcides and insecticides, organometallic compounds and some metabolites of detergents[3]. Forty-four pesticides (include 2 metabolites) nearly accounting for 2/3 of the total 67 chemicals were defined as endocrine disrupting pesticides (EDPs)[4,5],1). Table 1 lists the confirmed or suspected EDPs.EDPs include herbicides (alachlor, amitrole, atrazine, simazine, nitrofen, trifluralin, 2,4-D (2,4-Dichlorophenoxyacetic acid), 2,4,5-T (2,4,5-Trichlorophenoxyacetic acid)); fungicides (benomyl, metribuzin, hexachlorobenzene (HCB), vinclozolin, maneb, manzeb, zineb, metiram); insecticides (hexachlorocyclohexane (α, β, δ-isomers), lindene (γ-Hexachloroclo-hexane), chlordene, endosulfan and endosulfan sulfate, carbaryl, dicofol, aldrin, dieldrin, endrin and endrin aldehyde, DDT (DDD, DDE), heptachlor and heptachlor epoxide, methoxychlor, mirex, hexachlorocyclohenane, oxychlordane, toxaphene, synthetic pyrethroids (cypermethrin, fenvalerate, permethrin) and nematicides (aldicarb, carbofuran, 1,2-dibromo-3-chloropropane (DBCP))[6−8],2).

1 Characteristics of EDPs

1.1 Natural characteristics

EDPs generally have the characteristics such as lipotropy, chemical stability, being difficult to degrade, easy to volatilize, and long residual life. They may be enriched in body by biological concentration and magnification through food chains1). When they enter organisms, they are difficult or impossible to biodegrade and discharge from body. Therefore, they can be accumulated for a long time in organisms with long half-lives.

1.2 Structural characteristics

EDPs include organochlorines (such as DDT (DDD, DDE), dicofol, aldrin, endrin, dieldrin, heptachlor and heptachlor epoxide), organophosphates (such as malathion and hexachlorocyclohenane ethyl parathion), carbamates (such as carbaryl), synthetic pyrethroids (such as cypermethrin, fenvalerate, permethrin and esfenvalerate), dithio (such as maneb, manzeb, zineb and metiram), and others (such as amitrole and trifluralin). These different kinds of EDPs differ in chemical structures, but they have the similar endocrine disrupting functions.

In view of chemical structures, EDPs mainly exist in halogen-benzene, halogen-phenol, polyhalogen-alkane, metal alkyl, alkoxy-aryl and halogen-carrier, dicarbonyl imide, triazine and triazole pesticides[10]. Within the chemical structures, chemical groups play a decisive role to the biological activities of chemical compounds. There generally are 2—8 halogens or aromatic ring groups in a molecule of EDPs.

There was a significant difference in chemical structure between EDPs and natural estrone or other steroid estrogen in body. What is more, there also was a significant difference in chemical structure among EDPs. For example, andrusol, a kind of androgens, and estrone, a kind of estrogens, are nearly a four-ring structure, in spite of func-

1) Pesticide News No. 46, December 1999, 16—19.
2) Lyons, G., Pesticides posing hazards to reproduction, WWF, Godalming, UK, 1999, 1—3.

Table 1 The list of confirmed or suspected endocrine disrupting pesticides (EDPs)

No.	Pesticides (including 3 metabolizes)	Usage[a)]	Analysis methods issued available
1	Hexachlorocyclohenane	I	No
2	Carbaryl	I	Yes
3	Chlordane	I	No
4	Oxychlordane	Metabolite	No
5	Trans-Nonachlor	I	No
6	1,2-dibromo-3-chloropropane	I	No
7	DDT	I	Yes
8	DDE and DDD	I (DDT metabolite)	Yes
9	Kelthane (Dicofol)	I	Yes
10	Aldrin	I	Yes
11	Endrin	I	Yes
12	Dieldrin	I	Yes
13	Endosulfan	I	Yes
14	Heptachlor	I	Yes
15	Heptachlor epoxide	Metabolite	Yes
16	Malathion	I	Yes
17	Methomyl	I	No
18	Methoxychlor	I	No
19	Mirex	I	No
20	Toxaphene	I	Yes
21	Aldicarb	I	No
22	Cypermethrin	I	Yes
23	Esfenvalerate	I	Yes
24	Fenvalerate	I	Yes
25	Permethrin	I	Yes
26	Kepone	I	No
27	2,4,5-Trichlorophenoxyacetic acid	H	Yes
28	2,4-Dichlorophenoxyacetic acid	H	Yes
29	Amitrole	H	Yes
30	Atrazine	H	No
31	Alachlor	H	No
32	Simazine (CAT)	H	Yes
33	Nitrofen	H	Yes
34	Trifluralin	H	Yes
35	Metribuzin	H	Yes
36	Hexachlorobenzene (HCB)	F	Yes
37	Pentachlorophenol (PCP)	F, H	Yes
38	Benomyl	F	No
39	Manzeb	F	Yes
40	Maneb	F	Yes
41	Metiram	F	Yes
42	Vinclozolin	F	No
43	Zineb	F	Yes
44	Ziram	F	No

a) I stands for insecticide, H for herbicide, F for fungicide.

tionally difference in the physiology. DDT is a two-ring structure while alkyl phenol is single-ring structure, but both have similar endocrine disrupting functions. So far, there have no rational hypothesis that can credibly explain why these chemicals with different structure can combine with hormone receptor.

1.3 Functional characteristics

EDPs were widely used, and extensively exist in the environment, which caused a long-term exposure of organisms in low dosage. Compared with natural hormone the effect strength of EDPs is rather weak, but because organism endocrine system yet lack the feedback protection mechanism or infant organisms have weaker distinguishing ability to hormone receptor than adult's, infant animal and human bodies are far more sensitive to hormone level than adult's and even a little change in the exposed hormone dose can influence the whole lifetime.

