Development of aquatic life criteria for triclosan and comparison of the sensitivity between native and non-native species

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HIGHLIGHTS

- Toxicity tests of triclosan on 9 Chinese native aquatic species were conducted.
- Aquatic life criteria for triclosan were derived.
- There is no significant difference between native and non-native species to TCS.

ABSTRACT

Triclosan (TCS) is an antimicrobial agent which is used as a broad-spectrum bacteriostatic and found in personal care products, and due to this it is widely spread in the aquatic environment. However, there is no paper dealing with the aquatic life criteria of TCS, mainly result from the shortage of toxicity data of different taxonomic levels. In the present study, toxicity data were obtained from 9 acute toxicity tests and 3 chronic toxicity tests using 9 Chinese native aquatic species from different taxonomic levels, and the aquatic life criteria was derived using 3 methods. Furthermore, differences of species sensitivity distributions (SSD) between native and non-native species were compared. Among the tested species, demersal fish Misgurnus anguillicaudatus was the most sensitive species, and the fishes were more sensitive than the aquatic invertebrates of Annelid and insect, and the insect was the least sensitive species. The comparison showed that there was no significant difference between SSDs constructed from native and non-native taxa. Finally, a criterion maximum concentration of 0.009 mg/L and a criterion continuous concentration of 0.002 mg/L were developed based on different taxa, according to the U.S. Environmental Protection Agency guidelines.

1. Introduction

Personal care products (PCPs) reach the environment and can be found in all environmental medias [1,2]. The presence of PCPs in the environment and their possible effects on nontarget organisms are of great concern worldwide [3–5]. Among the PCPs, triclosan (5-chloro-2(2,4-dichlorophenoxy) phenol or TCS, CAS#3380–34–5) is a broad spectrum antimicrobial agent used in a variety of personal care products including soaps, deodorant, and toothpaste [6,7]. TCS has already been the subject of various scientific fields and has been detected in surface water worldwide in the recent years [8–18]. Toxicity tests showed that TCS is toxic to organisms [19–22], so it may impose a potential risk to the ambient water environment. However, comprehensive ecological risk assessment of TCS is hard to perform due to the absence of water quality criteria (WQC) for TCS.

WQC is an important basis for the development of water quality standards (WQSS), risk assessment, prediction and control, as well as governance body of water pollution [23]. Despite there were some toxicity data of TCS available on fish and algae, few taxonomic levels were tested, especially for native species in China. So, no final WQC was derived for TCS. In China, systematic water quality criteria studies are getting more attention in recent years, and U.S. Environmental Protection Agency (US EPA) guidelines and other...
species sensitivity distribution (SSD) methods have been used to derive water quality criteria for some toxicants with an emphasis on using Chinese native species [24–26].

In the present study, 9 acute toxicity tests and 3 chronic tests were conducted for 9 Chinese native species, and the WQC of TCS for freshwater aquatic life was derived using a battery of toxicity data according to the US EPA guidelines. The aquatic species from different taxonomic levels (3 Phyla and 7 Families) were selected, which included 4 fishes (Pseudorasbora parva, Carassius auratus, Misgurnus anguillicaudatus and Tanichthys albonubes (list the second class of protection animal of China, the wild species are rare and endangered)), a planktonic crustacean (Daphnia magna), a benthic crustacean (Neocaridina denticula sinensis), an insect (Chironomus plumosus), an annelid (Linnodrilius hoffmeisteri) and an amphibian (Rana limnocharis). Moreover, the SSD method of Holland National Institute for Public Health and the Environment (RIVM) [27] and the log-logistic SSD method were both applied to validate the results. Furthermore, the difference of sensitivity between native and non-native species was compared.

The objectives of this work are (1) a supplement to TCS toxicity database, (2) derivation of aquatic life criteria, and (3) comparison of the sensitivity difference between native and non-native species exposed to TCS, and discussion of the possibility of using non-native species toxicity data for site-specific ecological risk assessment of TCS. This work provides valuable information for environmental risk assessment and pollution management imposed by TCS in ambient water environment.

