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基于不同毒性终点的双酚 A(BPA)预测无效应浓度(PNEC)研究

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摘要: 双酚 A(BPA)已被证实是一种类雌激素类物质。本研究根据 BPA 对水生生物毒性效应的特点,按照不同的毒性终点将 BPA 的毒性数据进行归类,采用物种敏感度分布法(species sensitivity distribution, SSD)推导了 BPA 对水生生物的预测无效应浓度(predicted no effect concentration, PNEC)。结果表明:以雌激素效应为暴露终点的急、慢性 PNEC 分别为 25.11 μg·L^{-1}、1.075 μg·L^{-1};而以所有数据的急、慢性毒性效应为暴露终点推导的 PNEC 值分别为 355.7 μg·L^{-1}、7.549 μg·L^{-1}。BPA 对水生生物的雌激素效应更为敏感,建议在推导 BPA 这类内分泌干扰物的 PNEC 值时,应依据其毒性终点分别推导,从而得到更加合理的基准值。研究成果以期为我国地表水环境质量标准的制修订提供数据支持。

关键词: 双酚 A;淡水生物;雌激素效应;内分泌干扰;预测无效应浓度(PNEC)
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Predicted No Effect Concentration of Bisphenol A (BPA) Based on Different Toxicological Endpoints

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Abstract: Bisphenol A (BPA) has been confirmed to be an endocrine disrupting chemical. In the present study, the BPA toxicity data were classified based on different toxicological endpoints. Then, the acute and chronic PNEC (predicted no effect concentration) for protecting aquatic life were derived by use of species sensitivity distribution approach. The results showed that the acute and chronic PNECs of BPA derived from the estrogen effect data were 25.11 μg·L^{-1} and 1.075 μg·L^{-1}, respectively; while for all the toxicity data, the corresponding PNECs were 355.7 μg·L^{-1} and 7.549 μg·L^{-1}, respectively. Therefore, estrogen effects of BPA to organism were more sensitive than

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other effects. It is recommended that the PNECs for endocrine disrupting chemicals should be derived based on different toxicological endpoints. The results in the present study could provide data support for the establishment and revision of water quality standard in China.

Keywords: Bisphenol A (BPA); freshwater organism; estrogen effect; endocrine disruption; PNEC

双酚A(Bisphenol A, BPA)是重要的化工原料,被广泛应用于众多行业的环氧树脂、聚碳酸酯和聚酚氧树脂等材料的合成过程。据统计,每年约有270万吨BPA被生产使用,其中超过100吨进入大气中[1]。研究发现BPA具有雌激素效应,它对雌激素受体的亲和性是雌二醇的万分之一,过量摄入BPA能导致机体类分泌活动紊乱,从而影响生殖功能,破坏生殖系统,导致细胞癌变和器官发育畸形[2-3]。BPA能诱导生物体卵黄蛋白原(vitellogenin, VTG)含量增加,干扰生殖系统的功能和破坏生殖器官组织,以及对生物的生殖过程产生影响。环境中的BPA主要来源于工业废水、污水处理厂和垃圾填埋场渗滤液[4-5]。许多研究都提出塑料奶瓶以及可循环使用水桶等材料均含有BPA,由于BPA制品的大量使用,导致河流、湖泊以及沿海水域等都不同程度地有BPA存在[6-7]。国外如欧洲莱茵河、新加坡海岸周边水域、韩国西瓦湖及其周边河流、日本东京湾等部分水体中均有不同浓度的BPA被检测出来,浓度水平范围从数 $ng \cdot L^{-1}$ 到数 $\mu g \cdot L^{-1}$[8-11]。国内关于BPA在水体中的含量水平也有很多报道,如珠江流域、长江流域、辽河流域等地区,浓度范围在数 $ng \cdot L^{-1}$ 到数十 $\mu g \cdot L^{-1}$ 之间,跟国外部分水体的浓度水平相差不大[12-17]。

