Marine Pollution Bulletin 62 (2011) 21–28

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Viewpoint

Hazardous and Noxious Substances (HNS) in the marine environment: Prioritizing HNS that pose major risk in a European context

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ARTICLE INFO

Keywords:
Hazardous and Noxious Substances (HNS) spills
European Atlantic waters
Prioritizing HNS
Marine toxicological data
HNS spill preparedness and responsiveness

ABSTRACT

Increases in the maritime transportation of Hazardous and Noxious Substances (HNS), alongside the need for an effective response to HNS spills have led environmental managers and the scientific community to focus attention on HNS spill preparedness and responsiveness. In the context of the ARCOPOL project, a weight-of-evidence approach was developed aimed at prioritizing HNS that pose major environmental risks to European waters. This approach takes into consideration the occurrence probability of HNS spills in European Atlantic waters and the severity of exposure associated with their physico-chemical properties and toxicity to marine organisms. Additionally, a screening analysis of the toxicological information available for the prioritization of HNS was performed. Here we discuss the need for a prioritization methodology to select HNS that are likely to cause severe marine environmental effects as an essential step towards the establishment of a more effective preparedness and response to HNS incidents.

1. Introduction

A large volume of chemicals is currently produced and, for a significant number of these, shipping is the most important mode of transport in terms of volume (French McCay et al., 2006; Mamaca et al., 2009; Purnell, 2009). The constant growth in the volume of chemicals that are transported by sea increases the risk of accidental spillage and the severity of their impacts depending on several variables such as the substances hazardous properties. These groups of chemicals have been collectively termed Hazardous and Noxious Substance (HNS) that are defined as any substance other than oil, which if introduced into the marine environment is likely to create hazards to human health, to harm living resources and other marine life, to damage amenities and/or to interfere with other legitimate uses of the sea (IMO, 2000).

The growth in the maritime transportation of HNS, together with the need for an effective response to HNS spills have led authorities, environmental managers and the scientific community to focus on HNS spills preparedness and responses to them. The OPRC-HNS Protocol (The Protocol on Preparedness, Response and Co-operation to Pollution Incidents by Hazardous and Noxious Substances), adopted by IMO (2000), entered into force in 2007 and has been, at the time of writing, ratified by 25 countries (12 EU/EFTA countries), representing 36.1% of the global tonnage. Even though the probability of an HNS incident is considered small due to high safety standards, it does exist as recent shipping incidents involving HNS have shown. The *Ievoli Sun*, which sank in the English Channel in 2000, released 1000 tonnes of styrene. More recently, in 2007, the *MSC Napoli*, which carried >1600 tonnes of chemical products classified by IMO as dangerous goods, raised awareness of the potential ecological hazard of HNS spills (Law et al., 2003; Kirby et al., 2008).

An understanding of the ecological hazards involved in HNS spills is less well recognized than those involving oil pollution. Whereas most oils float on the sea and are immiscible with water, HNS chemicals exhibit a wider range of behaviours (i.e. sinking, floating, gassing, evaporating, and dissolution) and toxicities to marine organisms (CEFAS, 2009). There is a current paucity of knowledge about the effects of HNS on marine biota and the scarce available ecotoxicological HNS data result mostly from experiments conducted with freshwater organisms (Mamaca et al., 2005; Purnell, 2009), making it difficult to predict the effects on marine organisms and to prepare contingency plans for these substances.

In order to respond to incidents involving HNS, the systematic classification of scientific ecotoxicological data for marine organisms should be a priority issue. Due to the high number and diversity of HNS transported by sea, it is, in practice, unrealistic to consider a full scientific ecotoxicological data survey for all such chemicals. Hence, the prioritization of HNS that are most likely to pose severe hazards to marine organisms is needed.

The present study develops a weight-of-evidence approach based on a set of key risk criteria that include (i) the volumes of HNS transported in European Atlantic waters; (ii) reported HNS incidents in European waters; (iii) HNS physico-chemical properties and (iv) their toxicities to marine organisms. The study further aimed at drawing up a list of priority HNS that are likely to

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0025-326X/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.marpolbul.2010.09.016

pose a major risk to the marine environment if spilled in European Atlantic waters. The study also sought to collate the marine toxicological data available for each priority HNS. This approach is essential if we are to improve our knowledge about the significance of chemical spills to the marine environment and represents a step towards defining strategic risk information for the establishment of a more effective preparedness and response capability to HNS incidents.

