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Original Article

Potential Toxicity of Contaminants Leached From Cigarette Butts in Coastal Environments

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Abstract

Cigarette butts (CB) are the most common litter on beaches worldwide and their incorrect disposal may lead to contamination by many toxic substances. Once in water, CB can release contaminants generated by both manufacturing and burning of cigarettes, which can have their toxic potential increased. A relevant issue is the lack of guidelines for CB management and benchmark values regarding these chemicals and additives for environmental quality purposes. Also, the toxicity of CB leachates is important to address the mixture effect of these chemicals. The present study aimed to provide ecotoxicological information on the main contaminants present in CB leachates and its hazard was assessed in an Ecological Risk Assessment (ERA) context. Data on toxic effects for freshwater and marine organisms of substances reported to be leached from CB were obtained from the toxicity databases, and the hazard concentration (HC_{10}), a threshold for protecting 90% of community were determined based on the species sensitivity distribution (SSD) method. The most toxic substances for freshwater environments were benzo(a)anthracene, benzo(a)pyrene, acenaphthene and fluorene, Pb and nicotine. For marine environments, the most toxic chemicals were benzo(a)pyrene, acenaphthene, fluorene and naphthalene, Cu, Pb, and Cd. An overview of CB leachate toxicity to freshwater and marine organisms was produced, indicating a limited number of studies and a gap to be filled.

Keywords: aquatic toxicology, risk assessment, marine litter, marine pollution, tobacco.

INTRODUCTION

Annually, 6 trillion cigarettes are smoked, and around 4.5 trillion cigarettes are thrown into the environment (Araújo & Costa, 2019). Cigarette butts (CB) make up the most frequent solid waste category on beaches around the world (Litter Free Planet, 2009). In addition, they represent about 25 to 50% of all garbage found on streets and roads (Torkashvand *et al.* 2020). On the beaches of Santos, a coastal city that is the main tourist destination for the inhabitants of the city of São Paulo and its metropolitan region, cigarette butts were the second most frequently collected item, reaching 24.1% of all waste collected in the summer (Ribeiro *et al.* 2021). Of the 10 million litter items collected during the 2009 International Coastal Cleanup campaign, 21% were cigarette butts and filters, twice as many as any other type of litter (Moerman & Potts, 2011). In coastal environments, not all CB found on a beach are sourced from this location, as irregular disposal causes them to move to sewers and culverts. With rain or winds, they reach streams, rivers and eventually the ocean (Novotny *et al.*, 2009).

Filters of commercial tobacco or cigarettes are made up of a cellulose acetate, which is a natural polymer of glucose, acting as a barrier that retains part of the substances that would be inhaled by smoking (Puls *et al.*, 2004). The tipping paper around the filter makes connection with the rest of the cigarette and the ventilation holes allow the dilution of the smoke to be inhaled with

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air, also controlling the burning speed (Kurmus & Mohajerani, 2020). The used cigarette filter, and the remaining tobacco and tipping paper after smoking are the main constituents of the CB.

When smoked, cigarettes are converted into particulate and volatile phases. The particulate phase includes non-volatile chemicals, formed by the portion of smoke retained in the filter, containing more than 4000 potentially toxic substances (Xu *et al.,* 2019). The vapor phase contains the volatile chemical components made up of more than 500 compounds (Novotny *et al.*, 2009). During tobacco cultivation, different agrochemicals are used such as pesticides, herbicides, insecticides, fungicides and rodenticides, which increase the concentrations of by-products and other chemicals (e.g. trace metals) in the leaves (Moerman & Potts, 2011). In the manufacture of cigarettes, more than 600 additives are added, such as preservatives, flavors, intensifiers, humectants, sugars and ammonium compounds (Paumgartten *et al*., 2017). In addition, there are products generated through combustion from smoke, such as polycyclic aromatic hydrocarbons (PAHs). Tobacco is not classified as a food or medicine, so there are no legal maximum values for the addition of chemical products or additives (Litter Free Planet, 2009).

CB are sources of prolonged contamination from different chemical groups, such as metals, which have a rapid release, increasing the potential for damage to local organisms (Moerman & Potts, 2011). Moriwaki et al. (2009) reported the release of major and trace elements (Al, Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr, Ti e Zn) from CB in an aqueous solution. On the other hand, about 0.6 to 3.0% of the dry weight of tobacco is composed of nicotine which is used as a plant pesticide, with reported toxicity to animals and humans (Brčić Karačonji, 2005; Novotny *et al.,* 2011). As a result, aquatic species in urbanized areas are at risk of exposure to nicotine due to the runoff contaminated with smoked cigarette filters and their leachate (Wright *et al.*, 2015). Therefore, CB can be considered a diffuse font of contamination by a complex mixture of contaminants. Thus, it is necessary to identify the different constituents of this mixture, and identify their toxic effects not only individually, but also in a combined way.

Ecological Risk Assessment (ERA) is a process based on the probability that environmental concentrations of chemical substances induce effects, from the toxicity measured in the laboratory or in the field (USEPA, 1998). The risk of causing toxic effects is estimated using species sensitivity distribution curves (SSD), which consist of sigmoid functions of a single compound toxicity measured in a set of selected species that constitute a proxy of a hypothetical community. The objective of the present study was to produce the characterization and the hazard assessment of major chemical constituents of CB leachates in a context of ERA based on toxicity outcomes reported on literature and database analysis.

MATERIALS AND METHODS

Contaminant Identification in CB leachates

For this study, recent scientific literature was revised and 98 components of cigarettes were identified as contaminants of environmental concern. The keywords used to search scientific papers in the Web of Science database were "cigarette butt", "cigarette", "toxicity", and "tobacco". Only studies published in peer-reviewed papers published in scientific journals in which the chemical composition of cigarette butts were analyzed were included in the analysis. Articles published between 2010 and 2021 were selected (Araújo & Costa, 2019; Novotny *et al.*, 2011; Paumgartten *et al.,* 2017; Venugopal *et al.,* 2021). The most frequent substances that presented the highest levels in leachates were selected, and cataloged for chemical properties related to their environmental behavior using the CompTox Chemicals Dashboard database (https://comptox.epa.gov/dashboard/), from the United States Environmental Protection Agency (USEPA). The properties addressed in this study were the octanol-water partition coefficient ($LogK_{ow}$), vapor pressure, water solubility, adsorption coefficient normalized by organic carbon (K_{oc}) and half-life.