预测无效应浓度(predicted no effect concentration, PNEC)研究的基础是污染物的毒性数据。也是水质基准研究的重要依据。根据污染物毒性效应的不同,水质基准一般可分为急性和慢性基准。急性水质基准是为了应对环境污染的突发事件,而慢性水质基准主要是应对水生生态环境的日常维护和管理。目前关于BPA的PNEC研究相对较少。Staples等[18-19]比较深入地开展了BPA的PNEC研究,推导出BPA的PNEC为64 $\mu g \cdot L^{-1}$,随后在原有工作的基础上,用美国、荷兰、加拿大的推导方法再次推导BPA的PNEC的范围是11~71 $\mu g \cdot L^{-1}$。Wright-Walters等[20]用数据权重校正法推导出BPA在水体中的PNEC值为0.06 $\mu g \cdot L^{-1}$。日本、欧盟和加拿大等国家和组织都曾开展了BPA的PNEC相关研究工作,公布的BPA的PNEC分别为1.6 $\mu g \cdot L^{-1}$、1.5 $\mu g \cdot L^{-1}$、0.175 $\mu g \cdot L^{-1}$[21-23]。我国只有《食品容器及包装材料用聚碳酸酯树脂卫生标准》(GB14942—1994)中对酚类的浓度有相关规定[24],规定每升蒸馏水中含有酚类须≤0.05 mg。而关于BPA的地表水环境质量标准和其他行业标准,目前还没有基准限值。

不同的物种对同一污染物的敏感度不同,生物区系的差异会最终导致基准值的差异[25-26]。我国地理环境、气候以及生态环境要素、污染类型及分布模式较国外有很大差异性,而且经济发展阶段、文化多元化、人民生活方式和消费习惯与国外也有很大不同,因此水质基准不能直接拿国外的基准直接使用,而应该根据我国的区域特征进行基准的研究。目前我国水质基准研究近几年已经陆续开展,对常规污染物如重金属、有机物的基准研究相对较多[27-30]。而对于内分泌干扰物水质基准的研究相对较少[31-32]。内分泌干扰物由于在较低的浓度下就可能对水生生物产生不可逆转的毒性效应,影响生物的繁殖、发育等性状,因此不能简单地用污染物的致死效应进行PNEC的研究,需要结合其他敏感毒性终点开展PNEC的研究。基于此,本研究以BPA为例,对这类物质的PNEC开展探索性研究,以期为我国水质基准的研究提供重要的数据支持。

1 研究方法(Methodology)

1.1 数据收集及筛选

本研究收集整理了BPA毒性数据,数据主要来自美国环保局ECOTOX数据库和已经发表的文献。所选淡水物种为中国本土物种和已经在中国普遍存在的引进物种,暴露方式为流水暴露,急性毒性效应终点主要选取48 h~96 h内的半数效应浓度(EC_{50})、半数致死浓度(LC_{50})值;慢性毒性效应终点主要选取最低可见效应浓度(LOEC)、无可见效应浓度(NOEC)值。如果同一物种有多个符合条件的毒性数据时,则采用其几何均值作为最后的毒性数据[33-36]。如果同一物种的毒性值相差10倍以上,或者某一个物种的毒性值相对所有的毒性数据离散度过高,则视为异常值,将其去除。有些学者也建议采用10%效应浓度 EC_{10}、25%效应浓度 EC_{25} 推导PNEC[37],本研究优先采用受试生物的LOEC、EC_{50}、LC_{50}值。把符合上述条件的实验数据按照急