2. Prioritization procedure: approach and methodology

The threat caused by different HNS chemicals depends on several variables, for example, their intrinsic characteristics (i.e. physico-chemical and toxicological properties) and the volumes transported by sea. The effective response to a HNS spill incident should consider the HNS impact on the marine environment, which requires an ecotoxicological dataset for representative marine organisms. Producing such a dataset for all HNS is a difficult task due to the large numbers and the particular properties of compounds transported in European waters. Hence, a more realistic approach consists of the selection and prioritization of HNS chemicals that are likely to pose the most severe risks to the marine environment if spilled. The prioritization procedure represents a weight-of-evidence approach based on the following key risk criteria: (i) HNS volumes transported in European Atlantic waters; (ii) reported HNS incidents in European waters; (iii) HNS physico-chemical properties and (iv) toxicity to marine organisms.

Table 1
Summary of the HNS incidents at EU waters.

Ship name	Incident date	Country	HNS transported/ spilled	GESAMP Classification[a]			Physico-chemical properties[b]	Traffic ranking[c]
				Bioaccumulation	Biodegradation	Acute toxicity		
Canon	1987	UK	Xylene	3	NR	3	FE	8
			Butanol	0	R	0	D	31
			Butyl acrylate	2	R	3	FED	57
			Cyclohexanone	1	R	2	FED	44
			Sodium	–	–	–	–	–
			Anilin oil	0	–	3	FD	–
			Diphenyl-methan	–	–	–	–	–
			o-Cresol	2	R	3	SD	96
			Dibutyl phtalate	–	–	–	–	–
			Phosphoric acid	0	Inorg.	1	D	10
			Phthalic anhydride	1	R	2	S	–
Anna Broere	1988	Netherlands	Acrylonitrile	2	NR	3	DE	25
			Dodecyl benzene	0	NR	0	F	82
Alessandro Primo	1991	Italy	Acrylonitrile	2	NR	3	F	25
			Ethylene dichloride	1	NR	2	SD	47
Kimya	1991	UK	Sunflower oil	0	R	0	F	1
Grape One	1993	UK	Xylene	3	NR	3	FE	8
Weisshorn	1994	Spain	Rice	–	–	–	–	–
Fenes	1996	France	Wheat	–	–	–	–	–
Allegra	1997	UK	Palm oil	0	R	0	F	1
Albion II	1997	France	Calcium carbide	–	–	–	–	–
			Iodine	–	–	–	–	–
			Camphor	–	–	–	–	–
			Ammonia anhydrous	0	R	3	DE	4
Junior M	1999	France	Ammonium nitrate	0	R	3	D	–
Ievoli Sun	2000	UK	Styrene	3	R	3	FE	7
			Methyl hepthyl ketone	3	R	3	FED	–
			Isopropyl alcohol	0	R	0	D	–
Ballu	2001	Spain	Sulphuric acid	0	Inorg.	2	D	12
Lykes Liberator	2002	France	Aluminium	–	–	–	–	–
			Diethyl iodide	–	–	–	–	–
			Diethyl zinc	–	–	–	–	–
			Toluene	2	R	3	FE	16
Bow Eagle	2002	France, Channel	Ethyl acetate	0	R	1	DE	28
			Methyl-ethyl-ketone	0	R	1	DE	40
			Cyclohexane	3	NR	3	E	14
			Toluene	2	R	3	FE	16
			Benzene	1	R	2	E	3
			Ethanol	0	R	0	F	11
			Soya	–	–	–	–	–
			sunflower oil	0	R	0	F	1
			Vegetable oil	0	R	0	F	1
Jambo	2003	UK	Zinc sulphide	–	–	–	–	–
Ece	2006	France	Phosphoric acid	0	Inorg.	1	D	10
Rokia Delmas	2006	Isle of Ré, France	Cocoa beans	–	–	–	–	–
MSC Napoli	2007	UK	Several HNS					

[a] See Table 2 for more information on GESAMP classification.
[b] D: dissolver; S: sinker F: floater; E: evaporator, DE dissolver/evaporator; SD: sinker/dissolver; FD: floater/dissolver; FE: floater/evaporator; FED: floater/evaporator/dissolver.
[c] According to the list of the 100 HNS most transported in European Atlantic waters elaborated by HASREP (2005).

By using these four key risk criteria, this weight-of-evidence approach takes into consideration the probability (i.e. likelihood) of a spill in European Atlantic waters and the severity of exposure associated with the physico-chemical properties and toxicity of the HNS to marine life. The methodology developed in the present study will provide a tool to assist relevant bodies when developing contingency plans dealing with accidental HNS spills.

