Environment International 92–93 (2016) 301–316

Contents lists available at ScienceDirect

Environment International

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

Review article

An aggregate analysis of personal care products in the environment: Identifying the distribution of environmentally-relevant concentrations

Zachary R. Hopkins, Lee Blaney *

University of Maryland Baltimore County, Department of Chemical, Biochemical and Environmental Engineering, 1000 Hilltop Circle, ECS 314, Baltimore, MD 21250, USA

ARTICLE INFO

Article history:
Received 19 December 2015
Received in revised form 15 April 2016
Accepted 15 April 2016
Available online xxxx

Keywords:
Personal care products
Surface water
Wastewater
Micropollutants
Toxicity
Contaminants of emerging concern

ABSTRACT

Over the past 3–4 decades, *per capita* consumption of personal care products (PCPs) has steadily risen, resulting in increased discharge of the active and inactive ingredients present in these products into wastewater collection systems. PCPs comprise a long list of compounds employed in toothpaste, sunscreen, lotions, soaps, body washes, and insect repellants, among others. While comprehensive toxicological studies are not yet available, an increasing body of literature has shown that PCPs of all classes can impact aquatic wildlife, bacteria, and/or mammalian cells at low concentrations. Ongoing research efforts have identified PCPs in a variety of environmental compartments, including raw wastewater, wastewater effluent, surface water, wastewater solids, sediment, groundwater, and drinking water. Here, an aggregate analysis of over 5000 reported detections was conducted to better understand the distribution of environmentally-relevant PCP concentrations in, and between, these compartments. The distributions were used to identify whether aggregated environmentally-relevant concentration ranges intersected with available toxicity data. For raw wastewater, wastewater effluent, and surface water, a clear overlap was present between the 25th–75th percentiles and identified toxicity levels. This analysis suggests that improved wastewater treatment of antimicrobials, UV filters, and polycyclic musks is required to prevent negative impacts on aquatic species.

Contents

* Corresponding author at: University of Maryland Baltimore County, Department of Chemical, Biochemical and Environmental Engineering, 1000 Hilltop Circle, ECS 314, Baltimore, MD 21250, USA.
E-mail address: blaney@umbc.edu (L. Blaney).

http://dx.doi.org/10.1016/j.envint.2016.04.026
0160-4120/

Abbreviations

Acronym	Meaning
4DHB	4,4′-dihydroxybenzophenone
4HB	4-benzoylphenol
4MBC	3-(4-methylbenzylidene)camphor
4nOP	4-*n*-octylphenol
4OXI	2,6,6-trimethylcyclohex-2-ene-1,4-dione
4tBP	4-*tert*-butylphenol
4tOP	4-*tert*-octylphenol
4tPP	4-*tert*-pentylphenol
AC	acetyl cedrene
ADBI	celestolide
AHDI	phantolide
AHTN	tonalide
AP	acetophenone
ATII	traseolide
BM-DBM	avobenzone
BP	benzophenone
BP1	benzophenone-1
BP2	benzophenone-2
BP3	benzophenone-3
BP4	sulisobenzone
BP6	benzophenone-6
BP8	dioxybenzone
BR	bayrepel
BuP	butylparaben
BZA	benzyl acetate
BzP	benzylparaben
BZS	benzyl salicylate
CAM	camphor
D3	cyclotrisiloxane
D4	cyclotetraciloxane
D5	cyclopentasiloxane
D6	cyclohexasiloxane
DEET	*N*,*N*-diethyl-3-methylbenzamide
DPMI	cashmeran
EC	etocrylene
EC_{25}	quarter maximal effective concentration
EHS	octisalate
EP	ethylparben
ET	ethylhexyl triazone
HCA	hexyl cinnamaldehyde
HeptylP	heptylparaben
HHCB	galaxolide
HMS	homosalate
HS	hexyl salicylate
IAMC	isoamyl 4-methoxycinnamate
IB	isoborneol
IBA	isobornyl acetate
ID	indole
IMI	isomethyl ionone
L10	decasiloxane
L11	undecasiloxane
L12	dodecasiloxane
L13	tridecasiloxane
L14	tetradecasiloxane
L15	pentadecasiloxane
L16	hexadecasiloxane
L3	trisiloxane
L4	tetrasiloxane
L5	pentasiloxane
L6	hexasiloxane
L7	heptasiloxane
L8	octasiloxane
L9	nonasiloxane
LC_{50}	half maximal lethal concentration
LIL	lilial
MDJ	methyl dihydrojasmonate
MK	musk ketone
MP	methylparaben
MS	methyl salicylate
MX	musk xylene
NOEC	no observed effect concentrations
NP	nonylphenol
NPEO1	2-(4-nonylphenoxy)ethan-1-ol
NPEO2	2-[2-(4-nonylphenoxy)ethoxy]ethan-1-ol
OC	octocrylene
OD-PABA	padimate O
OMC	octinoxate
OPEO1	2-(4-octylphenoxy)ethan-1-ol
OPEO2	2-{2-[4-(2,4,4-trimethylpentan-2-yl)phenoxy]ethoxy}ethan-1-ol
OTNE	boisvelone
PBO	piperonyl butoxide
PBSA	2-phenylbenzimidazole-5-sulphonic acid
PCPs	personal care products
PP	phenylphenol
PP	propylparaben
SK	skatole
TC	triclosan
TCC	triclocarban
TP	terpinol
US EPA	United States Environmental Protection Agency
UV	ultraviolet
UV120	2,4-di-*tert*-butylphenyl 3,5-di-*tert*-butyl-4-hydroxybenzoate
UV324	2-(2H-benzotriazol-2-yl)-4,6-bis(2-phenyl-2-propanyl)phenol
UV327	2,4-di-*tert*-butyl-6-(5-chloro-2H-1,2,3-benzotriazol-2-yl)phenol
UV328	2-(2H-benzotriazol-2-yl)-4,6-ditertpentylphenol
UV329	octrizole
UV356	bumetrizole
UVFs	ultraviolet-filters
UVP	benazol P
WWTPs	wastewater treatment plants

1. Introduction

In 2012, the Bureau of Labor Statistics estimated that the average US household spends over $750/yr on personal care products (PCPs) (US Bureau of Labor Statistics, 2014). PCPs comprise a wide range of products (*e.g.*, soaps, detergents, sunscreens, fragrances, insect repellents, deodorants, lotions, cosmetics, and shampoos, among others) that contain active and inactive ingredients from the following chemical classes: UV-filters (UVFs), musks, insect repellents, antimicrobials, preservatives, and surfactants. The Personal Care Products Council, which is the leading trade organization for cosmetics and PCPs in the United States, estimates that annual retail sales are greater than $189 billion (van der Kooij et al., 1989). In general, PCPs are intended for external application onto the skin and, ultimately end up in the wastewater collection system unchanged from their applied form (Ternes et al., 2004). The increasing availability and diversity of PCPs available from consumer retailers is expected to result in higher loading of PCPs into wastewater systems and, consequently, the environment. The overall objective of this review focuses on aggregating recent literature findings to better understand the environmentally-relevant concentration ranges of PCPs in various compartments (*e.g.*, raw wastewater, wastewater effluent, and surface water, among others).

The motivation for this work stems from recent reports demonstrating the presence of specific PCPs in drinking water supplies (Diaz-Cruz et al., 2012; Rodil et al., 2012; Lee et al., 2010). For