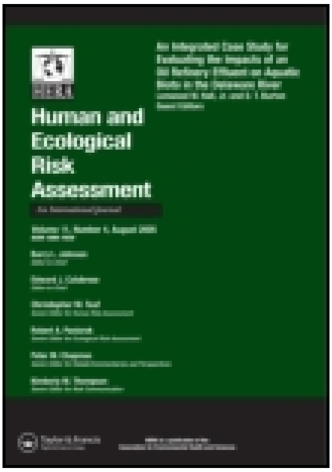

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ENVIRONMENTAL FATE ASSESSMENT ARTICLES

Tissue Residue Guideline for ∑DDT for Protection of Aquatic Birds in China

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ABSTRACT

DDT (1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane) is a chlorinated hydrocarbon insecticide that has been used worldwide. While the use of DDT has been phased out in many countries, it is still produced in some parts of the world for use to control vectors of malaria. DDE (1,1,-dichloro-2,2-bis(*p*-chlorophenyl)ethylene) and DDD (1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane) are primary metabolites of DDT and have similar chemical and physical properties. DDT and its metabolites (DDE and DDD) are collectively referred to as ∑DDT. The lipophilic nature and persistence of the ∑DDT result in biomagnification in wildlife that feed at higher trophic levels in the food chain. Wildlife in aquatic ecosystems depend on aquatic biota as their primary source of food, which provide the main route of exposure to ∑DDT. Studies about effects of ∑DDT on birds were reviewed. The tissue residue guidelines for DDT (TRGs) for protection of birds in China were derived using species sensitivity distribution (SSD) and toxicity percentile rank method (TPRM) based on the available toxicity data. Risks of ∑DDT to birds were assessed by comparing the TRGs and ∑DDT concentrations in fishes from China. The tissue residue guideline for protection of birds in China is recommended to be 12.0 ng ∑DDT/g food.

Key Words: risk assessment, DDT, TRG, BAF, ∑DDT, aquatic birds, tissue residue guideline, China.

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INTRODUCTION

DDT (1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane) is a chlorinated hydrocarbon insecticide that has been used worldwide since the 1940s to control insects (ATSDR 1994). DDT and its primary metabolites (DDD and DDE), referred to as $\sum$DDT, are persistent, bioaccumulative, and toxic substances. The lipophilic nature of $\sum$DDT allows them to biomagnify such that wildlife at the top of the food chain have greater concentrations of $\sum$DDT in their tissues (CCME 1999). Wildlife in aquatic ecosystems feed on aquatic biota, such as fishes, that provide the main exposure route to $\sum$DDT that accumulate in food webs.

Adverse effects on birds caused by $\sum$DDT include lethality, reproductive effects (particularly eggshell thinning), effects on both ovaries and testes, and alteration of metabolism, neural activity, and functions of the liver (USEPA 1975, 2007). Birds appear to be particularly sensitive to the endocrine disrupting effects of $\sum$DDT, which include infertility, reduced reproductive success and impaired reproductive behavior, and parental care (Giesy *et al.* 2003; Jones *et al.* 2013). Environmental exposure to DDT has been correlated with significant changes in the brain and specifically those structures associated with mating and song (Iwaniuk *et al.* 2006). $\sum$DDT have been cited as the main reason for the decline of bald eagles in the 1950s and 1960s (USEPA 2007; Clark *et al.* 1998), and disturbances of fecundities of populations of predatory birds have been associated with exposure to $\sum$DDT. Exposure to *p,p*′-DDE is associated with thinning of eggshells in some species. This unexpected effect is probably the most significant adverse effect of $\sum$DDT observed in birds (USEPA 1975). Generally, raptors, waterfowl, passerines, and other gallinaceous ground birds are more susceptible to eggshell thinning than domestic fowl and other gallinaceous birds, and DDE, specifically *p,p*′-DDE, is a more potent inducer of eggshell thinning than DDT (Lundholm 1997; USEPA 1975).