2.1. HNS volumes transported in European waters

The probability of occurrence of a spill in European Atlantic waters is assumed to be dependent on both the tonnage and frequency of HNS transported by sea. A European-funded project monitored the tonnage of chemicals transported in either bulk or packaged form and identified a list of 100 HNS chemicals most transported in European Atlantic waters (HASREP, 2005). This list of chemicals most transported by sea in terms of tonnage was used as a starting point for the prioritization procedure. At present, the paucity of information available on shipping frequencies limits the ability of including this within this risk assessment.

2.2. Reported HNS incidents in European waters

Several sources of information were reviewed to assemble the data on HNS shipping incidents in European waters such as IMO (2002), Cedre spill guide, Mamaca et al. (2009) and HELCOM (2003). Some of the incidents were well documented, whereas most have not been appropriately reviewed. Past incidents are not only essential references of what happened some time ago, they are also, when properly reported upon, first hand sources of information on what may happen again and what could better mitigate subsequent and resulting consequences. Eighteen of the most important incidents that have occurred recently in European waters were selected for closer examination. For each one of the 18 incidents, information based on the HNS transported/spilled, impacts on the marine environment, HNS physico-chemical properties and traffic ranking were compiled (Table 1).

2.3. HNS physico-chemical properties

HNS spilled into the sea may behave differently depending on their physico-chemical properties and local marine environmental conditions. The European Behaviour Classification System (Bonn Agreement, 1994) has been developed in order to classify chemicals according to their physico-chemical behaviours when spilled into the sea. The main principle of the system is the characterization of spilled loose chemicals as: (i) gases (G); (ii) evaporators (E); (iii) floaters (F); (iv) dissolvers (D); (v) sinkers (S) and (vi) the various combinations of these, that is: (vii) gases/dissolvers (GD); (viii) evaporators/dissolvers (ED); (ix) floaters/evaporators (FE); (x) floaters/evaporators/dissolvers (FED); (xi) floaters/dissolvers (FD); (xii) dissolvers/evaporators (DE) and (xiii) sinkers/dissolvers (SD). The European Behaviour Classification system for evaluating the short-term behaviours of chemicals spilled at sea was indirectly used in the selection of priority HNS. Dissolvers and sinkers have the highest potential ecological impacts on the marine environment after spillage as they will disperse easily and are, hence, bioavailable for aquatic organisms, both in the water column and the sediments. Unlike dissolvers and sinkers, floaters drift with the wind and/or currents and can reach sensitive areas along the coast impacting mainly marine mammals, birds and benthic life forms. The main hazards produced by gases and evaporators are air toxicity and usually represent a low threat to the marine environment except if they also dissolve in water. Considering the likely impact on the marine environment produced by dissolvers, floaters, and sinkers, the priority HNS list will cover mainly these behaviour categories.

2.4. Toxicity to marine organisms

The procedure to identify priority HNS to the marine environment should consider chemicals that have a combination of harmful characteristics to marine organisms. These include moderate to high toxicity in combination with bioaccumulation, persistence potential and/or long term carcinogenic effects.

- Toxicity. In order to rate the hazard posed by chemicals to aquatic organisms, the most common solution is still the use of acute toxicity test data. However, both acute and chronic ecotoxicological data should be taken into account in the selection of priority HNS if both LC50 and NOEC/LOEC are available.
- Bioaccumulation. The bio-concentration factor, BCF, is usually used as an indicator for bioaccumulation in conjugation with the *n*-octanol/water partition coefficient and $\log K_{ow}$ (Höfer, 1999).
- Persistence. The available information on persistence of HNS in the marine environment is dominated by data on "ready biodegradability". There are a wide range of tests, based on O_2

Table 2
Bioaccumulation, biodegradation and toxicity GESAMP guidelines for the categorization of HNS (adapted from GESAMP (2002)).

Numerical rating	Bioaccumulation			Bio-degradation	Aquatic toxicity				Carcinogenic effects
	Description	Criteria for $\log K_{ow}$	Criteria for BCF		Acute toxicity		Chronic toxicity		
					LC/EC/50 (mg/l)	Description	NOEC (mg/l)	Description	
0	No potential to bioaccumulate	⩽1 or >ca.7	No measurable		>1000	No toxic	>1	Negligible	C: carcinogen
1	Very low potential to bioaccumulate	⩾1–<2	⩾1–<10		100–1000	Practically no toxic	*>0.1 ⩽ 1*	Low	NC: no carcinogenic or no data available
2	Low potential to bioaccumulate	⩾2–<3	⩾10–<100	R: readily biodegradable	10–100	Slightly toxic	*>0.01 ⩽ 0.1*	Moderate	
3	Moderate potential to bioaccumulate	⩾3–<4	⩾100–<500	NR: not readily biodegradable	1–10	Moderately toxic	*>0.001 ⩽ 0.01*	High	
4	High potential to bioaccumulate	⩾4–<5	⩾500–<4000	Inor.:inorganic	0.01–1	Highly toxic	*⩽0.001*	Very high	
5	Very high potential to bioaccumulate	⩾5–<ca. 7	⩾4000		<0.01	Extremely toxic			

