# Microplastics and Nanoplastics in Aquatic Environments: Aggregation, Deposition, and Enhanced Contaminant Transport

## Supporting Information

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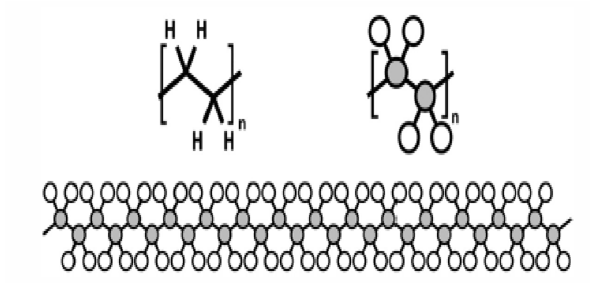
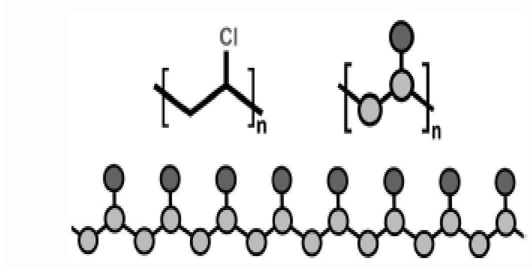
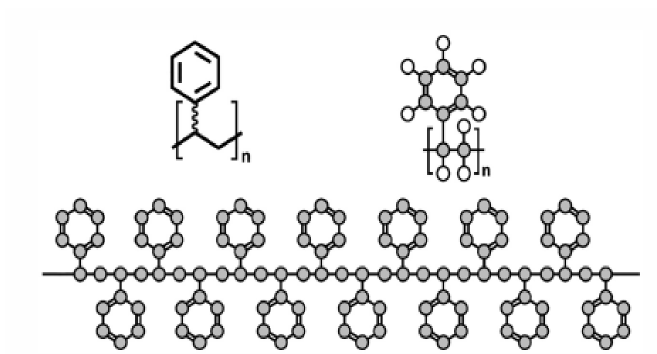
Figure S1: Molecular structures of some commonly detected plastics in the environment. (Adapted from Quinn and Crawford, 2016)



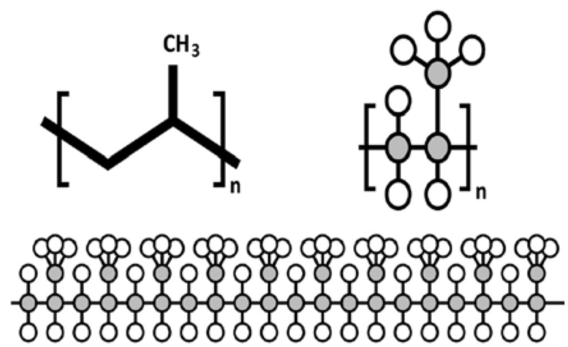

Polyethylene (PE)



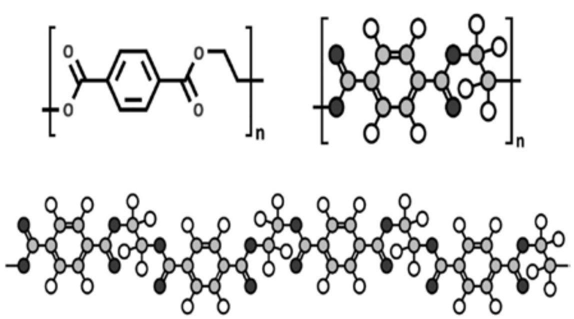

Polyvinyl chloride (PVC)



Polystyrene (PS)




Polypropylene (PP)




Polyethylene terephthalate (PET)

