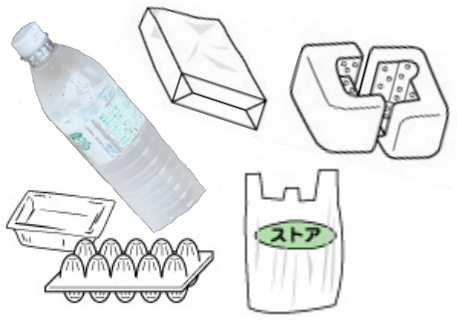
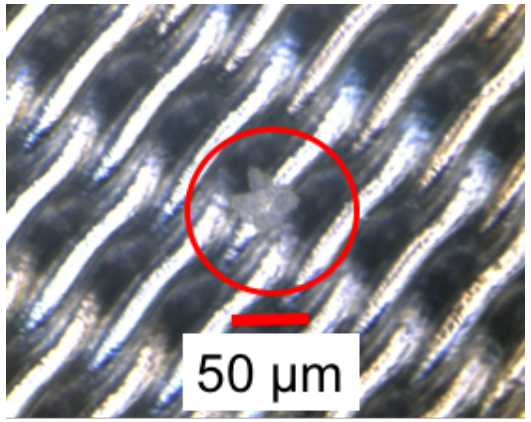
Hazardous chemicals in marine plastics and their threat to marine organisms





Shige TAKADA

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Tokyo University of Agriculture and Technology

Presented on
International Workshop "The Science of Microplastics in the World Ocean
Woods Hole Oceanographic Institution, Oct. 16, 2019

Major Conclusion

Plastic-mediated chemical exposure does occur and its significance depends on locations, background pollution, chemicals, species of biota, especially trophic levels.

Topics

- Hazardous chemicals in marine plastics
  - Chemicals adsorbed from seawater
  - Additive chemicals
- Transfer of the chemicals from ingested plastics to internal tissue of biota
  - Experimental evidences
  - Mechanism
- Significance of the plastics as exposure media : Field observations
- Effects of the plastic-mediated chemical exposure

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- Significance of the plastics as exposure media : Field observations
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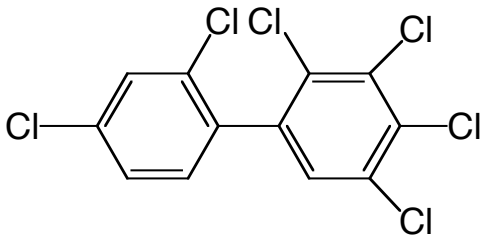
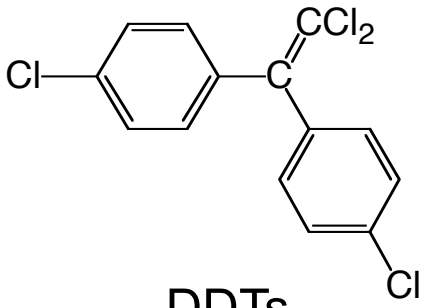
Plastics carry two types of chemicals in marine environment

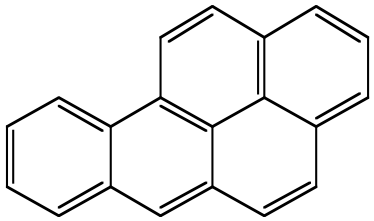
Sorption from seawater



Polychlorinated biphenyl (PCBs)

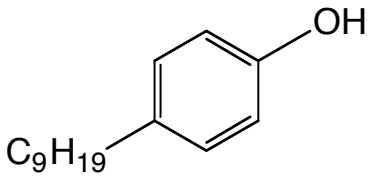


DDTs

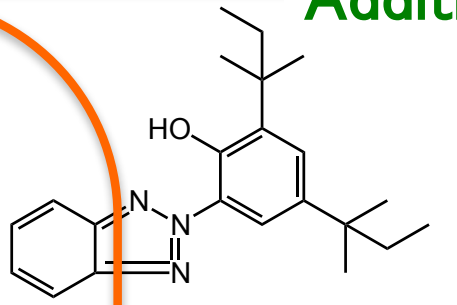


Polycyclic aromatic hydrocarbons (PAHs)

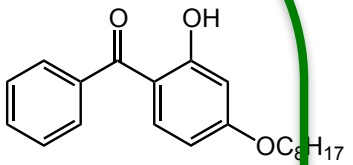
Additives



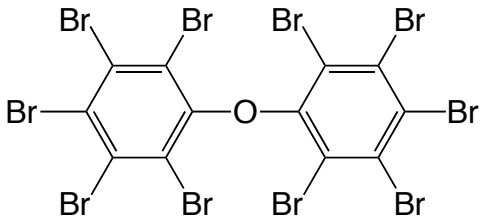
Nonylphenol



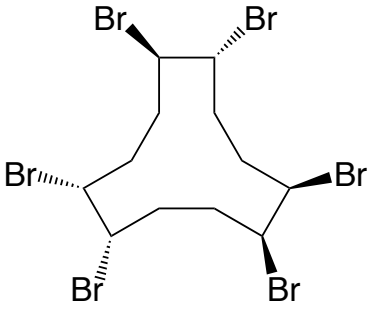
Benzotriazoles (e.g., UV-328)



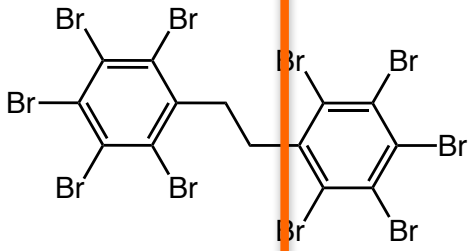
Benzophenones (e.g., BP-12)



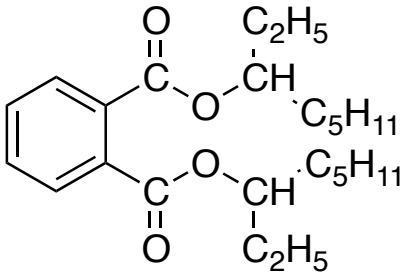
Polybrominated diphenyl ethers (PBDEs)



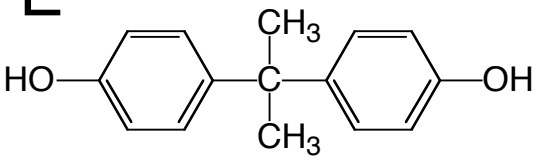
Hexabromocyclododecanes (HBCDs)