2. Materials and methods

2.1. Collection of published ecotoxicity data for TCS

The published ecotoxicity data of TCS were collected from the ECOTOX database (http://cfpub.epa.gov/ecotox), the CNKI (http://www.cnki.net) and ELSEVIER (http://www.sciencedirect.com).

2.2. Test chemicals and organisms

TCS, C12H7Cl3O2, ≥97% purity (HPLC), was purchased from Sigma–Aldrich.

According to the US EPA guidelines [28], data on at least eight families of aquatic animals drawn from three different phyla, and one aquatic plant are required in the derivation of WQC. In our study, in addition to the published ecotoxicity data, nine resident aquatic species in China were chosen for the acute and chronic toxicity tests. Prior to the toxicity tests, all test organisms were allowed to acclimatize to the dilution water during a minimum of 7 days. All toxicity tests were conducted strictly according to ASTM standard guidelines [29–31].

2.3. General test conditions

Dechlorinated tap water was used as dilution water for all tests. The measured quality parameters of dilution water were as follows: pH 8.00 ± 0.20, dissolved oxygen (DO) 8.30 ± 0.30 mg/L, total organic carbon 0.02 mg/L, and hardness as CaCO3 190 ± 0.10 mg/L. All tests were static-renewal whereby test solutions were totally replenished at 24 h intervals. The standard conditions were three replicate test containers each containing 10 organisms, at various concentrations, solvent control (DMSO) and blank control. All tests were undertaken at a light: dark photoperiod of 12:12 h. Test organisms were not fed during the acute test periods. Test chambers were immersed in a water bath adjusted to maintain the water temperature at 22 ± 2°C, unless otherwise noted. Temperature, DO, and pH were measured in test chambers daily in the acute toxicity tests and at least once a week in the chronic toxicity tests. Biological observations were performed at least once daily.

In the acute toxicity test, 48-h-EC50 (effective concentration in 50% of the test organisms over 48 h) for D. magna and 96-h-LC50 (lethal concentration in 50% of the test organisms over 96 h) for other aquatic animals were used as main endpoints. In the chronic toxicity test, 21-d-EC10 (effective concentration in 10% of the test organisms over 21 days) for D. magna and 30-d-EC10 (effective concentration in 10% of the test organisms over 30 days) for fishes were used. For fry growth, the specific growth rate (SGR) was chosen because it is less dependent on the initial size of the fish and the time between measurements than the other endpoint such as relative growth rate (RGR) [32]. The SGR was calculated as ((ln(final mass) − ln(initial mass)) × 100)/d of exposure [33].

2.4. Acute toxicity tests

All the organisms tested in this study were obtained from Chaolan Market, Chaoyang, Beijing. D. magna (<24 h age) were obtained from in-house cultures at our chemical laboratory of Chinese Research Academy of Environmental Sciences.

2.4.1. P. parva acute toxicity test

The mean wet weight of the fish was 0.20 ± 0.02 g. Fish fry were exposed to test solutions in 5 L glass aquaria for 96 h. Nominal exposure concentrations in the definitive test were 0.000, 0.018, 0.026, 0.040, 0.059, 0.089, 0.133, and 0.200 mg/L TCS, respectively.

2.4.2. C. auratus acute toxicity test

The mean wet weight of the fish was 4.00 ± 0.80 g. Fish were exposed to test solutions in 50 L glass aquaria for 96 h. Nominal exposure concentrations in the definitive test were 0.000, 1.350, 1.490, 1.640, 1.800, 1.980, 2.180, 2.400, and 2.640 mg/L TCS, respectively.

2.4.3. M. anguillicaudatus acute toxicity test

The mean wet weight of the fish was 0.68 ± 0.05 g. Fish were exposed to test solutions in 20 L glass aquaria for 96 h. Nominal exposure concentrations in the definitive test were 0.000, 0.020, 0.030, 0.044, 0.067, 0.100, 0.150 and 0.225 mg/L TCS, respectively.

2.4.4. T. albonubes acute toxicity test

The mean wet weight of the fish was 0.02 ± 0.01 g. Fish fry were exposed to test solutions in 2 L beakers for 96 h. Nominal exposure concentrations in the definitive test were 0.000, 0.749, 0.787, 0.826, 0.867, 0.910, 0.956, and 1.044 mg/L TCS, respectively.