An exposure on parental generation may result in an irreversible damage in the filial generation embryo in the early stage, fetus period and neonatal period through different ways. Even if being exposed in the prophase of embryo, fetus period or neonatal period, they did not take on apparent damage until the maturity of the filial generation and even until the middle ages. As a result of the delay effects of EDPs, adverse effects were always ignored[9].

2 Existence of EDPs in aquatic environment

EDCs pollution is an important environmental problem, which is giving rise to a serious impact on natural ecosystems. As EDCs were researched and distinguished from synthetic commodities and chemicals, more and more pesticides were classified in EDCs receiving extensive concern from both the environmental scientific field and public. Some scientists in North America and Europe have presently done a lot of helpful researches on the pollution of the EDPs in the surface water and ground water. According to the characteristics of the water resources and the commonly used pesticide kinds in their own countries, the priority list of the pesticides in the surface water and ground water was announced. 129 kinds of priority pollutants with different molecular structures and physicochemical properties and different courses of migration, transformation, accumulation and fate in aquatic environment were listed by USEPA[9]. In order to effectively ascertain samples to be sampled and subjects to be analyzed, the distribution and fate of priority pollutants in every element (water, sediments and aquatic biology) of aquatic environment need be clarified, and then the environmental element of priority sample can thus be selected out. Chapman et al.[10] studied and designed the optimum monitoring scheme according to the documents on the judgment of the water quality associated with 129 kinds of priority pollutants and on the fate and physicochemical properties of relevant pollutants in aquatic environment. The main points are: i) the 129 kinds of priority pollutants were divided into 10 sorts according to their physico-chemical properties and biological effects of the priority pollutants such as their dissolvability, degradability, volatility, octanol-water partition coefficient and fate; ii) the 129 kinds of priority pollutants were classified into five grades according to their long-term effects and bioaccumulation; and iii) that prior monitoring and sampling of the environmental elements were selected and recommended according to the classification data. Table 2 shows 20 pesticides as the priority list and the recommended priority sampling environmental elements in aquatic environment according to USEPA. Among 20 pesticides, nine (chlordane, DDD, DDE, DDT, dieldrin, heptachlor, TCDD, acrolein and toxaphene) may exist in sediments for a long time and can also be bioaccumulated. For these pesticides, the recommended priority sampling environmental elements are sediment and biota. It was already proved that aldrin can be bioaccumulated, but cannot exist in sediments for a long time, therefore, the priority sampling environmental elements recommended are water and biota. On the contrary, for endosulfan and endosulfan sulfate, which cannot be bioaccumulated, but can be absorbed easily in sediment, the priority element is sediment. It was inferred by their partition coefficient that endrin and endrin aldehyde might be bioaccumulated, though little information about their fate in water was reported, thus the proper priority elements should be water, sediment and biota. Heptachlor epoxide, which is stable, not only can exist in water but also can deposit in sediments and even can be bioaccumulated, thus all environmental elements including water, sediment and biota should be recommended to monitor. Isophorone should pick water sample to monitor due to well water solubility, while hexachloroclohexane isomers should sample in water and sediment according to their physico-chemical characteristics.

Pesticides in water body come mainly from wastewater containing pesticides and from rain-brushed pesticide particles in the atmosphere. The content of pesticides in water is not very high, but because pesticides may exist for a long time and even be accumulated in water, and they may cause chronic intoxication, such as carcinogenesis, teratogensis, and mutagenesis. Therefore, much information about pesticide pollution in aquatic environment has been obtained. Table 3 shows the comparison of concentrations (ng/g dry wt) of several EDPs in the sediments in rivers, lakes or estuaries from some Asian locations. However, most researches of pesticide pollution in aquatic environment focused on few indexes in water standards by routine monitoring. In China, production quantity of pesticides was large and pesticides were widely and extensively used. The priority black list of pesticides in aquatic environment had been established[17], in which many EDPs such as HCHs, DDT and nitrofen were included. Although studies on pesticide residues, especially on EDPs, in the surface water and ground water, were performed relatively late, more and more information was obtained when public and government showed more concerned about this issue.

3 Effects and mechanisms of EDPs on health of human and wildlife

3.1 Effects of EDPs on health of human and wildlife

The effects of EDPs on human and wildlife have been ascertained in the laboratory, and confirmed by investigation of human and wildlife which were exposed to EDPs.

Table 2 Priority monitoring 20 endocrine disrupting pesticides (EDPs) in aquatic environment and the priority sampling environmental elements recommended by USEPA

Pesticides	Classifications	Environmental elements[a)]		
		Water	Sediment	Biota
Aldrin	2	√		
Chlordane	2		√	√
DDD	1		√	√
DDE	1		√	√
DDT	1		√	√
Dieldrin	1		√	√
Endosulfan and endosulfan sulfate	3		√	
Endrin and endrin aldehyde	1	√	√	√
Heptachlor	1		√	√
Heptachlor epoxide	1	√	√	√
Hexachlorocyclohexane (α,β,δ-isomers)	3	√	√	
γ-Hexachloroclohexane (Lindene)	3	√	√	
Isophorone	3	√		
2,3,7,8-tetrachlorinated dibenzo-p-dioxins (TCDD)	1		√	√
Toxaphene	1		√	√
Acrolein	2		√	√

a) √ means the priority sampling and monitoring.