consumption, CO_2 evolution or dissolved organic carbon removal, that are designed to select rapidly biodegrading substances (Höfer, 1999).

- Carcinogenic effects. Whilst information available concerning HNS carcinogenic effects for marine organisms is scarce, carcinogens possess the potential for irreversible effects in them. For this reason, the carcinogenic impact on mammals, for which a large set of information is available, will be considered in the selection of priority HNS.

HNS that combine properties of moderate to high toxicity, bioaccumulation potential, persistence and/or long term carcinogenic effects represent the highest levels of hazard to the marine environment after a spill. In the present work, the revised hazard evaluation procedures elaborated by GESAMP – the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection – (GESAMP, 2002; IMO, 2008) was applied to numerically score the 100 most transported HNS in EU Atlantic waters defined in Section 2.1 above. The GESAMP bioaccumulation, biodegradation, toxicity and carcinogenic effects criteria (GESAMP, 2002) will be used as a tool for assessing the risk posed by the 100 HNS and selecting the priority HNS (Table 2).

3. Cut-off values for the prioritization process

In order to priorities HNS that pose the major risk for the marine environment, we propose the use of a cut-off values approach considering the 100 most transported HNS in EU Atlantic waters. Those compounds falling into one of the following categories were considered a priority:

(**1**)

- Bioaccumulation rank of at least 2 (low potential to bioaccumulate).
- Biodegradation of "Not Readily biodegradable".
- Acute toxicity rank of at least 3 (moderately toxic) and/or chronic toxicity rank of at least 2 (moderately toxic).

(**2**)

- Bioaccumulation rank of at least 3 (moderate potential to bioaccumulate).
- Biodegradation of "Readily biodegradable".
- Acute toxicity rank of at least 4 (highly toxic) and/or chronic toxicity rank of at least 2.

(**3**)

- Bioaccumulation rank of at least 2.
- Biodegradation of "Readily biodegradable".
- Acute toxicity rank of at least 3 and/or chronic toxicity rank of at least 2.
- Involved in previous incidents.

Also HNS that have long term carcinogenic impacts on mammals were considered for integration into the list of priority HNS.

Based on this approach, the list of priority selected HNS is given in Table 3.

Table 3
Priority list of HNS in EU Atlantic waters.

HNS	GESAMP Classification				Carcinogenic effects[b]	Previous incident	Physico-chemical properties[c]	Trafficranking[d]
	Bioaccumulation	Biodegradation[a]	Acute toxicity	Chronic toxicity				
Benzene	1	R	2	–	C	Bow Eagle	E	3
Styrene monomer	3	R	3	–	C	Ievoli Sun	FE	8
Xylenes	3	NR	3	0	NC	Cason	FE	7
Cyclohexane	3	NR	3	–	NC	Bow Eagle	E	14
Toluene	2	R	3	0	NC	Lykes Liberator, Bow Eagle	FE	16
Nonene (all isomers)	4	–	3	–	NC	–	FE	17
Aniline	0	R	3	2	C	–	FD	19
Acrylonitrile	2	NR	3	0	C	Anna Broere, A. Primo	DE	25
Nitrobenzene	1	R	3	–	C	–	SD	27
Isononanol	3	NR	3	1	NC	–	F	37
Alkyl (C5–C8, C9) benzenes	4	NR	4	–	NC	–	F	43
Nonylphenol poly(4–12) ethoxylates	4	NR	3	1	NC	–	D	48
Octane (all isomers)	5	R	4	–	NC	–	FE	53
1-Nonanol (Nonyl alcohol)	3	NR	3	1	NC	–	F	54
Butyl acrylate (all isomers)	2	R	3	–	NC	Cason	FED	57
Di (2-ethylhexyl) adipate	2	R	4	2	NC	–	F	65
Trichloroethylene	2	NR	3	–	C	–	SD	73
Hexane (all isomers)	3	R	4	–	NC	–	E	74
Heptane (all isomers)	4	R	4	–	NC	–	D	85
1-Dodecanol	2	R	4	–	NC	–	F	86
Cresols (all isomers)	2	R	3	0	NC	Cason	SD	96
Decanoic acid	4	R	4	1	NC	–	F	97
Perchloroethylene	2	NR	3	2	C	–	S	99