**Table S1.** Data and references for Figure 1

| Compartment leaving | Compartment entering | % of Plastic leaving compartment | Reference |
|---|---|---|---|
| Manufacture & Use | Mishandled (Ag & Land + Lakes & Rivers) | 25.6 - 28.0 % | Calculated from Jambeck et al., 2015 |
| Manufacture & Use | Agriculture & Land | 0.5 - 5 % | Kyrikou and Briassoulis, 2007; Scarascia-Mugnozza et al 2011; Sintim and Flury, 2017; Maliconico, 2017 |
| Manufacture & Use | Landfill | 21 - 42 % | Nizzetto et al., 2016 |
| Manufacture & Use | WWTP | 0.8 - 4.6 % | Calculated from Nizzetto et al., 2017 |
| Manufacture & Use | Oceans | 1.5 - 4.5 % | Nizzetto et al., 2016 |
| Manufacture & Use | Recycled | 6 - 26 % | Barnes et al., 2009; Dris et al., 2015 |
| WWTP | Effluent - Rivers & Lakes | * 0.1 - 5% (MP only) | Nizzetto et al., 2017; Horton et al., 2017; Carr et al., 2016 |
| WWTP | Solids - Land & Agriculture | 42 - 55% (of sludge) | Peccia and Westerhoff, 2015; Samolada and Zabaniotou, 2013 |
| WWTP | Solids - Landfill | 14 - 30 % (of sludge) | Peccia and Westerhoff, 2015; Samolada and Zabaniotou, 2013 |
| WWTP | Solids - Incineration | 15 - 27 % (of sludge) | Peccia and Westerhoff, 2015; Samolada and Zabaniotou, 2013 |
| Mishandled | Lakes & Rivers | † (25.6 - 28 %) w/ Land & Agriculture | Calculated from Jambeck et al., 2015 |
| Agriculture & Land | Lakes & Rivers | † (62 - 84 % ) w/ Oceans | Nizzetto et al., 2016 |
| Mishandled | Land & Agriculture | † (25.6 - 28 %) w/ Rivers & Lakes | Calculated from Jambeck et al., 2015 |
| Agriculture & Land | Oceans + Lakes & Rivers | 62 - 84 % | Nizzetto et al., 2016 |
| Fishing Industry | Oceans | 18 - 22.3 % | Andrady, 2011; Ivar do Sul and Costa, 2013 |
| All terrestrial sources | Oceans | 80 % | Andrady, 2011 |
| Lakes & Rivers | Oceans | 70-80 % (ocean plastics coming from rivers) | Horton et al., 2017 |
| Agriculture & Land | Oceans | 0-10 % | Calculated from Andrady, 2011; Horton et al., 2017 |

| Compartment | Concentration (#/m$^2$) | Concentration (#/L) | Reference |
|---|---|---|---|
| Lakes & Rivers | 0.020 - 0.892 | 0.0024 - 0.3168 | Horton et al., 2017 |
| Lakes & Rivers | | 0.00005 - 0.032 | Horton et al., 2017 |
| Lakes & Rivers | | 4.1373 (+/-2.4615) | Zhao et al., 2014 |
| Lakes & Rivers | 0.020 | | EerkesMedrano et al., 2015 |
| Lakes & Rivers | | 0.000028 | EerkesMedrano et al., 2015 |
| Lakes & Rivers | 0.01 - 20 | | Dris et al., 2016 |
| Lakes & Rivers | 0.043 | | EerkesMedrano et al., 2015 |
| Lakes & Rivers | | 0.0003168 (+/-0.00046646) | Lechner et al., 2014 |
| Lakes & Rivers | | 0.00194 (+/-0.00081) | McCormick et al., 2014 |
| Lakes & Rivers | | 0.01793 (+/-0.01105) | McCormick et al., 2014 |
| Lakes & Rivers | 8.465 | | Zhang et al., 2015 |
| Lakes & Rivers | 3.807 | | Zhang et al., 2015 |
| WWTP Influent | | 260 - 320 | Dris et al., 2015 |
| WWTP Effluent | | 14 - 50 | Dris et al., 2015 |
| WWTP Influent | | 636.7 (+/-38.8) | Talvitie et al., 2017 |
| WWTP Effluent | | 3.2 (+/-0.7) | Talvitie et al., 2017 |
| Sediments | ~0.21 - ~77,000 | 0.185 - 80 | HidalgoRuz et al., 2012 |
| Sediments | 13,759 (+/-16,685) | | EerkesMedrano et al., 2015 |
| Sediments | 1108 (+/-983) | | Imhof et al., 2013 |
| Sediments | 108 (+/-55) | | Imhof et al., 2013 |
| Sediments | ~0.05 - ~200 | | Dris et al., 2016 |
| Sediments | 75 - 1,300 (13,759) | | Horton et al., 2017 |
| Agriculture & Land | | 16 - 20 (+/-6) | Browne et al., 2011 |
| Agriculture & Land | | 4 - 8 (+/-4) | Browne et al., 2011 |
| Oceans | | 0.150 - 2.400 | Cole et al., 2011 |
| Oceans | ~0.00005 - ~5 | 0.000022 - 8.654 | HidalgoRuz et al., 2012 |
| Oceans | 0.0269 | | Zhang et al., 2015 |
| Oceans | 10^-6 - 0.000250 | | Hinojosa and Thiel, 2009 |
| Oceans | | 0.000167 (+/-0.000138) | Zhao et al., 2014 |