Table 3 Comparison of concentrations (ng/g dry wt) of several endocrine disrupting pesticides (EDPs) in the sediments in rivers, lakes or estuaries from some Asian locations

Locations	Year	Total DDT	Chlordane	HCHs	Refs.
Northern Coast, Vietnam	1998	6.2－10.4	NA[a)]	1.2－33.7	[11]
Masan Bay, Korea	1998	0.07－7.83	n.d.[b)]－0.18	0.01－0.59	[12]
Yesilirmak River, Turkey (wet wt)	1998－2000	71	NA	14－16	[13]
Hong Kong, China	1997－1998	0.27－14.8	n.d.－11.3	0.1－16.7	[14]
Wu-Shi estuary, Taiwan	1997－1998	n.d.－11.4	0.46－27.2	0.99－14.5	[15]
Beijing Guanting reservoir, China	2003－2004	3.25－17.2	0.087－0.54	0.28－10.8	[16]

a) NA, No data available; b) n.d., not detected under detection limit.

Pesticides are a kind of chemicals that are deliberately released into the environment where wildlife such as invertebrates, reptiles, fishes, birds and mammals lived in. Wildlife is especially vulnerable to pesticides, which can directly or indirectly jeopardize health and development of human themselves[2,8]. In fish, British scientist found that the oblique-teeth Fish *(Parabramis Pekinensis)* pose malformed genitals and there was certain concentration of vitellogenin in the body of some male trouts, whose testis are stunt in the lagoon located in the low reaches of sewage treatment plant. In USA, "ambisexual fishes" were found at the low reaches of a certain paper mill, while the mullet with smaller gonad and slower sexual maturity, and with laying eggs less and lower concentration of testosterone were found in other waters. By environmental monitoring, it was confirmed that there was certain concentration of environmental hormone such as DDT and its catabolite DDE in these waters. "Crazy fishes" and deformity fishes were also found in "Duck Lake" polluted by the pesticides in Hubei Province of China. In reptiles, after a organochlorined pesticide, dicofol, leakage accident in a freshwater lake in Florida, USA, it was found that the amount of short-nose caymans reduced sharply, penis of male cayman became smaller, female ovary deformed, and ovums were not ripe at all in the lake. After having detected the level of the environmental hormone in cayman blood, scientists found that the organochlorined pesticide DDT, which is a synthetic material and metabolic product of dicofol, remained high concentration in their body. In amphibian, a frog was found with six feet in Wuhan, China and some macrocephalic frogs in USA. After having studied for years, scientists found that macrocephalic frogs resulted from water sources that were contaminated by environmental hormone insecticides[18,19],1). In aves, investigation on the effects of EDPs on aves showed that birds laying egg reduced, eggshell became thinner, and it was difficult for fetation. The sea gulls from Great Lakes (USA) become feminization and suffer from thyroid tumor. The hatch rate of the American Gulls reduced in Lake Michigan. The bald eagles through the musky jungle were rare and without awe-inspiring appearance because of exposure of EDPs. In mammals, damaged sperms make pregnancy more difficult, and reproductive ability, therefore, obviously drop. The immunologic function of seals in Netherlands and white dolphins in Canada drop and their quantity reduce. The spermaries of the pumas dwindle and their sperm count reduced. After having surveyed 90 polar bears, Norwegian scientists found 4 young bears with male genitalia and female genitalia were hermaphrodite bears. In human, humans exposed occupationally are also at increasing risk, and there are studies linking exposure to EDPs at work to impotence, and reduced sperm counts, increased time to pregnancy, and increased rates of birth defects in offspring. Similarly, in the Yaqui children in Mexico, who are highly exposed to EDPs, developmental effects have been reported, and in women highly exposed to DDT, shortened lactation has been noted. Because EDPs can interfere with hormone system in human body, causing the endocrine system disturbance, the patients suffering from malignant tumor (mammary cancer, uterine cancer, etc.) and endometrial diseases obviously increase. Epidemiological studies found that there was a higher rate of the chromosome aberrance for those exposed to pesticides than control group, and the rate of the chromosome aberrance is 5 times higher in spray seasons than in off-spray seasons.

3.2 Mechanisms of EDPs on health of human and wildlife

EDPs can exert their effects in many ways on human and wildlife[20]. They can either bind to the hormone's receptor and mimic the hormone, or block the action of the hormone[21]. Alternatively, they can stimulate or inhibit the enzymes responsible for the synthesis or clearance of a hormone, and thereby give rise to an increased or decreased action of the hormone. Studies found that many EDPs have estrogenic (or anti-androgenic) activity, and some bind to the androgen or estrogen receptors. Those found to bind to the estrogen receptor include DDT and metabolites (although the anti-androgenic properties of *p′p′*-DDE may be of greater importance), methoxychlor, chlordecone, dieldrin, endosulfan and toxaphene. Some of them can induce estrogenic effects at relatively low levels. For example, administration of methoxychlor to the newborn rat at a dose level of 0.5 μg per day may cause accel-

1) Canadian Environmental Law Association, Draft —Regulating Pesticides to Protect Children's Health, 94p, December 1, 1999; Environment Canada Web site, "Endocrine disrupting substances in the environment," January, 2000, 1－4.

erated puberty and accelerated loss of fertility. Similarly, new born female rats injected with 1 mg per day of *o′p′*-DDT on 2—4 d after birth had early onset of puberty and accelerated loss of fertility. Even doses as low as 1 μg/d of either of these substances, given to pregnant female mice on days 11—17 of pregnancy, cause effects on the territorial behavior of male offspring[1)]. However, DDE induced eggshell thinning, one of the most well known effects noted in wildlife, is now not thought to result from DDE binding to a sex hormone receptor.