[a] R: readily biodegradable; NR: not readily biodegradable.
[b] C: carcinogenic; NC: no carcinogenic or no data available.
[c] D: dissolver; S: sinker F: floater; E: evaporator, DE dissolver/evaporator; SD: sinker/dissolver; FD: floater/dissolver; FE: FED: floater/evaporator; floater/evaporator/dissolver.
[d] According to the list of the 100 HNS most transported in European Atlantic waters elaborated by HASREP (2005).

Table 4
Acute and chronic toxicity of the priority HNS to aquatic organisms[a,b].

HNS	Test species	Toxicity test	Aquatic medium	Salinity (‰)/ temperature (°C)	Age/size	[ ] mg/l (effect)	Endpoint	References
Benzene	Crustacea *Crangon franciscorurn*	Acute toxicity	Seawater	32/20	18g	20 (96 h LC50)	Survival	Benville and Korn (1977)
	Crustacea *Artemia salina*	Acute toxicity	Seawater	NR/24	Nauplii <24 h	66 (24 h LC50)	Survival	Price et al. (1974)
	Fish *Gasterosteus aculeatus*	Acute toxicity	Seawater	NR/8	3 years 55 mm	24.83 (96 h LC50)	Survival	Moles et al. (1979)
	Fish *Morone saxatilis*	Chronic toxicity	Seawater	15.2–16.4/ 25–26	Juveniles 18.1 cm	3.6–8.1(28 day LOEC)	Growth	Korn et al. (1976)
Styrene	Crustacea *Artemia salina*	Acute toxicity	Seawater	24/NR	Nauplii <24 h	68 (24 h LC50)	Survival	Price et al. (1974)
	Crustacea *Americamysis bahia*	Acute toxicity	Seawater	NR/NR	NR	12.1 (96 h LC50)	Survival	US EPA (1978)
	Bivalve mollusc *Mytilus edulis*	Chronic toxicity	Seawater	NR /15	NR	0.2 (7 days LOEC)	Lysosomal stability and DNA damage	Mamaca et al. (2005)
	Fih *Symphodus melops*	Chronic toxicity	Seawater	NR /15	NR	0.2 (7 days LOEC)	Lysosomal stability and DNA damage	Mamaca et al. (2005)
Xylene	Crustacea *Crangon franciscorurn*	Acute toxicity	Seawater	15/16	1.8 g	*ρ*-Xylene 2(96h LC50) *o*-Xylene 1.3 (96h LC50) *m*-Xylene 3.7(96h LC50)	Survival	Benville and Korn (1977)
	Crustacea *Artemia* sp.	Acute toxicity	Seawater	30/19.5–23	NR	*ρ*-Xylene 27.8 (24h LC50) *o*-Xylene 24.64 (48h LC50) *m*-xylene 10.8 (48h LC50)	Survival	MacLean and Doe (1989)
	Fish *Moreno saxatilis*	Acute toxicity	Seawater	25/16	Juveniles 6 g	*ρ*-Xylene 2 (96h LC50) *o*-Xylene 11 (96h LC50) *m*-Xylene 9.2 (96h LC50)	Survival	Benville and Korn (1977)
	Algae *Pseudokirchneriella Subcapitata*	Chronic toxicity	Freshwater	NR/NR	NR/NR	*ρ*-Xylene 0.7 (8 days NOEC) *o*-Xylene 1 (8 days NOEC) *m*-Xylene 0.9 (8 days NOEC)	Growth	Herman et al. (1990)
Cyclohexane	Crustacea *Crangon franciscorurn*	Acute toxicity	Seawater	32/20	1.7 g	2.4 (96 h LC50)	Survival	Benville et al. (1985)
	Fish *Moreno saxatilis*	Acute toxicity	Seawater	32/20	Juveniles 8.5 g	8.3 (96 h LC50)	Survival	Benville et al. (1985)
	Crustacea *Daphnia magna*	Chronic toxicity	Freshwater	NR/20	Nauplii <24 h	1 (21 days EC 50) 0.74 (21 days LOEC) 0.53(21 days NOEC)	Reproduction	OECD SIDS (2003)
Toluene	Crustacea *Artemia* sp.	Acute toxicity	Seawater	NR/20-22	Nauplii <24 h	53.6 (24h LC50)	Survival	MacLean and Doe (1989)
	Crustacea *Crangon franciscorum*	Acute toxicity	Seawater	25/16	Mature 1.8 g	4.3 (96h LC50)	Survival	Benville and Korn (1977)
	Crustacea *Cancer magister*	Acute toxicity	Seawater	29–34/13	NR	28 (96h LC50)	Survival	Caldwell et al. (1977)
	Crustacea *Eualus* sp.	Acute toxicity	Seawater	26–28/12	6 cm	14.7 (96h LC50)	Survival	Korn et al. (1979)
	Crustacea *Palaemonetes pugio*	Acute toxicity	Seawater	15/20	Adults	9.6 (96h LC50)	Survival	Tatem (1975)
	Mollusc *Pacific oyster*	Acute toxicity	Seawater	25.3–30.3/ 20–21.5	Eggs	172 (48h LC50)	Survival	Legore (1974)
	Fish *Morone saxatilis*	Acute toxicity	Seawater	25/16	Juveniles 6 g	7.3 (96h LC50)	Survival	Benville and Korn (1977)
	Fish *Cyprinodon variegates*	Chronic toxicity	Seawater	25/29	Embryos	7.7 (28 days NOEC) 3.2 (28 days NOEC)	Growth Survival	Ward et al. (1981)
Nonene	Crustacea *Daphia magna*	Acute toxicity	Freshwater	20	Neonates <24 h	3.4 (24h LC50)	Survival	Adema (1985)
	Fish *Danio rerio*	Acute toxicity	Freshwater	24	4–6 weeks	3.2 (24 h LC50)	Survival	Adema (1985)
Aniline	Crustacea *Crangon septemspinosa*	Acute toxicity	Seawater	NR/10	6.4–8.3 cm	29.4 (96 h LC50)	Survival	Leese Mc et al. (1979)
	Crustacea *Daphnia magna*	Chronic toxicity	Freshwater	25	Neonates <24 h	0.004 (21 days NOEC)	Reproduction	Kühn et al. (1989)