The term tissue residue guideline (TRG) is a narrative statement or maximum numerical concentration of a substance in aquatic biota recommended to protect wildlife that consume aquatic biota (CCME 1998). The Canadian tissue residue guideline for total DDT for protection of wildlife consumers of aquatic biota is 14.0 ng/g diet wet mass (wm) (CCME 1999). This value was derived based on a LOAEC for eggshell thinning of 0.3 mg/kg-day from mallard ducks (*Anasplatyrhynchos*), and the value of intake of food per unit body mass (FI/BM) (0.94) for Wilson's storm petrel was used. The water quality criterion (WQC) for protection of avian wildlife value derived by the U.S. Environmental Protection Agency (USEPA), based on a LOAEC for reproductive effects on the brown pelican was 11 pg$\sum$DDT/L and the tolerable daily intake (TDI) was 0.027 mg/kg-day for brown pelicans (*Pelecanusoccidentalis*) (USEPA 1995). In the assessment presented here, three representative avian wildlife species, belted kingfisher, bald eagle, and herring gull, were selected.

Our study, the results of which are presented here, had three objectives: (1) derive TRGs for the effects of $\sum$DDT on birds by using the toxicity percentile rank method and the species sensitivity distribution, (2) assess the $\sum$DDT hazard to birds by comparing TRGs derived in this study with the actual concentrations of $\sum$DDT measured in fish in selected regions of China, and (3) derive wildlife criteria for $\sum$DDT in water for protection of birds. The assessment is

Table 1. Body masses and food ingestion rates of three representative avian birds in China.

Avian species	BM (kg)	FI (kg/d wm)	FI:BM	Reference
Night heron	0.706	0.239	0.34	Zhang *et al.* 2013
Little egret	0.342	0.148	0.43	Zhang *et al.* 2013
Eurasian spoonbill	2.232	0.514	0.23	Zhang *et al.* 2013

intended to serve as a scientific foundation for risk management of ∑DDT in China.

COLLECTION OF TOXICITY DATA AND DERIVATION METHODS

Selection of Representative Avian Species in China

The primary basis for selection of representative avian species was a natural history that included exposure of pollutants via aquatic food webs (USEPA 1995), such as fish-eating birds. The night heron (*Nycticoraxnycticorax*), little egret (*Egrettagarzetta*), and Eurasian spoonbill (*Plataleaieucorodia*) were selected as three representative avian species in China (Zhang *et al.* 2013), all of which are widely distributed in Chinese aquatic ecosystems and feed on aquatic prey (Barter *et al.* 2005). These three species have been studied extensively as bioindicators of wetlands' health and environmental pollution (Lam *et al*. 2008; Levengood *et al.* 2007; An *et al.* 2006). Body masses (BM) and rates of ingestion of food (FI) for these three avian species are shown in Table 1.

Collection of Toxicity Data for the Effects of ∑DDT on Birds

The information on no observed adverse effects concentration (NOAEC) and/or lowest observed adverse effects concentration (LOAEC) for effects of ∑DDT on birds have been summarized (USEPA 1995, 2007). Toxicity data for dietary exposure were converted to tolerable daily intake (TDI) values, which were calculated from body mass and food ingestion rates for selected surrogate birds. Relevant NOAEC and/or LOAEC were selected based on the principles listed in *Protocol for Derivation of Canadian Tissue Residue Guidelines for Protection of Wildlife That Consume Aquatic Biota* (CCME 1998). The three main principles included in the "protocol" were (1) selecting studies under suitable control conditions and with ecological-relevant endpoints considered; (2) selecting chronic or subchronic studies with a clear dose–response relationship; (3) selecting studies in which the form and dosage of tested chemicals were reported.

Methods for Deriving TRGs for the Effects of ∑DDT on Birds

Application of NOAEC or LOAEC as a reference dose could be over- or under-protective and not reflect the specific point of the dose–response relationship (Kannan *et al.* 2000). To address this limitation, the geometric mean (Geomean) of NOAEC and LOAEC values were used as the reference dose for adverse effects. If the NOAEC was not determined in a particular study, it was estimated by dividing the LOAEC by a factor of 5.6 (CCME 1998) (Eq. (1)). The TDI was calculated using Eq. (2). An uncertainty factor (UF) of 10 was selected to account for differences in interspecies sensitivities to $\sum$DDT as well as extrapolation from sub-chronic to chronic effects (CCME 1998; Kannan *et al.* 2000). The reference concentration (RC) for $\sum$DDT was calculated using the TDI in conjunction with FI and BM (Eq. (3)). Water quality criteria (WQC) for $\sum$DDT for protection of birds was calculated by dividing the RC by the bioconcentration factor (BAF, ratio of chemical concentrations in fish to water) (Ludwig *et al.* 1993) (Eq. (4)).