Hazard assessment

The ERA framework establishes 3 phases to address a stressor in which phase 1 consists of problem formulation (e.g. impacts of CB leachates). Phase 2 is the analysis when both exposure characterization (identification of relevant chemicals in CB leachates) and effects (toxicity evaluation using SSD) are determined. Phase 3 is the risk characterization where different approaches are employed (CETESB, 2020; USEPA, 1998), such as the risk quotients (RQ) by using measured environmental concentration (MEC) and provide the predicted no effect concentration (PNEC) widely used to evaluate effects of chemicals. In this study, we aimed to provide the PNEC of contaminants leached from CB, that can be used together with MEC, for RQ calculations in further studies in Brazilian coast, as one of the main approaches for ERA. Data on toxic effects levels only for aquatic organisms (marine and freshwater) were obtained from the ECOTOXicology Knowledgebase (https://cfpub.epa.gov/ecotox/), also from USEPA, producing thus a toxicity overview for a specific view of freshwater, estuarine, and marine ecosystems, once previous assessment combined all data into a single outcome (Venugopal *et al.,* 2021).

The criterion used to identify the searched contaminants in both databases was the registration number of the substance in the Chemical Abstracts Service database of the Chemical American Society (CAS number). Effect levels reported for 50% of the organisms tested (LC_{50} for acute effects and EC_{50} for chronic ones) were selected as the toxicity metric for the construction of SSD curves (TGD, 2003). They correspond to the distribution of the toxicity values in ascending order according to their respective position in percentage (Aldenberg & Jaworska, 2000) and a nonlinear function was used to calculate the 10th percentile hazard concentration (HC_{10}, also referred as EC_{10}), a threshold for protecting 90% of community. These analyses were performed using GraphPad Prism 6 and Microsoft Excel 2016. Then, the toxicity classification criterion was applied according to EC Directive 93/67/EEC on Safety of Chemicals, in which extremely toxic substances are those with effect concentrations lower than 1 mg L^{-1}, moderately toxic between 1 to 10 mg L^{-1} and slightly toxic if values are greater than 100 mg L^{-1} (EC, 2003).

RESULTS AND DISCUSSION

Identification of the Main Contaminants Present in Leachate

Twenty-three chemicals which were frequently reported to leach from CB were selected as the most frequent pollutants in aquatic ecosystems: nicotine, ammonia, phenol, acetaldehyde, nitrosamines, pyridine, glycerol, propylene glycol, Cd, Cr, Cu, Ni, Pb, Zn, naphthalene, acenaphthene, fluorene, benz(a)anthracene, benzo(a)pyrene, benzene, benzo(b)fluoranthene, benzo(k)fluoranthene and chrysene. The information about the substances commonly reported to be leached from CB is summarized in table 1. The selected properties for chemicals ranged -1.86 to 6.13 for $LogK_{ow}$, $9.6x10^{-10}$ to 902 mmHg for vapor pressure, $9.4x10^{-9}$ to 17.9 mol L^{-1} for water solubility, $9.4x10^{-9}$ to 17.9 for K_{oc}, and 3 to 378 days for half-life.

Table 1. Properties of the main contaminants present in CB leachates.

Substance	CAS Number	$LogK_{ow}$	Vapor Pressure (mmHg)	Water Solubility (mol L^{-1})	K_{oc} (L kg^{-1})	Half-Life (days)
Cadmium (Cd)	7440-43-9	-0.07	-	1.1	-	-
Lead (Pb)	7439-92-1	0.73	-	0.1	-	-
Copper (Cu)	7440-50-8	-0.57	-	6.6	-	-
Chromium (Cr)	7440-47-3	0.23	-	1.7	-	-
Nickel (Ni)	7440-02-0	-0.57	-	7.2	-	-
Zinc (Zn)	7440-66-6	-0.47	-	5.3	-	-
Acenaphthene	83-32-9	3.92	$2.1x10^{-3}$	$4.6x10^{-5}$	3890	39.0
Acetaldehyde	75-07-0	-0.34	902.00	17.9	2.9	7.6
Ammonia	7664-41-7	0.23	-	3	-	-
Benz(a)anthracene	56-55-3	5.60	$2.1x10^{-7}$	$5.2x10^{-8}$	200000	286.0
Benzene	1076-43-3	2.10	88.30	1.77	56.1	6.0
Benzo(a)pyrene	50-32-8	6.13	$5.5x10^{-9}$	$8.4x10^{-9}$	891000	224
Benzo(b)fluoranthene	205-99-2	5.78	$5.0x10^{-7}$	$9.4x10^{-9}$	261000	282
Benzo(k)fluoranthene	207-08-9	6.11	$9.6x10^{-10}$	$3.2x10^{-9}$	21900	351
Chrysene	218-01-9	5.81	$6.2x10^{-9}$	$1.2x10^{-8}$	157000	378
Phenol	108-95-2	1.46	0.35	0.92	26.9	4.6
Fluorene	86-73-7	4.18	$6.0x10^{-4}$	$1.1x10^{-5}$	5010	44
Glycerol	56-81-5	-1.86	$1.7x10^{-4}$	12.10	-	-
Naphthalene	91-20-3	3.30	0.09	$2.5x10^{-4}$	912	3
Nicotine	54-11-5	1.17	0.04	6.17	102	3.4
Nitrosamine	35576-91-1	-1.32	-	-	-	-
Pyridine	110-86-1	0.65	20.80	10.30	39.8	4.7
Propylene glycol	57-55-6	-0.92	0.13	13.20	2.3	-

The coefficient K_{ow} is an indicator of the lipophilicity expressed as the ratio between the solubility of a compound in octanol (nonpolar solvent) and water (polar solvent), indicating the tendency the compound to adsorb into soil, sediments, animal cells and tissues. Water solubility indicates the ability of substances to dissolve in liquid phase, while vapor pressure is related to its volatilization (Silva & Ferreira, 2003). The coefficient K_{oc} is related to the substance's potential to adsorb organic carbon from the matrix, and half-life is the degradation time of half the amount of compound (Silva & Ferreira, 2003). The description of these features combined is important to understand the transport and destination of chemicals in the environment (Castro, 2019). For chemical constituents of CB leachates, PAHs exhibited higher $LogK_{ow}$ values, indicating greater hydrophobic behavior, tendency to sorb to organic matter and sediments, and therefore these substances tend to accumulate in the sediments. Lower $LogK_{ow}$ values indicate hydrophilicity, i.e. substances that have a greater tendency to leach, as in the case of metals (Cd, Cu, Cr, Ni, and Zn), acetaldehyde, ammonia, glycerol, and nicotine. Half-life times ranged from a few days (naphthalene) to almost a year (chrysene), pointing to the PAHs as the most persistent compounds leached from CB.