(*continued on next page*)

Table 4 (*continued*)

HNS	Test species	Toxicity test	Aquatic medium	Salinity (‰)/ temperature (°C)	Age/size	[ ] mg/l (effect)	Endpoint	References
	Fish *Pimephales promelas*	Chronic toxicity	Freshwater	24.5	<24 h	0.735 (32 days LOEC) 0.422 (32 days NOEC)	Growth	Russom (1993)
Acrylonitrile	Crustacea *Artemia salina*	Acute toxicity	Seawater	NR/25	Nauplii <24h	14.34 (48h LC50)	Survival	Tong et al. (1996a)
	Crustacea *Crangon franciscorurn*	Acute toxicity	Seawater	NR	NR	10–33 (24h LC50)	Survival	Portmann and Wilson (1971)
	Fish *Lagodon rhomboides*	Acute toxicity	Seawater	NR/13.7–20.4	NR	24.5 (24h LC50)	Survival	Daugherty and Garrett (1951)
	Crustacea *Daphnia magna*	Chronic toxicity	Freshwater	24	Neonates <24 h	1 (21 days LOEC) 0.5 (21 days NOEC)	Reproduction	Tong et al. (1996b)
	Fish *Cyprinus carpio*	Chronic toxicity	Freshwater	22	Enbryo–larva	3.2 (7 days LOEC) 1.6 (7 days NOEC)	Survival	Tong (1999)
Nitrobenzene	Crustacea *Americamysis bahia*	Acute toxicity	Seawater	NR	NR	6.6 (96h LC50)	Survival	US EPA (1978)
	Fish *Cyprinodon variegatus*	Acute toxicity	Seawater	10–31/25–31	Juveniles 8–15mm	59 (96h LC50)	Survival	Heitmuller et al. (1981)
	Crustacea *Daphnia magna*	Chronic toxicity	Freshwater	25	Neonates <24 h	2.6 (21 days LOEC)	Reproduction	Kühn et al. (1989)
	Fish *Danio rerio*	Chronic toxicity	Freshwater	23	NR	5 (14 days NOEC)	Behaviour	Roderer (1990)
Isononanol	No data available							
Amylbenzene[c]	Fish *Pimephales promelas*	Acute toxicity	Freshwater	23.9	26 days	1.71 (96 h LC50)	Survival	Geiger et al. (1986)
Cyclohexylbenzene[c]	Crustacea *Daphnia pulex*	Acute toxicity	Freshwater	20	NR	0.55(48 h LC50)	Survival	Passino-Reader et al. (1997)
Nonylphenol polyethoxylates	Crustacea *Mysidopsis bahia*	Acute toxicity	Seawater	NR/25	NR	1.23 (48 h LC50)	Survival	Patoczka and Pulliam (1990)
	Crustacea *Balanus balanoides*	Acute toxicity	Seawater	32–34/6–8	Nauplli/ larvae	1.5 (96 h LC50)	Survival	Swedmark et al. (1971)
	Mollusc *Mytilus edulis*	Acute toxicity	Seawater	32–34/6–8	NR	5 (96 h LC50)	Survival	Swedmark et al. (1971)
	Fish *Gadus morhua*	Acute toxicity	Seawater	32–34/6–8	30 cm	6 (96 h LC50)	Survival	Swedmark et al. (1971)
