Conceptual considerations on the environmental risk assessment of microplastics

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Microplastics in the environment

- Synthetic organic polymer particles differing in size, shape, surface texture, chemical composition (polymers and additives) and specific density
- These properties may influence fate and effects in the environment
- Very slow disintegration and, especially, degradation of plastics in the environment

Photo: K. Duis

Introduction

Effects of microplastics on aquatic organisms (Duis & Coors 2016)

Physical effects

– High concentrations → reduced food uptake → lower energy reserves → physiological functions affected → effects at organism and population level (e.g. reduced growth and reproduction)

Effects of plastic additives (assessed under REACH)

Vectors for transport of hydrophobic pollutants

– Based on experimental results and modelling approaches, present concentrations of microplastics in water and sediments are not likely to contribute significantly to bioaccumulation of hydrophobic pollutants in aquatic organisms (see also Koelmans et al. 2016)

Vectors for invasive species and pathogens

Potential effects on sediment properties

Current environmental risk assessment procedures for chemical substances

Exposure assessment

Predicted environmental concentrations (PECs)

Measured environmental concentrations (MECs)

Effects assessment

No observed effect concentration (NOEC)

Assessment factor

Predicted no effect concentration (PNEC)

Risk characterisation

$$\frac{PEC}{PNEC} \geq 1 \rightarrow \text{Risk}$$

$$\frac{PEC}{PNEC} < 1 \rightarrow \text{Risk deemed acceptable}$$

Photos: K. Duis

Current environmental risk assessment procedures

PBT and vPvB assessment

- Substances that are persistent, bioaccumulative and toxic (PBT) or very persistent and very bioaccumulative (vPvB) identified in complementary approach
- Persistence, bioaccumulation potential and toxicity compared to trigger values defined in Annex XIII of the REACH regulation (EC 2011)

	PBT criteria	vPvB criteria
Persistence	DT_{50} > 60 d in marine water DT_{50} > 40 d in freshwater DT_{50} > 180 d in marine sediment DT_{50} > 120 d in freshwater sediment or soil	DT_{50} > 60 d in marine or freshwater DT_{50} > 180 d in marine or freshwater sediment or soil
Bioaccumulation	BCF > 2,000	BCF > 5,000
Toxicity	Long-term NOEC < 0.01 mg/L for freshwater or marine organisms Substance carcinogenic or toxic for reproduction	–

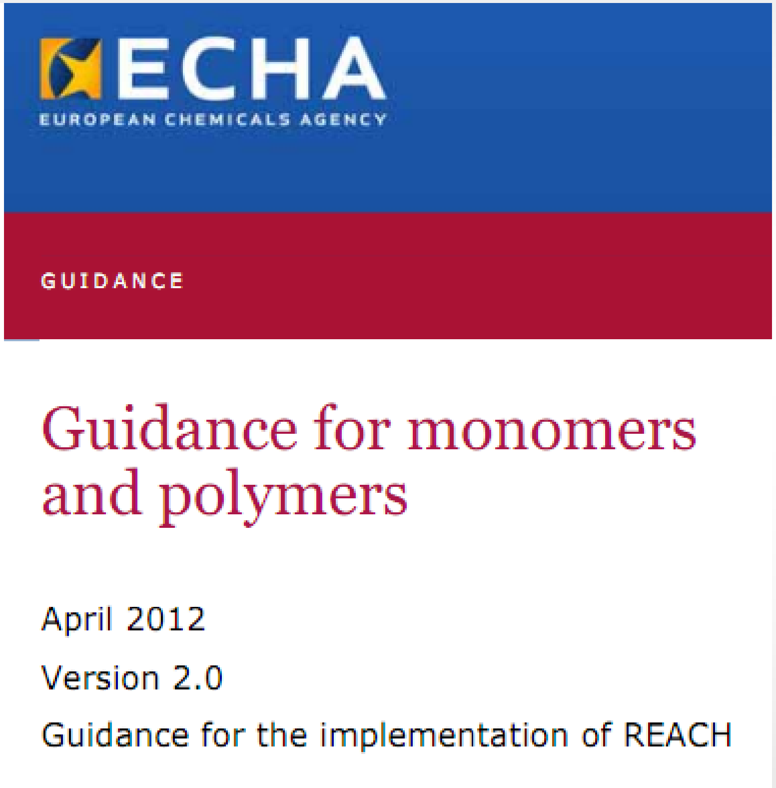
Simplified table; for further information see EC (2011)