$$\mathrm{NOAEL} = \mathrm{LOAEL}/5.6 \tag{1}$$

$$\mathrm{TDI} = (NOAEL \times \mathrm{LOAEL})^{0.5}/\mathrm{UF} \tag{2}$$

$$\mathrm{RC} = \mathrm{TDI}/(\mathrm{FI}/\mathrm{BM}) \tag{3}$$

$$\mathrm{WQC} = \mathrm{RC}/\mathrm{BAF} \tag{4}$$

Two methods were used to derive tissue residue guidelines (TRG) for protection of aquatic birds in China from effects of $\sum$DDT. The species sensitivity distribution (SSD) is a probability distribution function method that can be used to describe the range of tolerances among species (Leo *et al.* 2002). It has been used widely in aquatic ecological risk assessment and derivation of water quality criteria (WQC) for aquatic biota (Caldwell *et al.* 2008; Hall *et al.* 2009). This method could also be applied in risk assessment for wildlife if there are sufficient toxicity data for wildlife. However, for the $\sum$DDT there is a relatively large amount of information on multiple endpoints for multiple species. The SSD method was used in this study to derive TRGs to protect fish-eating birds from the effects of $\sum$DDT, by selecting the most sensitive endpoint data (TDIs) for each species to construct a SSD (USEPA 2005). The SSD approach has the basic assumption that sensitivities of species can be described by a specified statistical distribution, such as the normal distribution. Assuming the selected data on toxicity of $\sum$DDT can be described by using a log-normal distribution, the Origin 8 program was used to fit the distribution. HC_5 (Hazard concentration affecting 5% of species) that protects 95% species from contaminants was calculated.

The toxicity percentile rank method (TPRM) is the standard method recommended by USEPA for derivation of water quality criteria for protection of aquatic organisms (USEPA 1985). TDIs for avian species were ordered from greatest to least (most tolerant to least tolerant), and ranks "R" were assigned to TDIs from 1 for the least to N (N is the number of avian species) for the greatest. The cumulative probability "P" was calculated for each species with the equation of $P = R/(N+1)$. Finally, four TDIs that have cumulative probabilities closest to 0.05 (always the four leastTDIs) are selected to calculate the toxicity reference value (TRV) (Eqs. (5)–(8)).

$$\mathrm{S}^2 = \left\{\left[\sum \mathrm{lnTDI})^2\right] - \left[\sum \mathrm{lnTDI})^2\right]/4\right\}/\left\{\sum (\mathrm{P}) - \left[\sum (\sqrt{}\mathrm{P}]\right]^2/4\right\} \tag{5}$$

$$\mathrm{L} = \left\{\sum (\mathrm{lnTDI}) - \mathrm{S}\left[\sum (\sqrt{}\mathrm{P}]\right]\right\}/4 \tag{6}$$

$$\mathrm{A} = \mathrm{S}(\sqrt{}(0.05) + \mathrm{L} \tag{7}$$

$$\mathrm{TRV} = \mathrm{e}^{\mathrm{A}} \tag{8}$$

REVIEW OF TOXICITY STUDIES OF EFFECTS OF ∑DDT ON BIRDS

Acute toxicity of DDT to birds has not been well established. LC_{50} values for DDT for several birds, such as robins, clapper rail, chicken, ring-necked pheasant, Japanese quail, northern bobwhite, and mallard, were determined and results showed that gallinaceous birds were more sensitive and ducks were less sensitive (USEPA 1995). LC_{50} values for DDT concentrations in brain were also determined for several avian species. The geometric mean of LC_{50} values based on concentrations of DDT in brain range from 23 ppm wm for blue jay to 109 ppm wm for cardinal, and 300–400 ppm DDE wm in brain caused death in grackles, red-winged blackbirds, brown-headed cowbirds, and starlings.

Long-term exposure of birds to DDT has been demonstrated to result in eggshell thinning in several species. The sub-chronic and chronic toxicity of ∑DDT to several birds, such as chicken, ring necked pheasant, Japanese quail, mallard duck, American black duck, bald eagle, American kestrel, and brown pelican, has been documented (USEPA 1995). NOAELs and/or LOAELs for several endpoints for these birds have been calculated and summarized. Also, ∑DDT toxicity data for avian species were collected for several measurement endpoints, including biochemical, behavior, reproduction, growth, and survival (USEPA 2007) (Table 2).

