Plastic as a Vector for Pollutants in Estuarine and Marine Environments

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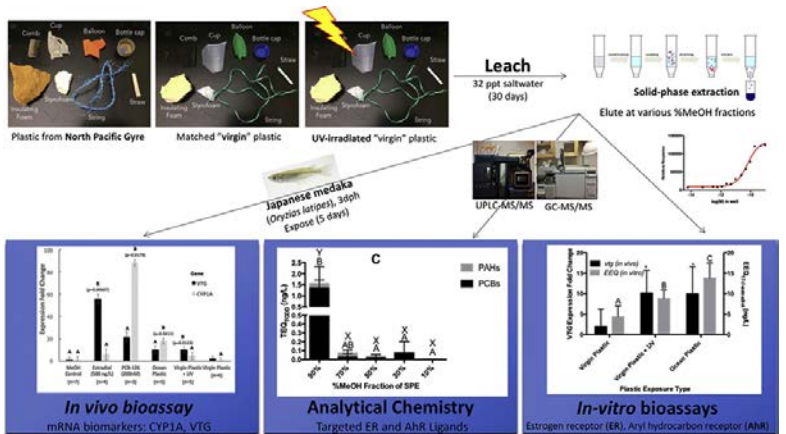
(University of California, Riverside)

Impacts of Microplastics in the Urban Environment Conference

Rutgers University

March 28-29, 2019



More than 5 Trillion Plastic Pieces Float in the Oceans

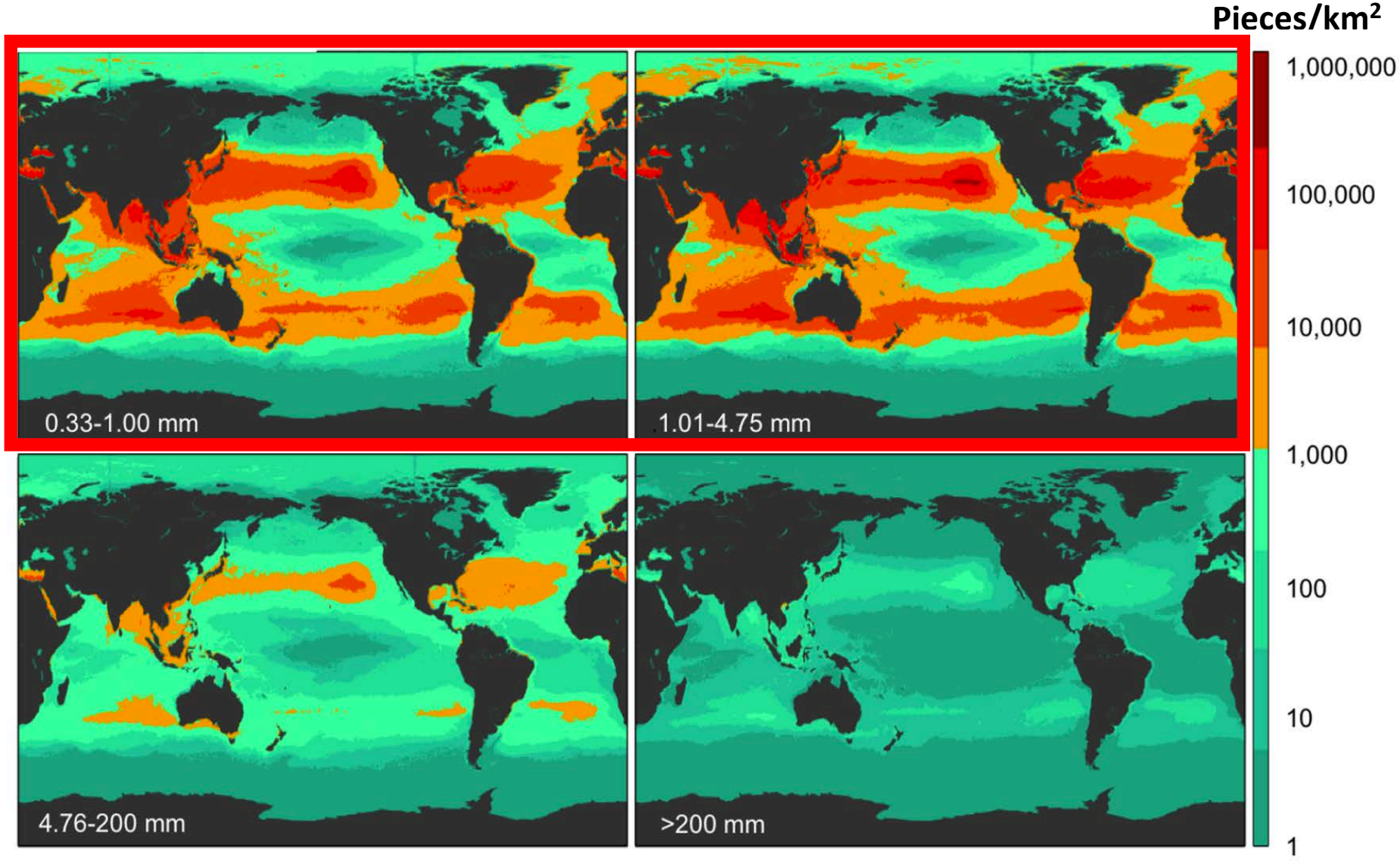
Eriksen et. al PLoS ONE (2014)

More than 5 Trillion Plastic Pieces Float in the Oceans

Micro:Macro plastic ratio (count)
12.4:1

Micro-plastic
<4.75 mm

Macro-plastic
>4.75 mm



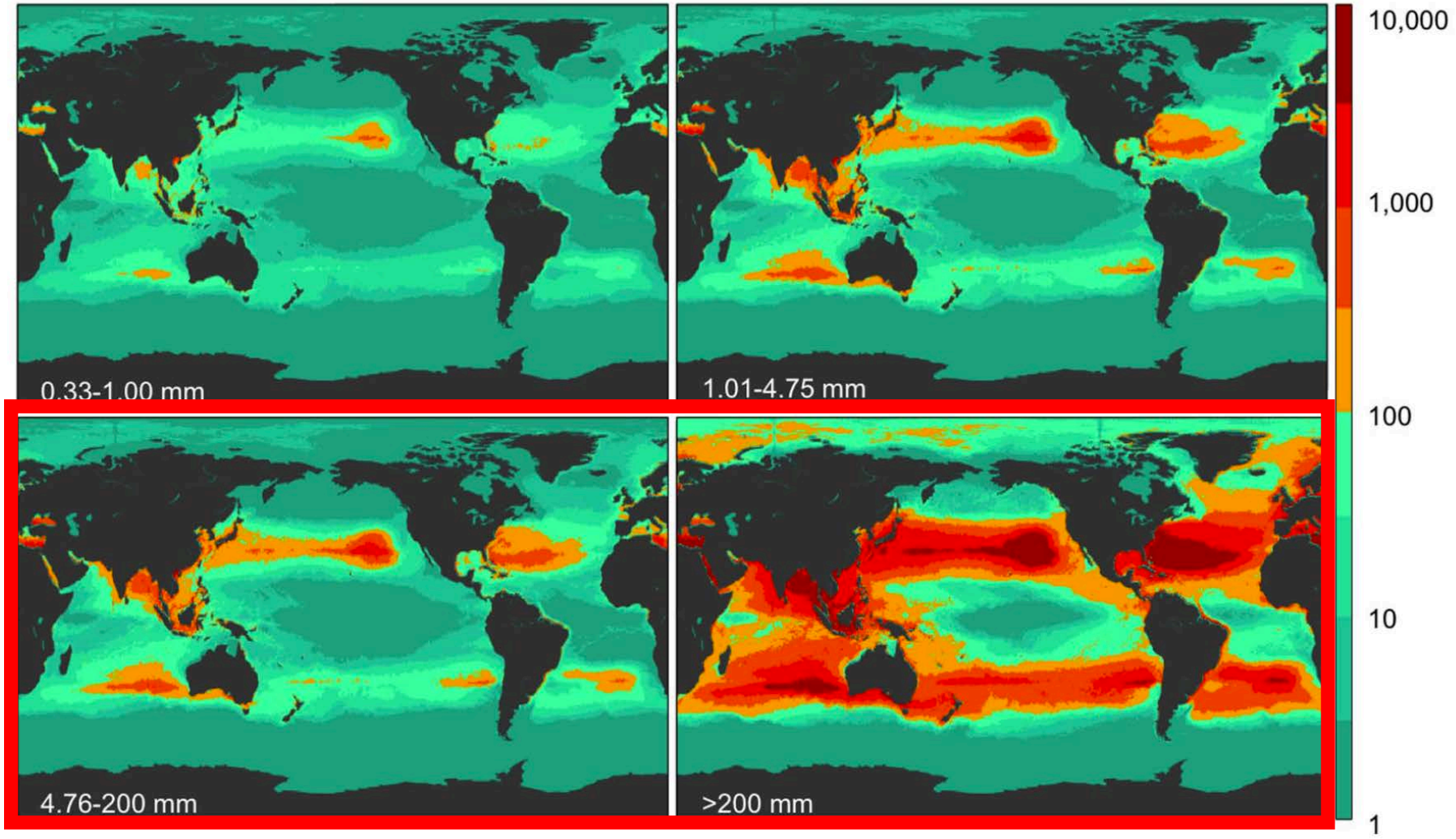
Model results for global count density in four size classes. Eriksen et. al (2014), PLOS ONE.