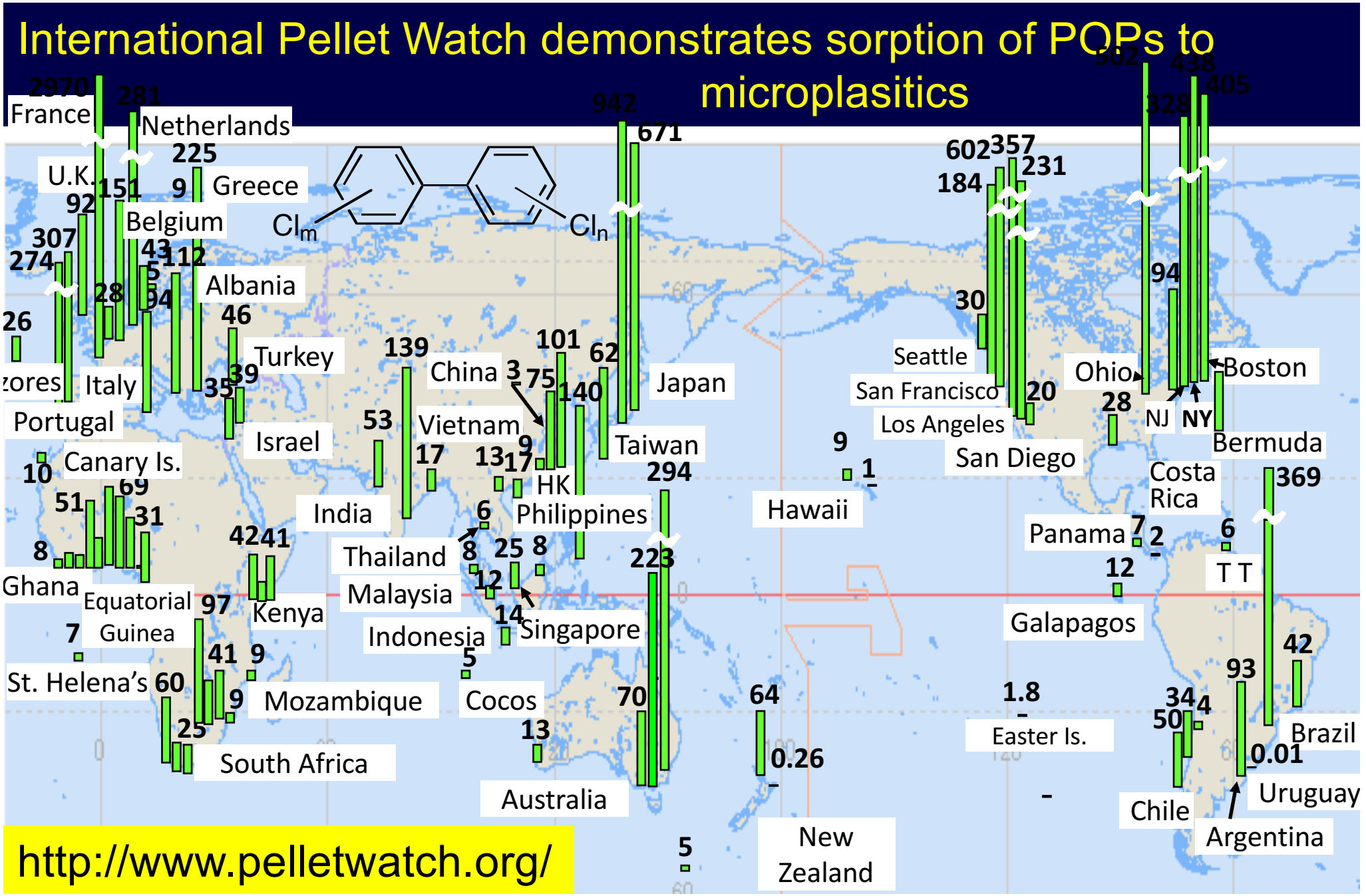
DBDPE



Phthalates (DEHP)



Bisphenol A

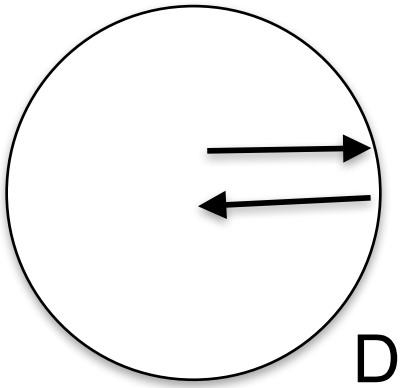


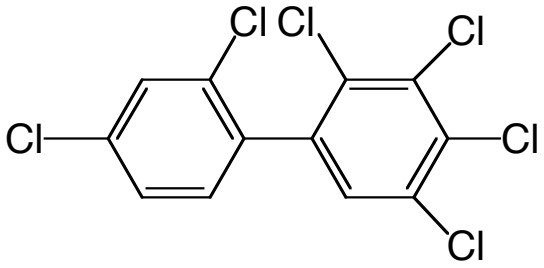
PCBs concentrations in beached plastic pellets (ng/g)

*sum of concentrations of CB#66, 101, 110, 149, 118, 105, 153, 138, 128, 187, 180, 170, 206

Slow desorption and fast transport may cause sporadic high concentration of PCBs in plastic from open ocean

~ mm





Diffusive transfer in plastic matrix takes time

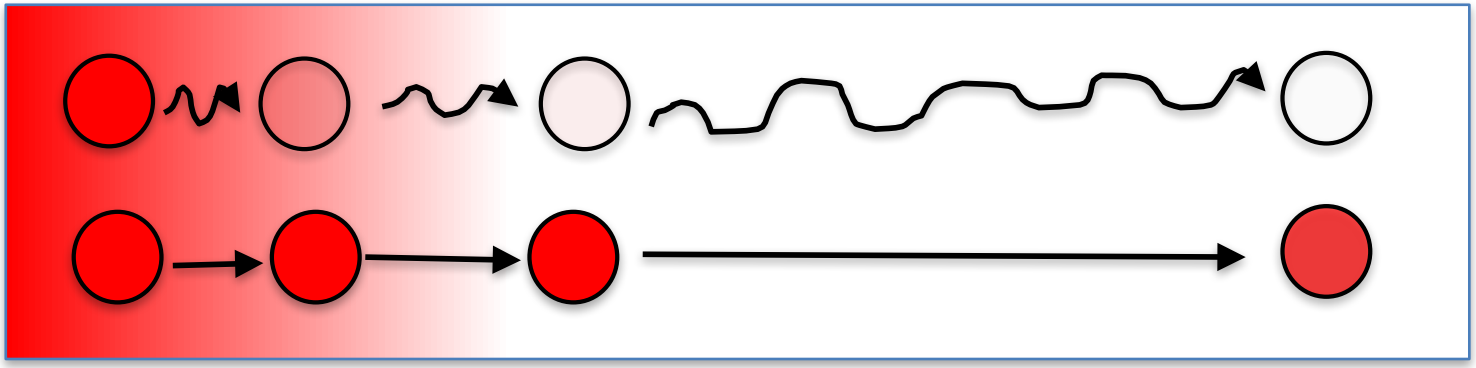
Plastic fragment/pellet with 3 mm diameter

