Evaluation of population-level ecological risks of fish-eating birds to dioxinlike PCBs exposure

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Introduction

Polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/DFs) and some non- and mono-ortho-polychlorinated biphenyl congeners that can attain planar configuration (dioxinlike PCBs), which are chemically stable and persistent, are thought to be biomagnified via foodchain. Many studies have revealed that higher levels of these compounds have been observed in fish-eating birds, a top consumer in aquatic biota [1]. Among these compounds, Dioxinlike PCBs has contributed more than 80% of the total TEQs found in eggs of fish-eating birds [1]. In order to evaluate the effects of these compounds on fish-eating birds, therefore, it is important to elucidate exposure pathways and characteristics of dioxinlike PCBs.

The conventional ecological risk assessment method of chemicals entails comparing the predicted no effect concentration (PNEC) determined from laboratory toxicity tests with the predicted or observed concentration in a target organism or a surrounding environmental media. Utilizing such a result of simplistic individual-level effect to draw conclusions regarding chemical effects on population is, however, questionable. Since risk management decisions should be based on protecting populations, the methods for population-level ecological risk assessment of chemicals have been of increasing interest for risk assessors and managers.

In this study, a population-level ecological risk assessment of dioxinlike PCBs on fish-eating birds was performed to judge the need for risk management measures to protect aquatic wildlife from dioxinlike PCBs contamination in Japan. Egg mortality risk and the changes in population growth rate, λ, in relation to the contamination levels of dioxinlike PCBs in eggs of four different types of fish-eating birds were determined by integrating the results from both bioaccumulation and life-history models.

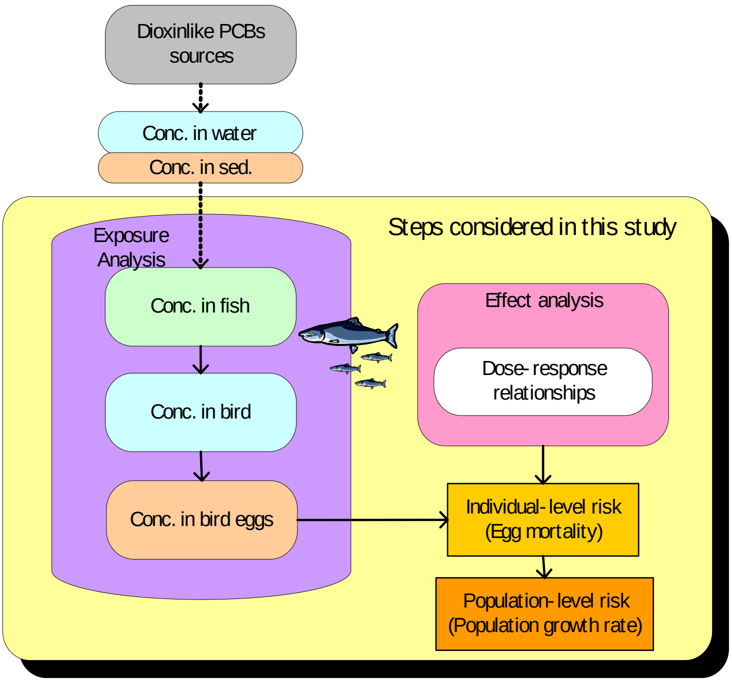
Methods

The risk analyses procedure used in this study was mainly based on Murata et al [2]. Since the detailed description of the methods has been found elsewhere [2], only a brief description of the method is presented here. A marked difference between this study and the previous study is that λ is used to measure the chemical effects on bird populations in this study, while the decremented population size is used to measure the chemicals effects in the previous study.

Grey Heron, great cormorant, osprey and kingfisher populations were selected as the target species in this study because sufficient data related to life history and toxicity are available for those species or related species. The target area was Tokyo Bay and its the surrounded area because the area is strongly affected anthropogenic activities and considered to be one of the most polluted areas with these compounds in Japan. Implementing the population level risk assessment for this area can help to identify the degree of risk for other areas in Japan.

The depiction of the analyses is shown in Figure 1. In the exposure analysis phase, dioxinlike PCBs levels (pg-TEQ/g-egg) in eggs for the target species were determined using both monitoring data and simple bioaccumulation model. The differences in dioxinlike PCBs levels among each bird population were reflected factors such as their habitat, body size and foods. In the effect analysis phase, a literature search was conducted to compile information on dose-response relationships in terms of TEQs, and the dose-response functions were obtained assuming log-normal distribution using the method proposed in ECOFRAM [3]. The dose-response functions used in this study are based on the relationship between TEQ concentrations in eggs and hatching success.