性、慢性分为 2 类,再分别把毒性效应终点按照雌激素效应以及其他毒性效应进行归类,然后对比分析。

1.2　物种敏感度分布法

物种敏感度分布(species sensitivity distribution, SSD)法是基于不同的物种对同一污染物的敏感度不同的理论,认为不同物种对同一污染物的敏感性差异遵循一定的概率分布模型,由不同物种毒性数据的频数分布拟合出某种概率分布函数,即敏感度分布曲线[38]。SSD 法的具体步骤:(1)确定毒性数据的累积概率 p,即把毒性数据由低到高排列并分配等级(1,2,…,N),并除以 N + 1 可得到 p 值;(2)将毒性效应值按照不同的模型拟合成 SSD 曲线,选择最优模型确定最终的 SSD 曲线;(3)根据 SSD 曲线计算出危险浓度 HC_p,一般取 p 值为 5,即保护 95% 以上的生物对应的浓度。本研究采用 Origin 8 软件构建 SSD 曲线,分别对各组毒性数据进行拟合,推导出各组的 PNEC,对比分析各组结果。

2　结果(Results)

2.1　BPA 毒性数据汇总

对收集的 BPA 毒性数据进行筛选,最终获得 52 个毒性数据,包括 26 个急性毒性数据和 26 个慢性毒性数据;急性毒性数据中有 10 个雌激素效应数据,慢性毒性数据中有 16 个雌激素效应数据。表 1、表 2 为 BPA 对水生生物的毒性数据统计表。

表 1　BPA 急性毒性效应统计表

Table 1　Statistical values for acute toxicity of Bisphenol A

中文名 Chinese name	拉丁学名 Species scientific name	毒性终点 Endpoint	暴露时间/h Exposure time/h	效应浓度/(μg·L⁻¹) Effect concentration /(μg·L⁻¹)	毒性效应 Toxic effect	参考文献 References
雌激素效应 Estrogenic effect						
虹鳟 Rainbow trout	Oncorhynchus mykiss	LOEC	72	25	VTG 升高 Rise of vitellogenin	[39]
斑马 Zebra fish	Danio rerio	LOEC	96	50	VTGmRNA 表达升高 Rise of vitellogenin mRNA expression	[40]
黑斑蛙 Shading frog	Rana nigromaculata	NOEC	72	200	VTG 升高 Rise of vitellogenin	[41]
青鳉 Medaka	Oryzias latipes	NOEC	48	100	胚胎死亡率上升 Increase mortality of embryo	[42]
水螅 Polyps	Hydra vulgaris	LOEC	72	460	生殖受抑制 Inhibition of reproduction	[43]
花斑溪鳉 Mangrove killifish	Kryptolebias marmoratus	NOEC	96	600	金属硫蛋白基因表达受阻 Blocked gene expression of metallothionein	[44]
蚤状钩虾 Gammarid	Gammarus pulex	LOEC	24	830	异性配对能力下降 Decrease of heterosexual matching ability	[45]
鳊鱼 Bream	Abramis brama	LOEC	96	2 282.8	肝细胞 VTG 升高 Rise of vitellogenin in liver cells	[46]
石首鱼 Drum fish	Micropogonias undulatus	LOEC	12	5 707	卵母细胞数量下降 Decrease of oocytes	[47]
鲤鱼 Common carp	Cyprinus carpio	LOEC	72	6 076	雌激素受体受到影响 Estrogen receptor was affected	[48]
其他毒性效应 Other toxic effect						
糠虾 Gammarid opossum shrimp	Amercamysis bahia	LC_{50}	96	1 030	死亡 Death	[49]
羊角月牙藻 Selenastrum	Selenastrum capricarnutum	LC_{50}	96	2 700	死亡 Death	[50]
鲤鱼 Common carp	Cyprinus carpio	LC_{50}	96	4 250	死亡 Death	[51]
黑头呆鱼 Fathead minnow	Pimephales promelas	LC_{50}	96	4 700	死亡 Death	[50]
青鳉 Medaka	Oryzias latipes	LC_{50}	72	5 100	死亡 Death	[42]
蚤状钩虾 Gammarid	Gammarus pulex	LC_{50}	48	5 600	死亡 Death	[45]
摇蚊 Chironomidae	Chironomus riparius	LC_{50}	24	6 030	死亡 Death	[52]
斑马鱼 Zebra fish	Brachydanio rerio	LC_{50}	96	6 300	死亡 Death	[53]