Long time (~ 1 year) to reach equilibrium

Non-equilibrium : slow sorption/desorption

Polluted waters

Open ocean

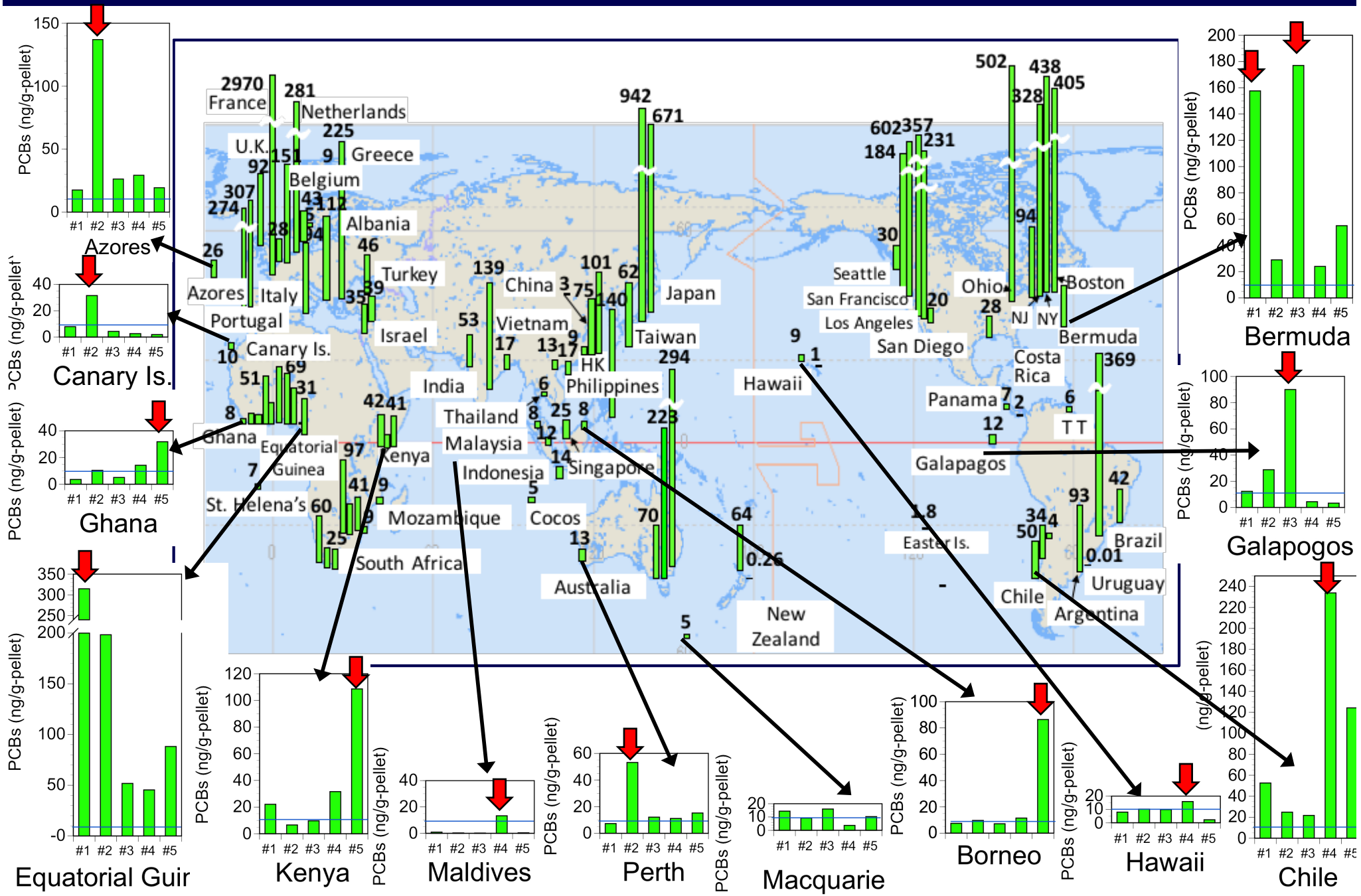


slow

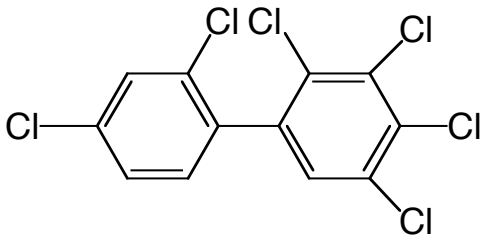
rapid

Sporadic high concentrations of PCBs found in pellets from remote areas :

Microplastics carry contaminants to remote areas



Plastics carry two types of chemicals in marine environment



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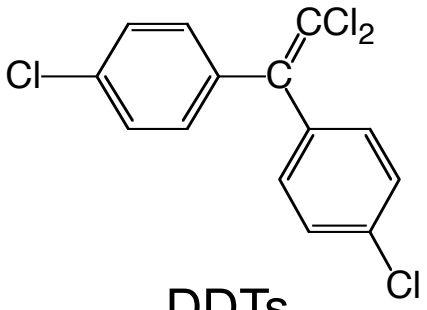

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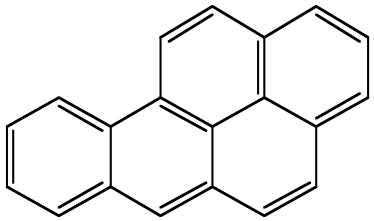

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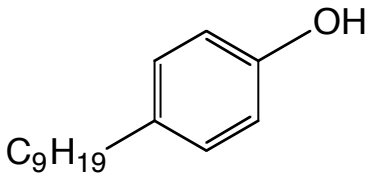

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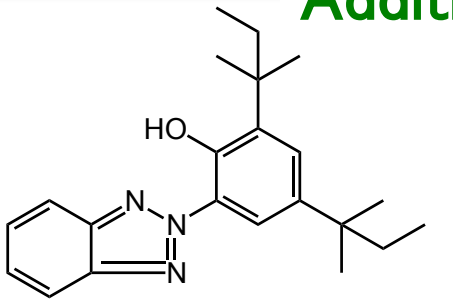

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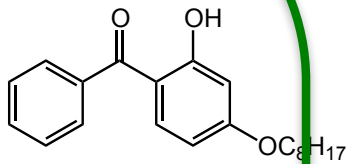
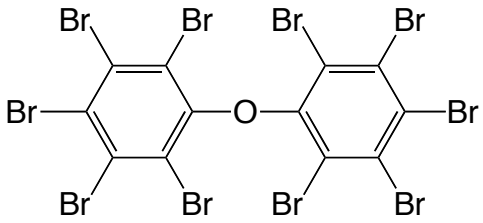


Benzophenones (e.g., BP-12)



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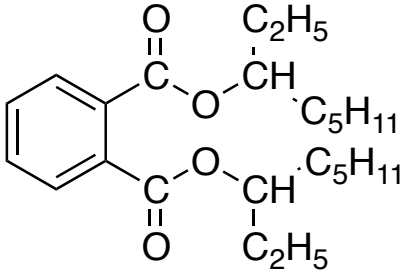

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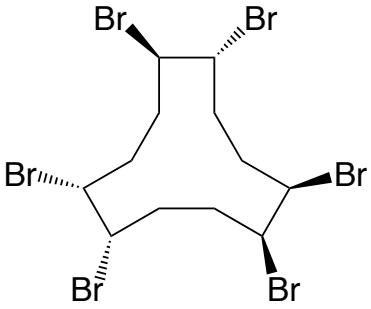

