The environmental criteria for assessing the ecological risk of Bisphenol A in Chinese surface fresh water

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Abstract. For the situation where the endocrine disrupting chemicals pollution to surface water environment getting worse and worse, this study chooses Bisphenol A (BPA) as a subject to discuss its damage to national surface water environment and assess its ecology risk. By using its NOEC data from the literature which have been published, A model of species sensitivity distribution were established based on Log-logistic distribution. In the Log logistic distribution, according to our calculation, we gain its two main factors, α=2.18, β=0.53. After establishing the species sensitivity distribution, we use Kolmogorov-Smirnov and Anderson-Darling method to test how well the model fits the data. The P-P plot and histogram with fitting probability curve about toxicity data were employed to ensure our original theoretical model is suitable. ThenThe model were used to calculate the HC5, it turns out that HC5=4.23ug/L. The HC5 were used to identify which species is endangered under such specific concentration. By using HC5, the continuous criterion concentration (CCC) were reckoned which is 1.41ug/L.

1. Introduction
Endocrine disrupting chemicals (EDCs) enter the environment in several different ways, mainly through soil leaching, atmospheric deposition, direct discharge, surface runoff and other ways. Data analysis shows that EDCs can disturb the endocrine function of organisms, lead to reproductive organs[1], reproductive functions and reproductive behavior abnormalities, cause fertility decline, and even biological reproductive function damage, and eventually lead to population decline and species extinction[2].

Bisphenol A (BPA) is an important raw material in chemical industry[3]. Recently, 63% percent of bisphenol A is used for poly-carbonate synthesis, 27% for epoxy resin production, and the remaining 10% for special resins and other products such as flame retardants. The potassium or sodium salts are used as raw materials for polyurethanes, and to A lesser extent as rubber antiaging agents. In this study, we attempted to establish an SSD model of Bisphenol A for aquatic organisms, estimate the continuous criterion concentration (CCC) of Bisphenol A, and provide reliable data reference for the formulation of environmental quality standards for Bisphenol A.
2. Materials and Methods

2.1. Data Sources

The data involved in this study are all from published literature. Through literature, the non-effect concentration (NOEC) of bisphenol A on aquatic organisms was selected as toxicity data to construct SSD model. Chronic toxicity data of 18 different species were selected for this study, including chordates, molluscs, nematodes, cnidaria, arthropods, algae, etc. Table 1 shows the specific data.

| Species Classification | Species               | NOEC(ug/L) | References |
|------------------------|-----------------------|------------|------------|
| Chordate salmonidae    | Salmo trutta$^1$      | 1.75       | [1]        |
| Molluscidae            | Marisa cornuarietis$^2$ | 2.10      | [2]        |
| Nematodes small rod family | Caenorhabditis elegans$^2$ | 22.80 | [3] |
| Mollusciidae           | Physella acuta$^1$    | 100.00     | [4]        |
| Chordate odopylidae    | Oryzias latipes$^1$   | 120.00     | [5]        |
| Chordate guilidae      | Poecilia reticulata$^2$ | 137.00   | [6]        |
| Spiny cells hydrodidae | Hydra oligactis$^1$   | 170.00     | [7]        |
| Chordate cyprinidae    | Danio rerio$^2$       | 400.00     | [8]        |
| Phylum arthropoda polyspiny hookidae | Hyalella azteca$^1$ | 490.00 | [9] |
| Phylum arthropoda fleas | Daphnia magna$^1$    | 800.00     | [10]       |
| Arthropod fleas        | Ceriodaphnia dubia$^1$ | 940.00   | [11]       |
| Brachiocephalidae, Rotifers | Brachionus calyciflorus$^1$ | 1800.00   | [12]       |
| Chordate Ranidae       | Rana temporaria$^2$   | 10.00      | [13]       |
| Spiny cells hydrodidae | Hydra vulgaris$^1$    | 42.00      | [14]       |
| Phylum arthropoda chironomidae | Chironomus riparius$^1$ | 100.00 | [15] |
| Chordate cyprinidae    | Cyprinus carpio$^1$   | 100.00     | [16]       |
| Chlorophyta chlorella family | Pseudokirchneriell subcapitata$^1$ | 1360.00 | [17] |
| Chordate salmonidae    | Oncorhynchus mykiss$^2$ | 3640.00 | [18] |

Note: 1 represents the native species of China, 2 represents the introduced species.