Macroplastics Far Outweigh Microplastics by Mass

Macro to Micro Plastic Ratio (mass)
6.6:1

Micro-plastic
<4.75 mm

Macro-plastic
>4.75 mm



Model results for global count density in four size classes. Eriksen et. al (2014), PLOS ONE.

Macro-plastic accumulates in estuaries and rivers

Tijuana Estuary, California

Photo: cleansd.wordpress.com

Plastic: A Cocktail of Contaminants

Photo from Rios et al. (2007), Marine Pollution Bulletin.

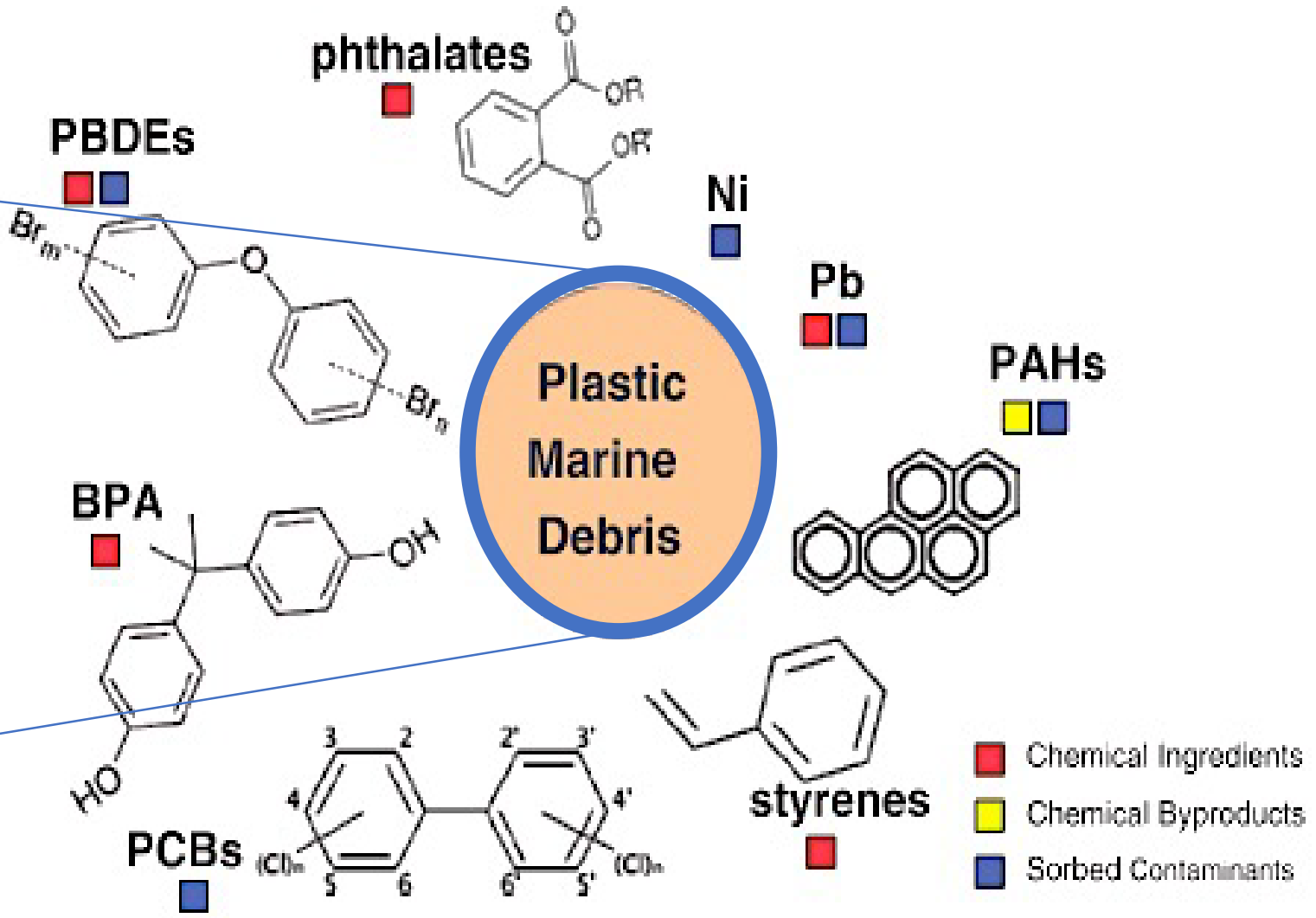
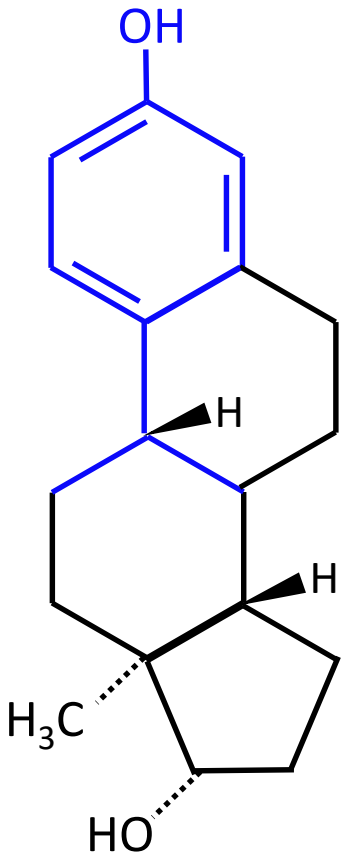


Figure from Bergmann et al. (2015), Marine Anthropogenic Litter.