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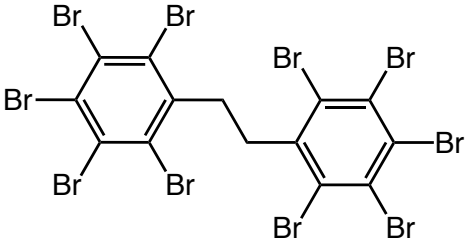
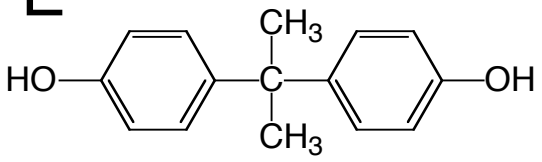
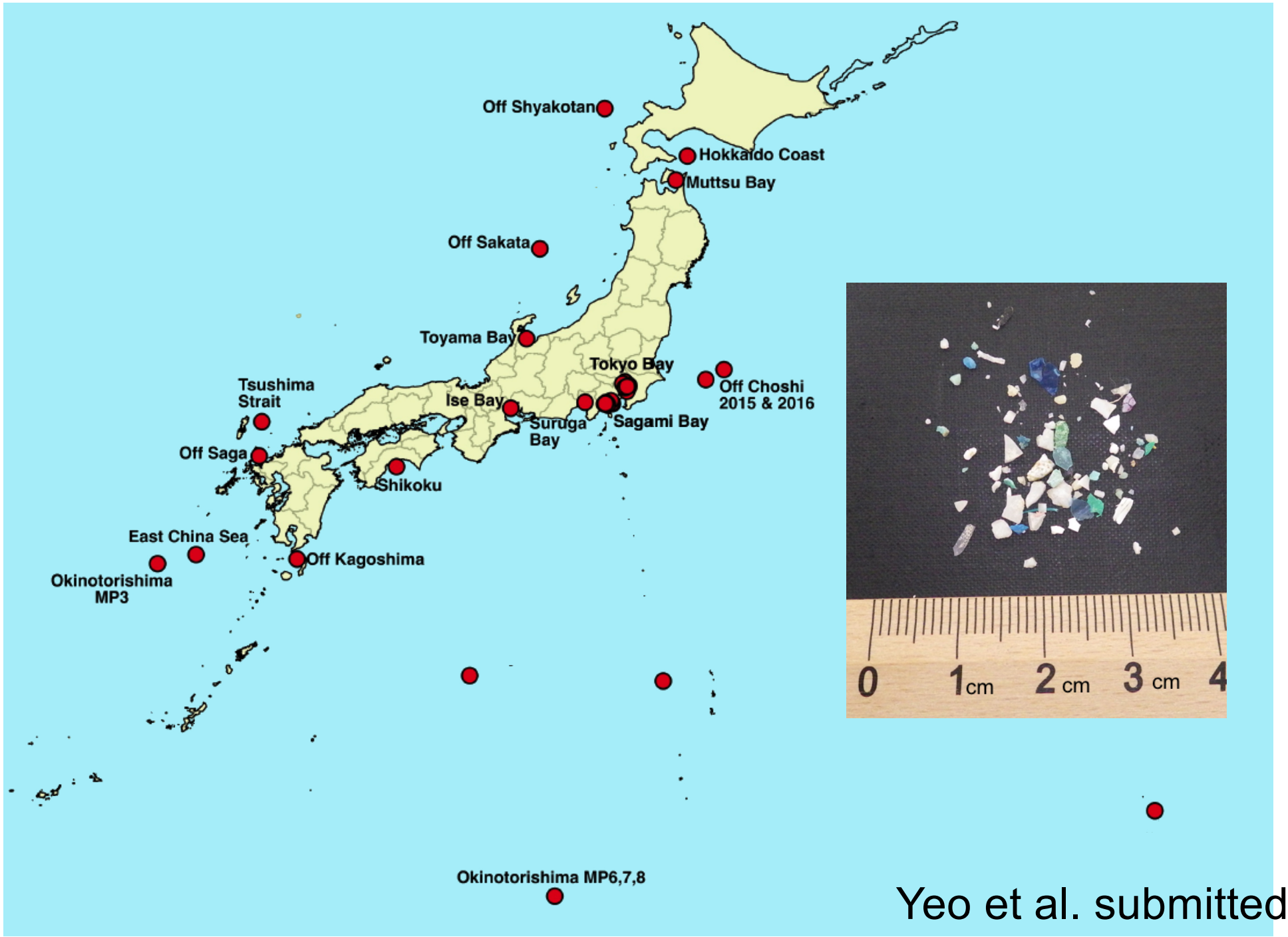