Anti-androgenic pesticides that bind to the androgen receptor include: the dicarboximide fungicides, vinclozolin and procymidone; *p′p′*-DDE, certain pyrethroids, and the herbicide linuron. Researchers have evaluated the potency of the following pyrethroids in terms of their interaction with androgen binding sites, and in descending order this was: fenvalerate > phenothrin > fluvalinate > permethrin > resmethrin. In the case of vinclozolin, it is the metabolites that are active anti-androgens. Some organophosphate and carbamate pesticides have been associated with a reduced egg count in birds and sperm quality drop in male animals. When given to female pregnant rats at low levels of 1—100 mg/kg of aldicarb, a carbamate insecticide and suspected endocrine disruptor, it has been shown to depress acetylcholinesterase activity more in the foetus than in the mother [1)].

Some EDPs (such as amitrole, zineb, maneb, alachlor, etc.) acted as the thyroid can affect thyroid hormone level. Amitrole (or aminotriazole), a kind of triazine herbicides, appears to interfere with thyroid hormone synthesis and can cause cancer of the thyroid. It is a triazine herbicide with a no observed adverse effect level for thyroid hyperplasia of 2 mg/kg in the diet of rats. Similarly, alachlor, an aniline-type herbicide, is associated with thyroid follicular tumours in rats, and is believed to be an endocrine disruptor.

Some EDPs (such as aldicarb and carbaryl) can hinder the function of nervous system of the organism, and thus influence the regulating effect of pallium, hypothalamus and pituitary gland on hormone, conducing abnormal synthesis, release and transmission of the hormone. For example, when organophosphorus pesticides entering the human body, namely combining with the internal cholinesterase, the stable phosphoric cholinesterase can be formed, which may make cholinesterase lose its activity, therefore, fail to accumulate to acetylcholine and cause the nerve conduction physiologic function turbulence. Accordingly, a series of poisoning symptoms may appear because of the nerve conduction physiologic function turbulence. Some EDPs influenced the internal hormone level through effects on the metabolism function of liver and kidney. Organophosphorus pesticides and OCPs can induce liver sterols hydroxylase and microsomal enzyme to accelerate the metabolism and excretion of the endogenous hormone. In addition, OCPs also exist, to some extent, effects on some other enzymes. Aldrin and dieldrin may increase the activity of glutamatepyruvate transaminase and aldolase in an adult mouse. Some EDPs may influence immune functions of the organisms. DDT may inhibit AFP enzyme and *p′,p′*-DDT may cause obvious drop in phagocytic activity of white blood cells and their ability to form the antibody in organisms.

EDPs with fairly low dose level may have the noted effects. For example, when pregnant rats exposed at a vinclozolin dose level of 3 mg/kg/d, it has been found that the male rats in womb were feminised (in that abnormal numbers of nipples were seen). Similarly, at a dose level of 25 mg/kg/d given from the fourteenth day of pregnancy to three days after birth, procymidone caused intersex characteristics in male rats, but these workers did not determine a no-observed adverse effect level. Linuron has a similar structure to the pharmaceutical anti-androgen, flutamide, and at a dose level of 40 mg/kg/d from weaning through puberty; it reduced seminal vesicle weights in male rats and delayed puberty[2)]. And life forms at the high trophic level live on ones at lower trophic level. The concentration of the difficultly decomposed chemicals in the organism will increase progressively with the rising trophic level. The chemicals in the environment, even with extremely low concentration, also may exert significant effects especially on life-forms with high trophic level by biological magnification and then threaten the human health. When pesticides with stable natures and high lipotropy, such as DDT and dieldrin, have once been taken in vivo of animals, namely, accumulated in the adipose tissue of the animals, it was difficult to be resolved and discharged from body. Researches of the Tour Lake (USA) showed that the concentration of DDT in fat in aquatic birds was unexpectedly 760000 times as high as that in the lake water [20].

Hormone has ever played an important role in the division course of normal cell in early life. So, in the ovum or the uterus, the EDPs can change the division course of the normal cell. In addition, mature animals might be influenced, too, while the young and tender life is only further more vulnerable to EDPs. However, the impacts of the exposure in early life on such learning ability, behavior and reproduction ability and immunity ability to cancer or other diseases are difficult to be found until later stage of life [21]. The possible mechanism that the EDPs exert an influence on the hormone is:[22−24],[3)]

(1) Effects of EDPs on steroid synthesis and metabolism. EDPs affect hormone synthesis and/or metabolism.

1) See footnote 1) on page 2260.
2) See footnote 2) on page 2257.
3) Butterfield, M., Rosenberg, D., Exposure: environmental links to breast cancer, film screening, Ottawa, October 1998, 12—28.

Some EDPs (such as imidazole, propiconazole, epoziconazole, ketoconazole, fenarimol, TBT pesticides and several OCPs) have been found to block steroid synthesis in the course of biosynthesis. For example, when female rats were exposed to 25 mg/kg endocrine-disrupting pesticides everyday from the fourteenth day of pregnancy, pregnancy period was lengthened and the survived pup count dropped. It was suggested that ketoconazole inhibited the synthesis of oestradiol near term, possibly by inhibiting aromatase activity. Another pesticide, fenarimol, is known to inhibit aromatase activity, and this has also been shown to delay birth. TBT is also believed to act by inhibiting aromatase, as it appears to act by blocking the conversion of testosterone to oestradiol. It therefore has well-known androgenic activity in molluscs, and for example, it can cause female dog whelk to grow penises (imposex) at concentrations as low as 2.5 nanograms per litre. It therefore was well known that these EDPs block the synthesis of dihydrotheelin. Besides, the aromatic ring groups can block the synthesis of estrogen, just as the synthesis of suprarenalis and melatonin can be changed by carbon disulfide, which may be produced during the metabolism of such bactericides as zineb, maneb.

