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Baseline

Spatial and temporal analysis of the risks posed by polycyclic aromatic hydrocarbon, polychlorinated biphenyl and metal contaminants in sediments in UK estuaries and coastal waters

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ABSTRACT

The environmental risks of 22 contaminants, comprising 6 metals, 10 PAHs and 6 PCB congeners occurring in UK estuaries and coastal waters were assessed as single substances. Sediment samples were taken within 12 nautical miles of the English and Welsh coastlines between 1999 and 2011. The measured environmental concentrations were compared to quality standards including ERL, ERM and EAC, all of which have been established internationally. Out of a total of 38,031 individual samples analysed, 42.6% and 7.7% exceeded the ERL/EAC and ERM values, respectively. The highest Risk Characterisation Ratios (RCRs) for metals, PAHs and PCBs were observed for copper, fluorene and CB118 (2,3′,4,4′,5-pentachlorobiphenyl). In general, the highest concentrations of PAHs and PCBs were observed in 2011 in the Lower Medway indicating a potential risk to the aquatic environment. This study suggests that re-suspension of contaminants banned over 20 years ago is still an ongoing issue.

1. Introduction

Estuaries are seen as one of the most productive marine ecosystems in the world and crucial to the life history and development of many aquatic groups (Chapman and Wang, 2001; Dauvin, 2008). These important ecosystems are also strongly susceptible to pollution from anthropogenic input via rivers, marine traffic and coastal construction. Organisms living in or near these environments are exposed to a range of chemicals, including polychlorinated biphenyls (PCBs), metals and polycyclic aromatic hydrocarbons (PAHs) that have the potential to affect sensitive species at both the individual and population level (Beyer et al., 2014). PCB contamination started in the 1940s, peaked in the 1970s and declined afterwards, due to prohibition of use in many countries. Nevertheless, concentrations of PCBs are still very high in many regions due to their hydrophobic nature and low solubility in water; properties which initially contributed to their widespread use (Sprovieri et al., 2007). PCBs may leach from residues within old electrical transformers and other dielectric fluids present in landfill, and once in the environment, can absorb to particulate matter and accumulate in sediments (Kang et al., 2000; Fox et al., 2001; Wiberg and Harris, 2002). As such sediments commonly form the final sink for PCBs, presenting a secondary form of contamination with bioavailability being increased through re-suspension after storms or dredging activities (Lee et al., 2001). Like PCBs, PAHs also bind to sediments due to their hydrophobicity and, in such matrices, they can persist for decades due to their low level of degradation in anaerobic environments (Sprovieri et al., 2007). PAHs normally reach the marine environment as a result of fossil fuel combustion, waste incineration and oil spills, posing a threat to benthic organisms due to their acutely toxic, mutagenic and carcinogenic properties (Law and Biscaya, 1994; Connell et al., 1997; Kannan et al., 2005). Metals are also released into the marine environment, as a result of both natural and anthropogenic inputs and are also strongly affiliated with particulate matter (Zhang et al., 2007). Sediment bound contamination has been shown to affect the water quality and resulting impacts have been documented in a range of marine invertebrate and vertebrate species (Besselink et al., 1997; Leung et al., 2005; Damiano et al., 2011). It is often difficult to pinpoint which combination is responsible for the observed impacts, as the contaminants may act in a number of possible additive, synergistic or antagonistic stressor effect combinations. The issues around environmental chemical mixture toxicity are currently poorly understood and is probably underestimated as a result (Beyer et al., 2014). A contaminant cocktail of individual chemicals, each of which is individually below a no observable effects

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concentration (NOEC), may contribute to a manifestation of significant effects through combined or joint toxicity (Brian et al., 2007; Kortenkamp, 2008). This can be influenced further by non-chemical factors dependent on the uptake, bioaccumulation and biomagnification of each contaminant and the characteristics of the organism being exposed (Beyer et al., 2014).

Within the UK, the Clean Seas Environment Monitoring Programme (CSEMP) is one of the means by which our national and international commitments to monitoring in estuarine and marine waters are met. The major drivers for the current programme are the European Union (EU) Water Framework Directive (WFD) (European Commission, 2000), the EU Marine Strategy Framework Directive (MSFD) (European Commission, 2008a) and the Co-ordinated Environmental Monitoring Programme and Joint Assessment and Monitoring Programme of the Oslo and Paris convention (OSPAR). Under WFD, chemical status is assessed out to 12 nautical miles against seawater Environmental Quality Standards (EQSs) established by the EU. The list of chemical determinants to be studied was initially specified within the WFD and has since been extended as a result of the Environmental Quality Standards Directive (EQSD) (European Commission, 2008b). A small number of EQSs have also been set for sediments and biota under WFD. The MSFD requires all European marine waters to meet Good Environmental Status (GES) by 2020, and one of the eleven descriptors (descriptor 8) by which this will be assessed relates to chemical contaminants and their effects (Law et al., 2010; Lyons et al., 2010). Within OSPAR, Environmental Assessment Criteria have been established for a range of contaminants in sediments and biota and for a range of biological effects responses in biota (OSPAR, 2009).