DBDPE



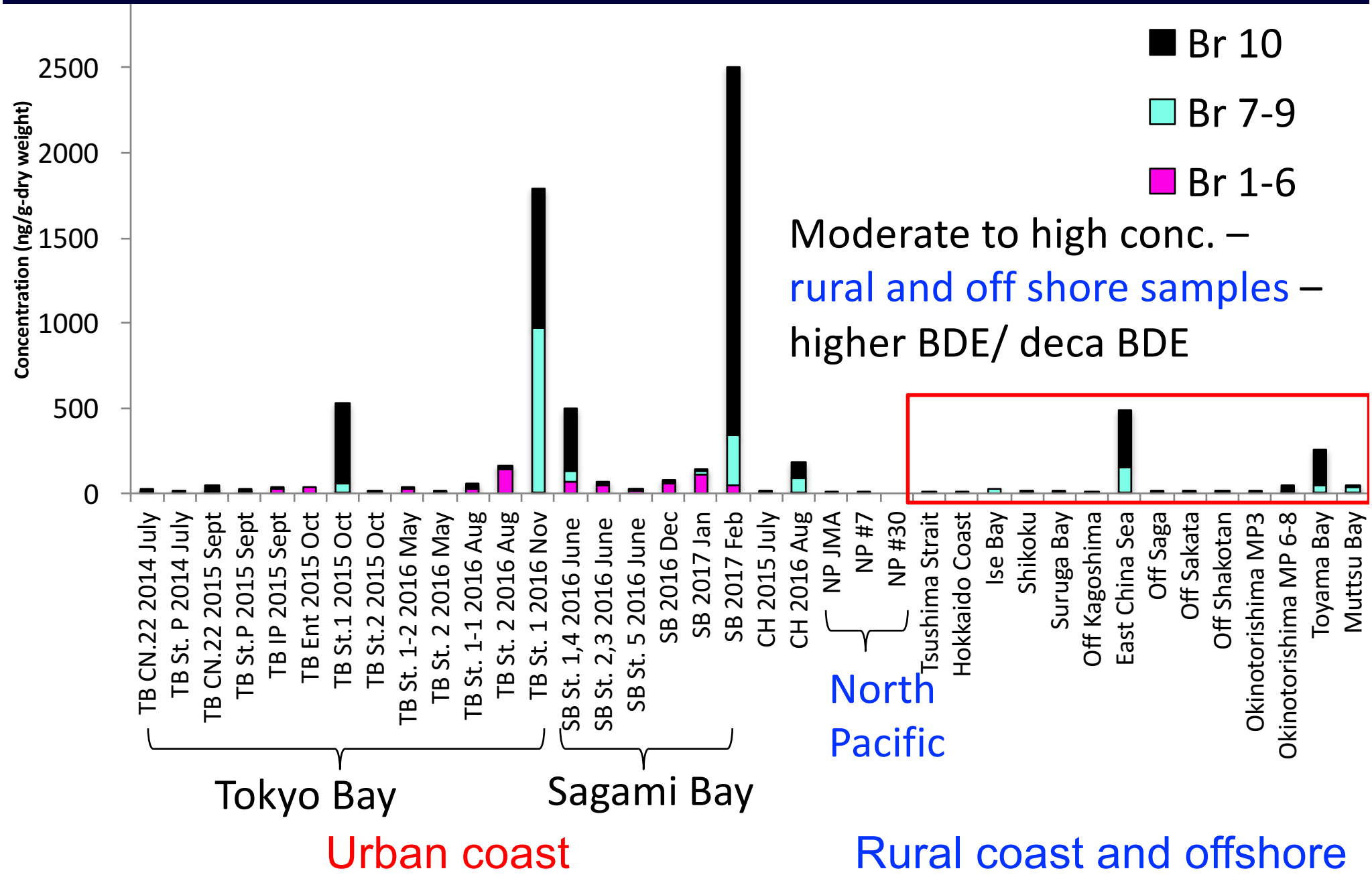
Bisphenol A

Buoyant microplastics from Japan coasts and pacific ocean



Yeo et al. submitted

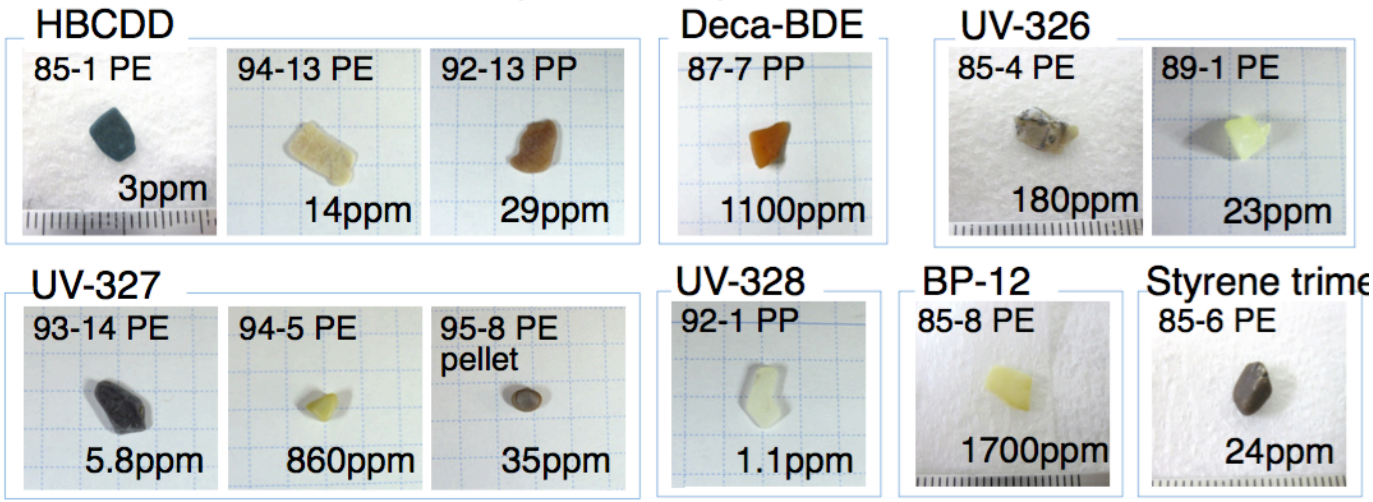
BDE209 was sporadically detected in suspended microplastics in seawater



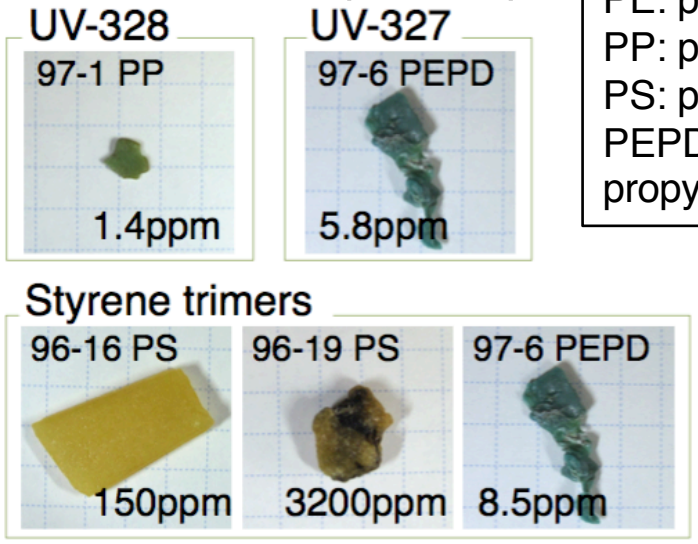
Additives (e.g., UV-326, UV-327, UV-328, BP-12, BDE209) are **sporadically** detected in plastics in seabirds' stomach

Detection frequency : ~ 2 %

Northern fulmar (n=159) dissected



Albatross (n=35)



PE: polyethylene
PP: polypropylene
PS: polystyrene
PEPD: polyethylene propylene diene

Bolus

Tanaka, K., van Franeker, J.A., Deguchi, T., and Takada, H., **2019**. Piece-by-piece analysis of additives and manufacturing byproducts in plastics ingested by seabirds: Implication for risk of exposure to seabirds. ***Marine Pollution Bulletin* 145, 36-41.**

Table3. Ingestion frequency of plastic with additives.

	Detection % in fragments	Ingestion %
Northern fulmar		
Deca-BDE	0.6%	9%
HBCDD	1.9%	27%
UV-328	0.6%	9%
UV-326	1.3%	18%
UV-327	1.9%	27%
BP-12	0.6%	9%
∑ STs	0.6%	9%
Albatross		
UV-328	2.9%	17%
UV-327	2.9%	17%
∑ STs	8.6%	50%

Topics

- Introduction of plastic pollution and microplastics
- Spread of plastics in marine environments:
  - Sediment cores
  - Marine organisms : seabirds, fish, bivalves
- Hazardous chemicals in marine plastics
  - Chemicals adsorbed from seawater
  - Additive chemicals
- Transfer of the chemicals from plastics to internal tissue
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- Significance of the plastics as exposure media : Field observations
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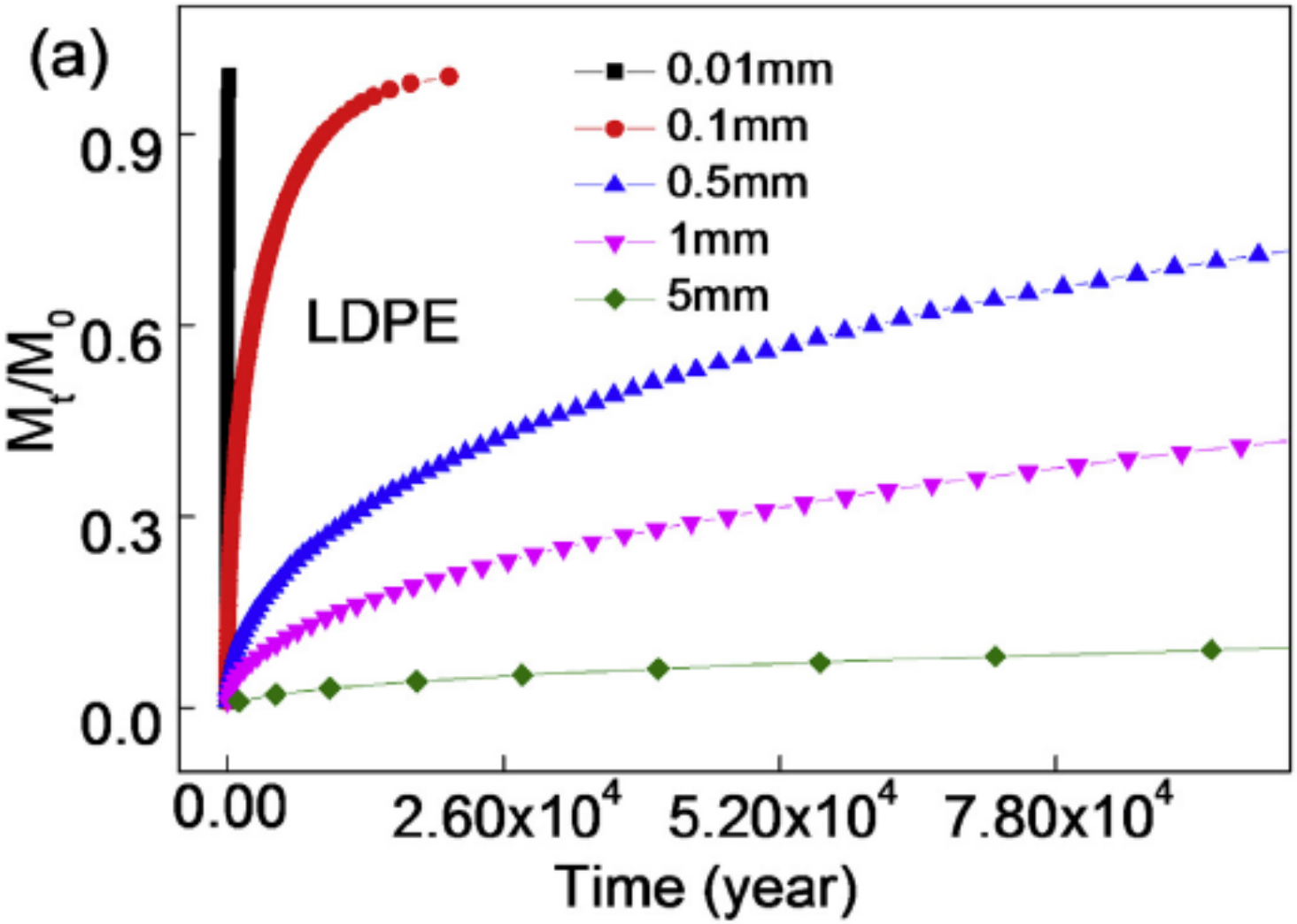
Hydrophobic and large molecule additive such as BDE209 is difficult to leach from plastic to water.