(2) The effects on hormone receptor identification/combination. The processes of identification-combination involved are much more complicated than what the summary suggests, and for example, there are not only many feedback mechanisms, but also the nervous, endocrine and immune systems which are sophisticatedly interconnected [18]. In addition, apart from the sex hormone and thyroid hormone there are many other hormone involved, including at least retinoids, progestins, and corticosteroids. Hormone interacts with the specific target tissue directly through the receptors in cell or the combined membrane receptors. The special compounds as natural ligands are a key to the function of hormone. The receptors in cell such as sex steroids, adrenal gland steroid, thyroid gland hormone, vitamin D and retinoic acid, through their interaction with the special DNA series, regulate the transportation of the gene. The new messager RNAs are composed, processed and transmitted into a new protein. Some EDPs (such as methoxychlor, kepone and DDT), which acted as seemingly natural ligands as competitors to block linking or as antagonism to change this course, may interfere with the function of the female receptor. Vinclozolin, a kind of fungicide, was taken as a function to resist androgen because its metabolites have affinity to the androgen receptor. And it is interestedly found that *p′p′*-DDE, a metabolite of DDT, can combine with androgen receptor and also can block inducting to the response of testosterone in cell.

(3) Effects on storage, release and clearance of hormone. EDPs may exert their multiple effects by interfering with the brain's pituitary. Some EDPs may exert their action by interfering with the brain's release of hormone, which in turn regulate the production of other hormone that control the growth and the activity of many other endocrine glands. Indeed, the pituitary has been termed the conductor of the endocrine orchestra, and pollutants that cause the region in the brain to malfunction may therefore have multiple effects. For most hormones have little storage *in vivo*, the speed of releasing hormones to blood plasma reflects their formed speed. The release of some hormone depends on the activity of second messenger channel such as cAMP, 4, 5-biphosphate and Ca^{2+}. Some metal ion may interfere with the flow of Ca^{2+}, and thus interfere with the release of hormone. Some EDPs interfere with the communication system of membrane. For example, the reaction of the cell relies on the calcium ion flow on the membrane (calcium /calmodulin rely on cellular reaction to begin), therefore, and also changes with the change of metal cations (such as lead, cadmium and zinc). Lindene can reduce the phosphatidylinositol backward flow in the membrane, and can reduce the activities of protein kinase C. The hormones may be transported to the action site of cell by lymph, blood and extracellular fluid, then to the site of metabolism inactivation and degradation. Finally, the hormones will be cleared up. Those EDPs that can change liver enzyme may influence the clearance of the hormone. For example: DDT homologues are the intense inducer of the activity of the liver microsome monooxygenase, therefore, being treated through DDT homologue, liver microsome monooxygenase may cause the increase of the testosterone androgen, and as a result, the degenerative process of the endogenous androgen is accelerated through the monooxygenase system. Likewise, it is reported that lindene will increase the clearance of the estrogen.

4 Transportation and degradation of EDPs in aquatic environment

4.1 Transportation of EDPs in aquatic environment

The majority of EDPs enter the water environment from agricultural sources, through leaching from the soil, surface runoff, spray drift, soil erosion and volatilization. The extent of losses of pesticides to aquatic environment depends on a wide range of factors including method of application, formulation, weather conditions, soil type and topography, farming practice and crop type. Other sources of pesticides to aquatic environment include direct discharge from industry, treated effluent discharges, farmland subsiding water and aerial deposition[25]. And also some EDPs may transplant a longer distance, for example, DDTs and HCHs and their pollution sources have been transferred from the industrialized countries of Northern Hemisphere southwards to the tropical-subtropical areas (such as China and India) in recent 20 years, and the content of DDTs is the highest in the terrestrial and oceanic environment of southeast Asian areas1). Because high temperature and pluvial climatic conditions in tropical regions facilitated the diffusion of pesticides to the atmosphere and movement with the atmospheric circulation, these pesticides are finally subsided with the atmosphere granules into water environment in other areas[26].

The EDPs applied into the fields may transport to ground water by precipitation or surface water leaching. During the transportation, transformation and degradation may occur too. The course that pesticides applied in soil surface (or at a certain depth) transfer downwards to the groundwater (if possible) can be divided into two stages[27]: One is pesticide migration into the plant root zone, and transition within root zone, the other is pesticide migration into the seepage zone under the root zone and transition within the seepage zone. The differences between the two stages lie in different factors influencing the course. The migration of pesticides in root zone is influenced by such factors as absorption and transpiration of plant, medium adsorption and degradation, volatilization and irrigation, and pesticide gasification. The migration in the seepage zone is just influenced by adsorption and degradation. Transportation of EDPs in aquatic environment depends mainly on pesticide properties and conditions in water. Transportation of EDPs may occur through the courses of sorption, volatilization, hydrolyzation, photolysis, biological richenment and biodegradation.

EDPs in water mainly are from soil runoff, paddy field and industrial sewage and are concentrated by aquatic plants and animals, and then transfer to birds, fishes and human. Biological migration is another kind of more effective pathways. For example, salmon may transfer the environmental estrogen from ocean to freshwater lake of Alaska through migration, and make the concentration of environmental estrogen 2 times higher than that of other lakes[28].

4.2 Degradation of EDPs in aquatic environment

In theory, as long as the environmental growing conditions are suitable, all the biological source molecules can be microbially degradated. However, because artificially synthesized chemicals as EDPs usually possess a functional group as substituent chlorine and a novel structural permutation that seldom exist in nature, they are difficult to be degradated and persistent in the environment[29]. EDPs are difficult to be biodegradated in aquatic environment and are extremely apt to increase biological concentration through the food chains in the ecosystem. The trace pesticides in aquatic environment, which are even in too low concentration to be measured, can reach a surprisingly high concentration through the enrichment of 3 or 4 trophic levels. Because most of EDPs are lipotropy, and difficult to be degraded in environment and lack of specifical metabolic system in the human body, these pesticides are easy to accumulate in the human body, specifically in the adipose tissues[30].