DERIVATION OF TRGS AND WQCS

NOAECs and/or LOAECs for the most sensitive toxicity endpoints were selected to derive the TDIs of DDT for birds (Tables 2 and 3). TDIs for these avian species were calculated using Eq. (2). If the NOAEC was not determined in a particular study, it was estimated using Eq. (1). Two methods, SSD and TPRM, were used to estimate two TRGs for ∑DDT for birds based on TDIs (Table 3).

Derivation of TRG by SSD

SSD distribution of ∑DDT for avian species was constructed by the Origin 8 program (Figure 1), using the toxicity data in Table 3. HC_5 (Hazard concentration affecting 5% of species) that protects 95% species from ∑DDT was calculated to be 3.86 ng/g-day, with a R^2 value of 0.98094.

RCs based on values of FI:BM (0.23, 0.34, and 0.43) for three representative birds (eurasian spoonbill, night heron, and little egret) in China were calculated to be 16.78, 11.35, and 8.98 ng ∑DDT/g food, respectively (Eq. (3); Table 1). The geometric mean of these three RCs was 12.0 ng ∑DDT/g food, which is the estimated TRG of ∑DDT for birds in China.

The bioaccumulation factor (BAF) of DDT (ratio of chemical concentrations in fish to water) was 127,000 (LeBlanc 1995). By use of Eq. (4), the WQC of ∑DDT for protection of birds was calculated to be 94.5 pg∑DDT/L.

Derivation of TRG TPRM

As the standard method for derivation of water quality criteria for protection of aquatic organisms, TPRM was used in this study to derive the TRG for avian species. The four least TDIs, for brown pelican, barn owl, homing pigeon, and Japanese

Table 2. Summary of sub-chronic and chronic avian toxicity values for $\sum$DDT (USEPA 1995, 2007).

Avian species	Compound	Toxic endpoint	Exposure duration	LOAEC/NOAEC (mg $\sum$DDT/ kg food)	LOAEC/NOAEC (mg $\sum$DDT/ kg BM-day)
Chicken (*Gallus domesticus*)	DDT	Reduced laying	8 weeks	10/	0.67/
	DDE	Reproduction	45 days	/40	/1.98
	DDT, DDE	Mortality	28 weeks	5/	0.293/
	DDE	Eggshell thinning	14 days	3/	0.366/
	DDE	Eggshell thinning	1 year	10/	1.24/
Japanese quail (*Coturnixcoturnix*)	DDT	Pairs breaking eggs	16 weeks	40/10	4/1
	DDT	Fertility	3 generations	50/5	5/0.5
	DDT	Eggshell thinning	26 weeks	2.5/	0.25/
	DDT	Mortality	26 weeks	25/10	2.5/1
	DDE	Mortality	24 weeks	300/100	30/10
	DDT	Mortality	24 weeks	/100	/10
Mallard duck (*Anasplatyrhynchos*)	DDT	Eggshell thinning	11 months	20/2	1.2/0.12
	DDE	Eggshell thinning	45 days	40/	2.25/
Ring necked pheasant (*Phasianuscolchicus*)	DDT	Mortality	14 weeks	100/10	5.8/0.58
	DDT, DDE	Eggshell thinning	30 days	10/	0.6/
	DDE	Embryo mortality	2 years	10/	0.6/
	DDT	Reproductive success	2 years	25/10	1.5/0.6
	DDT	Feeding behavior	105 days	N	0.411/
	DDT	Reproduction	10 weeks	N	6.02
	DDT	Body weight	90 days	/600	/35.6
	DDE	Eggshell thinning	11 weeks	/10	/0.592
American black duck (*Anus rubripes*)	DDE	Reproductive effects	6 months	10/	0.58/