Some Plastic Additives Mimic Estrogen

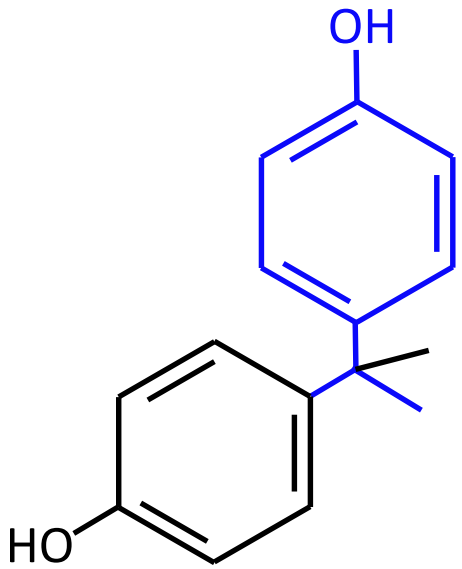
Endogenous Hormone



17-β-estradiol

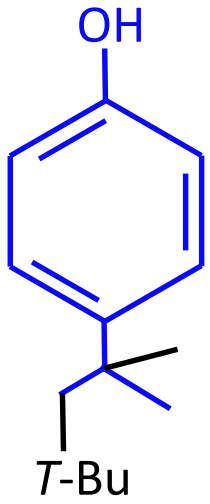
EEF=1

Plastic Additives



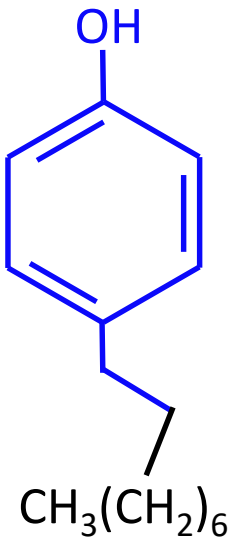
Bisphenol A

EEF= 2×10^{-4}



4-*tert*-octylphenol

EEF= 2×10^{-5}



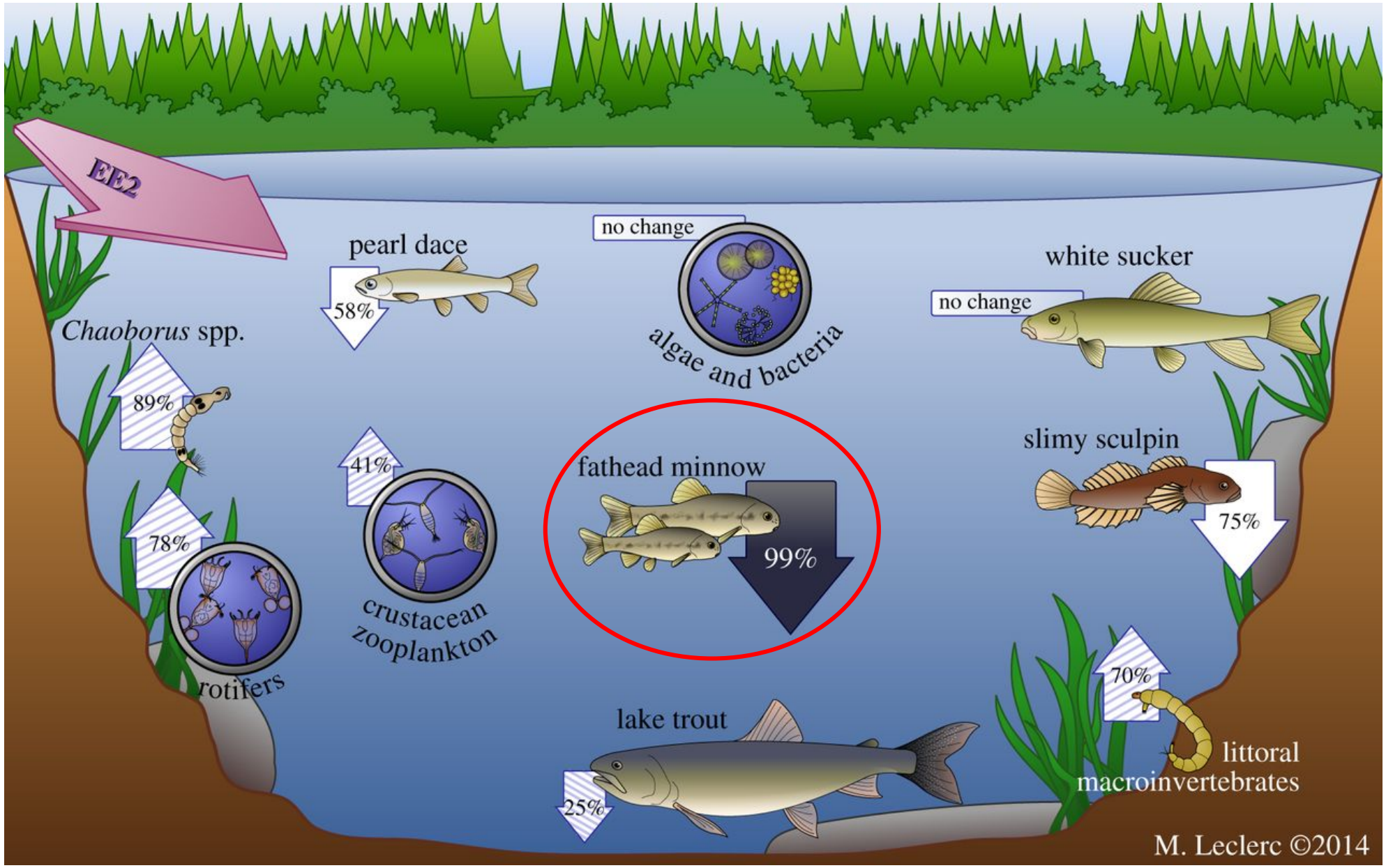
4-n-nonylphenol

EEF= 1×10^{-5}

$$\textbf{Estradiol Equivalency (EEQ)} = \mathrm{EEF_{compound} x Conc._{compound}}$$

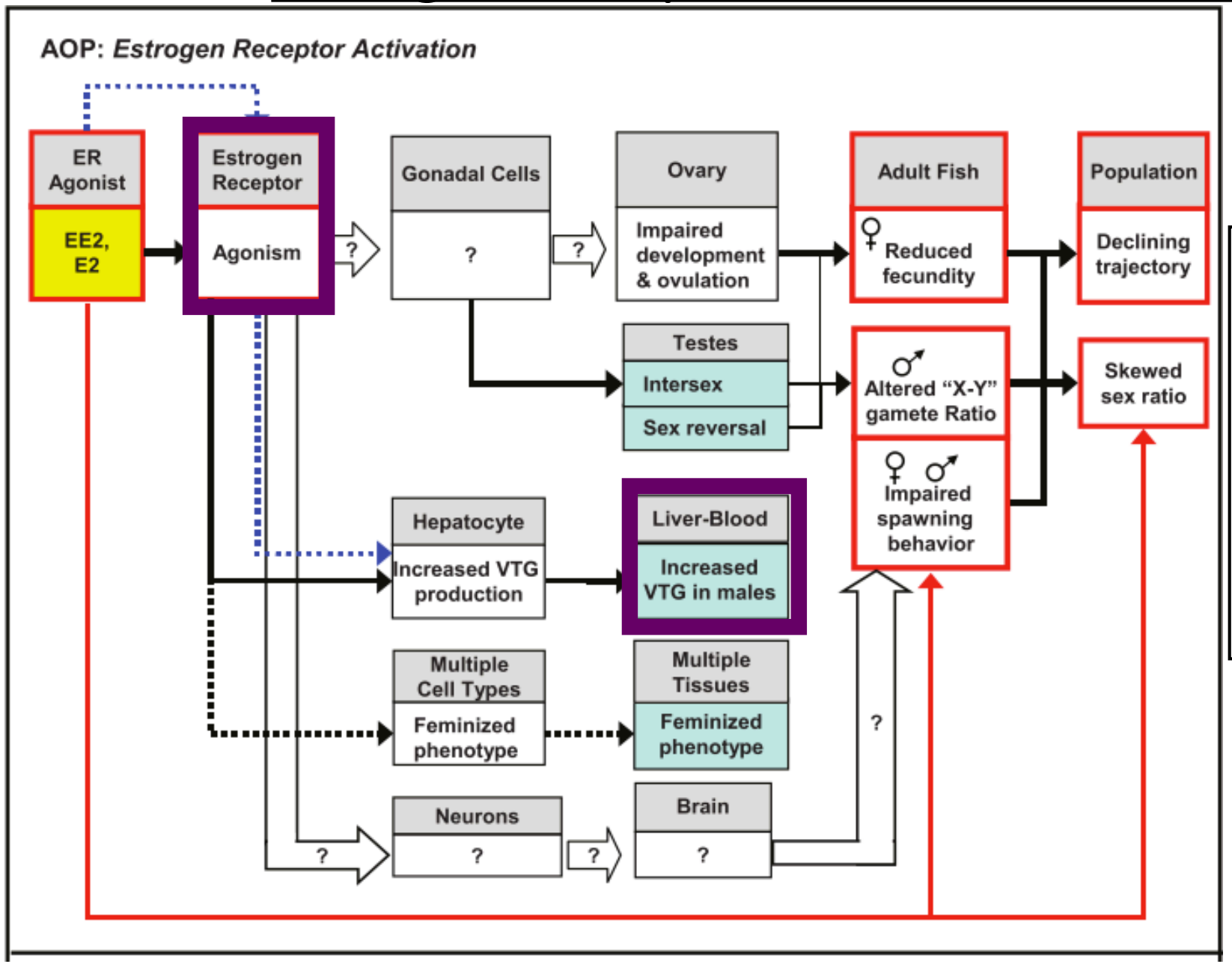
$$\textbf{Estradiol Equivalency Factor (EEF)} = \frac{\mathrm{EC_{50}(E_2)}}{\mathrm{EC_{50}(Compound)}}$$

Estrogenic compounds can cause **population collapse**



Kidd, Karen A., et al. *Phil. Trans. R. Soc. B* (2014)

Estrogen Receptor Adverse Outcome Pathway



Key

- Established mechanistic linkage with quantitative or semi-quantitative data
- Plausible linkage with limited data
- Empirical linkage based on quantitative exposure-response data
- Predictive model linkages based on chemical structure/property and quantitative exposure-response data
- Hypothetical linkage
- Potential biomarker associated with exposure/response information

Figure from Ankley, et al. (2010). Environmental Toxicology & Chemistry

Plastic: A **Cocktail** of Contaminants

- Plastic concentrates hydrophobic organic contaminants (HOCs) **10^7 more than water**[1]

Photo from Rios et al. (2007), Marine Pollution Bulletin.