The microbial degradation pathways of EDPs include anaerobic degradation and aerobic degradation. In aquatic environment, anaerobic degradation is the major degradation pathway[25]. For different microorganisms, their biochemical pathways to attack pesticides and the toxicity and mobility of their metabolites are different. Generally, the toxicity of the metabolites is higher and the mobility of them is stronger than their parent compounds, and some metabolites may be accumulated in natural environment. For example, DDE, a metabolic residue of DDT, may persist in the environment for a long time, and it even may influence the degradation level of its parent DDT[31,32]. Because pesticides possess different molecular structures and physico-chemical properties, their sensitivities are greatly different. The number and the position of chlorine atoms in benzene may influence biodegradation. The more the number of the substituted chlorine atoms in benzene, the more difficultly the compounds are degraded. When substituted in the separated positions by chlorine atoms in benzene, the compounds are degraded most difficultly. For example, the biodegradation of 2,4,5-T is much slower than 2,4-D[31]. At present, there are more researches on the degradation of EDPs in laboratory, focusing mainly on their half-life and stability under different anaerobic conditions and different pH value conditions in the aqueous solution. However few studies on degradation of EDPs under really natural conditions were carried out in aquatic environment [33]. The influences of EDPs on animals and human are different as their metabolic pathway varies. It has been well known that EDPs entering animal and human have 3 possible fates discharged outside of body, absorbed by the organism or degraded into other compounds. At present, the strategies adopted to cope with EDPs are that besides stopping production or restricting use, it still needs to find and adopt various methods to eliminate persistent and/or bioaccumulative EDPs in environment.

5 Status and challenges on EDPs determination in aquatic environment

5.1 Status in quo on determination of EDPs in aquatic environment

EDPs in aquatic environment influence water quality, aquatic systematic structure and function, variety of aquatic organisms and human health[34]. Many countries have successively taken some measures to prevent the damage of the existing EDPs in water. In October 1987, the environmental ministers of European Community

1) Allsopp, M., Johnston, P. (ed.), Unseen poisons in Asia: A review of persistent organic pollutant levels in South and Southeast Asia and oceania, Greenpeace International, 2000, 3.

agreed to restrain pesticides in drinking water under 0.5 μg/L for total pesticides and under 0.1 μg/L for the single pesticide[35]. Japanese Environmental Agency also issued the communique about the countermeasures of EDCs, in May 1998[1)]. The basic researches on EDCs were stressed in every country of the world. Several research programs have been conducted and great progress has been achieved in recent decade. The studies include how to analyze simultaneously trace endocrine disrupting pesticide multiresidues in environment, food and biologic samples[36−38]. Pre-treatment methods for sediment and biologic samples mainly were soxhlet extraction, sonication extraction technique and supercritical fluid extraction (SFE) and microwave assistant extraction (MAE). And the major pre-treatment methods for water samples include liquid-liquid extraction (LLE), solid-phase extraction (SPE) and solid-phase microextraction (SPME) technology. Parvticularly, SPE and SPME, two recently developed methods, were widely applied in extraction, purification and enrichment of water samples[39,40]. Methods for analysis and determination of EDCs include Gas Chromatogram (GC), High Performance Liquid Chromatogram (HPLC), Electrochemistry method (modified electrode method) and biological analysis methods (as biosensor detection method, enzyme-linked immuno-sorbent assay (ELISA) and cell assay)[39]. As noted above, EDPs possess greatly different properties, so it is difficult to analyze simultaneously EDPs. Nevertheless, with some effective pre-treatment methods applied, the compounds with different properties can be divided into groups and then analyzed[40−43]. For instance, OCPs (including HCB, PCP, DDT, DDE, DDD, chlordane, oxychlordane, dicofol, aldrin, dieldrin, heptachlor, heptachlor epoxide, endosulfan and methoxychlor) can be simultaneously determined as an analysis group. The aquatic environment is a complicated multimedia system including many such environmental elements as water, sediment and aquatic lives. Concentrations of EDPs in aquatic environment differ greatly in every element, and they generally decreased in the order: biota>sediments>water. At present, the analysis and study on EDPs in aquatic environment (especially in drinking water source) are in the ascendant, and the new analysis methods were constantly developed [44,45],[2)]. Recently, novel methods to analyze simultaneously EDPs are being developed, which will undoubtedly be a development tendency of analytical chemistry in the 21st century.

5.2 Challenges of analysis for EDPs in aquatic environment

It is urgent to set up a whole set of feasible analysis methods of EDPs in aquatic environment. However, it is difficult to analyze EDPs at fairly low even trace concentrations in aquatic environment containing water, suspended matter, sediment and aquatic biology. For instance, concentrations of some EDPs are at ppt-ppb magnitude and even under the detection limits. For sediment and biologic samples with complicated constitutes, effective pre-treatment will be needed. In order to analyze EDPs at 1×10^{-9} g/L in samples with complicated media, from sample collection, extraction, purification, concentration to the final choice and employ of qualitative and quantitative analysis means, every step of pre-treatment courses needs to be studied further.