American kestrel (*Falco sparverius*)	DDE	Eggshell thinning	5.5 months	3/0.3	1.1/0.11
	DDE	Mortality	1 year	10/	1.1/
Bald eagle (*Haliaeetusleucocephalus*)	DDT	Mortality	112 days	48/3	3/0.3
	DDT	Mortality	120 days	/10	/0.324
	DDT	Growth	55 days	10/	0.713/
Brown pelican (*Pelecanusoccidentalis*)	DDT	Reproductive effects	5 years	0.15/	0.027/
Northern bobwhite quail (*Colinusvirginianus*)	DDT	Organ weight change	242 days	10/	1.79/
	DDT	Growth	56 days	N	/25
	DDT	Mortality	242 days	/250	/26.8
	DDT	Organ weight change	2 months	500/50	51.6/5.16
Homing pigeon (*Columba livia*)	DDT	Mortality	42 days	N	9.1/
	DDT	Organ weight change	56 days	N	0.237/
	DDD	History	4 days	N	0.4/
	DDT	Physiology	3 weeks	N	3/
Cowbird (*Molothrusater*)	DDT	Mortality	8 days	500/	76/
	DDT	Mortality	13 days	/100	/16.7
Bengalese finch (*Lonchurastriata*)	DDT	Mortality	6 weeks	N	85.3/9.84
	DDE	Mortality	6 weeks	N	59.4/11.9
	DDT, DDE	Reproduction	6 weeks	N	2.41/
Screech owl (*Otusasio*)	DDE	Eggshell thinning	20 months	N	2.8/
White throated sparrow (*Zonotrichiaalbicollis*)	DDT	Mortality	11 weeks	25/5	5.21/1.04

(Continued on next page)

Table 2. Summary of sub-chronic and chronic avian toxicity values for $\sum$DDT (USEPA 1995, 2007). *(Continued)*

Avian species	Compound	Toxic endpoint	Exposure duration	LOAEC/NOAEC (mg $\sum$DDT/ kg food)	LOAEC/NOAEC (mg $\sum$DDT/ kg BM-day)
	DDT	Growth	6 weeks	5/	1.04/
Double crested cormorants (*Phalacrocoraxauritus*)	DDT	Mortality	9 weeks	/25	/1.1
	DDT	Chemical changes	9 weeks	12.5/5.0	0.552/0.221
Starling (*Sturnus vulgaris*)	DDE	Mortality	7 weeks	25/5	3.44/0.687
Barn owl (*Tyto alba*)	DDE	Reproduction	1 year	2.83/	0.211/
Ringed turtle dove (*Streptopeliarisoria*)	DDE	Hormone changes	8 weeks	20/2.08	1.42/0.148
	DDT	Enzyme changes	29 days	10/	1.14/
	DDE	Reproduction	126 days	40/	4.58/

Table 3. The selected toxic data used to derive TDI for birds.

Avian species	Compound	Toxic endpoint	LOAEL/NOAEL[a]	TDI[b]
Chicken	DDT, DDE	Mortality	0.293/	12.4
Japanese quail	DDT	Eggshell thinning	0.25/	10.6
Mallard duck	DDT	Eggshell thinning	1.2/0.12	37.9
Ring necked pheasant	DDT	Feeding behavior	0.411/	17.4
American black duck	DDE	Reproductive effects	0.58/	24.5
American kestrel	DDE	Eggshell thinning	1.1/0.11	34.8
Bald eagle	DDT	Growth	0.713/	30.1
Brown pelican	DDT	Reproductive effects	0.027/	1.14
Northern bobwhite quail	DDT	Organ weight change	1.79/	75.6
Homing pigeon	DDT	Organ weight change	0.237/	10.0
Cowbird	DDT	Mortality	76/	3211.6
Bengalese finch	DDT, DDE	Reproduction	2.41/	101.8
Screech owl	DDE	Eggshell thinning	2.8/	118.3
White throated Sparrow	DDT	Growth	1.04/	43.9
Double crested cormorants	DDT	Chemical changes	0.552/0.221	34.9
Starling	DDE	Mortality	3.44/0.687	153.7
Barn owl	DDE	Reproduction	0.211/	8.9
Ringed turtle dove	DDE	Hormone changes	1.42/0.148	45.8

[a]mg/kg-day; [b]ng/g-day.

quail were used to calculate the TRG for birds based on the centile rank method. R = 1, 2, 3, 4, and N = 18 (Table 4).