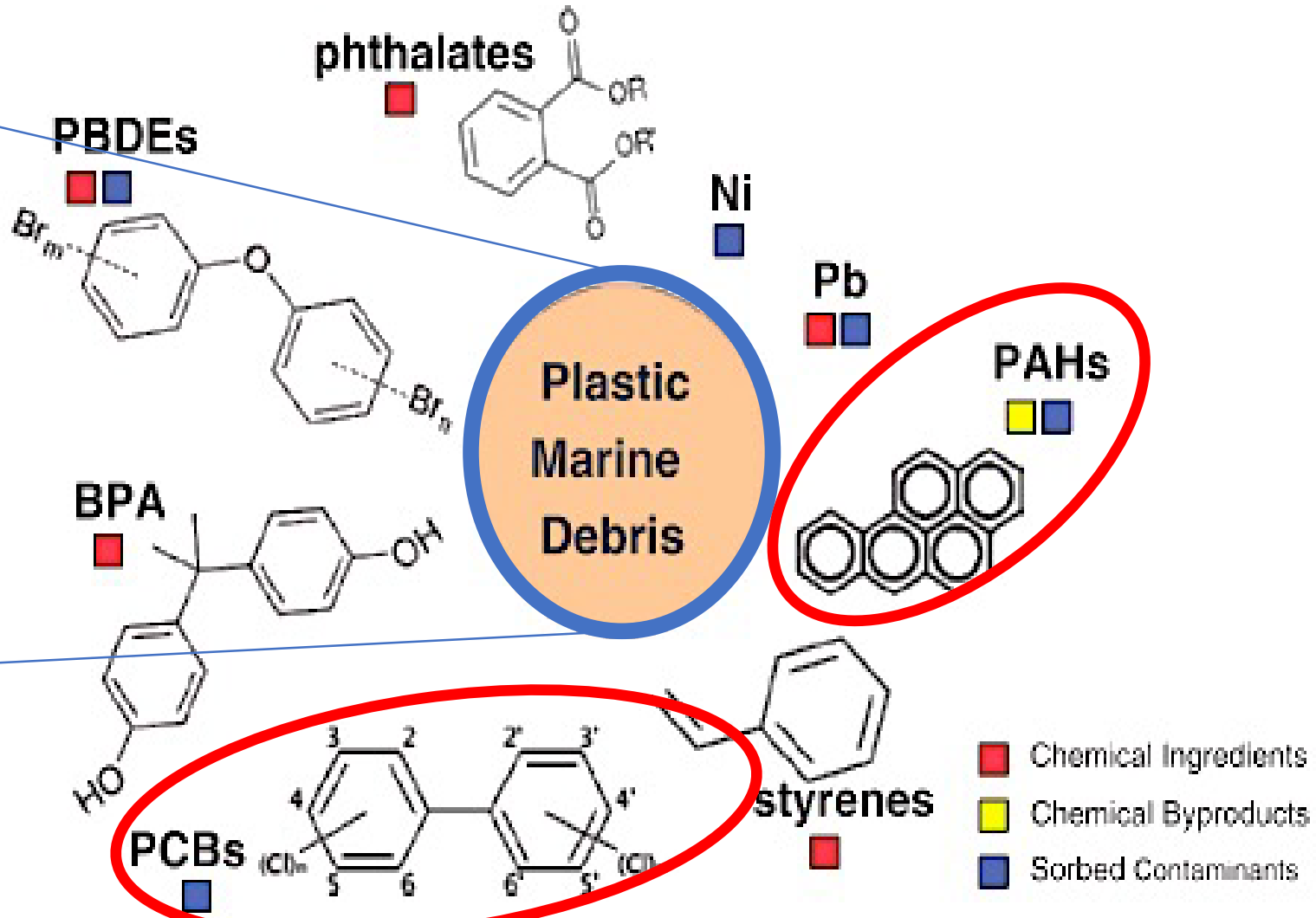
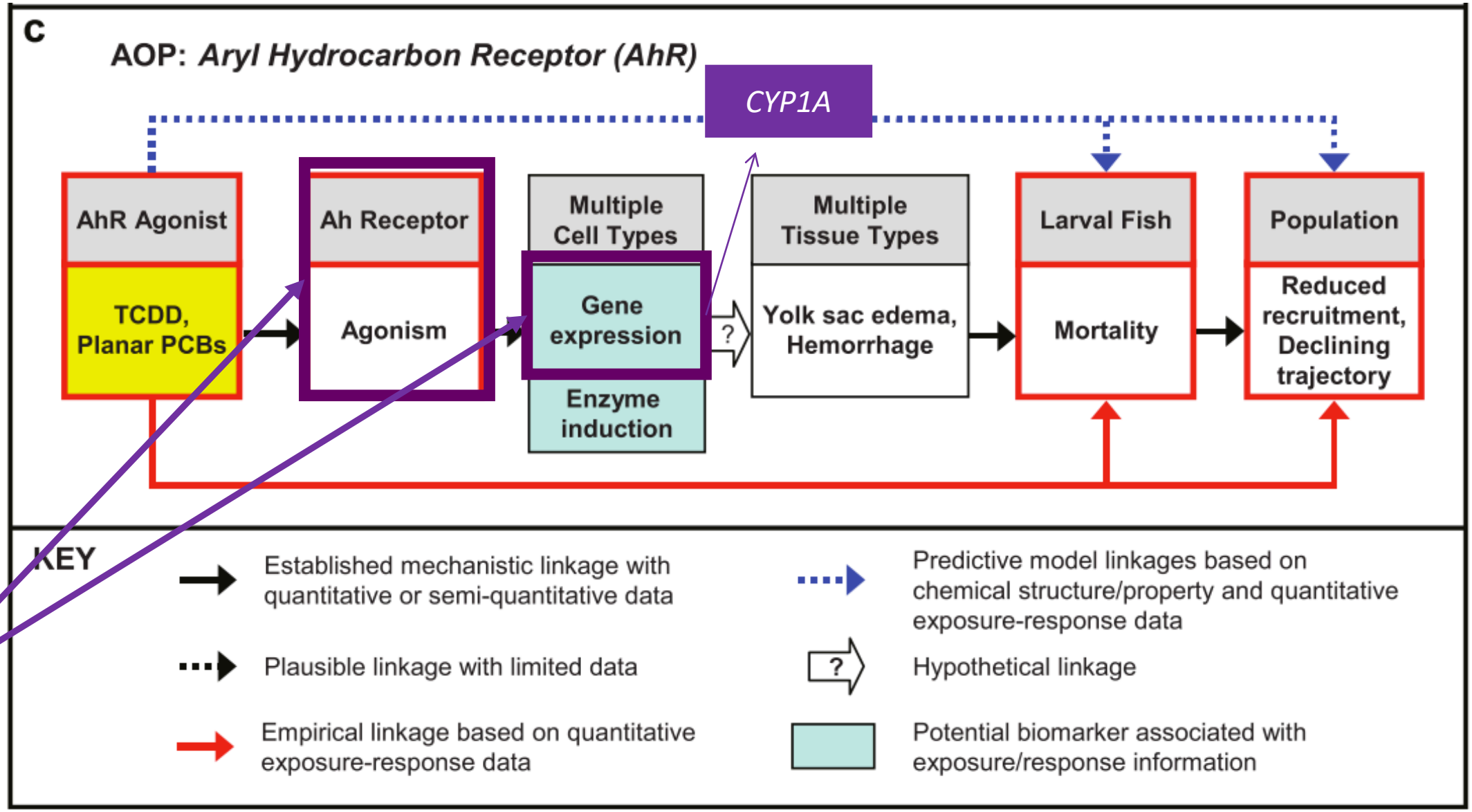


Figure from Bergmann et al. (2015), Marine Anthropogenic Litter.

[1]Koelmans et. al (2016).
Environmental Science & Technology.