		Chronic toxicity	Seawater	32–34/6–8	30 cm	<1 (several months NOEC)	Behaviour	Swedmark et al. (1971)
	Fish *Pleuronectes flesus*	Acute toxicity	Seawater	NR/15–17	NR	3 (96h LC50)	Survival	Swedmark et al. (1971)
Octane	Crustacea *Artemia salina*	Acute toxicity	Seawater	NR/20	Nauplii	3.5 (24 h LC50)	Survival	Abernethy et al. (1986)
	Mullusc *Mytilus edulis*	Acute toxicity	Seawater	33/15	40–50 mm	0.12 (0.07 h EC50)	Feeding behaviour	Donkin et al. (1989)
1-Nonanol	Crustacea *Nitocra spinipes*	Acute toxicity	Seawater	7/21	3–6 weeks	25 (96 h LC50)	Survival	Bengtsson et al. (1984)
	Fish *Pimephales promelas*	Acute toxicity	Freshwater	25	<24 h	5.5 (96 h LC50)	Survival	Broderius and Kahl (1985)
Butyl acrylate	Crustacea *Daphnia magna*	Acute toxicity	Freshwater	20–22	Neonates <24 h	230 (24 h LC50)	Survival	Bringmann and Kuhn (1977)
	Fish *Osteichthyes* sp.	Acute toxicity	Freshwater	NR	NR	5 (72 h LC50)	Survival	Paulet and Vidal (1975)
Di 2-ethylhexyl adipate	Crustacea *Daphnia magna*	Acute toxicity	Freshwater	25	Neonates <24 h	0.66 (48h LC50)	Survival	Felder et al. (1986)
		Chronic toxicity	Freshwater	NR	Neonates <24 h	0.024–0.056 (21 days MATC)	Reproduction Growth	
	Fish *Oncorhynchus mykiss*	Acute toxicity	Freshwater	12	NR	0.78 (96 h LC50)	Survival	Felder et al. (1986)
Trichroroethylene	Crustacea *Mysidopsis bahia*	Acute toxicity	Seawater	20/22	3 days	14 (96 h LC50)	Survival	Ward et al. (1986)
	Crustacea *Palaemonetes pugio*	Acute toxicity	Seawater	NR/30	NR	2 (96 h LC50)	Survival	Borthwick (1977)
	Mollusc *Elminius modestus*	Acute toxicity	Seawater	NR	NR	20 (48 h LC50)	Survival	Pearsons and McConnell (1975)
	Fish *Cyprinodon variegatus*	Acute toxicity	Seawater	20/22	5–6 mm	52 (96 h LC50)	Survival	Ward et al. (1986)
	Fish *Limanda limanda*	Acute toxicity	Seawater	NR	NR	16 (96 h LC50)	Survival	Pearsons and McConnell (1975)
Hexane	Crustacea *Artemia salina*	Acute toxicity	Seawater	NR/19	Nauplii 2 days	1.51 (24 h EC50)	Intoxication	Foster and Tullis (1985)
Heptane	Crustacea *Daphia magna*	Acute toxicity	Freshwater	28	NR	82.5 (96 h LC50)	Survival	Das and Konar (1988)
	Fish *Leuciscus idus melanotus*	Acute toxicity	Freshwater	NR	NR	270 (48 h LC50)	Survival	Juhnke and Luedemann (1978)

Table 4 (*continued*)