The occurrence and impacts of cigarette butts on beaches and cities are influenced by several factors such as solar intensity, winds, currents, rivers, bathers, residents, bad destination of the butts by smokers and efficiency of cleaning services (Lima *et al.*, 2021). In water, CB can float for long periods before sinking, allowing their environmental mobility by currents and tides. On beaches, for example, CB may be dispersed by wind, tide variations and urban runoff through drainage systems. In cities and urban areas, the presence of CB is related to commercial availability and population density (Araújo & Costa, 2019; Novotny *et al*., 2009). Studies indicate that the longer in the environment, the greater the pollution and that just one butt can pollute up to 1000L of water (Araújo & Costa, 2019), with leaching as the main process of chemical transfer to environmental compartments.

Cigarette Butt Toxicity and Hazard assessment

In this study, PNEC values were estimated using data on the toxic effects of contaminants followed by SSD analysis which was used to compare the groups of chemical substances identified as constituents of CB leachates, allowing thus the determination of protection thresholds for each chemical. Figure 1 illustrates two SSD for nicotine for freshwater and ammonia for saltwater, and the and the remain curves are available in Supplementary material.

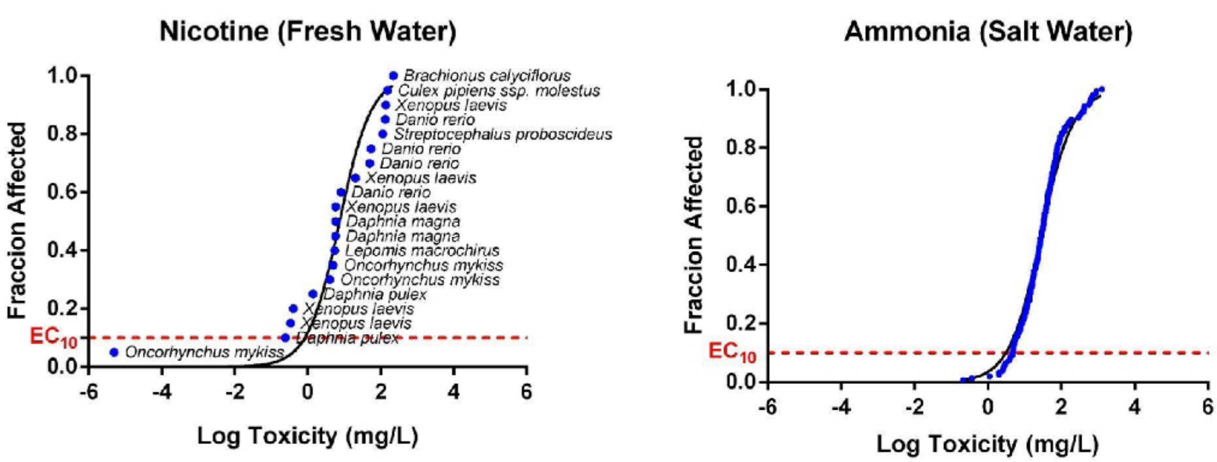

Figure 1. Examples of SSD, determined for nicotine (freshwater) and ammonia (saltwater) for PNEC determinations.

From the SSD analysis, it was possible to observe that the most toxic substances for freshwater environments were the PAHs benzo(a)anthracene, benzo(a)pyrene, fluorene, acenaphthene, the metal Pb, and nicotine (which have the lowest HC_{10} values) (Table 2). For marine environments, the most toxic contaminants were the metals Cu, Cd and Cr, and the PAHs benzo(a)pyrene, fluorene, naphthalene and acenaphthene. In addition, there is a lack of toxicity data for nicotine, requiring more studies with the production of toxicity data to advance knowledge about these effects (Table 3). The toxicity classification of chemicals leached from CB is shown in figure 2. For freshwater, Pb, benz(a)anthracene, acenaphthene, fluorene, benzo(a)pyrene and nicotine were considered extremely toxic, acetaldehyde and pyridine were moderately toxic, and propylene glycol and glycerol were slightly toxic. For saltwater, extremely toxic chemicals were the metals Cu, Pb, Cd, Zn, and Cr, the PAHS acenaphthene, fluorene, benzo(a)pyrene and naphthalene, followed by the moderately toxic ones Ni, ammonia, acetaldehyde, phenol and pyridine, and the slightly toxic compound propylene glycol. Therefore, 62.50% of the substances analyzed for salt water are extremely toxic and for freshwater 63.64% are extremely toxic, highlighting the contribution of these chemicals to the impact of CB pollution in marine and freshwater environments.

Table 2. Hazard concentrations (HC_{10}) for freshwater of the major contaminants present in CB leachates and their respective confidence interval (CI 95%).

Substance	Exposure	HC_{10}	CI 95%	
			Bottom Limit	Top Limit
Lead (Pb)	Fresh Water	0.09	0.07	0.12
Benz(a)anthracene	Fresh Water	$1x10^{-3}$	$8.4x10^{-4}$	$2.6x10^{-3}$
Acenaphthene	Fresh Water	0.10	0.09	0.11
Acetaldehyde	Fresh Water	3.90	3.24	4.70
Fluorene	Fresh Water	0.17	0.11	0.16
Benzo(a)pyrene	Fresh Water	0.32	0.22	0.45
Nicotine	Fresh Water	0.82	0.64	1.08
Pyridine	Fresh Water	87.10	79.60	95.30
Propylene glycol	Fresh Water	110.00	56.41	214.60
Glycerol	Fresh Water	979.80	704.60	1362.00

Table 3. Hazard concentrations (HC_{10}) for saltwater of the major contaminants present in CB leachates and their respective confidence interval (CI 95%).