续表 1

泥鳅 Mud fish	Misgurnus anguillicadatus	LC_{50}	96	6 430	鱼鳃结构破坏 Damage of gill structural	[54]
中国林蛙 Chinese frog	Rana chensinensis	LC_{50}	72	7 305	死亡 Death	[55]
大型蚤 Daphnia	Daphnia magna	EC_{50}	48	7 750	死亡 Death	[56]
大扁藻 Tetraselmis	Platmonas helgolanidica	EC_{50}	96	9 320	细胞密度受抑制作用 Inhibition of cell density	[57]
微型裸腹溞 Moina	Moina micrura	LC_{50}	48	9 630	死亡 Death	[58]
隆线溞	Daphnia carinata	LC_{50}	48	11 640	死亡 Death	[58]
轮虫 Rotifera	Brachionus calyciflorus	LC_{50}	24	13 760	死亡 Death	[59]
日本沼虾 Japanese crayfish	Macrobrachium nipponense	LC_{50}	48	63 900	死亡 Death	[60]

注:LOEC 为最低可见效应浓度,NOEC 为无可见效应浓度;EC_{50} 为半数效应浓度,LC_{50} 为半数致死浓度值。

Note: LOEC stands for lowest observed effect concentration; NOEC stands for no observed effect concentration; EC_{50} stands for 50% effect concentration; LC_{50} stands for 50% lethal concentration.

表 2 BPA 慢性毒性效应统计表

Table 2 Statistical values for chronic toxicity of Bisphenol A

中文名 Chinese name	拉丁学名 Species scientific name	毒性终点 Endpoint	暴露时间/h Exposure time/h	效应浓度/($\mu g \cdot L^{-1}$) Effect concentration/($\mu g \cdot L^{-1}$)	毒性效应 Toxic effect	参考文献 References
雌激素效应 Estrogenic effect						
摇蚊 Chironomidae	Chironomus riparius	LOEC	21	1	雌雄比增加 Increase of male and female ratio	[52]
褐鳟 Brown trout	Salmo trutta f. fario	LOEC	28	1.75	精液质量下降 Decrease of the quality of the semen	[61]
黑斑蛙 Shading frog	Rana nigromaculata	LOEC	30	2	VTG 升高 Rise of vitellogenin	[41]
新西兰泥螺 Mud snail	Potamopyrgus antipodarum	LOEC	21	5	晶胚数增加 Increase number of embryos	[39]
中国林蛙 Chinese frog	Rana chensinensis	LOEC	30	11.4	雌激素受体受到影响 Estrogen receptor was affected	[62]
鲫鱼 Gold fish	Crucian carp	LOEC	14	250.59	VTG 升高 Rise of vitellogenin	[63]
端足虫 Millipede	Hyalella azteca	LOEC	42	490	影响繁殖率 Reproduction rate was affected	[64]
轮虫 Rotifera	Brachionus calyciflorus	LOEC	11	500	生殖率上升 Rise of reproduction rate	[59]
大型蚤 Daphnia	Daphnia magna	LOEC	21	600	繁殖能力下降 Decrease of reproduction rate	[56]
黑头呆鱼 Fathead minnow	Pimephales promelas	LOEC	43	640	VTG 升高 Rise of vitellogenin	[65]
大羊角螺 Horn snail	Marisa cornuarietis	NOEC	84	640	卵孵化时间推迟 Delay of eggs hatch time	[66]
虹鳟 Rainbow trout	Oncorhynchus mykiss	LOEC	21	1 000	VTG 升高 Rise of vitellogenin	[67]
水螅 Polyps	Hydra oligactis	LOEC	35	1 000	精巢发育受到抑制 Inhibition of testis development	[68]
斑马鱼 Zebra fish	Danio rerio	LOEC	21	1 000	VTG 升高 Rise of vitellogenin	[67]
青鳉 Medaka	Oryzias latipes	LOEC	21	3 120	VTG 升高 Rise of vitellogenin	[69]
日本沼虾 Japanese crayfish	Macrobrachium nipponense	LOEC	19	7 760	VTG 升高 Rise of vitellogenin	[60]