2.4.5. D. magna acute toxicity test

The species were exposed to 100 mL test solution in 150 mL beakers for 48 h. Nominal concentrations in the definitive test were 0.000, 0.232, 0.278, 0.333, 0.400, 0.480, 0.576 and 0.691 mg/L TCS, respectively.

2.4.6. N. denticulata sinensis acute toxicity test

The mean wet weight of the crustacean was 0.02 ± 0.01 g. Shrimp were exposed to test solutions in 2 L beakers for 96 h. Nominal exposure concentrations in the definitive test were 0.000, 0.591, 0.650, 0.715, 0.787, 0.865, 0.952, and 1.047 mg/L TCS, respectively.

2.4.7. C. plumosus acute toxicity test

The mean wet weight of the organism was 0.03 ± 0.01 g. The species were exposed to 25 mL test solutions in glass culture dish for 96 h. Nominal exposure concentrations in the definitive test were 0.000, 2.066, 2.273, 2.500, 2.750, 3.025, 3.328, 3.660, 4.026 and 4.429 mg/L TCS, respectively.
2.4.8. *L. hoffmeisteri* acute toxicity test

The mean body length of the tubificus was 3.00 ± 0.50 cm. The species were exposed to 25 ml test solutions in glass culture dish for 96 h. Nominal exposure concentrations in the definitive test were 0.000, 0.364, 0.545, 0.818, 1.227, 1.841, 2.761, 4.142 and 6.212 mg/L TCS, respectively.

2.4.9. *R. limnocharis* acute toxicity test

The mean body length of the tadpoles was 1.60 ± 0.20 cm. Tadpoles were exposed to test solutions in 2 L beakers for 96 h. Nominal exposure concentrations in the definitive test were 0.000, 0.265, 0.318, 0.382, 0.458, 0.550, 0.660, 0.792 and 0.950 mg/L TCS, respectively.

2.5. Chronic toxicity tests

2.5.1. *M. anguillicaudatus* chronic toxicity test

The fish used in the chronic toxicity test were the same as in the acute toxicity test. Thirty-day short-term chronic toxicity tests were conducted. The fish were fed with brine shrimp at a rate of 0.1% body weight twice daily. Endpoints observed included survival, growth and body weight. Nominal exposure concentrations in the definitive test were 0.000, 0.003, 0.005, 0.007, 0.010, 0.015 and 0.023 mg/L TCS, respectively.

2.5.2. *T. albonubes* chronic toxicity test

Thirty-day short-term chronic toxicity tests were conducted. The fish were fed with brine shrimp at a rate of 0.1% body weight twice daily. Endpoints observed included survival, growth and body weight. Nominal exposure concentrations in the definitive test were 0.000, 0.080, 0.096, 0.116, 0.139, 0.167 and 0.200 mg/L TCS, respectively.

2.5.3. *D. magna* chronic toxicity test

Three weeks survival-reproduction tests using neonates of *D. magna* (<24 h old) were conducted in 150 ml beakers filled with 100 ml test solutions. The daphnias were fed once a day with green algae (*Scenedesmus obliquus*) that had a cell concentration of 1.0 x 10^5 cell/mL in the test solution. The survival, growth and reproduction were recorded daily. The endpoints included the time to first brood, number to first brood, number of broods and total number of spawning. Nominal concentrations in the definitive test were 0.000, 0.018, 0.024, 0.031, 0.040, 0.053, 0.068, 0.089, 0.115, 0.150 and 0.195 mg/L TCS, respectively, with ten replicate test containers each containing one organism.

2.6. Chemical analysis

The concentration of TCS in the solutions of each group at the beginning and end of the experiments was detected. Briefly, the solutions were filtered through a 0.45-mm filter membrane and followed by high performance liquid chromatography (HPLC) detection, using an LC-10AD system (SHIMADZU, Tokyo, Japan), a ODS column (150 mm × 4.6 mm, particle size 5 μm; Shim-pack CLC-ODS, SHIMADZU, Japan), mobile phase of methanol and water (90:10, v/v) with a flow rate of 1.0 ml/min. The column temperature was 40°C, a loading volume of 10 μL and ultra violet (UV) detection was at 230 nm. TCS had a retention time of 5 min. Following the establishment of a response to a known concentration, the result of measured/nominal concentration was 93.14–102.58%. The variability of TCS concentration was less than 20%, in compliance with the requirement of the toxicity test guidelines. Therefore, all subsequent toxicity results were expressed on the nominal concentrations of TCS.