Substance	Exposure	HC_{10}	CI 95%	
			Bottom Limit	Top Limit
Copper (Cu)	Salt Water	0.01	0.01	0.01
Lead (Pb)	Salt Water	0.27	0.25	0.30
Cadmium (Cd)	Salt Water	0.30	0.26	0.33
Zinc (Zn)	Salt Water	0.34	0.32	0.35
Chromium (Cr)	Salt Water	0.47	0.37	0.59
Nickel (Ni)	Salt Water	1.23	1.14	1.34
Acenaphthene	Salt Water	0.06	0.05	0.07
Fluorene	Salt Water	0.16	0.07	0.35
Benzo(a)pyrene	Salt Water	0.21	0.78	0.58
Naphthalene	Salt Water	0.29	0.26	0.32
Ammonia	Salt Water	3.09	3.01	3.18
Acetaldehyde	Salt Water	3.17	1.17	8.58
Phenol	Salt Water	5.34	5.10	5.58
Pyridine	Salt Water	23.33	16.18	33.65
Propylene glycol	Salt Water	241.30	204.80	284.20

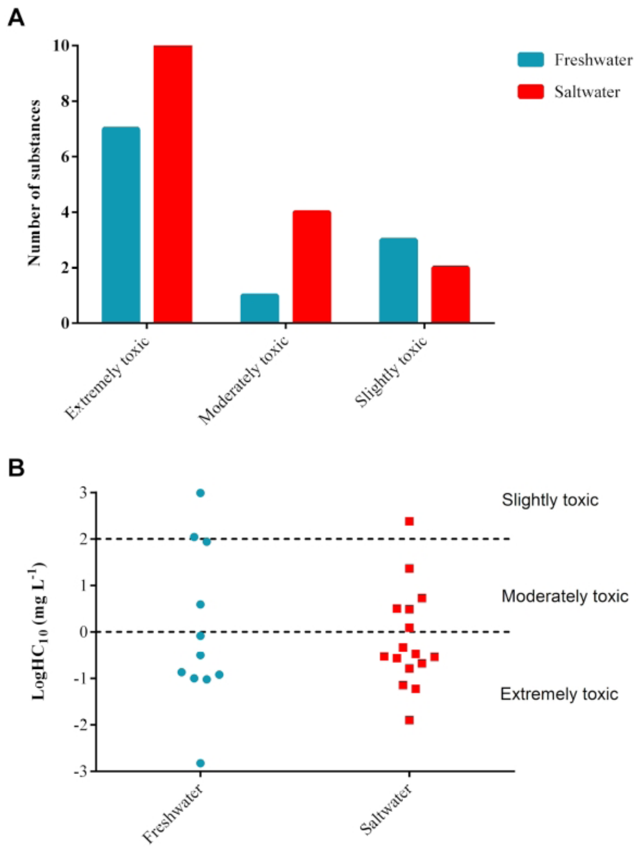

Figure 2. Toxicity classification of contaminants leached from CB expressed as number of substances (A), and log-transformed data (B).

In general, the metals Cu, Pb, Cd, Zn and Cr and the PAHs acenaphthene, fluorene, benzo(a)pyrene and naphthalene are the main chemicals leached from CB, once they were classified as extremely toxic. Individually, there is solid literature on its toxicity and for CB, leachates represent a diffuse source of these chemicals. Metals are trace elements that are essential to biodiversity, as components of enzymatic structure for example, but elevated levels are known to cause different effects at cellular levels such as oxidative stress, membrane and protein alterations, redox homeostasis, changes in cellular metabolism, and immunological responses (Le Saux *et al.*, 2020). Other effects are related to genotoxicity and neurotoxicity (Vargas *et al.* 2001; Lee *et al.* 2019). As for the PAHs, they are considered narcotic substances, presenting similar metabolic effects with a nonspecific mode of action and additive toxicity (Di Toro *et al.* 2000). On the other hand, nicotine is considered a contaminant of emerging concern related to the smoking lifestyle (Oropesa *et al.* 2017), induces neurostimulation and analgesic effects (Zhang *et al*. 2020), but in this study, we observe limited information of its toxicity towards marine organisms.

Since leachates are complex mixtures, synergistic effects of chemical constituents are expected to occur, which corresponds to the interaction between different compounds increasing toxicity when compared to each compound isolated (Brickus & Aquino Neto, 1999). In this sense, it is important to look at the toxic effects considering the leachate as a whole residue, as summarized in Table 4. For freshwater organisms, waterborne toxicity has been reported for cladocerans, amphibians, and fish, while effects were reported on marine bacteria, gastropods, polychaete worms, brine shrimp, copepods, and fish. Such results demonstrate that CB leachates potentially produce adverse effects on organisms from different trophic levels and traits, but we highlight that a proper ERA, important for specific management actions, can be achieved by increasing the models tested since the number of studies for aquatic environments is limited to 10.

Table 4. Summary of CB leachates toxicity for different organisms of freshwater and marine environments