Based on the values in Table 4 and Eqs. (5)–(8), the calculated results were S = 10.28, L = –1.88, A = 0.42, and TDI = 1.52 ng∑DDT/g -day. Using the values

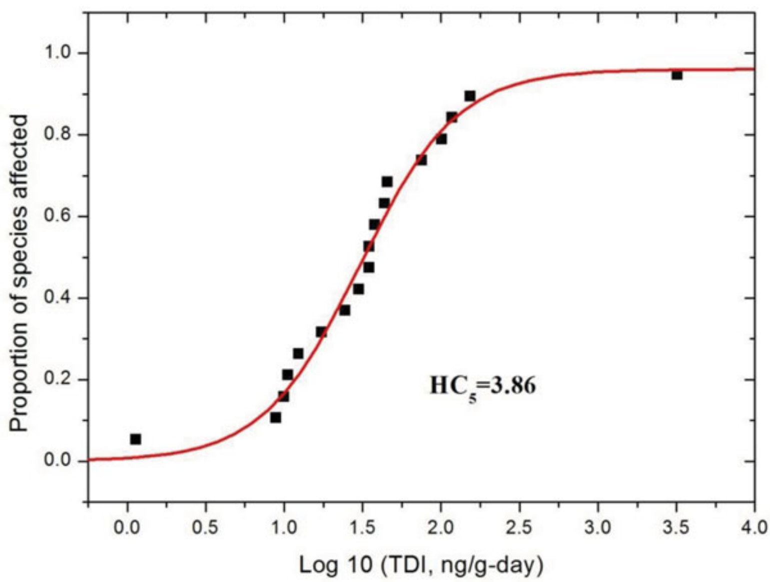

Figure 1. Species sensitivity distribution for avian toxicity data of ∑DDT.

Table 4. The TDIs and relevant values used to calculate TRG in TPRM (ng/g-day).

Rank	Avian species	TDI	ln TDI	(ln TDI)^2	P = R/(N+1)	$P^{0.5}$
4	Japanese quail	10.6	2.36	5.57	0.21	0.46
3	Homing pigeon	10.0	2.30	5.30	0.16	0.40
2	Barn owl	8.9	2.19	4.78	0.11	0.33
1	Brown Pelican	1.14	0.13	0.02	0.05	0.22
Sum			6.98	15.67	0.53	1.41

of FI:BW for three representative birds (0.23, 0.34, 0.43) in China (Table 1), RCs for these three birds were calculated to be 6.61, 4.47, and 3.53 ng ∑DDT/g food. The geometric mean of these three RCs was 4.7 ng/g food, which was the TRG of ∑DDT for birds. Based on the BAF for ∑DDT, which is 127,000 (LeBlanc 1995) and Eq. (4), the WQC of ∑DDT for protection of birds was calculated to be 37.0 pg ∑DDT/L.

RISK ASSESSMENT OF ∑DDT TO AQUATIC BIRDS

Concentrations of ∑DDT in Fish from the Chinese Aquatic Environment

Concentrations of ∑DDT in fishes from different zones in China were reviewed. Concentrations of ∑DDT in the four species of fish (crucian carp, topmouth culter, common carp, and bighead carp) were 3.24–37.1 ng ∑DDT/g wm, with *p,p'*-DDE being the dominant isomer (Guo *et al.* 2012). This is consistent with the field survey conducted during 1999–2001 in the Tai Lake (Ch: *Taihu*) area that showed that ∑DDT in fishes ranged from 3.7 to 23.5 ng ∑DDT/g wm (Feng *et al.* 2003).

Concentrations of ∑DDT in freshwater and marinefish purchased from markets in Hong Kong ranged from 1.1 to 127 ng ∑DDT/g wm, and 2.3 to 1018 ng/g wm, respectively (Cheung *et al.* 2007). Ten species of fish collected in the Pearl River Delta between 2005–2006 were analyzed and the concentrations of ∑DDT were 4.47–100.28 ng/g wm (Leung *et al.* 2010). Five species of fish were collected from a local market in Zhoushan City, an island in the East China Sea, and the concentrations of ∑DDT were measured to be 0.45-8.62 ng/g wm (Jiang *et al.* 2005). A total of 390 individual fish were randomly collected between November 2004 and January 2005 from local markets in 11 coastal cities of Guangdong Province, and the range of concentrations of ∑DDT in all fish was 0.14–698.9 ng/g wm, with an average concentration of 6.0 ng ∑DDT /g wm (Meng *et al.* 2007).