2.7. Statistical analysis and SSD generation

Probit methodology was employed to calculate the 48-h-EC50, 96-h-LC50 values and corresponding 95% confidence intervals depending on the raw data distribution. Data of the chronic toxicity tests were analyzed, and the EC50 for the most sensitive biological endpoint in each test was estimated.

Three procedures, the US EPA guidelines for aquatic life criteria [28], the software ETX2.0 [19] exploited by the RIVM and the log-logistic SSD method [34–36] were used to derive the WQC for TCS. The data analysis softwares are SPSS 20.0 and OriginLab 8.0.

3. Results and discussion

3.1. Results of toxicity tests of nine native aquatic organisms and published toxicity data

Toxicity values of TCS to 8 aquatic species and an endangered species are shown in Tables 1 and 2. No mortality was observed in the control groups and the solvent control groups. Results of acute toxicity tests showed that *M. anguillicaudatus* with a 96-h-LC50 of 0.045 mg/L was the most sensitive species to TCS followed by *P. parva*, *D. magna*, *R. limnocharis*, *N. denticulata sinensis*, *T. albonubes*, *C. auratus*, *L. hoffmeisteri*, while the least sensitive species was C. plumosus with a 96-h-EC50 of 2.890 mg/L. Results of the present study indicate that TCS is highly toxic to native freshwater aquatic organisms. Liang et al. [37] reported that the 96-h-LC50 of TCS on fish *H. sinensis* was 1.47 mg/L. This is consistent with our study (0.889–1.839 mg/L for fishes except 0.045 mg/L for *M. anguillicaudatus* and 0.071 mg/L for *P. parva*). Previous study also reported that *P. parva* is sensitive to brominated flame retardant TBBPA (Tetrabromobisphenol A) [25], and Wang et al. [38] reported that *P. parva* is sensitive to aromatic pollutants, especially to pesticides. So it might be a sensitive species to antimicrobial agent, too. In addition, our previous study found that demersal fish *M. anguillicaudatus* is sensitive to some organochlorine pesticide. Brausch and Rand also indicated that TCS could affect benthic animals due to its transfer characteristics [39]. Therefore, TCS might have special toxic modes of action on *M. anguillicaudatus* and *P. parva*. Among different species, the fishes were more sensitive than the aquatic
invertebrates of Annelid and insect, and the insect was the least sensitive species. The chronic data and the other acute toxicity value cannot be compared with previous studies due to the lack of resident toxicity data in China.

Results of our study and previous studies using non-native species (Table 3) were compared. Previous studies reported that 96-h-EC50 for fish Pimephales promelas, Lepomis macrochirus and Oryzias latipes were 0.260, 0.370 and 0.602 mg/L, respectively [19,20], and this was in accordance with our study. In the previous study we found that 96-h-EC50 for amphiphilic R. limnocharis was 0.518 mg/L. It is in agreement with previous studies that toxicity values for amphibian Xenopus laevis, Acris Blanchardi, Bufo woodhousii and Rana sphenocephala were 0.259, 0.367, 0.152 and 0.562 mg/L, respectively [21,22]. Orvos et al. [19] reported that the 48-h-EC50 of TCS on planktonic crustacean D. magna and C. dubia were 0.390 and 0.168 mg/L, and this was in accordance with our study that the 48-h-EC50 of TCS on D. magna was 0.338 mg/L. In general, the sensitivities of the native species tested in this study were similar to those reported in previous studies. The acute toxicity of the shrimp N. denticulata sinensis, the insect C. plumosus and the annelid L. hoffmeisteri cannot be compared with previous studies due to lack of toxicity data for resident and non-native freshwater species. For chronic test, Orvos et al. [19] reported that 21 days NOEC (no observed effect concentration) for the survival of D. Magna was 0.2 mg/L, whereas the 21-d-EC10 for total number of spawning was 0.029 mg/L and no mortality was observed in all concentration groups in this study, which indicated that end-point of total number of spawning is more sensitive than survival. The 30-d-EC10 for growth of fish T. albonubes was 0.087 mg/L, and previous studies reported that the 21 days LOEC (lowest observed effect concentration) for growth of fish O. latipes [40] and 96 days LOEC for survival of O. mykiss [19] were 0.2 and 0.071 mg/L TCS. Similarly, as mentioned in the above paragraph, demersal fish M. anguillicaudatus is also the most sensitive species in the chronic tests in this study.