Species	Results	Reference
Freshwater		
Daphnia magna (cladoceran)	Smoked filters caused 100% mortality at a concentration equivalent to 2 $CB.L^{-1}$. Remnant tobacco caused 100% of mortality at a concentration equivalent to 0.5 $CB.L^{-1}$.	Register (2000)
Xenopus laevis (amphibian)	LC_{50} values of 0.68-1.65 $CB.L^{-1}$ for the regular cigarette, 1.08-1.14 $CB.L^{-1}$ for the mentholated cigarette, and 9.70-26.8 $CB.L^{-1}$ for the electronic cigarette. EC_{50} values for common cigarette were 0.34-1.21 $CB.L^{-1}$, it was 0.30-0.96 $CB.L^{-1}$ for the mentholated cigarette, and 15.58-20.34 $CB.L^{-1}$ for the electronic cigarette.	Parker & Rayburn (2017)
Ceriodaphnia cf. dubia (cladoceran) and *Vibrio fischeri* (bacteria - saltwater)	For cladoceran, EC_{50} ranged from 0.03-0.08 $CB.L^{-1}$ (immobilization endpoint). For bacteria EC_{50} ranged from 0.3-2.7 $CB.L^{-1}$. (bioluminescence endpoint).	Micevska *et al.* (2006)
Pimephales promelas (fish)	LC_{50} values of 13.5 $CB.L^{-1}$ reported for non-smoked and tobacco-free filters, 4,3 $CB.L^{-1}$ for smoked and tobacco-free filters, and 0.97 $CB.L^{-1}$ for tobacco smoked filter.	Slaughter *et al.* (2011)
Oreochromis niloticus (Nile Tilapia)	LC_{50} for smoked brand 1 was 1.35 $CB.L^{-1}$, and 2.27 $CB.L^{-1}$ for brand 2. Non-smoked brand 1 presented a LC_{50} of 5.56 $CB.L^{-1}$, and 7.31 $CB.L^{-1}$ for brand 2. Also, decreased activity of antioxidant enzymes and lipid peroxidation were reported, with smoked cigarettes 5.3x more toxic than non-smoked cigarettes.	Osuala *et al.* (2017)
Saltwater		
Austrocochlea porcata, Nerita atramentosa and Bembicium nanum (gastropod species)	100% mortality observed for all species after at 100%, equivalent to 5 $CB.L^{-1}$.	Booth *et al.* (2015)
Hediste diversicolor (polychaete)	Burrowing activity impaired at the concentration of 2 $CB.L^{-1}$.	Wright *et al.* (2015)
Artemia sp. (brine shrimp)	LC_{50} values of 4.53 $CB.L^{-1}$, and morphological effects (reduction or absence of antennae, change in color, and abdominal deformities).	Abessa *et al.* (2020)
Nitokra sp. (estuarine copepod)	EC_{50} of 0.1 $CB.L^{-1}$ for waterborne exposures and EC_{50} of 0.01 $CB.L^{-1}$ for whole sediment exposures.	Lima *et al*. (2021)
Atherinops affinis (marine fish)	LC_{50} of 5.1 $CB.L^{-1}$ for non-smoked and tobacco-free filters, 1.8 $CB.L^{-1}$ for smoked and tobacco-free filters, and 1.1 $CB.L^{-1}$ for tobacco smoked filters.	Slaughter *et al.* (2011)
Periophthalmus waltoni (marine fish)	LC_{50} (96h) values of 1.37 $CB.L^{-1}$ for smoked cigarette butts with tobacco, 2.9 $CB.L^{-1}$ for smoked CBs without tobacco, and 7.46 $CB.L^{-1}$ for unsmoked filters.	Soleimani *et al.* (2023)

Cigarette butts are certainly among the most hazardous types of solid waste for human and environmental health (Araújo & Costa, 2019). Their prevalence in coastal areas such as mangroves and beaches has been extensively documented in scientific literature including in Brazil (Lima *et al.*, 2021; Ribeiro *et al.,* 2021). Furthermore, recent studies have also pointed to the massive occurrence of BCs in urban areas (Ribeiro *et al.,* 2022), while recent studies also show the contamination of groundwater and supply waterways (Torkashvand *et al.,* 2021), posing risk to human health. So far, there is no legislation focused on the management of this specific type of material, including and their toxic constituents (Lima *et al.,* 2021). However, many regulations on solid waste indicate the need for shared responsibility among public administrations, consumers and companies exploiting the economic activity. In this regard, the Solid Waste Plan into force in Brazil, for example, recommends the implementation of reverse logistics policies (Brasil, 2010) that would be used to enable payment mechanisms over tobacco companies operating in national territory. Similar measures would generate the necessary funding to collect and provide an environmentally adequate destination to this toxic waste.

CONCLUSION

In this study the major chemical constituents present in the CBs leachate were identified. For freshwater ecosystems, most of them were classified as extremely toxic (effect levels lower than 1 mg L^{-1}), as the metal Pb, PAHs (benzo(a)anthracene, acenaphthene, acetaldehyde, fluorene and benzo(a)pyrene), and nicotine. For marine environments, extremely toxic chemicals were the metals (Cu, Pb, Cd, Zn and Cr), and PAHs (acenaphthene, fluorene, benzo(a)pyrene and naphthalene). It was also observed that more toxicity information on some constituents is necessary, specifically for the nicotine in saltwater. Special attention is required on the toxicity of CB leachates as a complex mixture, since studies are limited to a few species. To deal with that, toxicity assessment using neotropical species as those employed in protocols in Brazil will increase the knowledge about the impacts of BC in coastal environments.

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CREDIT AUTHOR STATEMENT

WGM: Data curation, Investigation, Writing- Original draft preparation, Writing- Reviewing and Editing.

RBC: Methodology, Investigation, Writing- Reviewing and Editing, Supervision.

ÍBC: Visualization, Investigation, Writing- Reviewing and Editing.

LBM: Conceptualization, Methodology, Investigation, Writing- Reviewing and Editing, Supervision.