**Table S2.** Summary of sorption studies of contaminants to plastic particles

| Plastic type and size | Contaminant | Key findings | References |
|---|---|---|---|
| PP virgin pellets | PCBs, DDE, and nonylphenols (NP) seawater | • Contaminants sorb about 1 million times more contaminants than immediate seawater | Mato et al., 2001 |
| HDPE, PVC (d = 140 µm, PVC) | alkylbenzene; toluene and o-xylene | • PVC > HDPE > biopolymers | Wu et al., 2001 |
| LDPE and HDPE | PAH | •HDPE > LDPE (four times more; as a result of the higher surface area of the former) | Muller et al., 2001 |
| PP, PE | PCBs (sea water) | •PE > PP | Mato et al., 2002 |
| Plastic pellets | PCBs | •Weathered pellets sorbed more PCBs<br>• PE > PS<br>•Sorbed chemicals unevenly distributed among pellets | Endo et al., 2005 |
| PE (t = 2.286 × $10^{-3}$ cm)<br>PVC (t = 1.78 × $10^{-3}$ cm)<br>PS (t = 3.05 × $10^{-3}$ cm) | PCBs | • Average sorption: PE > PS > PVC<br>• PE showed the highest uptake of PCBs and partition coefficients | Pascall et al., 2005 |
| Plastic particles (d = 200 – 250 µm) | phenanthrene | •Desorption rate: sediments > plastics<br>•PE >> PP > PVC > natural sediments | Teuten et al.,2007 |
| PE (d = 2-3 mm)<br>PP (d = 2-3 mm)<br>POM (d < 2 mm)<br>Plastic eroded pellets (PEP) | phenanthrene<br>synthetic fresh water | • Equilibrium distribution coefficient: PEP > PE > POM > PP<br>•Phenanthrene partitions to plastic debris several magnitudes over seawater | Karapanagioti and Klontza, 2008 |
| HDPE,MDPE, LDPE and PVC (0.25 mm screen) | toluene (landfill) | •Affinity for contaminants in landfills: Plastic > lignocellulosic materials<br>•Fast desorption from rubbery plastics compared to glassy plastics | Saquing et al., 2010 |
| PET, HDPE, LDPE, PVC, and PP | PAHs and PCBs | •Long term field investigation as opposed to laboratory studies where temperature is controlled<br>•Sorption of both contaminants consistent: HDPE > LDPE > PP >> PET > PVC | Rochman et al., 2013(a) |
| PE beached and virgin | Cr, Co, Ni, Cu, Zn, Cd and Pb (filtered seawater) | •Beached PE > virgin PE | Holmes et al., 2012 |
| HDPE(w×l×h= 4.2×4.7×2.8)<br>LDPE (w×l×h=4×4.4× 2) mm | PAHs | LDPE > HDPE | Fries and Zarfl, 2012 |
| PP,PS,PET,PVC, HDPE, LDPE (l= 3 mm, d= 2 mm) | PAHs (marine water) | •PS ≈ HDPE ≈ LDPE > PP > PET and PVC<br>•PS appears to be a source and sink for PAHs | Rochman et al., 2013(b) |
| PVC and PE (200–250 µm) | phenanthrene (Phe) and 4,4'-DDT | •Contaminant transport rely more on concentration than on salinity<br>•Phe-PE >> DDT-PVC = DDT-PE >> Phe-PVC<br>•Phe: PE > PVC , DDT: PVC > PE | Bakir et al., 2014 |
| HDPE, PVC, LDPE and PP (d = 3 mm)<br>PET (l × d = 2 × 3 mm) | Al, Cr, Mn, Fe, Co, Ni, Zn, Cd and Pb (sea water) | HDPE < LDPE, PVC, PET, PP and PS. | Rochman et al., 2014 |
| PS, PE and PP ( d < 250 µm) | PAHs;<br>HCHs<br>CBs<br>(Sea water) | •PS show greater affinity for the three contaminants studied except the few most hydrophobic PAHs;<br>•HCHs: PP > PE<br>•CBs: PE > PP<br>•PAHS: PS > PE > PP | Lee et al., 2014 |