Previous studies reported that the 96-h-EC50s for algae Chlorella spp., Selenastrum capricornutum, S. subspicatus and N. pelliculosa were 0.065, 0.092, 0.001 and 0.019 mg/L, respectively [19,42,43]. Therefore, compared with other taxonomic levels the algal was the most sensitive taxa and the algal growth was affected at concentrations less than 1 μg/L. High TCS sensitivity in algae is likely due to TCS antibacterial characteristics, by uncoupling of oxidative phosphorylation [44], membrane destabilization [45], or disruption of lipid synthesis through the FabI (fatty acid synthesis) and FASII (enoyl acyl carrier protein reductase) pathways [46] which are similar between algae and bacteria [47].

### Table 3
Acute toxicity data of TCS to non-native aquatic organisms.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Species</th>
<th>EC50/EC10 (mg/L)</th>
<th>Time (days)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B. woodhousii</td>
<td>0.152</td>
<td>4</td>
<td>[21]</td>
</tr>
<tr>
<td>2</td>
<td>C. dubia</td>
<td>0.168</td>
<td>2</td>
<td>[19]</td>
</tr>
<tr>
<td>3</td>
<td>X. laevis</td>
<td>0.259</td>
<td>4</td>
<td>[22]</td>
</tr>
<tr>
<td>4</td>
<td>P. promelas</td>
<td>0.260</td>
<td>4</td>
<td>[19]</td>
</tr>
<tr>
<td>5</td>
<td>O. mykiss</td>
<td>0.288</td>
<td>4</td>
<td>[41]</td>
</tr>
<tr>
<td>6</td>
<td>A. blanchardi</td>
<td>0.367</td>
<td>4</td>
<td>[21]</td>
</tr>
<tr>
<td>7</td>
<td>L. macrochirus</td>
<td>0.370</td>
<td>4</td>
<td>[19]</td>
</tr>
<tr>
<td>8</td>
<td>T. platyurus</td>
<td>0.470</td>
<td>1</td>
<td>[40]</td>
</tr>
<tr>
<td>9</td>
<td>R. sphenocephala</td>
<td>0.562</td>
<td>4</td>
<td>[21]</td>
</tr>
<tr>
<td>10</td>
<td>O. latipes</td>
<td>0.602</td>
<td>4</td>
<td>[20]</td>
</tr>
<tr>
<td>Algae</td>
<td>S. subspicatus</td>
<td>0.001</td>
<td>4</td>
<td>[19]</td>
</tr>
<tr>
<td>Algae</td>
<td>N. pelliculosa</td>
<td>0.019</td>
<td>4</td>
<td>[19]</td>
</tr>
</tbody>
</table>