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SUPPLEMENTARY MATERIAL

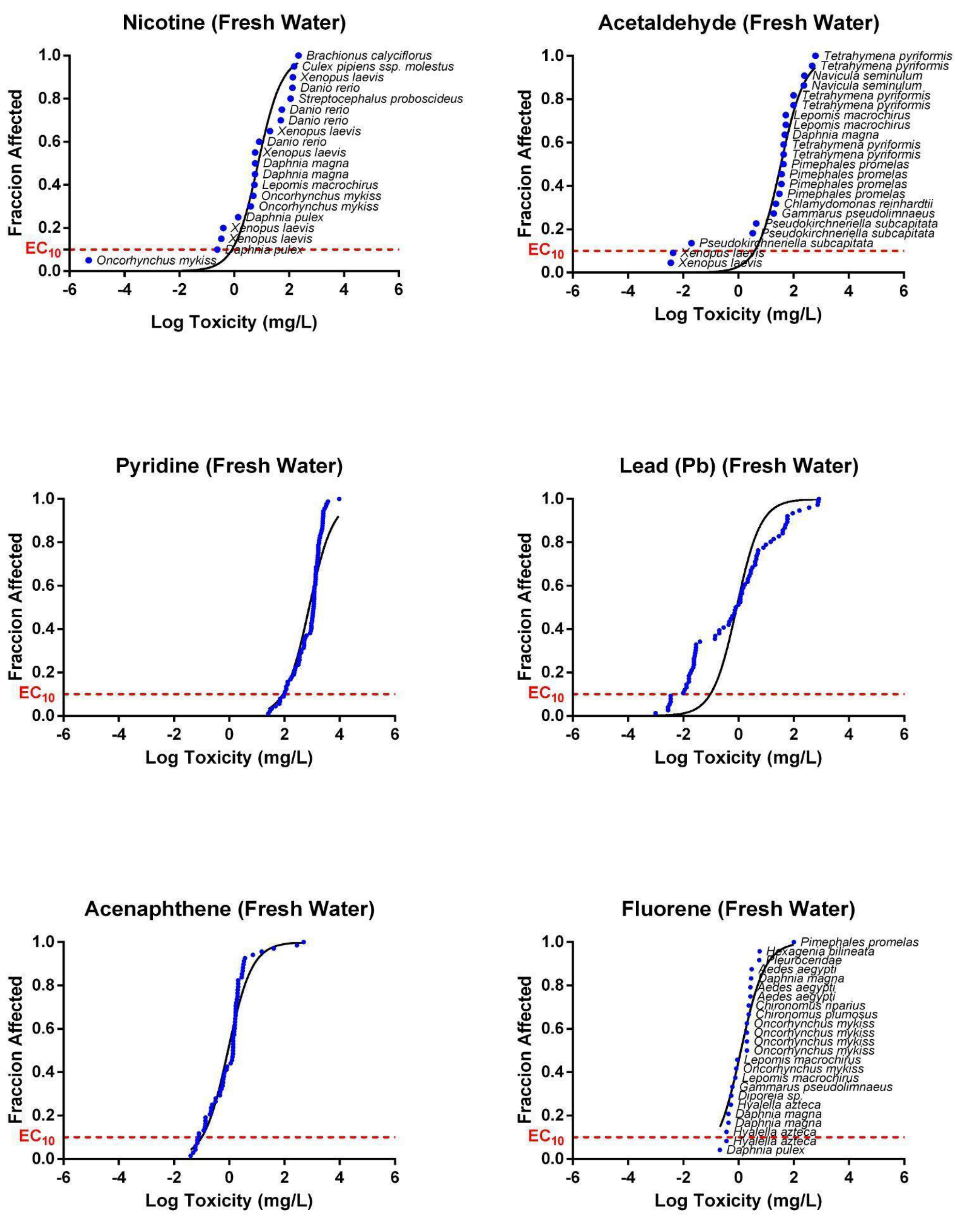

Figure 1 – Species sensitivity distribution (SSD) for freshwater.

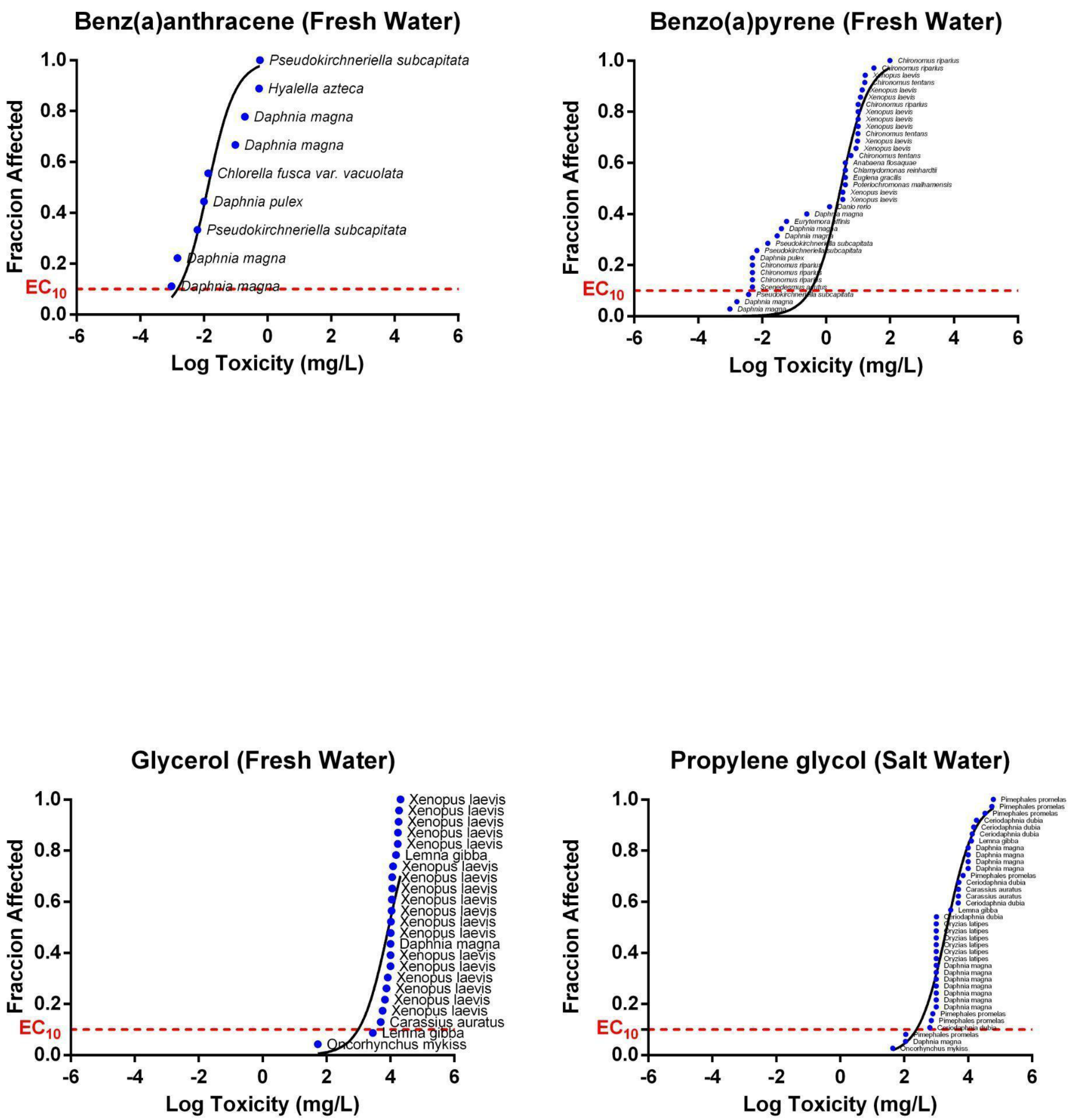

Figure 2 – Species sensitivity distribution (SSD) for freshwater and saltwater.