Aryl Hydrocarbon (**AhR**) Adverse Outcome Pathway

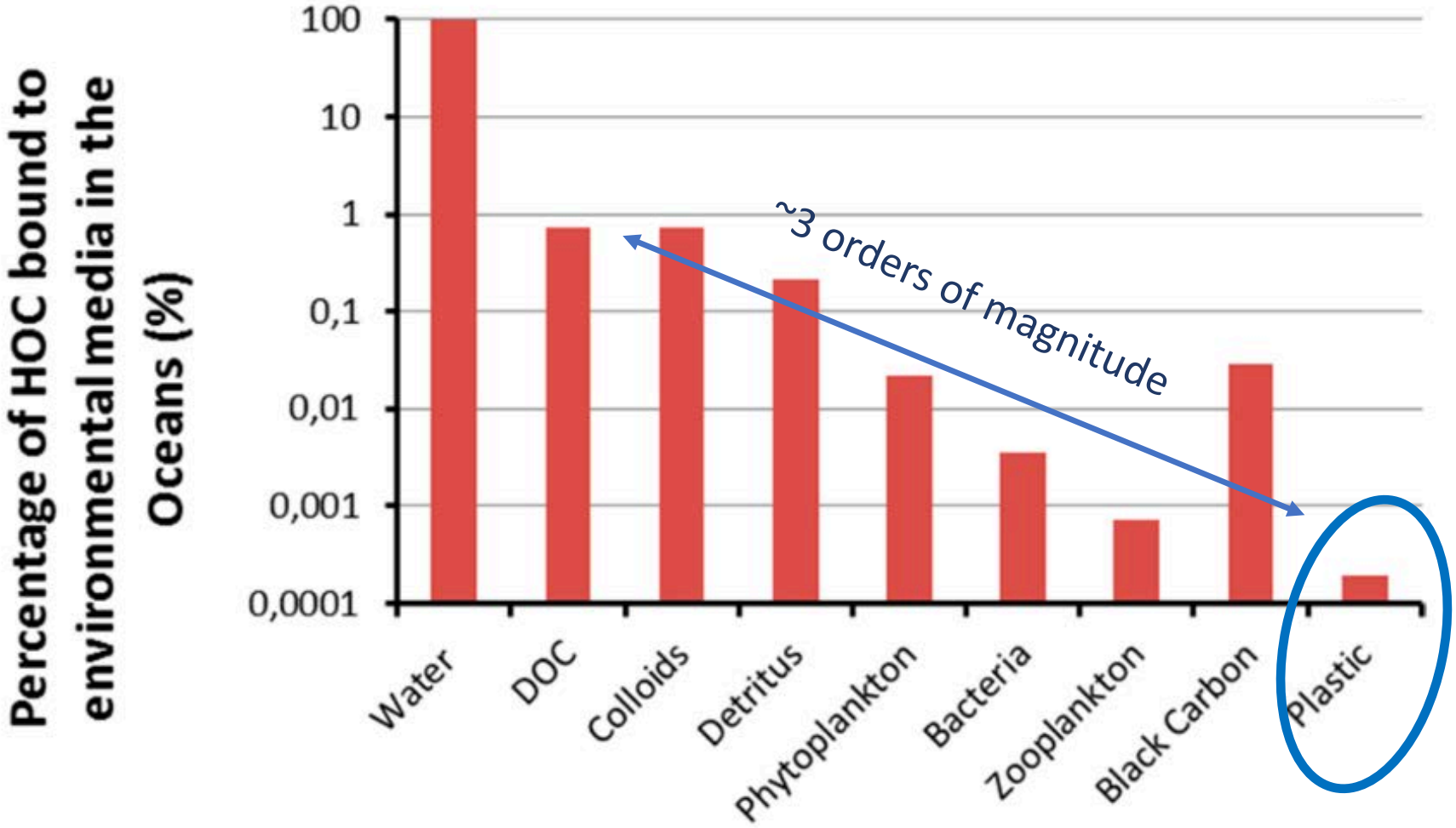


Biomarkers used in this study

Figure from Ankley, et al. (2010). Environmental Toxicology & Chemistry

Plastic likely a negligible source of contaminants in **open ocean**

- Plastic concentration in **whole ocean** ≈ 2×10^{-9} g/L[1]
- Plastic concentration in **highly contaminated river**: 8×10^{-2} g/L[2]



Figure[1]

[1]Koelmans, et. al (2016). Environmental Science & Technology.
[2]Moore et. al (2011). Journal of Integrative Coastal Zone Management

Macro-plastic accumulates in estuaries and rivers

Tijuana Estuary, California

Photo: cleansd.wordpress.com

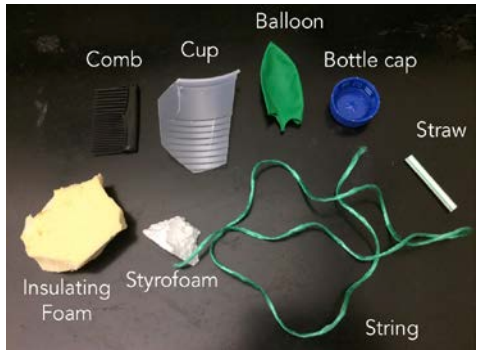
Hypotheses

1) **UV radiation and weathering** release estrogenic **additives** from plastic
2) Hydrophobic Organic Contaminants (HOCs) leach from **ocean plastic**
3) Under **environmentally realistic** conditions, plastic leaches pollutants at concentrations indicative of ecological harm

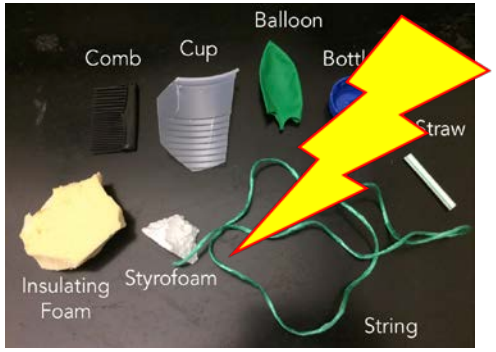
Figure: Koelmans, et. al (2016). Environmental Science & Technology.

Experimental Design

Plastic from **North Pacific Gyre**



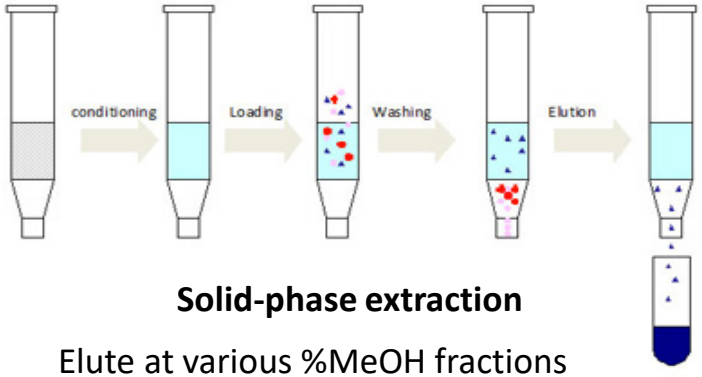
Matched "**virgin**" plastic



UV-irradiated "virgin" plastic

Leach

Plastic concentration:0.1 g/L
32 ppt saltwater
(30 days)

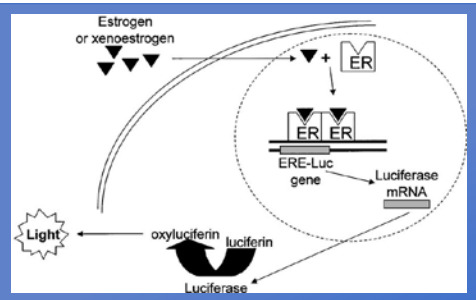


Solid-phase extraction

Elute at various %MeOH fractions

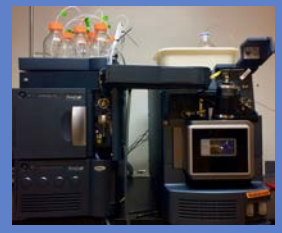
In vivo bioassay

mRNA biomarkers: CYP1A, VTG



In-vitro bioassays

Estrogen receptor (**ER**), Aryl hydrocarbon receptor (**AhR**)