### Table 4
Ranked GMAs with SACRs according to USEPA guidelines.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Species</th>
<th>SMAs (mg/L)</th>
<th>GMAs (mg/L)</th>
<th>SACRs</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M. anguillicaudatus</td>
<td>0.045</td>
<td>0.045</td>
<td>5.00</td>
<td>In this study</td>
</tr>
<tr>
<td>2</td>
<td>P. parva</td>
<td>0.071</td>
<td>0.071</td>
<td>–</td>
<td>In this study</td>
</tr>
<tr>
<td>3</td>
<td>D. magna</td>
<td>0.338</td>
<td>0.338</td>
<td>11.66</td>
<td>In this study</td>
</tr>
<tr>
<td>4</td>
<td>R. limnocharis</td>
<td>0.518</td>
<td>0.518</td>
<td>–</td>
<td>In this study</td>
</tr>
<tr>
<td>5</td>
<td>N. denticulata sinensis</td>
<td>0.772</td>
<td>0.772</td>
<td>–</td>
<td>In this study</td>
</tr>
<tr>
<td>6</td>
<td>T. albonubes</td>
<td>0.889</td>
<td>0.889</td>
<td>10.22</td>
<td>In this study</td>
</tr>
<tr>
<td>7</td>
<td>X. kelleri</td>
<td>1.470</td>
<td>1.470</td>
<td>–</td>
<td>[37]</td>
</tr>
<tr>
<td>8</td>
<td>C. auratus</td>
<td>1.839</td>
<td>1.839</td>
<td>–</td>
<td>In this study</td>
</tr>
<tr>
<td>9</td>
<td>L. hoffmeisteri</td>
<td>2.046</td>
<td>2.046</td>
<td>–</td>
<td>In this study</td>
</tr>
<tr>
<td>10</td>
<td>C. plumosus</td>
<td>2.890</td>
<td>2.890</td>
<td>–</td>
<td>In this study</td>
</tr>
<tr>
<td>Algae</td>
<td>Chlorella spp</td>
<td>0.065</td>
<td>–</td>
<td>–</td>
<td>[43]</td>
</tr>
<tr>
<td>Algae</td>
<td>S. capricornutum</td>
<td>0.092</td>
<td>–</td>
<td>–</td>
<td>[42]</td>
</tr>
</tbody>
</table>

### Figure 1
Species sensitivity distribution of native, non-native and total species toxicity data for TCS.

### Table 2
Chronic toxicity of TCS to three resident aquatic organisms.

<table>
<thead>
<tr>
<th>Species</th>
<th>Endpoints</th>
<th>Functions</th>
<th>R²</th>
<th>p</th>
<th>EC10 (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. anguillicaudatus</td>
<td>Growth</td>
<td>$y = 1.5822x + 2.221$</td>
<td>0.9394</td>
<td>&lt;0.01</td>
<td>0.009</td>
</tr>
<tr>
<td>T. albonubes</td>
<td>Growth</td>
<td>$y = 5.2638x - 6.4808$</td>
<td>0.8939</td>
<td>&lt;0.01</td>
<td>0.087</td>
</tr>
<tr>
<td>D. magna</td>
<td>Time to first brood (days)</td>
<td>$y = 1.5045x - 2.3882$</td>
<td>0.9730</td>
<td>&lt;0.01</td>
<td>0.015</td>
</tr>
<tr>
<td>D. magna</td>
<td>Number to first brood (n)</td>
<td>$y = 4.6941x - 3.9019$</td>
<td>0.9271</td>
<td>&lt;0.01</td>
<td>0.042</td>
</tr>
<tr>
<td>D. magna</td>
<td>Total number of spawning (n)</td>
<td>$y = 1.6896x + 1.2411$</td>
<td>0.9571</td>
<td>&lt;0.01</td>
<td>0.029</td>
</tr>
<tr>
<td>D. magna</td>
<td>Number of broods (n)</td>
<td>$y = 2.5486x - 1.1721$</td>
<td>0.9086</td>
<td>&lt;0.01</td>
<td>0.083</td>
</tr>
</tbody>
</table>
the 15% of species) was shifted to the left of non-native species. A low HC5 (hazardous concentration for the 5% of species) indicated that Chinese freshwater organisms with acute exposures to TCS were more sensitive than the non-native species at the tail of SSD. However, the HC50 (hazardous concentration for the 50% of species) for native taxa was higher than that for non-native taxa. The reason might be the lack of toxicity data for Annelid and insect in non-native taxa, while the two taxa were demonstrated to be tolerance to TCS in our study (2.046 mg/L for L. hoffmeisteri, 2.890 mg/L for C. plumosus).