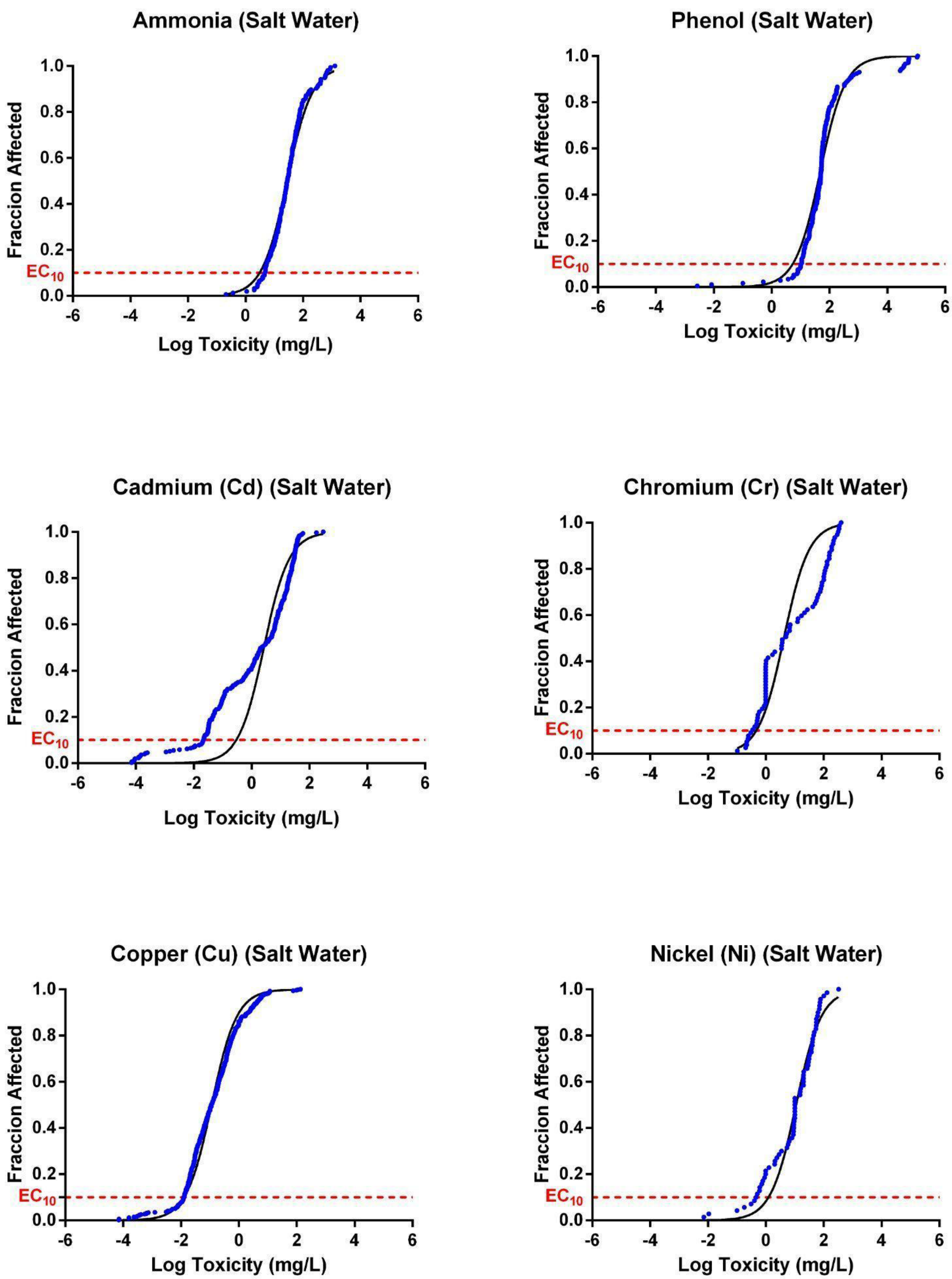

Figure 3 – Species sensitivity distribution (SSD) for saltwater.