2.2. Method of Species Sensitivity Distribution

In general, the log-logistic distribution can be used to better fit the non-effect concentration toxicity data of different species. Therefore, species sensitivity model was constructed based on log-logistic distribution in this study. The corresponding function expression of log-logistic distribution is:

\[ Y = \frac{1}{1+\exp[(\alpha - X)/\beta]} \]

Where, Y represents the cumulative probability, X represents the logarithmic transformation value of toxicity data, \( \alpha \) and \( \beta \) are two parameters.

The models were tested using the probability plots and kindle-of-fit tests. The function of probability graph is to estimate the empirical probability of the collected toxicological endpoint data and test whether it can be fully fitted into the curve of the constructed theoretical model. There are two kinds of probability graph in common use, one is the straight statistical graph, the other is the P-P graph. The commonly used anastomosis test includes Kolmogorov-Smirnov test and Anderson-Darling test, both of which are suitable for the continuity test.

3. Result and Discussion

3.1. Species Sensitivity Distribution

Based on SSD evaluation method, the species sensitivity model of Bisphenol A was established, and the parameters and were estimated by maximum likelihood method. SSD model based on log-logistic distribution:
Y = \frac{1}{1 + \exp\left(\frac{2.18 - X}{0.53}\right)}

The 95% confidence interval of α is (1.72, 2.62), and the standard error is 0.22. The 95% confidence interval of β is (0.37, 0.80) with a standard error of 0.10. The HC₅ was calculated by the species sensitivity distribution model obtained is 4.23ug/L. The SSD distribution model is shown in Figure 2.

Figure 1. Aquatic organisms’s species sensitivity distribution based on BPA

Note: a-Salmo trutta, b-Marisa cornuarietis, c-Caenorhabditis elegans, d-Physella acuta Chironomus riparius Cyprinus carpio, e-Orzias latipes, f-Poecilia reticulata, g-Hydra oligactis, h-Danio rerio, i-Hyalella Azteca, j-Daphnia magna, k-Ceriodaphnia dubia, l-Brachionus calyciflorus, m-Rana temporaria, n-Hydra vulgaris, o-Pseudokirchneriell subcapitata, p-Oncorhynchus mykiss

3.2. Test of the SSD model

Kolmogorov-Smirnov test and Anderson-Darling test are adopted in this paper, both of which can objectively reflect the fitting degree of the continuous curve. The test results are shown in Table 3. The P values of both tests are greater than 0.05, indicating that the two tests we used do not reject the null hypothesis, that is, the cumulative probability distribution of toxicity data conforms to the log-logistic distribution curve of the null hypothesis. The SSD model obtained has good fitting property and reflects the effect of Bisphenol A on aquatic organisms.

| Test                  | Statistic   | Probability |
|-----------------------|-------------|-------------|
| Kolmogorov-Smirnov    | D=0.132582  | P=0.8801    |
| Anderson-Darling      | AD=0.30494  | P=0.9336    |

Frequency histogram and fitting probability curve and P-P graph (Figure 3) reflect the fitting effect of SSD curve. It is concluded from the P-P diagram that the cumulative proportion of variables and the cumulative proportion corresponding to the specified distribution approximate a straight line, which indicates that the proposed LOG-logistic distribution-based SSD model and the collected toxicity data are well fitted. From the frequency histogram corresponding to the SSD curve (Figure 4), it can be seen that: the cumulative probability of variables basically conforms to the normal distribution curve, indicating that the SSD model can fully fit the toxicity data we have collected.
3.3. Continuous Criterion Concentration

The HC₅ was calculated by the species sensitivity distribution model obtained is 4.23ug/L. The continuous reference concentration is HC₅ divided by a coefficient AF (evaluation factor), whose value ranges from 1 to 5. The determination of AF is related to the quality of data, the selection of toxicity endpoints, data orientation and representativeness and diversity. In this paper, considering the HC₅ value that has been calculated and the relevant data involved in other similar literatures, the value of AF is 3. Based on the above content, the continuous reference concentration of Bisphenol A for aquatic organisms was obtained as 1.41ug/L. It was found that under similar conditions, the continuous reference concentration (CCC) value of Bisphenol A for aquatic organisms set by the European Union was 1.5ug/L[19], which could be considered to be very close to the 1.41ug/L value obtained in this paper.

4. Conclusion

In this paper, A species sensitivity distribution (SSD) model was constructed to estimate the 5% hazard concentration (HC₅) of Bisphenol A to aquatic organisms in China's water environment as 4.23ug/L. The continuous reference concentration is 1.41ug/L. When the SSD model is used to calculate the continuous reference concentration, there are great uncertainties, which affect the value of AF. At
present, there is no clear method to reduce these uncertainties. The study of methods to reduce uncertainty will greatly promote the development of SSD models.