In this paper, data for metals, PAHs and PCBs in coastal and estuarine sediments collected annually between 1999 and 2011 have been assessed. The guidelines provided by OSPAR and US EPA (2013) were incorporated in order to enable a simple assessment. A risk characterisation ratio (RCR) was introduced to facilitate the comparison of metals, PCBs and PAHs with one another, as the RCRs incorporated their Ecotoxicological Assessment Criteria (EACs), Effects Range Low (ERLs) and Effects Range Median (ERMs). Similar approaches have been proposed by Ghekiere et al. (2013) and van der Oost et al. (2003). Persuad

Table 1
CSEMP sediment inshore sampling stations.

Region	Station name	Station	Latitude	Longitude
Anglia	Upper Medway (Burham)	1	51.3337	0.476
Anglia	Lower Medway (Sun Pier)	2	51.3884	0.52026
Anglia	Blackwater (South of East Mersea)	3	51.7608	0.9971
Anglia	Thames Lower (Mucking)	4	51.495	0.4727
Anglia	Thames (Woolwich)	5	51.4972	0.063
Cardigan Bay	Dovey (Ynys-hir)	6	52.549	−3.9672
Cardigan Bay	Mawddach (Bontddu)	7	52.7347	−3.9899
Eastern Channel	Poole Harbour (Upper South Deep)	8	50.6864	−1.99
Eastern Channel	Poole Harbour (Wytch)	9	50.6854	−2.0297
Eastern Channel	Solent (East Brambles Buoy)	10	50.7871	−1.22965
Eastern Channel	Southampton Water (Dockhead)	11	50.8763	−1.3803
Humber Wash	Humber (Inside Spurn Head)	12	53.5909	0.0831
Humber Wash	Humber (Grimsby Road)	13	53.5863	−0.0434
Humber Wash	Humber (Sunk Island)	14	53.6264	−0.1039
Humber Wash	Wash (Off Boston)	15	52.942	0.127
Humber Wash	Wash (Cork Hole)	16	52.8839	0.3921
Humber Wash	Wash (Off Kings Lynn)	17	52.9151	0.3568
Irish Sea	Cumbria Coast (St Bees Head)	18	54.5	−3.65
Irish Sea	Dee (Mostyn Bank)	19	53.3372	−3.2753
Irish Sea	Mersey Channel (C1 Buoy)	20	53.527	−3.161
Irish Sea	Mersey (Seacombe Ferry)	21	53.4096	−3.0094
Irish Sea	Mersey (Gladstone)	22	53.453	−3.0242
Irish Sea	Morecambe Bay	23	54.033	−3.1
Irish Sea	Ribble (u/s 11-mile post)	24	53.7267	−3.0001
Irish Sea	Ribble (u/s 8th Mile Post)	25	53.7302	−2.93665
Severn	Milford Haven (Cosheston Point)	26	51.7007	−4.9185
Severn	Severn Lower (Bedwin)	27	51.5611	−2.7725
Severn	Severn Lower (Peterstone)	28	51.4709	−3.0256
Severn	Severn Middle (Purton)	29	51.7281	−2.4755
Tyne Tees	Northumberland Coast 1	30	55.6124	−1.7592
Tyne Tees	Northumberland Coast 2	31	55.6111	−1.7682
Tyne Tees	Tees (Billingham-Bamlett's Bight)	32	54.5916	−1.2522
Tyne Tees	Tees mouth	33	54.6296	−1.163
Tyne Tees	Tees (Seal Sands)	34	54.5947	−1.1807
Tyne Tees	Durham Coast (off Seaham)	35	54.8157	−1.2779
Tyne Tees	Tweed (Yarrow Slake)	36	55.7703	−2.0255
Tyne Tees	Tyne (Hebburn)	37	54.985	−1.5263
Tyne Tees	Tyne (Ferry Crossing)	38	54.9985	−1.4408
Tyne Tees	Wear (Alexandra Bridge)	39	54.9134	−1.4057
Tyne Tees	Wear (Low Southwick)	40	54.9143	−1.4071
Tyne Tees	Wear (Sandy Point) 1	41	54.9168	−1.364
Tyne Tees	Wear (Sandy Point) 2	42	54.9164	−1.3642
Western Channel	Off Tamar (Jennycliffe Bay)	43	50.3489	−4.1309
Western Channel	Tamar (Warren Point)	44	50.4228	−4.2003
Western Channel	Tamar (Hamoaze)	45	50.3839	−4.1971