Figure 1: Conceptual model for population-level risk assessment of dioxinlike PCBs for fish-eating bird



Life-history data such as survival probability and fecundities for the target species were collected and examined to apply into the life-history models. An in-depth description of life-hitsory models has been found elsewhere [4]. The life-history model used in this analysis is represented as:

$$N(t+1) = M \cdot N(t)$$

$$\begin{bmatrix} n_{1,t+1} \\ n_{2,t+1} \\ n_{3,t+1} \\ n_{4\le,t+1} \end{bmatrix} = \begin{bmatrix} f_1 & f_2 & f_3 & f_{4\le} \\ p_1 & 0 & 0 & 0 \\ 0 & p_2 & 0 & 0 \\ 0 & 0 & p_3 & p_{4\le} \end{bmatrix} \begin{bmatrix} n_{1,t} \\ n_{2,t} \\ n_{3,t} \\ n_{4,t} \end{bmatrix}$$

where

N (t) : vector of the number of organisms in each age class
t: time, year
M: leslie population projection matrix
ni,t : the number of organisms in each age class *i*
fi : average fecundity at age *i*
pi : age-specific survivorship probability at age *i*

In order to link effects on individuals to effects on population, the estimated dose-response functions were used to alter average fecundity in relation to TEQ levels in egg. λ calculated for different exposure levels for each species was used as the measure of population-level effects resulting from dioxinlike PCB exposures. λ can be in theory estimated as the only real and positive eigenvalue of the leslie population projection matrix. Life-history data for each species used in the analyses were shown in Table 1.

Table 1: Life-history parameters of four bird populations used in this study

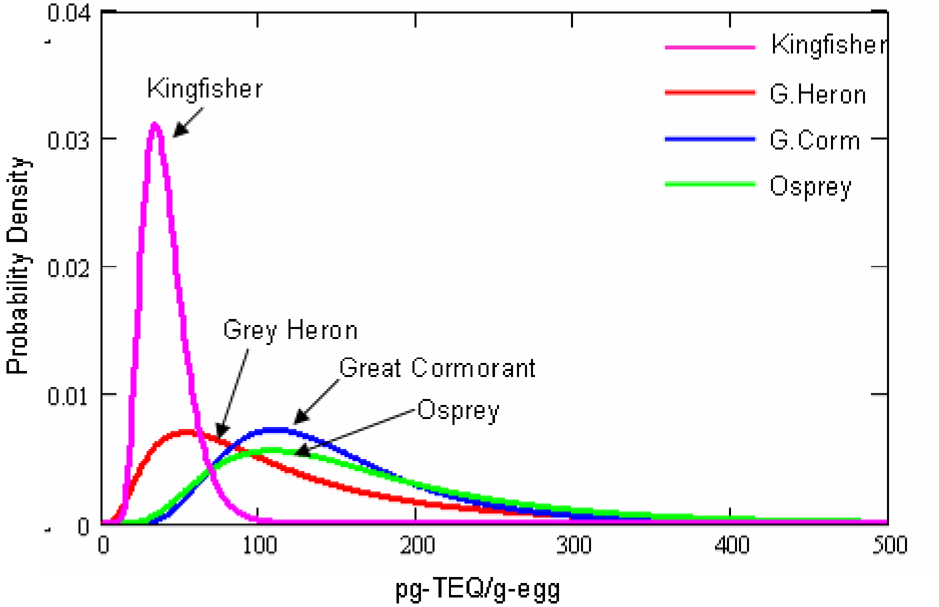
Description	Symbol	Grey Heron [1)]	Great Cormorant [2)]	Osprey [2)]	Kingfisher [2)]
Average Fecundity, *fi*	f_1	0	0.332	0	0.851
	f_2	0.90	0.450	0	0.851
	f_3	1.35	0.782	0.308	0.851
	f_4	1.40	1.033	0.308	0.851
Survivorship Probability, *pi*	p_1	0.441	0.847	0.821	0.28
	p_2	0.691	0.864	0.821	0.28
	p_3	0.643	0.864	0.85	0.28
	p_4	0.789	0.864	0.85	0.28

[1)] Parameters for grey heron were obtained from Fernandez-Cruz and Campos [5] and Mead et al.[6]
[2)] Parameter for great cormorant, osprey and kingfisher were obtained from Murata [7] .

Results and Discussions

The predicted probability density distributions for dioxinlike PCBs levels in eggs currently found in the Tokyo Bay area for each bird population are shown Figure 2. All the probability density distributions except for great cormorant were estimated using simple bioaccumulation model. The probability density distribution for great cormorant was based on the measured values [8].The probability density distributions for each species indicated that a higher levels of dioxinlike PCBs are observed in osprey, while a lower levels of dioxinlike PCBs are observed in kingfisher. Differences in habitats, lipid content in eggs, foods for each bird population reflected the differences in shapes of probability distributions among the populations.

Figure 2: Estimated probability density distribution of dioxinlike PCBs (in TEQ) in eggs among grey Heron, great cormorant, osprey and kingfisher populations



The estimated parameters of the dose-response functions determined using the ECOFRAM method are shown in Table 2. Since an appropriate dose-response function for kingfisher was not available, the dose-response function of chicken, the most sensitive to TEQs among birds, was tentatively used for kingfisher.