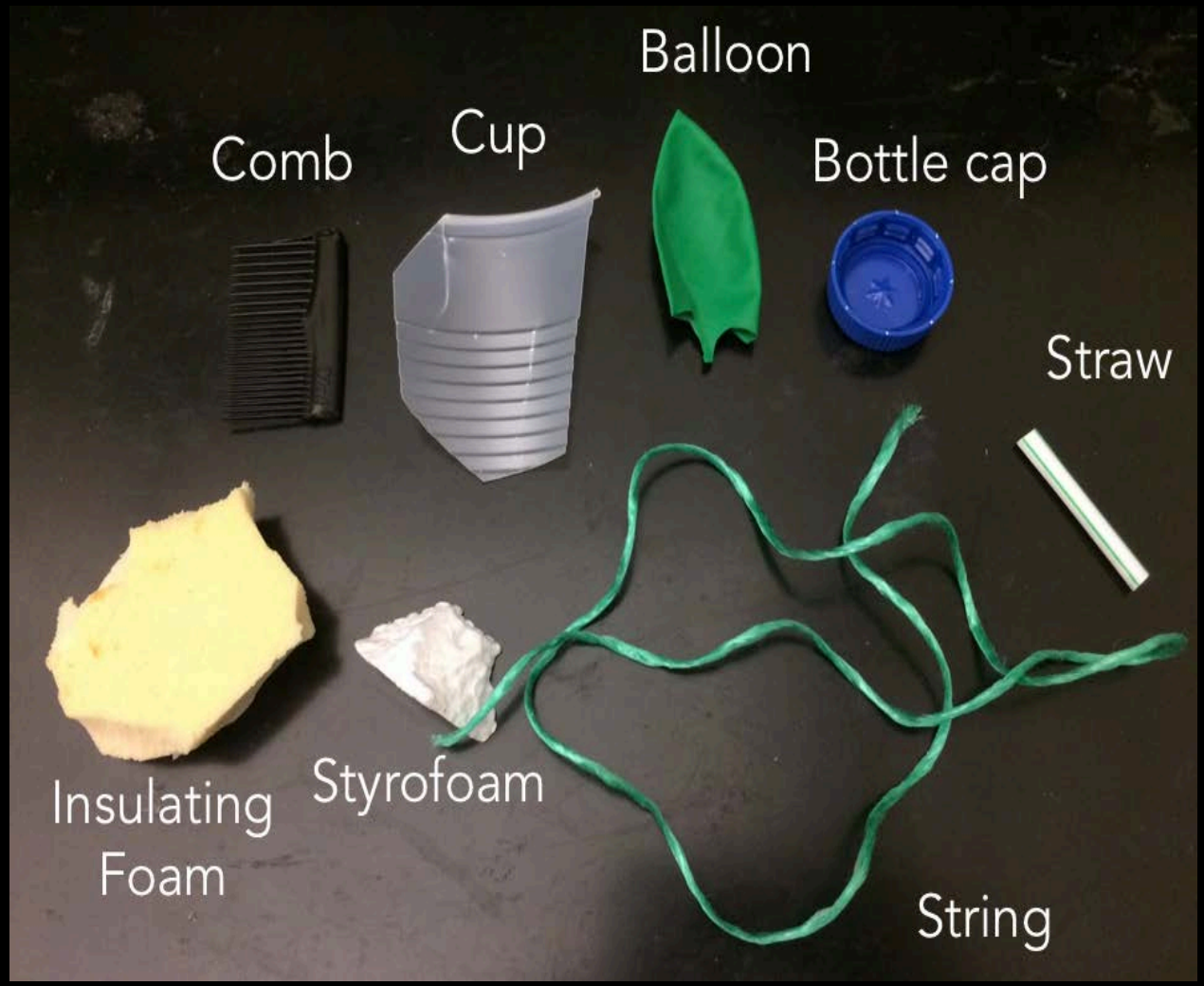
Analytical Chemistry

Targeted ER and AhR Ligands

Selection of Plastic Items

North Pacific Gyre-recovered plastic

Matched "virgin" plastic

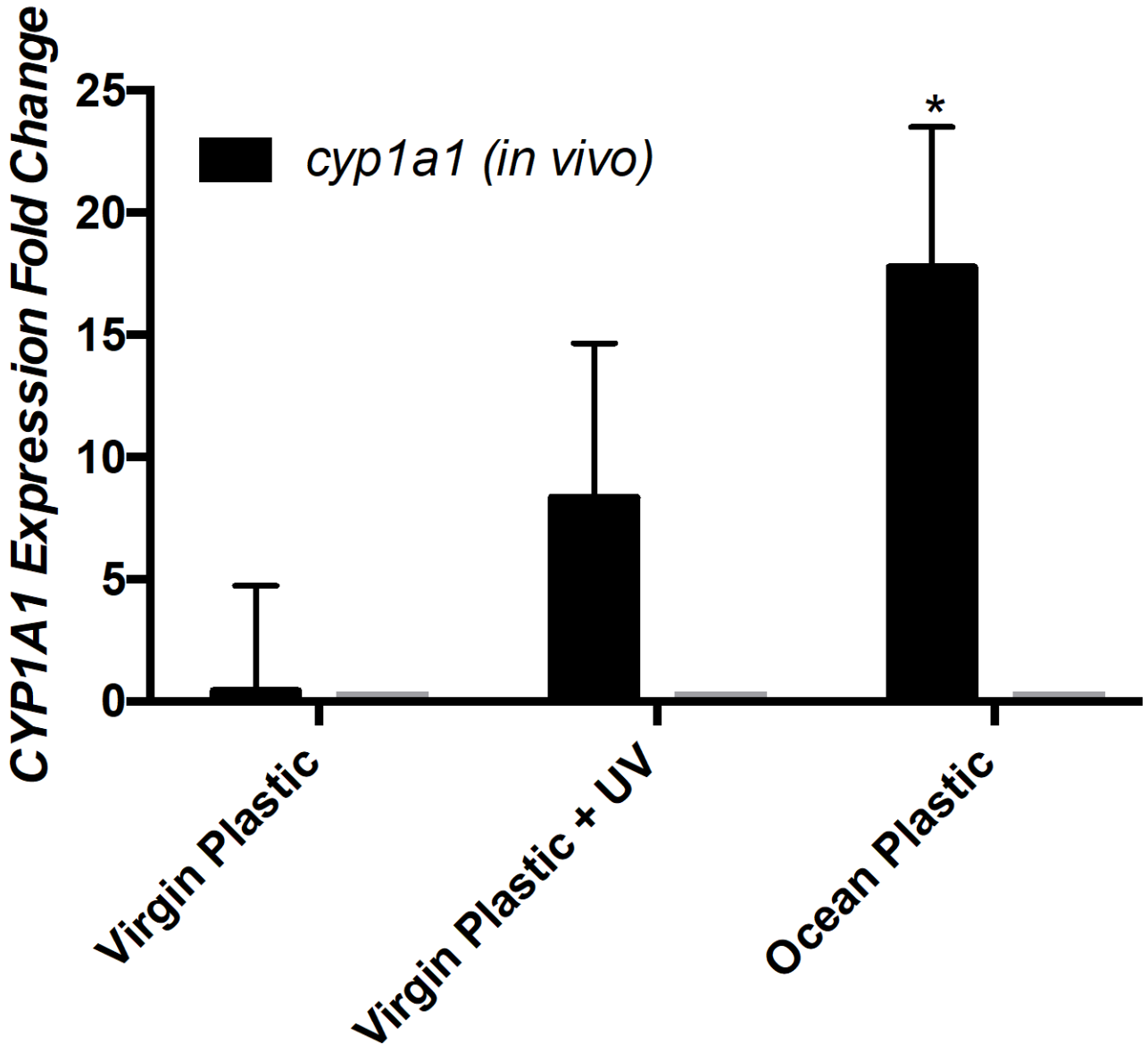


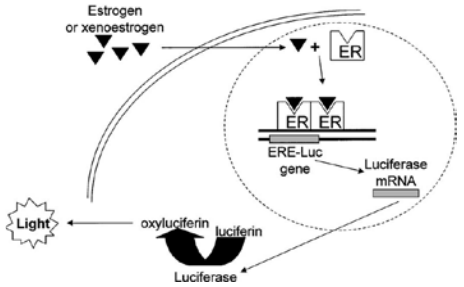
Note: Polymer types confirmed using Fourier-Transform Infrared Spectroscopy

Gyre-recovered plastic leaches **AhR Agonists**

Japanese medaka
(*Oryzias latipes*), 3dph
5 day exposure
In vivo

CYP1A expression reported as relative to plastic-free control





CYP1A-bla LS180
Aryl hydrocarbon receptor
in vitro

Plastic-free control TEQ: <MDL (0.006 ng/L)

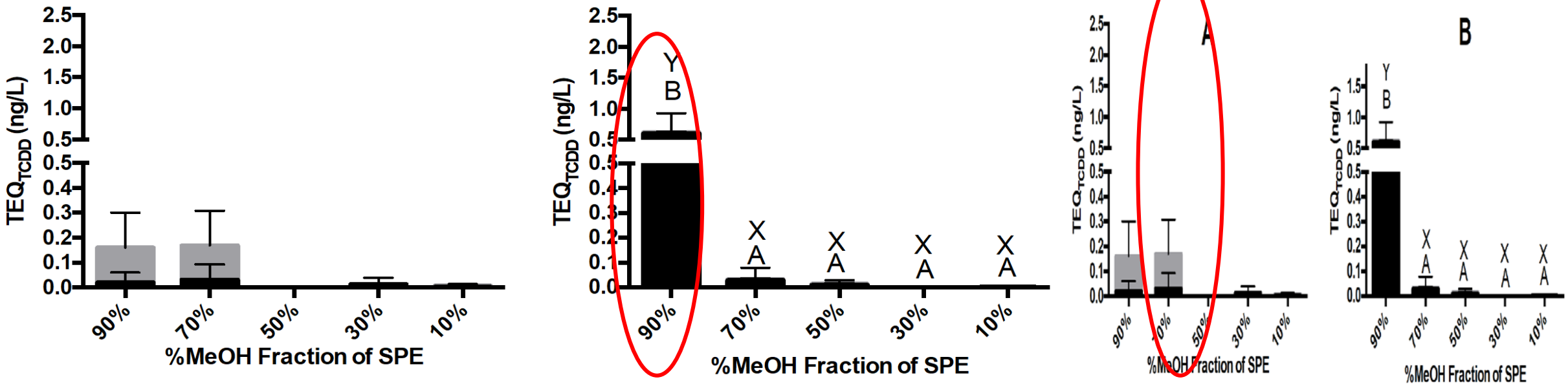
Coffin et. al (2018), Environment International.