续表 2

其他毒性效应 Other toxic effect						
淡水鲑鱼 Salmon	*Salmo salar*	LOEC	42	10	肝脏 BPA 含量影响 BPA concentration was affected in liver	[70]
虾虎鱼 Goby	*Acanthogobius flavimanus*	NOEC	21	25	mRNA 表达受到抑制 Inhibition of mRNA gene expression	[71]
鲤鱼 Common carp	*Cyprinus carpio*	LOEC	12	708	肝细胞酶活性升高 Rise of enzyme activity in liver	[51]
青鳉 Medaka	*Oryzias latipes*	NOEC	60	803	身长和体重受到抑制 Inhibition of body length and weight	[72]
摇蚊 Chironomidae	*Chironomus riparius*	LOEC	20	1 000	幼虫湿重增加 Increase of larvae wet weight	[73]
端足虫 Millipede	*Hyalella azteca*	LOEC	42	1 100	体重和长度受到影响 Body length and weight were affected	[64]
斑马鱼 Zebra fish	*Brachydanio rerio*	LOEC	21	2 000	基因片段表达显著提高 Significant increase of gene expression	[74]
水螅 Polyps	*Hydra oligactis*	LOEC	35	3 000	触手变短 Shorter tentacles	[68]
大型蚤 Daphnia	*Daphnia magna*	LOEC	21	5 000	增加蜕皮速率 Increase of molting rate	[75]
膨胀浮萍 Duckweed	*lemna gibba*	LOEC	7	22 000	生长较对照组有明显变化 Significant growth difference between control and treated groups	[64]

2.2　BPA 的 PNEC 推导

本研究分别采用不同的函数模型对获得的毒性数据进行曲线拟合,主要的模型包括 SGompertz、Slogistic1、DoseResp、SRichards1、Boltzmann 等。发现 Slogistic1 模型较其他模型对毒性数据有较好的拟合效果,但是不同的毒性数据最佳拟合模型略有不同。主要根据模型的决定系数(R^2)和残差平方和(residual sum of squares, RSS)来确定最终的拟合模型,R^2越大,RSS 越小,拟合结果越准确。不同模型的拟合结果如表 3 所示:

表 3　不同模型拟合参数统计表

Table 3　Statistical parameter values for different models

数据分类 Data classification	拟合模型 Fitting model	决定系数 R^2	残差平方和 Residual sum of squares (RSS)
所有急性毒性数据 All acute toxicity data	**Slogistic1**	**0.91631**	**0.05448**
	Boltzmann	0.91082	0.09682
	DoseResp	0.90082	0.08682
	SGompertz	0.89671	0.19064
所有慢性毒性数据 All chronic toxicity data	**Slogistic1**	**0.96538**	**0.05632**
	DoseResp	0.96156	0.06787
	SGompertz	0.90656	0.17246
	Boltzmann	0.93156	0.06787
急性雌激素效应数据 Acute estrogenic effect data	**SGompertz**	**0.95069**	**0.02615**
	Slogistic1	0.95024	0.02639
	DoseResp	0.94329	0.02578
	SRichards1	0.94247	0.02615
急性其他毒性效应数据 Acute other toxic effect data	**BiDoseResp**	**0.99489**	**0.00361**
	Boltzmann	0.99212	0.00742
	Slogistic1	0.98679	0.01347
	DoseResp	0.99212	0.00742
慢性雌激素效应数据 Chronic estrogenic effect data	**Slogistic1**	**0.89939**	**0.09278**
	DoseResp	0.87846	0.09792
	SGompertz	0.88786	0.11434
	SRichards1	0.89701	0.09693
慢性其他毒性数据 Chronic other toxic effect data	**Slogistic1**	**0.90742**	**0.04909**
	DoseResp	0.90433	0.05621
	Boltzmann	0.89403	0.09621
	SRichards1	0.88043	0.10162

注:粗体为最终选择的最佳模型对应的相关参数。

Note: The boldface numbers are the parameters of the best fitted model.