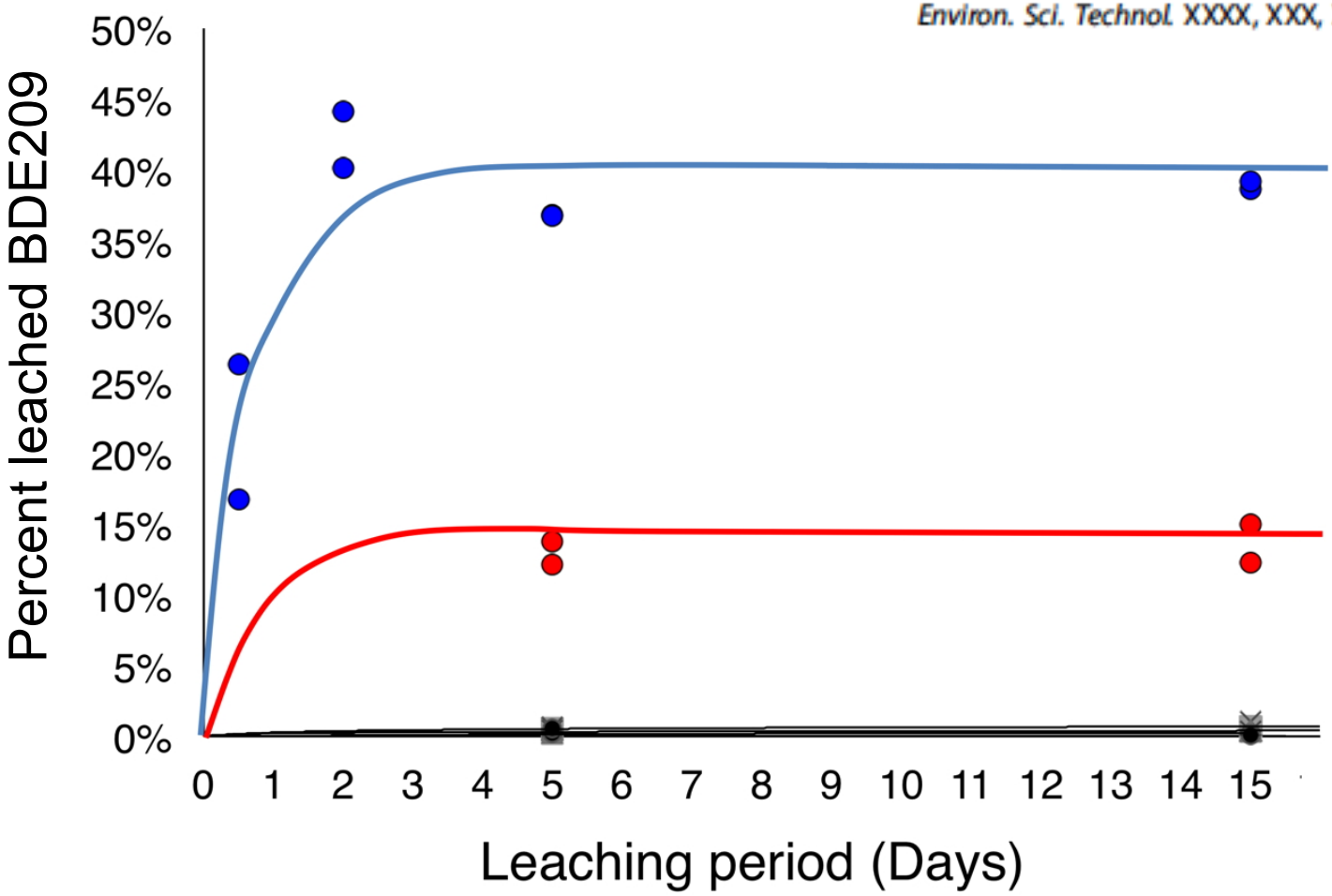
Sun, B., Hu, Y., Cheng, H., and Tao, S., 2019. Releases of brominated flame retardants (BFRs) from microplastics in aqueous medium: Kinetics and molecular-size dependence of diffusion. Water Research 151, 215-225.

Stomach oil and fish oil accelerated the leaching of BDE209

Facilitated Leaching of Additive-Derived PBDEs from Plastic by Seabirds' Stomach Oil and Accumulation in Tissues

Kosuke Tanaka,[†] Hideshige Takada,[*,†] Rei Yamashita,[†] Kaoruko Mizukawa,[†] Masa-aki Fukuwaka,[‡] and Yutaka Watanuki[§]

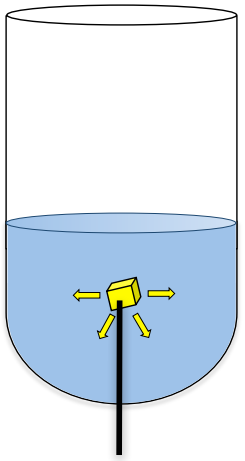
DOI: 10.1021/acs.est.5b01376
Environ. Sci. Technol. XXXX, XXX, XXX−XXX



Fish oil

Stomach oil

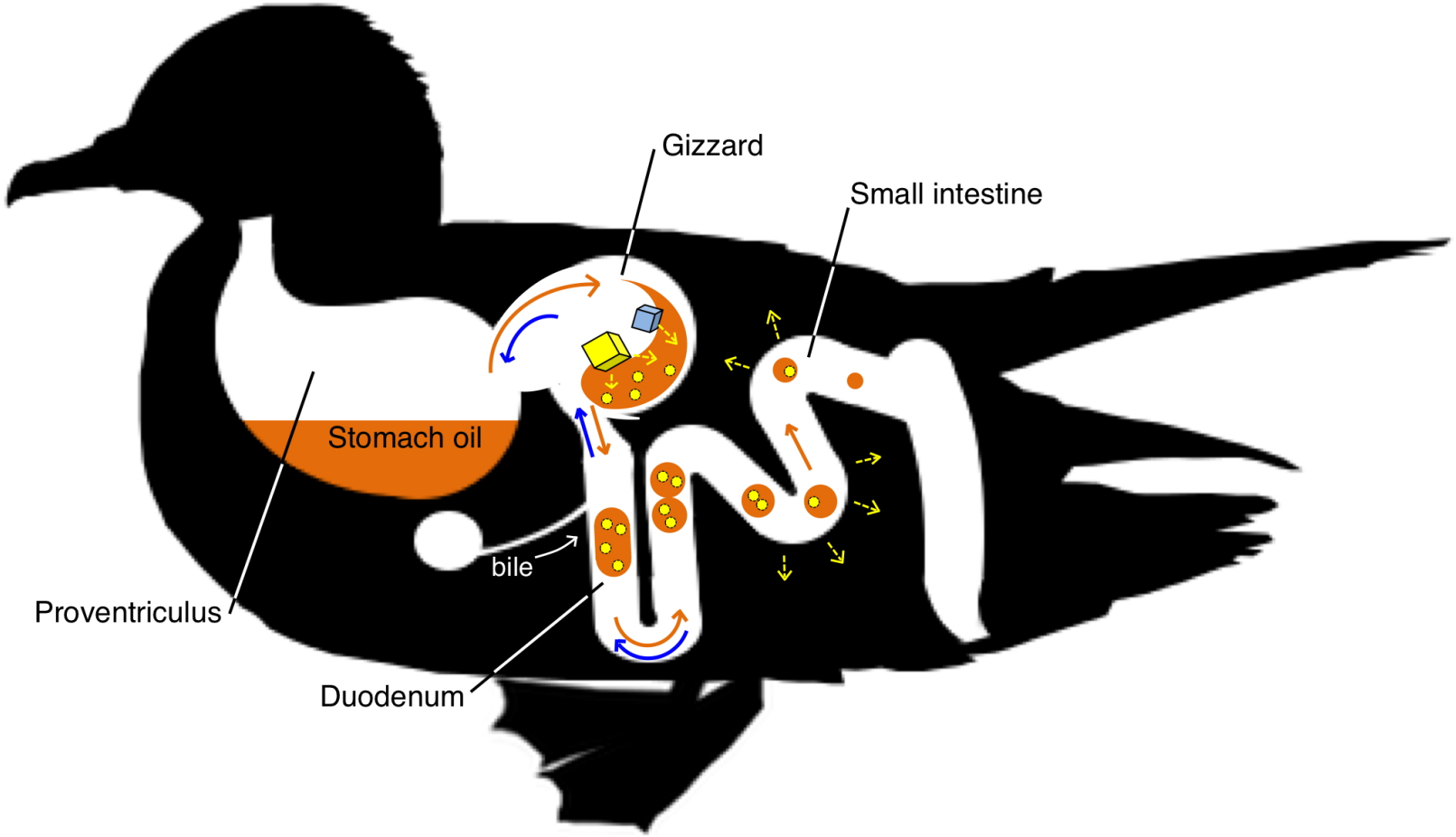
Pepsin solution
Sea water
Distilled water