Assessment of polymers within REACH

- In view of their high molecular weight, polymer molecules are considered as being of low concern

→ Exempted from registration and evaluation, unless:

  - Content of (unreacted) monomers exceeds certain limits or
  - They contain certain additives triggering registration and evaluation (ECHA 2012)



ECHA
EUROPEAN CHEMICALS AGENCY

GUIDANCE

Guidance for monomers and polymers

April 2012

Version 2.0

Guidance for the implementation of REACH

Comparison of MECs of microplastics and lowest microplastic levels causing significant physical effects (LOECs) in laboratory tests

- Data for marine environment and marine test organisms
- No assessment factor used

MEC*	LOEC	MEC / LOEC
Sea surface layer: up to 9 items/L [a] Water column: up to 10 items/L [b]	Acute effects, sea urchin larvae: ≥ 3 x 10^5 items/L [e] Chronic effects, copepods: ≤ 2,6 x 10^5 items/L [f]	≈ 0.00003
Subtidal sediment: up to 3,600 items/kg dw [c]	Chronic effects, lugworms: 10 g/kg Sediment ww [g] ≈ 10^6 Partikel/kg dw	0.002
Beaches: up to 30% (w/w) [d]	No data	≈ 30 (based on LOEC for lugworms)

* Measured environmental concentrations = sum of microplastics

Duis & Coors 2016; Data from: [a] Hidalgo-Ruz et al. 2012, [b] Desforges et al. 2014, [c] Leslie et al. 2013, [d] Carson et al. 2011, [e] Kaposi et al. (2014), [f] Lee et al. (2013), [g] Wright et al. 2013

Environmental risk assessment for marine environment for 2015 and 2100 (Van Cauwenberghe 2015)

Exposure assessment

- Water column (coastal, open ocean) and sediment (coastal, deep sea)
- Global plastic production data (1950-2013)
- 2014 ff.: Annual increase in plastic production = 4.5% (as 2008-2013)
- 15% of the litter is floating, 15% is beached
- Degradation of floating and beached plastic debris: 0.2-2.5% per year
- 'Business as usual' scenario
  - 1.7 - 4.7% of annual plastic production ends up as marine litter (Jambeck et al. 2015)
- 'Best-case' scenario
  - Immediate stop in plastic loss and littering into the environment

Approaches to assess potential environmental risks of microplastics

Environmental risk assessment for marine environment for 2015 and 2100 (Van Cauwenberghe 2015)

Effects assessment

- Pelagic organisms
  - NOEC values from chronic tests
  - Species sensitivity distribution
    - Derivation of the hazardous concentration for 5% of the species
    - PNEC derived using assessment factor of 5 (TGD, EC 2003)
- Benthic organisms
  - Chronic NOEC for lugworm
  - PNEC derived using assessment factor of 1000

Risk characterisation

- $PEC/PNEC \geq 1 \rightarrow$ Risk
- $PEC/PNEC < 1 \rightarrow$ Risk acceptable

Approaches to assess potential environmental risks of microplastics

Environmental risk assessment for marine environment for 2015 and 2100 (Van Cauwenberghe 2015)

	PNEC	PEC (sum of microplastics)				
		2015		2100		
Water column (items/L)						
		Min	**Max**		**Min**	**Max**
Coastal	640	0.0005	2	Best case	0.003	12
				Business as usual	0.03	129
Open ocean		0.0001	0.3	Best case	0.0008	2
				Business as usual	0.01	21
Sediment (items/kg ww)						
		Min	**Max**		**Min**	**Max**
Coastal	540	10	3,500	Best case	55	21,000
				Business as usual	597	220,000
Deep sea		1	16	Best case	4	92
				Business as usual	40	987

Approaches to assess potential environmental risks of microplastics

PBT and vPvB assessment of microplastics

Persistence

– Extremely slow degradation (mineralisation) of plastics in the environment: estimated lifetime in the range of hundreds of years (Moore 2008, Barnes et al. 2009)