When water flow as a pollutant carrier changes (hydrology processes) because of the influence of climate, soil, biology and mankind activity, composition and amount of pollutants may change with temporal and spatial change. The dilution, diffusion, decomposition and deposition of pollutants in the water body possess inherent law, as well as uncertainty and variation. Because of variety and diversification of EDPs though at low concentrations, it is difficult to ascertain their biological threshold values or acceptable levels in aquatic environment and therefore difficult to control and to determine. At present, monitoring EDPs become increasingly concerned by governments and functional departments and standards of EDPs become stricter and stricter in many countries. Standard analysis methods have been developed and presently issued for twenty-nine EDPs (Table 1). The methods have been developed but presently not issued for 9 pesticides (atrazine, alachlor, methomyl, aldicarb benomyl, etc.), and methods for more EDPs need to be developed and studied further.

Human and wildlife are especially vulnerable to EDPs because these chemicals are deliberately released into the environment and have effects on reproduction, growth, neurological development, behavior and immune function, and endocrine systems. And because EDPs have a great destructibility to endocrine function of human and biology and may cause enormous threat to global ecological environment, they should arouse our attention. Exposure to EDPs in water poses a significant health risk to human. The long-term consequences of such exposure are difficult to assess but scientific information suggests that a highly precautionary approach is needed to avoid serious health problems in the future. However, recent studies on EDPs in aquatic environment focus mainly on oceanic environment and then in fresh water supply source. Epidemiological studies of EDPs should be further conducted so that the full extent of the problem can be assessed. In the mean time the precautionary principle should be applied to minimizing exposure to vulnerable groups. Governments should establish more study programs on the effects of EDPs in aquatic environment especially in drinking water

1) Masahiko, Takino, Environmental monitoring and analysis technology (in Japanese), 1999, 26(8): 49−57.
2) Codex Alimentarius, Pesticide Residues in Food, Vol. 2 (suppl. 1), FAO, Rome/WHO, Geneva, 1993.

supply source to eliminate exposures to EDPs where possible.

Acknowledgements This work was supported by the Ministry of Science and Technology, China (Grant No. 2003CB415005).

References

1. Colborn, T., Dumanoski, D., Myers, J. P., Our Stolen Future: Are We Threatening Our Fertility, Intelligence, and Surival? Scientific Detective Story, New York: Dutton Books, 1996, 3.
2. The Institute of World Resources, United Nations Environment Program, United Nations Development Program et al., World Resource Resport—Environmental Changes and Human Health (1998—1999), Beijing: China Environmental Science Press, 1999, 3.
3. Colborn, T., Endocrine disruption from environmental toxicant, in Environmental and Occupational Medicine (ed. Rom, W. N.), 3rd ed., Philadelphia: Lippincott-Raven Publishers, 1998, 5.
4. State Environmental Protection Agency (SEPA), Department of Policy and Code, A Collection of Agreements on International Environment Concluded and Subscribed by China, Beijing: Academe Press, 1999, 5—19, 20—26.
5. State Environmental Protection Agency (SEPA), Department of International Cooperation, Annual Documents on Green Globe (1999—2000)(in Chinese), Beijing: China Environmental Sciences Press, 2001, 102—117.
6. Song, H. Y., Wang, J., Environmental endocrine-disrupting chemicals and pesticides (in Chinese), Pesticide Science and Management, 2001, 22(2): 23—25.
7. Ma, C. C., Gu, Z. R., Pollution of chemical pesticides with environmental hormone and monitoring and controlling (reviews) (in Chinese), Journal of Shanghai Agriculture, 2003, 19(4): 98—103.
8. Kavlock, R. J., Daston, G. P., Derosa, C. et al., Research needs for the risk assessment of health and environmental effects of endocrine disrupters: a report of the US EPA-sponsored workshop, Environ. Health Perspect., 1996, 104(suppl.4): 715—740.
9. Callahan, M. A., Slimak, M. W., Gabel, N. W. et al., Water-Related Environmental Fate of 129 Priority Pollutants. Volume II. EPA-440/4-79-029b,Washington DC: U.S. Environmental Protection Agency, December 1979, 49—57.
10. Chapman, P. M., McDonald, B. G., Lawrence, G. S., Weight-of-Evidence Issues and Frameworks for Sediment Quality (and Other) Assessments, Human and Ecological Risk Assessment, 2002, 8(7): 1489—1515.
11. Nhan, D. D., Am, N. M., Carvalho, F. P. et al., Organochlorine pesticides and PCBs along the coast of north Vietnam, Sci. Total Environ., 1999, 237/238: 363—371.
12. Khim, J. S., Kannan, K., Villeneuve, D. L. et al., Characterization and distribution of trace organic contaminants in sediment from Masan Bay, Korea. 1. Instrumental Analysis, Environ. Sci. Technol., 1999, 33: 4199—4205.
13. Bakan, G., Ariman, S., Persistent organochlorine residues in sediments along the coast of mid-Black Sea region of Turkey, Mar. Pollut. Bull., 2004, 48: 1031—1039.
14. Richardson, B. J., Zheng, G. J., Chlorinated hydrocarbon contaminants in Hong Kong surficial sediments, Chemosphere, 1999, 39: 913—923.
15. Doong, R. A., Peng, C. K., Sun, Y. C. et al., Composition and distribution of organochlorine pesticide residues in surface sediments from the Wu-Shi River estuary, Taiwan, Mar. Pollut. Bull., 2002, 45: 246—253.
16. Wang, X. T., Chu, S. G., Xu, X. B., Organochlorine pesticide residues in water from Guanting Reservoir and Yongding River, China, Bull. Environ. Contam. Toxicol., 2003, 70: 351—358.
17. Zhou, W. M., Fu, D. Q., Sun, Z. G., Priority black list of pollutants in water established in China (in Chinese), Environmental Science Resarch, 1991, 4: 912—915.
18. Colborn, T., Vomsaal, F. S., Soto, A. M., Developmental effects of endocrine disruption chemicals in wildlife and humans, Environ. Health Perspect, 1993, 101(4): 378—384.
19. Safe, S. H., Environmental and dietary estrogen and human health: Is there a problem? Environ. Health Perspect, 1995, 103(4): 343—351.
20. Crisp, T. M., Clegg, E. D., Cooper, R. L. et al., Environmental endocrine disruption: An effect assessment and analysis, Environ. Health Perspect, 1998, 106(Suppl 1): 11—56.
21. Arnold, S. F., Klotz, D. M., Collins, B. M. et al., Synergistic activation of estrogen receptor with combinations of environmental chemicals, Science, 1996, 272: 1489—1492.
22. Gilbertson, M., Linking water quality to wildlife and human health, focus, International Joint Commission, November 1998, 18—19.
23. Chance, G. W., Harmsen, E., Children Are Different: Environmental Contaminants and Child Health. Canadian Public Health Review, Vol. 89, Supplement 1, May/June 1998, 10—14.
24. Pernille, A., Grandjean, P., Jorgensen, T. et al., Hartvig, Organochlorine exposure and risk of breast cancer, Lancet, 352(9143), 1998, 1816—1820.
25. Warren, N., Allana, I. J., Carter, J. E. et al., Pesticides and other micro-organic contaminants in freshwater sedimentary environments—a review, Applied Geochemistry, 2003, 18: 159—194.
26. Wania, F., Mackag, D., Tracking the distribution of persistent organic pollutants, Environ. Sci. Technol., 1996, 30: 390A.
27. Carsel, R. F., Mulkey, L., The pesticide root zone mode (PRZM): a procedure for evaluating pesticide Lashing treats to groundwater, Ecological Modeling, 1985, 30: 49—69.
28. Ewald, G., Larsson, P., Linge, H. et al., Biotransport of organic pollutants to an island Alska Lake by migrating sockeye salmon (Onchorhynchus nerka), Arctic, 1998, 51(1): 40—47.
29. Ou, X. M., Wang, X. G., Huang, D. F. et al., Progress in studies on pesticide degradation by bacterium (in Chinese), World Pesticides, 2003, 25(6): 30—35.
30. Li, G. Y., Tan, R. S., The relationship of environmental endocrine-disrupting chemicals and people health (in Chinese), Overseas Iatrology and Hygienics Fascicule, 2001, 28(4): 193—196.
31. Boul, H. L., Cambarn, M. L., Hucker, D. et al., Influence of Agricultural Practices on the Levels of DDT and Its Residues in Soil, Environ. Sci. Technol., 1994, 28: 1397—1402.
32. Sayler, C. S., Hooper, S. W., Layton, A. C. et al., Catabolic plasmids of environmental and ecological significance: A review, Microbial Ecology, 1990, 19: 1—20.
33. Tomlin, C. D. S., The Pesticide Manual: A World Compendium, Farnham: British Crop Protection Council, 2000, 11—19.
34. Song, X. J., Technological prevention and cure measures of point pollution resources of pesticides and chemical fertilizer in Beijing (in Chinese), Environment Protection, 2000, (9): 30—32.
35. Leistra, M., Smelt, J. H., An appraisal of methods for measurement of pesticide transformation in the groundwater zone, Pesticide