BDE209
in plastic

This suggests that **fatty components** in digestive tract facilitates leaching of hydrophobic additives.

Oily components in digestive fluid facilitate leaching of hydrophobic additives and their accumulation in adipose and liver



Tanaka, K., Yamashita, R., and Takada, H., *Transfer of hazardous chemicals from ingested plastics to higher-trophic level organisms,* in *Hazardous chemicals associated with plastics in environment,* H. Takada and H.K. Karapanagioti, Editor. 2018, Springer Berlin Heidelberg: p. 267–280.

Plastics compounded with 5 additives

Polyethylene pellets with 5 additives

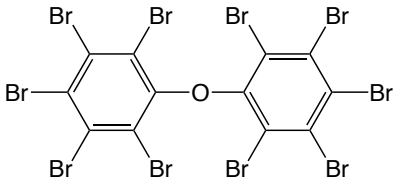
Additives + PE powder

mixed
melted,
molded
by using extruder

Additives:

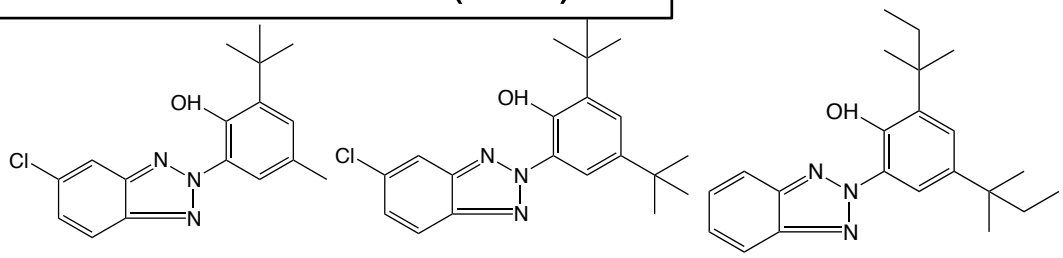
Brominated flame retardants

- BDE209



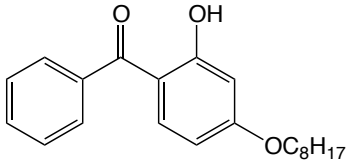
Benzotriazole UV-stabilizers (BTs)

- UV-326
- UV-327
- UV-328



Benzophenone UV-stabilizers (BPs)

- BP-12



Concentration of each chemical was 0.4 % by weight in polymer.

Tanaka, K. et al., 2019, Current Biology (under revision)

Field Feeding Experiment of additive-compounded plastic to chicks of streaked shearwater

Exposure group

PE pellets compounded with 5 additives

(5 pieces /individual)