Table 2 shows egg mortality risk calculated by integrating the results of exposure and effects analyses. Assuming dioxinlike PCBs contamination levels observed in the Tokyo Bay area, egg mortality risks for grey heron, great cormorant, osprey and kingfisher populations were 5.8, 6.8, 12 and <1 %, respectively. In spite of the most sensitive dose-response function applied to kingfisher, the egg mortality risk of kingfisher was the lowest. This can be explained by a small value of the standard deviation, in other words, the narrow range of adverse effects levels observed, in the dose-response function used for kingfisher compared with those used for other target species.

The relationship between λ and dioxinlike PCBs levels in eggs are shown in Table 2 and Figure 3. The estimated λ for grey heron, great cormorant, osprey and kingfisher populations were 1.063, 1.406, 1.032, and 1.131, respectively, in case of the current dioxinlike PCBs contamination levels in the Tokyo Bay area. Since λ greater than 1 indicate, in theory, an increase in population size in a subsequent year, the resulting λ for each bird population imply that adverse population-level effects are of little concern for all the target bird populations in relation to dioxinlike PCBs levels found in the Tokyo Bay are. Judging from the results above, current contamination levels of dioxinlike PCBs in the Tokyo Bay area pose little risk on the fish-eating bird populations, thus, along with a decreasing trend of dioxin and dioxinlike PCBs in the Tokyo Bay, there is at present no need for risk reduction measures for protecting fish-eating bird populations for dioxinlike PCBs.

Table 2: The estimated egg mortality risk for grey heron, great cormorant, osprey and kingfisher. GM: Geometric Mean; GSD: Geometric Standard Distribution

Target Species	Exposure Distribution		Dose-response Function			Egg Mortality Risk (%)	λ[λ'] [1)]
	GM	GSD	GM	GSD	Ref.		
Grey Heron	98	2.18	3700	8.778	a)	5.8	1.063 [1.074]
Great Cormorant	134	1.57	3700	8.778	a)	6.8	1.406 [1.434]
Osprey	147	1.75	6100	22.456	b)	12	1.032 [1.041]
Kingfisher	38	1.43	320	1.749	c)	< 1	1.131 [1.131]

[a)] Powell et al. [9]; [b)] Hoffman et al.[10] ; [c)] Brunstrom and Andersson.[11]

[1)] The value of λ is estimated using the geometric mean (GM) of dioxinlike PCB levels in eggs for each bird population, while λ' , estimated assuming no exposure to dioxinlike PCBs, is the reference value.

In addition to the effects of dioxinlike PCBs, factors such as environmental and demographic fluctuation, coexistent compounds, species interactions, and density effects could affect population size of the fish-eating birds in wildlife. It would be very difficult to draw conclusions regarding chemical effects only without considering such factors for wildlife. The proposed population-level risk assessment framework can be expanded to integrate the related factors and incorporate uncertainty into the analyses framework. Further analyses and applications of the methods will determine the extent of its applicability and reliability for specific risk assessment tasks and predictions for the population-level risk management of chemicals.

Acknowledgement
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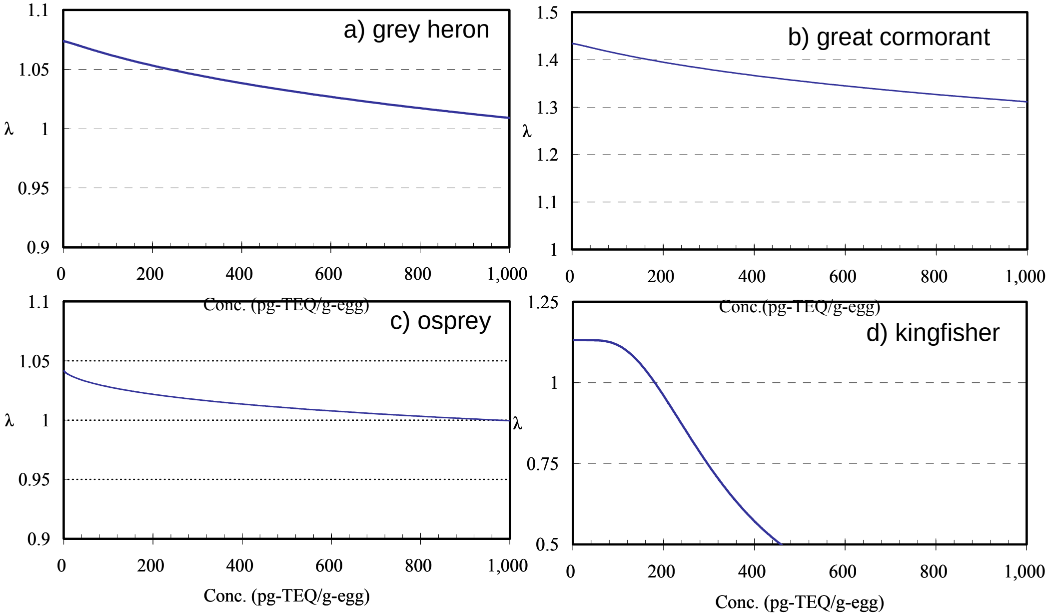
Figure 3: Relationships between population growth rate (λ) and dioxinlike PCBs levels in eggs (pg-TEQ/g-egg) for a) grey heron, b) great cormorant, c) osprey and d) kingfisher



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