将所有的急性毒性数据、所有的慢性毒性数据、急性雌激素效应数据、慢性雌激素效应数据、急性其他毒性效应数据和慢性其他毒性效应数据分别用最佳模型进行拟合，结果如图 1 所示。最终通过计算，得出以所有数据的急、慢性毒性效应为暴露终点推导的 PNEC 值分别为 355.7 μg·L^{-1}、7.549 μg·L^{-1}；而雌激素效应为暴露终点的急、慢性预测无效应浓度 PNEC 分别为 25.11 μg·L^{-1}、1.075 μg·L^{-1}，以其他毒性效应终点推导的 BPA 的急、慢性 PNEC 分别为：3 023 μg·L^{-1}、235.2 μg·L^{-1}。

3 讨论(Discussion)

3.1 实验条件对毒性效应的影响

温度、暴露时间对毒性效应值有一定的影响。Oehlmann 等[76]用苹果螺作为受试生物，进行了 150 d 的 BPA 暴露实验，发现 20 ℃和 27 ℃的 EC_{10}分别为 14.8 ng·L^{-1}和 998 ng·L^{-1}，温度对苹果螺的暴露终点浓度影响很大；对鹦鹉螺的暴露实验的数据表明鹦鹉螺在产卵期和非产卵期对 BPA 的暴露终点效应值也差别很大。Jobling 等[39]把斑马鱼、虹鳟以及