Co-planar PCBs account for AhR Activity

"Virgin" Plastic

UV-Irradiated "Virgin" Plastic

North Pacific Gyre recovered Plastic



Plastic-free control chemical TEQ <MDL (0.01 ng/L)

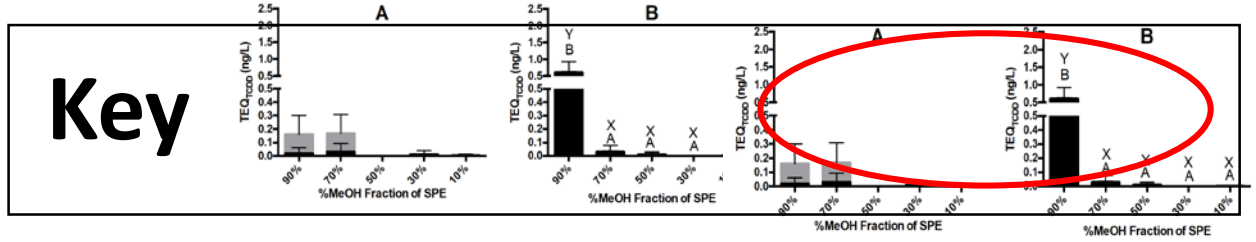
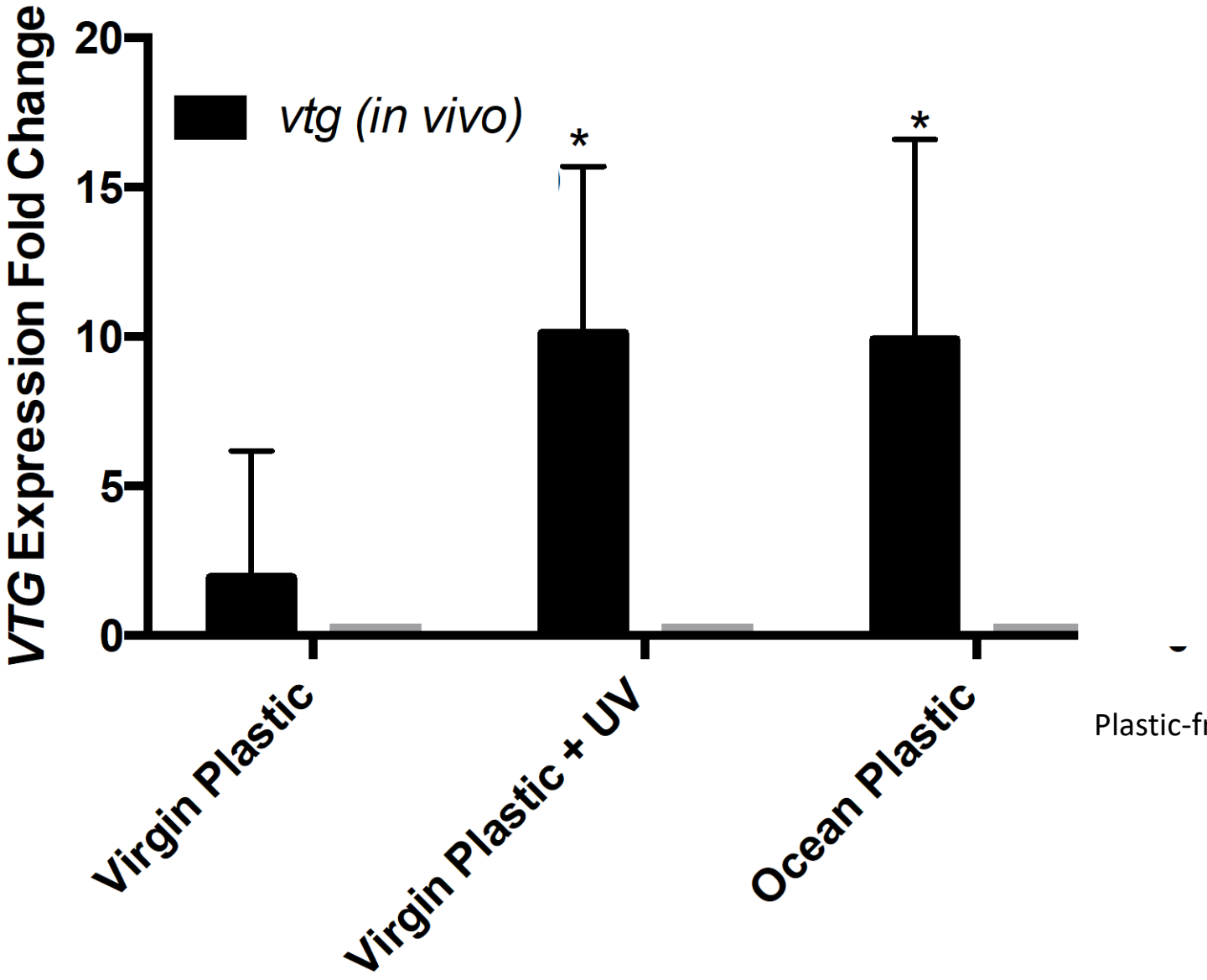


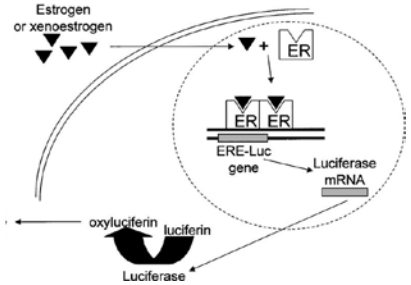
Figure: Coffin et. al (2018), Environment International.

Irradiated & Gyre-recovered plastic leaches **ER Agonists**

Japanese medaka
(*Oryzias latipes*), 3dph
Expose (5 days)



VTG expression reported as relative to plastic-free control



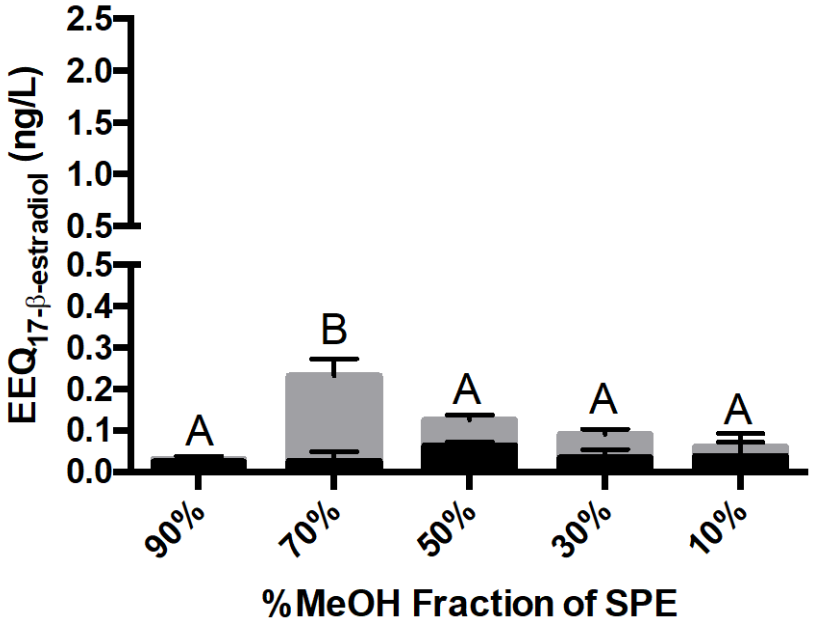
VM7Luc4E2
Estrogen receptor reporter

Plastic-free control EEQ <MDL (0.03 ng/L)

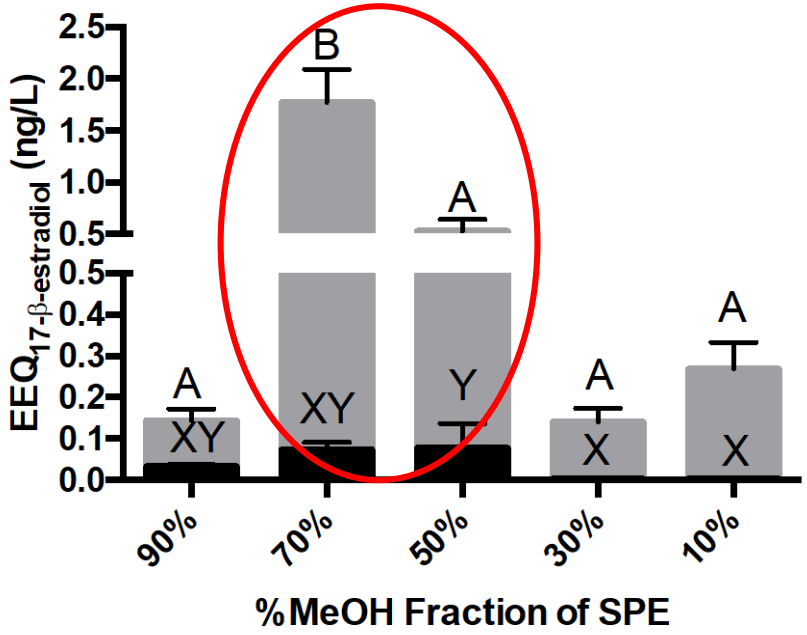
Coffin et. al (2018), Environment International.