Six fishes were collected from Northwestern waters of Hong Kong for analyses, and the concentrations of ∑DDT in fish were 0.3–16.3 ng/g wm (Hung *et al.* 2006). A wide variety of fish were collected from local supermarkets of Dalian, Tianjin, and Shanghai in Chinato be analyzed for ∑DDT, and the concentrations of ∑DDT in fish from Dalian, Tianjin, and Shanghai were 0.84–212.16 ng/g wm, 2.91–11.48 ng/g wm, and 0.31–37.3 ng/g wm, respectively (Yang *et al.* 2006). Concentrations of ∑DDT in 18 fishes from the Qiantang River ranged from 2.65 to 133.51 ng/g wm (Zhou *et al.* 2007). Concentrations of ∑DDT in fishes from markets in Hongkong and Guangdong were greater than those from other regions, such as the Dalian and Qiantang rivers. Fishes from other regions have similar or lesser concentrations of ∑DDT.

Assessment of Risks of ∑DDT to Aquatic Birds in China

Birds in aquatic ecosystems depend on aquatic biota, such as fish, as their primary source of food. ∑DDT could accumulate to large concentrations in fish via the aquatic food chain with a BAF (ratio of concentrations in fish to water) value of 127,000 (LeBlanc 1995). Accordingly, consumption of fishes by birds is a primary route of exposure to persistent substances, such as ∑DDT. The risks of ∑DDT to birds were assessed by comparing the concentrations of ∑DDT in fish to TRGs derived in this study.

The TRGs of ∑DDT for birds in China derived by SSD and TPRM were 12.0 ng/g food wm and 4.7 ng/g food wm, respectively. Concentrations of ∑DDT in fish from different regions in China ranged from less than 1 ng/g wm to more than 1000 ng/g wm. Several concentrations of ∑DDT exceeded the TRG, which indicated that ∑DDT in fish could cause adverse effects to birds via food consumption.

RESULTS

TRGs of ∑DDT for protection of avian species in China, derived here by the two methods, were 12.0 and 4.7 ng ∑DDT/g wm diet, respectively. The TRG value of ∑DDT derived by using the TPRM was smaller than the TRG determined by SSD. Because the four lowest toxicity data values were used in the TPRM, the criterion calculated was small, which might lead to over-protection for Chinese birds. While in the derivation of TRG for ∑DDTby using the SSD approach, toxicity data on about 18 avian species were employed that covered a large sensitivity range. Therefore, the TRG of 12.0 ng ∑DDT/g wm diet was recommended as criterion for protection of aquatic birds in China from DDTs.

The water quality criterion (WQCs) for protection of birds in China, derived here by the two methods, were 94.5and 37.0 pg for ∑DDT/L, respectively. As the SSD was more reasonable than TPRM in derivation of TRG for ∑DDT, the WQC by SSD was accordingly recommended to be criterion for protecting Chinese birds from DDTs.

DISCUSSION

The TRG value for ∑DDT derived in our study is 12.0 ng ∑DDT/g wm diet, which is similar to the Canadian TRG for protection of piscivorous birds from effects of ∑DDT (14.0 ng/g diet wm) (CCME 1999). The Canadian TRG was derived based on a LOAEC for eggshell thinning in mallard with a food intake ratio (FI:BM) of 0.94 for Wilson's storm petrel. Derivation of TRGs of ∑DDT for birds might be improved with studies that refine estimates of uncertainty factors for wildlife in China. The WQC value derived for protecting birds in China is 94.5 pg ∑DDT/L, which is about eight times larger than the avian wildlife value of 11 pg ∑DDT/L derived by USEPA (USEPA 1995). The wildlife value by USEPA was derived using the LOAEC for reproductive effects of pelicans, which is based on field studies rather than laboratory studies because they were judged to be more relevant than laboratory tests that do not capture the full life cycle, range of exposures, nor measure the actual effect endpoints. Basing these guidelines on three commonly studied birds does not necessarily evaluate and thus protect the most sensitive avian species in China. Also in future studies, protection of birds may be strengthened by incorporating field and laboratory studies into the development of WQC.

The criteria values derived here was based on laboratory test endpoints and natural history of three species of birds endemic to China that could be used for risk evaluation for $\sum$DDT of birds in China and provide reasonable protection for birds in China. The estimated criteria are bracketed by criteria in Canada and the United States, indicating that these calculated values are reasonable estimates that can be updated as more studies become available on resident species. The method may also serves as a general procedure for developing WQC in China for other contaminants.

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