HNS	Test species	Toxicity test	Aquatic medium	Salinity (‰)/ temperature (°C)	Age/size	[ ] mg/l (effect)	Endpoint	References
	Fish *Oreochromis mossambicus*	Acute toxicity	Freshwater	27.8	NR	365 (96 h LC50)	Survival	Ghatak et al. (1988)
1-Dodecanol	Crustacea *Nitrocra spinipes*	Acute toxicity	Seawater	7/21	3–6 weeks	1 (96 h LC50)	Survival	Bengtsson et al. (1984)
	Fish *Pimephales promelas*	Acute toxicity	Freshwater	25	0.12 g	1.01 (96 h LC50)	Survival	Veith et al. (1983)
m-Cresol	Crustacea *Daphnia magna*	Acute toxicity	Freshwater	NR	Neonates <24 h	18.8 (96h LC50)	Survival	Parkhurst et al. (1979)
	Fish *Danio rerio*	Acute toxicity	Freshwater	NR	NR	15.9 (96 h LC50)	Survival	Wellens (1982)
	Fish *Oncorhynchus mykiss*	Acute toxicity	Freshwater	14	Fry 0.78 g	3.88 (96 h LC50)	Survival	Saglam and Ural (2005)
Decanoic acid	Diatom *Nitzschia closterium*	Acute toxicity	Seawater	NR	NR	0.3 (72 h LC50)	Survival	Henkel KGaA safety data sheet
	Crustacea *Artemia salina*	Acute toxicity	Seawater	NR	NR	36 (16 h LC50)	Survival	Henkel KGaA safety data sheet
Perchloroethylene	Crustacea *Americamysis bahia*	Acute toxicity	Seawater	NR	NR	10.2 (96h LC50)	Survival	US Environmental Protection Agency (1978)
	Crustacea *Crangon septemspinosa*	Acute toxicity	Seawater	NR	NR	17.4 (96 h LC50)	Survival	Horne et al. (1983)
	Crustacea *Acartia tonsa*	Acute toxicity	Seawater	22/21.5	NR	13.2 (96 h LC50)	Survival	Horne et al. (1983)
	Fish *Cyprinodon variegatus*	Acute toxicity	Seawater	26/22.5–22.8	NR	9,8 (96 h LC50)	Survival	Horne et al. (1983)
	Crustacea *Daphnia magna*	Chronic toxicity	Freshwater	NR	NR	0.4 (21 days NOEC)	Reproduction	Hahn et al. (1989)
	Fish *Jordanella floridae*	Chronic toxicity	Freshwater	25	Fry	3.69 (28 days LOEC)	Survival	Smith et al. (1991)
	Fish *Pimephales promelas*	Chronic toxicity	Freshwater	25	30–35 days	0.5 (32 days NOEC)	Growth	Ahmad et al. (1984)
	Fish *Danio rerio*	Chronic toxicity	Freshwater	23	NR	0.6 (14 days, NOEC)	Behaviour	Roderer (1990)

[a] NR: not reported.
[b] LC50: median effective lethal concentration; LOEC: lowest observed effect concentration; NOEC: no observed effect concentration; MATC: maximum acceptable toxicant concentration.
[c] Alkyl (C5–C8, C9) benzenes.

4. Review of acute and chronic toxicological data for the priority HNS in European Atlantic waters

The main objective of this review was to gather toxicological information available for the 23 priority HNS, selected in Section 3 of this study. For this, a dataset was created with acute and chronic toxicity data for marine species representative of different taxonomic groups, mainly crustaceans and fish (Table 4). If no data were available for acute or chronic toxicity in marine organisms, data available for freshwater organisms is provided. The major sources of information, here referred to, were peer-reviewed literature and technical reports obtained using on-line databases. Standard terms used included: median effective (lethal) concentration E(L)C50, lowest observed effect concentration (LOEC), no observed effect concentration (NOEC) and Maximum Acceptable Toxicant Concentration (MATC). This dataset has the merit of assembling a brief and concise profile of the different priority HNS that can assist relevant bodies to predict HNS adverse effects in the marine environment.

As pointed out in Table 4, marine chronic toxicity data is lacking for most of the priority HNS, and for some of them – nonene, alkyl (C5–C8, C9) benzenes, butyl acrylate, di(2-ethylhexyl)adipate, heptane and cresol – only freshwater acute toxicity data are available. Therefore, studies to gather toxicological data for these priority HNS on the marine biota should be undertaken.

Acknowledgements

The ARCOPOL – The Atlantic Regions' Coastal Pollution Response Project (contract nr. 2008-1/061) is funded by the Atlantic Area Trans-National Programme (Priority 2: Marine Environment and Renewable Energy) with support by the European Regional Development Fund (ERDF). Teresa Neuparth was supported by a Postdoctoral fellowship (BPD/2008-1/061/2009-004) within the framework of the ARCOPOL project.

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