BPA, 4-*tert*-octylphenol account for majority of **ER Activity**

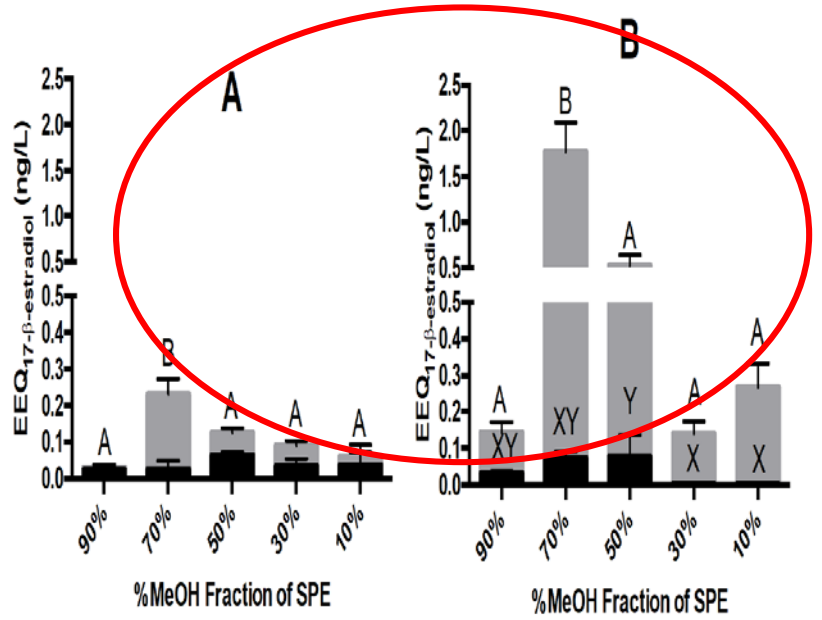
"Virgin" Plastic



UV-Irradiated "Virgin" Plastic



North Pacific Gyre recovered Plastic



Plastic-free control chemical EEQ <MDL (0.01 ng/L)

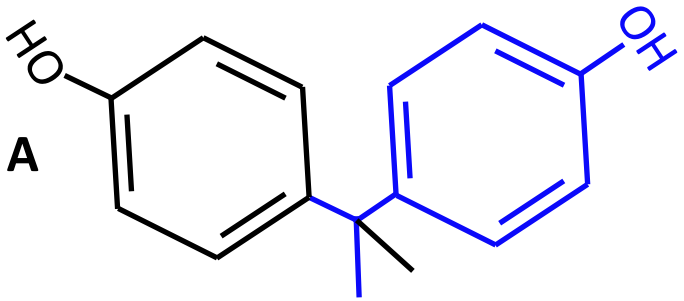
Figure: Coffin et. al (2018), Environment International.

Conclusions

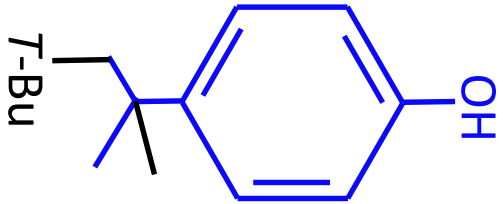
1) **UV radiation and weathering** released estrogenic **additives** from plastic

- UV-irradiated and ocean plastic induced ***vtg*** in Japanese medaka fish
- UV-irradiated and ocean plastic had higher **ER** activity *in vitro*
- **BPA, 4-*tert*-octylphenol** responsible for majority of ER activity

Bisphenol A

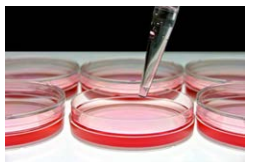


4-*tert*-octylphenol

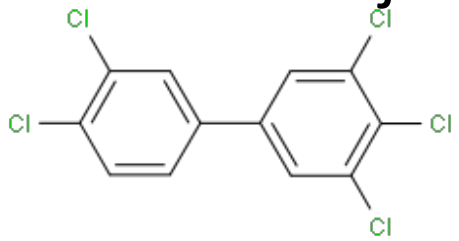


2) Hydrophobic Organic Contaminants (HOCs) leached from **ocean plastic**

- Ocean plastic induced ***cyp1a1*** in Japanese medaka fish
- Ocean plastic, irradiated plastic had higher **AhR** activity *in vitro*
- **PCBs** responsible for majority of AhR activity



PCB 126



Further Considerations…

- Plastic may transport HOCs from contaminated sites to less contaminated sites[1]

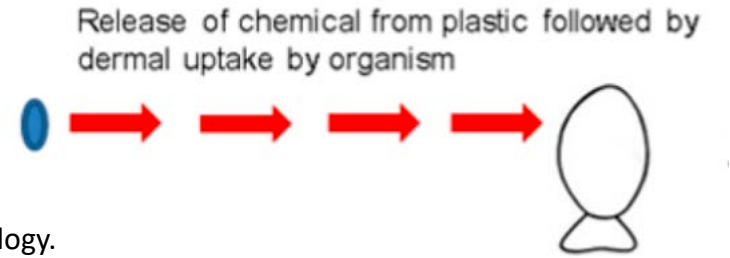


Figure: Koelmans, et. al (2016). Environmental Science & Technology.

- Plastic may act as *cleaning mechanism* for HOCs[1]

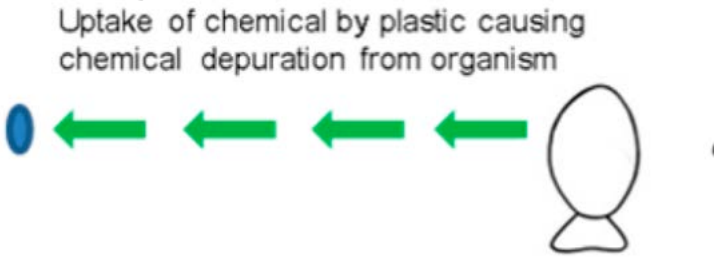


Figure: Koelmans, et. al (2016). Environmental Science & Technology.

- **Ingestion** enhances desorption of HOCs[2] and additives[3]

Photo: Algalita Marine Research and Education

Photo: Chris Jordan

Potential for biomagnification

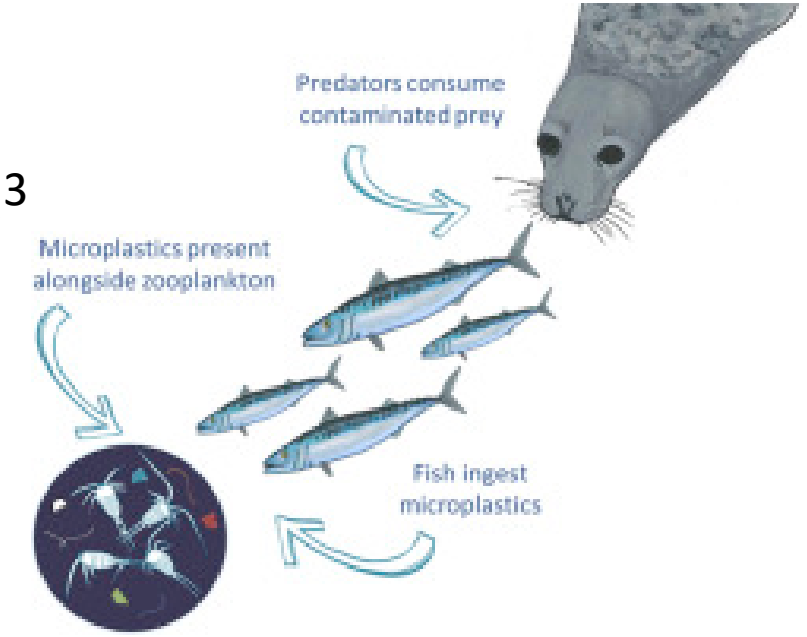


Figure: Nelms, et. al (2018). Environmental Pollution.

[1]Koelmans, et. al (2016). Environmental Science & Technology.
[2]Bakir et. al (2014). Environmental Pollution.
[3]Coffin et. al (2019). Environmental Science & Technology.

Acknowledgements

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J.C. Leapman

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Questions?

More information on study available online:

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open access

Comparisons of analytical chemistry and biological activities of extracts from North Pacific gyre plastics with UV-treated and untreated plastics using *in vitro* and *in vivo* models

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