→ (Micro-) plastics are vP (DT_{50} > 60 d in water, DT_{50} > 180 d in sediment or soil)

Bioaccumulation

– Uptake into a wide range of species, but so far, no clear evidence of bioaccumulation (= increase of internal concentrations in relation to concentrations in the environment) or biomagnification (= increase of concentrations at higher trophic level)

Toxicity

– Chronic LOEC for copepods: ≤ 0.125 mg/L (Lee et al. 2013)

– Further studies needed to evaluate if concentrations < 0.01 mg/L cause long-term effects

Knowledge gaps (1)

Fate and occurrence in the environment

- Fragmentation and degradation rates
- Size distributions in the environment
- Occurrence in the freshwater and, especially, terrestrial environment

Photo: K. Duis

Effects in the environment

- Toxicity thresholds for freshwater (incl. sediment) and, especially, terrestrial organisms
- Influence of the characteristics (e.g. size, shape, chemical composition) of microplastics on their ecotoxicity

Photo: D. Leib

Hidalgo-Ruz et al. 2012, GESAMP 2015, Syberg et al. 2015, Duis & Coors 2016

Knowledge gaps (2)

Environmental risk assessment

- ERA procedures for chemical substances do not cover all aspects relevant for an ERA of microplastics, e.g.
  - Fragmentation in the environment → increase in particle abundance (and, possibly, toxicity) over time
  - Different types of effect (chemical effects of monomers and additives, physical effects of particles, effects on sediment properties, and function as vector for pollutants, invasive species and pathogens)
- Assessment factors and trigger values used in these ERA procedures may not be appropriate for microplastics
- ERA procedures for chemical substances are generally used for single substances;
  for microplastics: ERA for sum of microplastics or, at least, certain types of microplastics

Photo: K. Duis

Parallels between nanomaterials and microplastics

Examples for parallels (Syberg et al. 2015)

– Size and shape are likely to affect fate and effects
– Similar types of effects: physical, chemical, vectors for contaminants
– Persistence

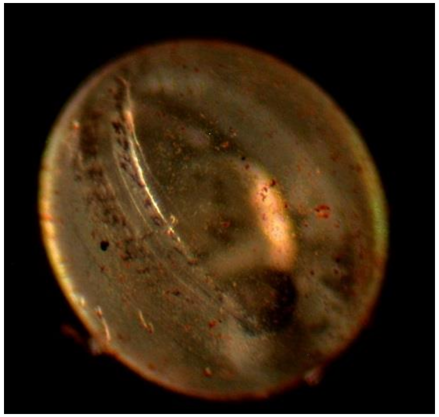


Photo: M. Weil

Knowledge obtained in nanoecotoxicology and concepts for the ERA of nanomaterials might be useful for approaches to assess potential environmental risks of microplastics

– Sediments = sink for particles → sediment testing (Baun et al. 2008)
– Chronic testing due to persistent nature of particles (Oomen et al. 2014)
– Strategies to study bioaccumulation (passive diffusion not relevant for particle uptake) (Kühnel & Nickel 2014)

Conclusions (1)

- Present concentrations of microplastics in the water column and in most sediments are much lower than concentrations causing physical effects in laboratory tests, but concentrations in some coastal sediments are of concern
- Plastics extremely persistent → it can be assumed that all plastic that has entered the environment is still there (in unfragmented or fragmented form) (Thompson et al. 2005, UNEP 2016)
- Due to the fragmentation of macroplastics, concentrations of micro-plastics in the environment will continue to increase even if release of plastics into the environment is stopped
- By 2100, microplastic levels in most coastal and a some deep sea sediments have been predicted to reach or exceed ecotoxicological threshold levels (PNECs) (Van Cauwenberghe 2015)

Conclusions (2)

- Current ERA procedures for chemical substances do not cover all aspects that are relevant when evaluating potential risks of microplastics
- When developing approaches to assess microplastics, concepts for the ERA of nanomaterials might be useful
- In view of the persistence of plastics and high concentrations recorded e.g. in some coastal sediments, development and effective implementation of strategies to reduce the release of macro- and microplastics into the environment are urgently required – regardless of the lack of a comprehensive regulatory framework for environmental risk assessment of microplastics

Photo: K. Duis

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