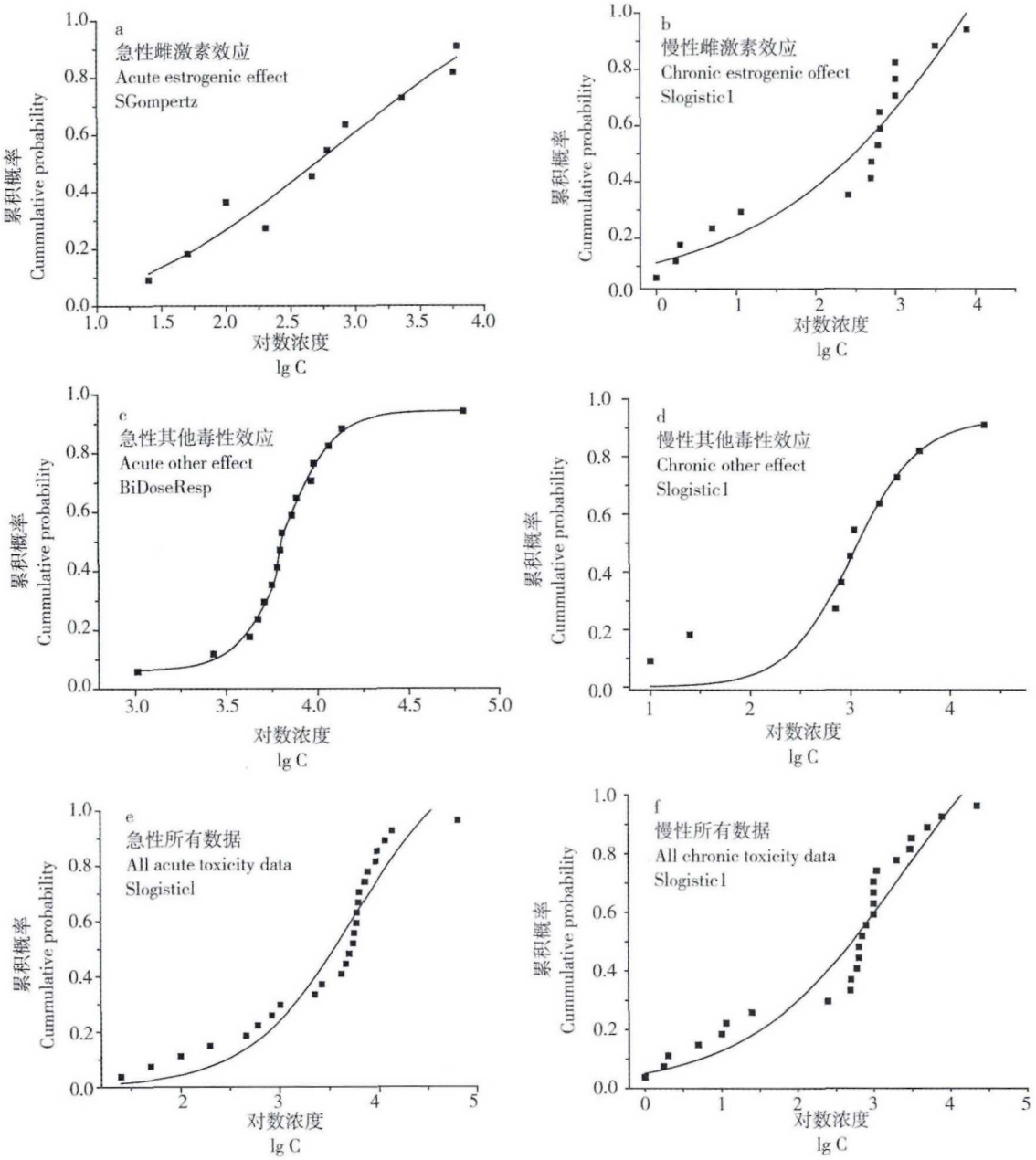

图 1 BPA 的物种敏感度分布曲线

Fig. 1 Species sensitivity distribution of BPA

泥螺等暴露于不同浓度的 BPA 溶液中,在暴露实验的不同阶段,受试生物对同一浓度的 BPA 的响应值变化很大。Staples 等[19] 在推导美国水域中 BPA 的 PNEC 时数据较少,未考虑温度变化的影响;同时,在暴露时间段的选择上,采用了 4 d ~ 164 d 的数据。本研究所收集到的实验数据绝大多数也未考虑温度变化对实验数据的影响,暴露实验的温度基本在 18 ℃ ~25 ℃之间;毒性数据中,涉及到不同实验条件的毒性数据相对较少,我们根据暴露时间的不同,将所有数据按照急性和慢性进行了分类。随着对 BPA 的 PNEC 研究的不断深入,温度、酸碱度等其他环境因子也应该逐渐被涉及。

3.2　不同毒性终点获得的 PNEC 值比较

考虑到 BPA 的雌激素效应明显,因此本研究把 BPA 对水生生物较为敏感的雌激素效应终点单独分析,并与所有毒性数据得出的 PNEC 进行对比,结果发现:将所有的急性毒性数据不进行分类,得到的急性 PNEC 为 355.7 $\mu g \cdot L^{-1}$,以所有急性毒性数据得出的 PNEC 值比单纯用雌激素效应得出的 PNEC 高出 14 倍。这一结果可能是由于急性暴露实验中受试生物对 BPA 的雌激素效应远高于致死等效应所致。以所有慢性毒性数据得出的 PNEC 值与单纯用雌激素效应数据得出的 PNEC 在同一数量级。当受试生物暴露于高剂量 BPA 流水环境中才会出现器官坏死、细胞变性、死亡等现象,在此之前 BPA 可能已经对受试生物产生雌激素效应,如对排卵量、精子活跃度、激素分泌等产生了影响。因此雌激素效应更能反映 BPA 对水生生物的危害,得出的 PNEC 值更能保护敏感水生生物。所以本研究根据雌激素效应暴露终点得出的 BPA 的急慢性 PNEC 分别为 25.11 $\mu g \cdot L^{-1}$ 和 1.075 $\mu g \cdot L^{-1}$。由于类雌激素的化学物质对水生生物的毒性作用存在多种途径,因此建议在推导该类物质的 PNEC 时,应该依据暴露终点的不同分开研究,由最敏感的毒性终点确定最终的 PNEC 值,从而对水生生物进行更有利的保护。