| | | | |
|---|---|---|---|
| PE (d = 10−180 µm)<br>PS (d = 70 nm) | PCBs | •Salinity increased sorption for both plastic types<br>•PS > PE | Velzeboer et al., 2014 |
| PE microbeads<br>(d = 164 - 327 µm) | 3 H-phenanthrene<br>14 C-DDT<br>(sea water) | •DDT preferentially sorbed than phenanthrene in binary mixture<br>•Rough particles adsorb higher contaminants than smooth ones. | Napper et al, 2015 |
| PE, PS and PVC<br>(d = 150, 230, 250 µm) | Perfluorochemicals: PFOS and FOSA | • $K_{d\,FOSA} > K_{d\,PFOS}$<br>•pH and salinity: FOSA unaffected while low values favour PFOS sorption<br>•FOSA: PE > PVC > PS | Wang et al., 2015 |
| PE (d = 3.8 mm) | PAHs | • Sorption capacity: 21°C > 10°C | Crawford and Quinn, 2017 |
| PS (d = 70 nm) | PAHs<br>(fresh water) | • Sorption unaffected by aggregate size | Liu et al., 2016 |
| PE (d = 152.53 ± 57.92 µm)<br>PA (d = 109.44 ± 44.53 µm)<br>PS (d = 168.55 ± 57.50 µm)<br>PVC (d = 57.64 ± 26.50 µm) | n-Hexane, cyclohexane, benzene, toluene, chlorobenzene, ethylbenzoate, and naphthalene | •Sorption capacity: PS > PVC > PE > PA | Huffer and Hofman, 2016 |
| PE debris<br>(d = 250 - 280 µm) | PPCPs<br>Dissolved organic matter (humic acid): 0-20 mg/L | • PPCPs sorbed to plastics according to their hydrophobicity<br>•Increase in humic acid decreased affinity for only three contaminant.<br>•Increase in salinity affected sorption of one contaminants and not significant for the rest | Wu et al., 2016 |
| PP<br>(d = 0.425–0.85 mm) | PCB: 3,3′,4,4′-tetrachlorobiphenyl (simulated seawater, 3.5% NaCl solution)<br>$C_{PCB}$ = 1 mg/L | •Sorption capacity increases as particle size and temperature decreases<br>•Sorption capacity: simulated seawater > ultrapure water > n hexane | Zhan et al., 2016 |
| PVC (d = 1.6 × 0.8 mm)<br>PS (d = 0.7–0.9 mm) | Cu and Zn<br>(seawater) | •Maximum concentration of Cu and Zn greater in PVC than PS<br>•Cu sorbed faster than Zn on PVC | Brennecke et al., 2016 |
| PE (d = 50 nm)<br>PS (d = 20 - 40 µm) | lubricating oil | •Sorption: PE > PS<br>•Sorption capacity: independent of pH but increases with salinity and temperature | Hu et al., 2017 |
| PE (d = 100 - 150 µm)<br>PS<br>PVC | phenanthrene | •Sorption: PE > PS > PVC > natural sediment | Wang and Wang, 2017 |

d = diameter, l = length, t = thickness, w = width
PE = polyethylene; HDPE=high-density polyethylene; LDPE = low-density polyethylene; POM = polyoxymethylene; PP = polypropylene; PS = polystyrene; PVC= polyvinyl chloride; PA = polyamide; PET = polyethylene terephthalate. FOSA = Perfluorooctanesulfonamide, PFOS perfluorooctanesulfonate, PAH = polycyclic aromatic hydrocarbon, PPCPs = pharmaceuticals and personal care products, PCB = polychlorinated biphenyls, HCH = hexachlorocyclohexane, DDE = dichlorodiphenyldichloroethylene, DDT = dichloro diphenyl trichloroethane

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