Management Science, 2001, 57 (4): 333—345.

36. Ren, J., Jiang, K., Progress in studies on environmental endocrine-disrupting chemicals (in Chinese), Chemistry Progress, 2001, 13(2): 135—142.
37. Castillo, L. E., Ruepert, C., Solis, E., Pesticide residues in the aquatic environment of banana plantation areas in the North Atlantic Zone of Costa Rica, Environ. Toxicol. Chem., 2000, 19: 1942—1950.
38. Nogueira, J. M. F., Sandra, T., Sandra, P., Multiresidue screening of neutral pesticides in water samples by high performance liquid chromatography-electrospray mass spectrometry, Analytica Chimica Acta, 2004, 502(2): 209—215.
39. Ying, G. S., Analysis methods of foreign origin estrogen (in Chinese), Overseas Iatrology and Hygienics Fascicule, 1995, 22(4): 216—220.
40. Colborn, T., Smolen, M. J., Epidemiological analysis of persistent organochlorine contaminations in cetaceans, Rev. Environ. Contam. Toxicol., 1996, 146: 91—172.
41. Volker, L., Wulf, A., Alicio, A. P. et al., Pesticides in surface water, sediment, and rainfall of the northeastern Pantanal Basin, Brazil. J. Environ. Qual., 2002, 31(5): 1636—1648.
42. Zhang, Z. L., Hong, H. S., Wang, X. H. et al., Determination and load of Organophosphorus and Organochlorine pesticides at water from Jiulong River Estuary, China Mar. Pollut. Bullet., 2002, 45(12): 397—402.
43. Bakan, G., Ariman, S., Persistent organochlorine residues in sediments along the coast of mid-Black Sea region of Turkey, Mar. Pollut. Bullet., 2004, 48: 1031—1039.
44. Chau, A. S. Y., Afgan, B. K., Analysis of Pesticides in Water, Vol. 1: Significance, Principles, Techniques and Chemistry of Pesticides. Vol. 2: Chlorine and Phosphorus-Containing Pesticides, Boca Raton, FL: CRC Press Inc., 1982, 91—113, 238.
45. Castilho, J. A., Fenzl, N., Guillen, S. M. et al., Organochlorine and organophosphorus pesticide residues in the Atoya river basin, Chinandega, Nicaragua. Environ. Pollut., 2000, 110: 523—533.

(Received March 9, 2005; accepted April 15, 2005)