3.3　与国外 PNEC 比较

将本研究获得的 BPA 的 PNEC 与其他国家推导的 PNEC 相比,发现相差不大。慢性 PNEC 与其他国家的保持在一个数量级范围(表 4)。PNEC 的差异很大程度上跟所采用的研究方法有关。从研究方法上来讲,其他国家大多采用评价因子法,即选用一个最敏感的物种,然后将其毒性值除以不确定性因子即得到最终的 PNEC 值。这种方法的优点在于它所需基础数据少、计算方法简单;但由于该法属于经验法,最终 PNEC 的值依赖于敏感生物的毒性值,所以不确定性很高。而本研究采用的物种敏感度分布法,充分利用了获得的所有物种的毒性数据,从某种程度上来说可以代表整个生态系统。当然这种方法的缺点就是由模型差异造成的最终基准值的差异很大。

表 4　BPA 的预测无效应浓度 PNEC 值比较

Table 4　Comparison of BPA's predicted no effect concentration (PNEC) values

相关研究 Relative research	PNEC/($\mu g \cdot L^{-1}$)	暴露终点 Exposure endpoint
欧盟[7] European Union (EU)[7]	1.5	基于多种淡水生物和海水生物毒性数据,借助统计学分析得到毒性效应值 7.5 $\mu g \cdot L^{-1}$ 除以不确定因子 5 得到。Based on a variety of freshwater organisms and seawater biological toxicity data, toxic effect value of 7.5 $\mu g \cdot L^{-1}$ was acquired with the aid of statistical analysis, and the value was divided by the uncertain factor of 5.
加拿大[23] Canada[23]	0.175	基于受试生物褐鳟精子活跃度及排卵延迟等现象的最低可观测浓度 1.75 $\mu g \cdot L^{-1}$ 除以不确定因子。10 得到 Based on sperm activity and ovulation of the tested brown trout, the lowest observed effect concentration of 1.75 $\mu g \cdot L^{-1}$ was acquired, and the value was divided by the uncertain factor of 10.
日本[78] Japan[78]	1.6	以三代暴露于流动淡水中黑头呆鱼为受试生物的卵孵化率的无效应浓度 16 $\mu g \cdot L^{-1}$ 除以不确定因子 10 得到。Based on three generations of egg hatchability of tested fathead minnow via flow - through exposure, the no observed effect concentration of 16 $\mu g \cdot L^{-1}$ was acquired, and the value was divided by the uncertain factor of 10.
Wright-Walterser 等[20] Wright-Walterser et al[20]	0.06	基于水生生物的毒性数据,用数据权重校正法推导得到。Based on the aquatic toxicity data, the final value was derived by using the updated weight of evidence approach.
本研究 This study	25.11	基于多种淡水生物急性雌激素效应数据,并用物种敏感度理论分析得到。Based on many freshwater acute estrogenic effect data, the final value was derived by using species sensitivity distribution method.
	1.075	基于多种淡水生物慢性雌激素效应数据,并用物种敏感度理论分析得到。Based on many freshwater chronic estrogenic effect data, the final value was derived by using species sensitivity distribution method.

综上,本研究将 BPA **的毒性效应数据按照毒性终点进行分类后,得出的** PNEC **值差距较大,用雌激素效应终点推导出的** PNEC **更能保护敏感水生生物物种,得出的** BPA **急性和慢性** PNEC **分别为** 25.11 μg·L^{-1}、1.075 μg·L^{-1}。**因此建议在推导这类内分泌干扰物的** PNEC **时,应基于我国淡水生物对该类物质的毒性终点不同分类推导,选择较为敏感的毒性终点,从而能够得到合理的** PNEC。

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