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References
[1] Lahnsteiner F, Berger B, Kletzl M, et al. Effect of bisphenol A on maturation and quality of semen and eggs in the brown trout, Salmo trutta f. fario. Aquatic Toxicology, 2005, 75(3):213-224.
[2] Van der Hoeven, N., Experiments on the effect of BPA on the snail species Marisa cornuarietis as described in three papers by Oehlmann: Evaluation of the applied statistics and analysis of the raw data. Ecostat Report 2005. 05/011.
[3] Hoshi H, Kamata Y, Uemura T. Effects of 17beta-estradiol, bisphenol A and tributyltin chloride on germ cells of Caenorhabditis elegans. Journal of Veterinary Medical Science, 2003, 65(8):881.
[4] Sánchez-Argüello P, Aparicio N, Fernández C. Linking embryo toxicity with genotoxic responses in the freshwater snail Physa acuta: single exposure to benzo(a)pyrene, fluoxetine, bisphenol A, vinclozolin and exposure to binary mixtures with benzo(a)pyrene. Ecotoxicology & Environmental Safety, 2012, 80(3):152-160.
[5] Metcalfe C D, Metcalfe T L, Kipurissis Y, et al. Estrogenic potency of chemicals detected in sewage treatment plant effluents as determined by in vivo assays with Japanese medaka (Oryzias latipes). Environmental Toxicology & Chemistry, 2001, 20(2):297-308.
[6] Haubruge E, Petit F. Reduced Sperm Counts in Guppies (Poecilia reticulata) Following Exposure to Low Levels of Tributyltin and Bisphenol A. Proceedings Biological Sciences, 2000, 267(1459):2333-2337.
[7] Fukuhori N, Kitano M, Kimura H. Toxic effects of bisphenol A on sexual and asexual reproduction in Hydra oligactis. Archives of Environmental Contamination & Toxicology, 2005, 48(4):495-500.
[8] Keiter S, Baumann L, Färber H, et al. Long-term effects of a binary mixture of perfluorooctane sulfonate (PFOS) and bisphenol A (BPA) in zebrafish (Danio rerio). Aquatic Toxicology, 2012, 118-119(2):116.
[9] Springborn S., Bisphenol A (BPA)-chronic toxicity to amphipods (Hyalella azteca) under flow-through conditions. Unpublished report, 2006a No. 13796.6106.
[10] Brennan S J, Brougham C A, Roche J J, et al. Multi-generational effects of four selected environmental oestrogens on Daphnia magna. Chemosphere, 2006, 64(1):49-55.
[11] Tatarazako N, Takao Y, Kishi K, et al. Styrene dimers and trimers affect reproduction of daphnid (Ceriodaphnia dubia). Chemosphere, 2002, 48(6):597–601.
[12] Springborn S., Bisphenol A (BPA)-Chronic toxicity to Rotifers (Brachionus calyciflorus) under static conditions. Unpublished report, 2006b No. 13796.6108.
[13] Petri S. Koponen, Jussi V. K. Kukkonen. Effects of bisphenol A and artificial UVB radiation on the early development of Rana temporaria. Journal of Toxicology & Environmental Health Part A, 2002, 65(13):947-959.
[14] Pascoe D, Carroll K, Kanntanut W, et al. Toxicity of Ethinylestradiol and Bisphenol A to the Freshwater Cnidarian Hydra vulgaris. Archives of Environmental Contamination & Toxicology, 2002, 43(1):56-63.
[15] Segner H, Carroll K, Fenske M, et al. Identification of endocrine-disrupting effects in aquatic vertebrates and invertebrates: report from the European IDEA project. Ecotoxicol Environ Saf, 2003, 54(3):302-314.
[16] Bowmer, T., Gimeno, S., The effects of bisphenol A on the development of the male carp.
reproductive tract when exposed during sexual differentiation-implication for test design and risk assessment. 2001. Unpublished TNO report.

[17] Alexer H C, Dill D C, Smith L W, et al. Bisphenol a: Acute aquatic toxicity. Environmental Toxicology & Chemistry, 2010, 7(7):19-26.

[18] Bayer, A.G., Fish, juvenile growthtest (Oncorhynchus mykiss) of bisphenol-A. 1999. Germany: Leverkusen.

[19] Guo L, Li Z, Gao P, et al. Ecological risk assessment of bisphenol A in surface waters of China based on both traditional and reproductive endpoints. Chemosphere, 2015, 139:133-137.