Although there were differences for HC5 and HC50 between native and non-native taxa, the comparison of SSD showed that there was no statistically significant difference (Kolmogorov–Smirnov test: ks = 1.342, n1 = 10, n2 = 10, p = 0.06). Considering the lack of toxicity data for Annelid and insect in non-native taxa, the difference was also not significant (ks = 1.054, n1 = 8, n2 = 10, p = 0.22) when removing the two taxa toxicity values. Similarly, sensitivities among North American and European taxa with different geographic distributions to a series of pollutants have been shown to be no statistically significant difference [49,50]. Moreover, the difference between SSDs of Australian and non-Australian organisms to endosulfan was not significant [51]. Jin et al. [26] also reported that there was no statistically significant difference between SSDs of native and non-native species when exposed to 2,4-dichlorophenol. In addition, in our study, there was no statistically significant difference between the sensitivity of native and total species (Fig. 1) as well (ks = 0.78, n1 = 10, n2 = 20, p = 0.59). Previous study found that natural history, habitat type and geographical distribution of the species used to construct the SSD did not have a significant influence on the assessment of hazard [51,52], and this was in accordance with our study.

3.3. Aquatic life criteria derivation

The US EPA guidelines of aquatic life criteria prescribed that only the toxicity data of resident species could be used in the calculation of criteria [28]. In the present study, using 10 species toxicity values (Table 4), 3 methods were used to derive the aquatic life WQC of TCS including US EPA guidelines, software ETX 2.0 (exploited by RIVM) and log-logistic (SSD) method.

Using the methods described in US EPA guidelines, the species mean acute values (SAMVs) and the genus mean acute values (GMAMVs) were calculated. The species acute chronic ratios (SACRs) were calculated as a ratio of acute and chronic values. Ranked GMAMVs with SACRs are listed in Table 4. A criterion maximum concentration (CMC) of 0.009 mg/L TCS was obtained by dividing FAV (final acute value, 0.017 mg/L TCS) by two. The final acute-chronic ratio (FACR) was calculated as geometric means of the three SACRs (10.22, 11.66 and 5.00) to be 8.41. The FCV (final chronic value, 0.002 mg/L) was obtained by dividing the FAV by the FACR. FPV (final plant value) was the toxicity data of Chlorella spp. and S. capricornutum, calculated to be 0.085 and 0.092 mg/L. The lower value between FCV and FPV was selected as the Criterion Continuous Concentration (CCC) 0.002 mg/L.

In addition, the values of HC5 derived based on the ETX 2.0 and the constructed log-logistic SSD were 0.054 and 0.060 mg/L respectively. Therefore, the CMCs of TCS developed with the two SSD methods were 0.027 and 0.030 mg/L when the factor is 2, which were in the same order of magnitude with the CMC (0.009 mg/L) calculated according to the US EPA guidelines.

Due to the wide use of the TCS, the levels of TCS in aquatic environments ranged from ng/L to pg/L [8,16,53], therefore its risk to the aquatic organisms cannot be ignored. The potential environmental risk of TCS could be assessed by using risk quotient (RQ) according to the European technical guidance document (TGD) [54]. In China, the highest concentration for TCS reported so far in surface water was 478 ng/L in Shijing River [9], and it is lower than the CCC of 0.002 mg/L in this study. The CCC in this study might provide useful information in site-specific ecological risk assessment because our study and previous studies both indicated that there was no significant difference between the sensitivity of native and non-native species. So it is possible to use non-native species toxicity data for site-specific ecological risk assessment of TCS. Taking into account that the higher concentrations detected so far in surface waters for TCS was 5160 ng/L in India [8,53] and 2300 ng/L in U.S. streams [53], and the CCC was 0.002 mg/L, the RQ values were calculated to be 2.58 and 1.15 which indicated that the TCS might pose risk to the aquatic species in these places.

4. Conclusions

This study is a contribution in the assessment of the effect of TCS in the aquatic environment. Toxicity values of 9 acute and 3 chronic tests for 9 native species from 3 Phyla and 7 Families were obtained in this study, in which demersal fish M. anguillicaudatus was the most sensitive species, and the fishes were more sensitive than the aquatic invertebrates of Annelid and insect, and the insect was the least sensitive species. Comparing the species sensitivity distributions, there was no significant difference between native species and non-native species. It indicates that toxicity data from different geographic region can be used in site-specific ecological risk assessment of TCS. Furthermore, the CMC derived using US EPA guidelines is similar with the results of RIVM ETX2.0 and the log-logistic SSD method, the CMC and CCC of aquatic life criteria for TCS are 0.009 and 0.002 mg/L, respectively.

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