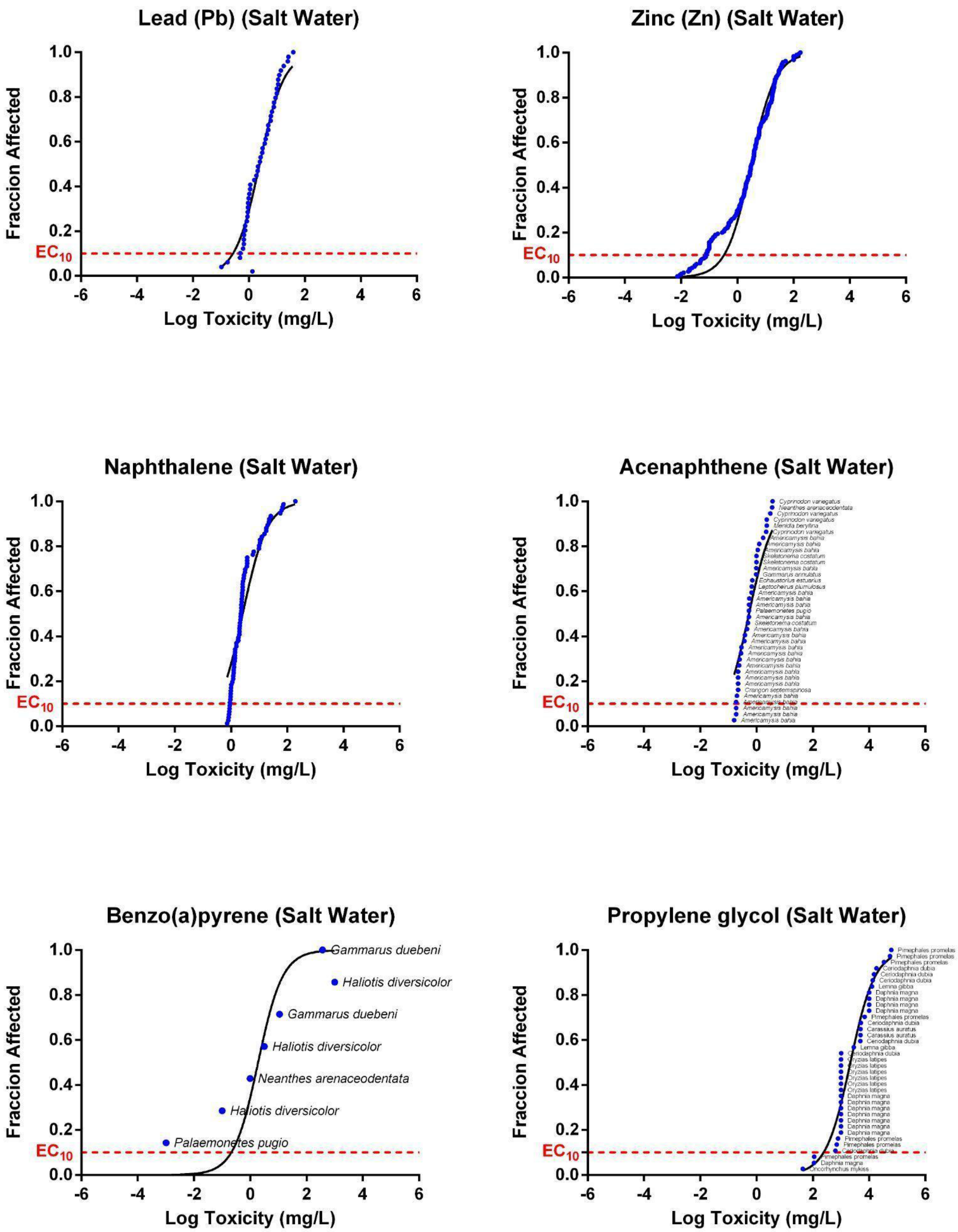

Figure 4 – Species sensitivity distribution (SSD) for saltwater.

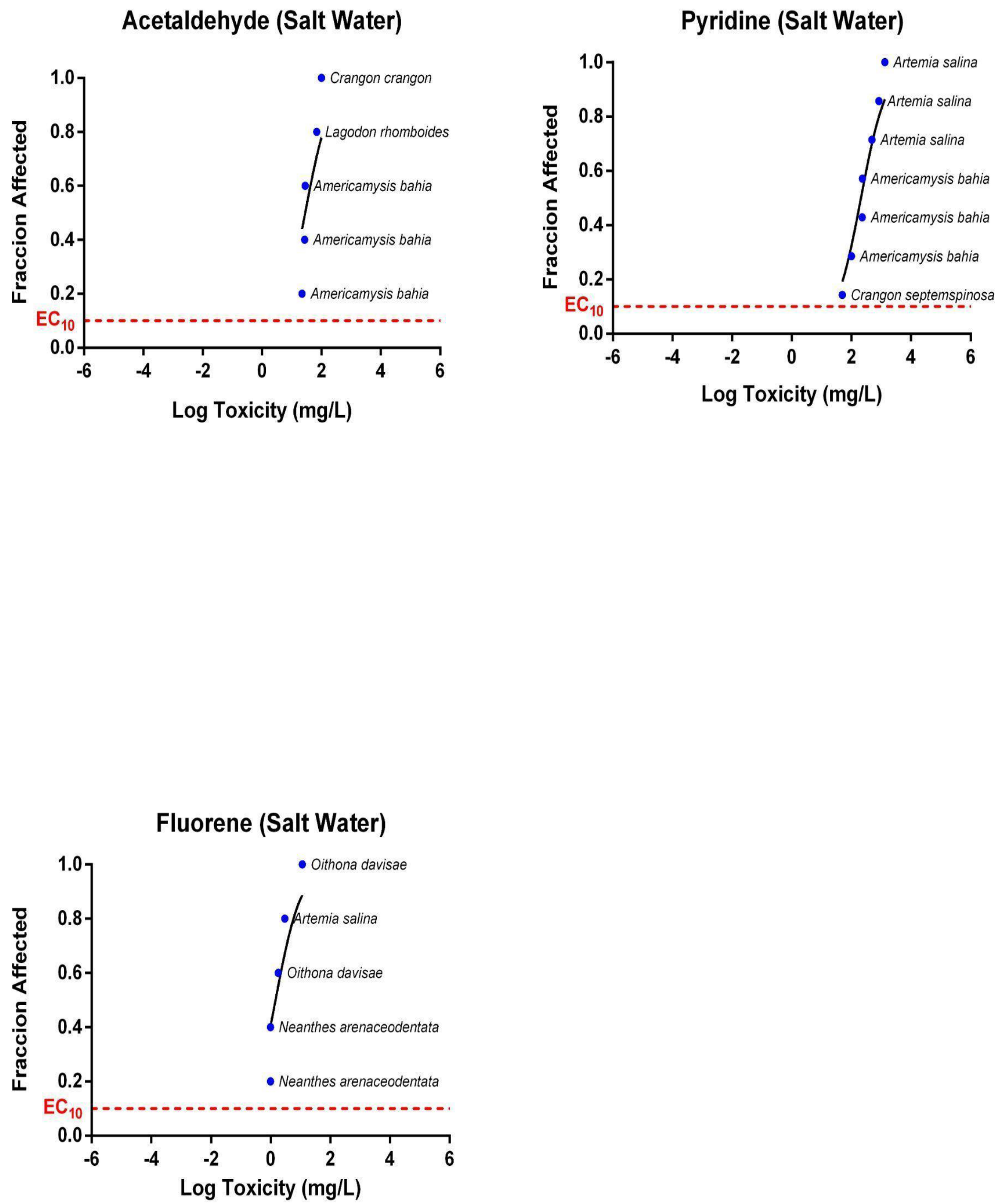

Figure 5 – Species sensitivity distribution (SSD) for saltwater.