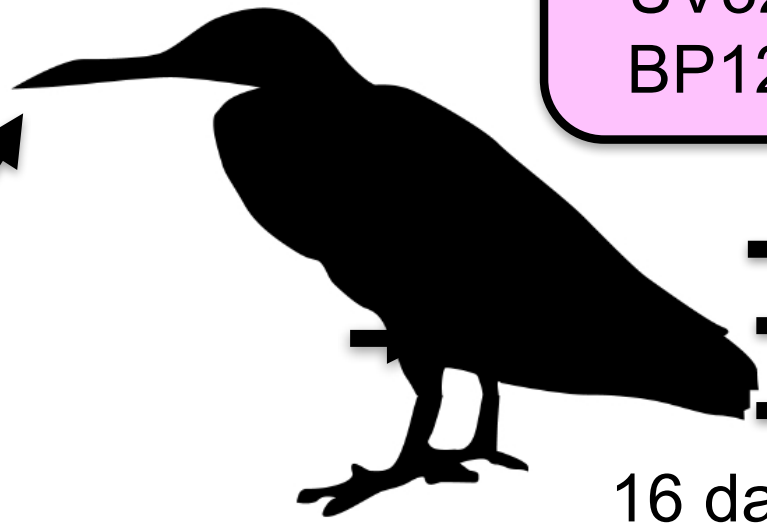
+

natural diet

Additives

BDE209
UV326, UV327, UV328
BP12

Chicks



→ Liver
→ Adipose
→ Preen Gland oil

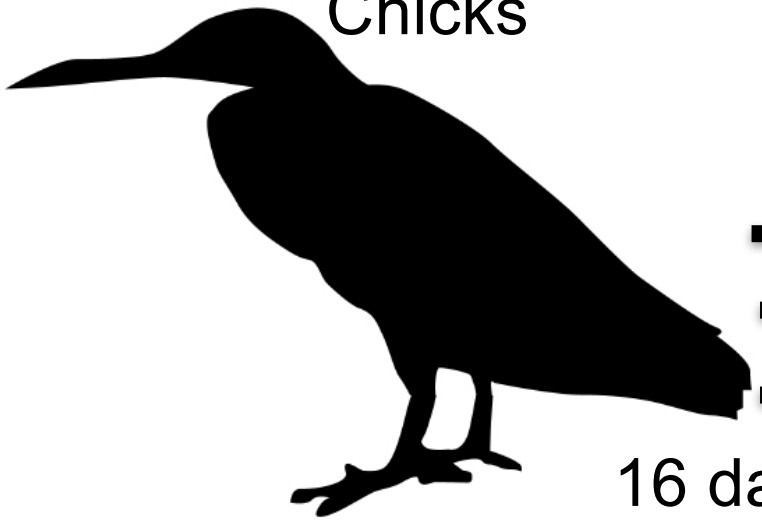
16 days

Control group

natural diet

natural diet

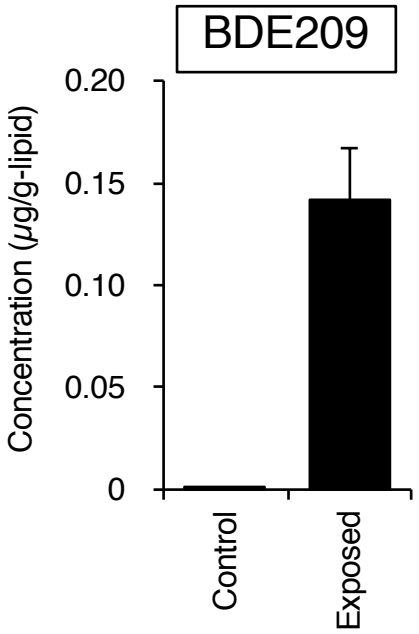
Chicks

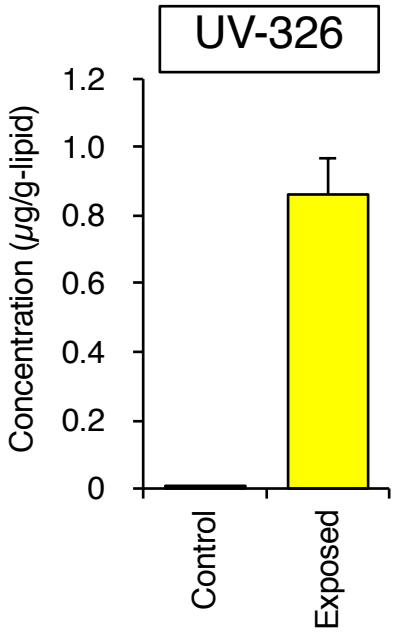


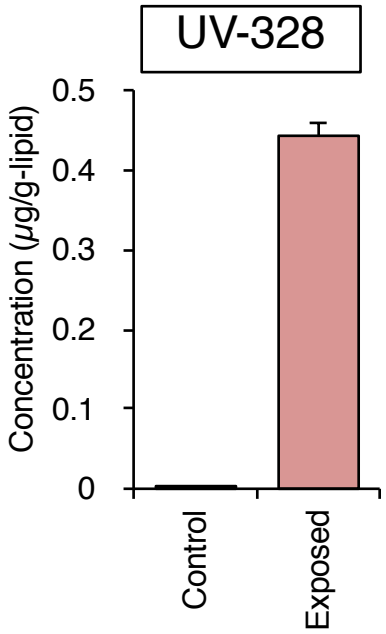
→ Liver
→ Adipose
→ Preen Gland oil

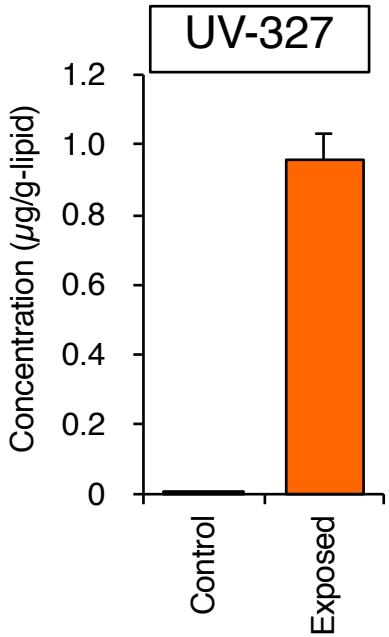
16 days

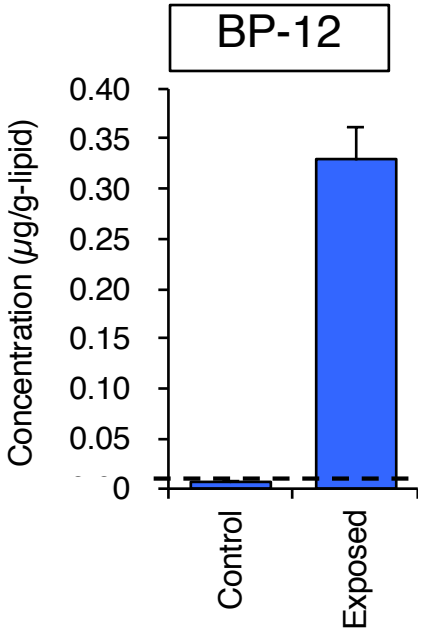
Results_abdominal adipose (16 day)

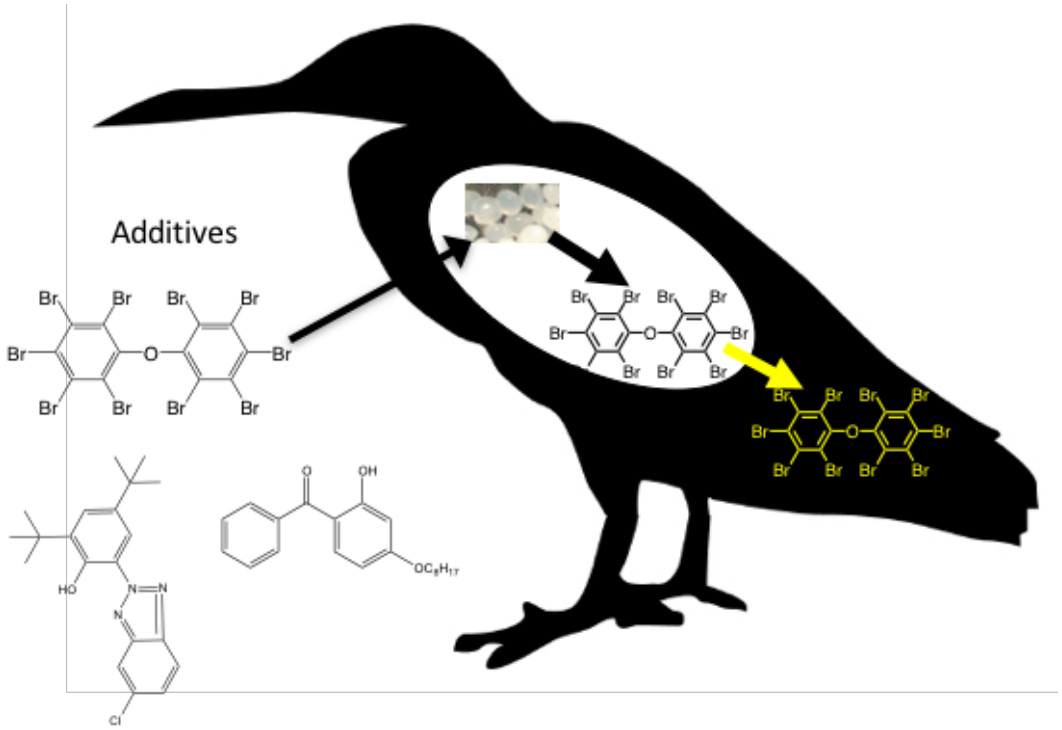






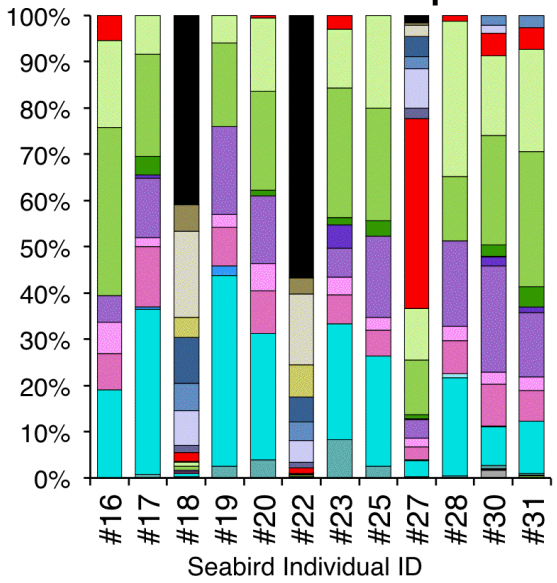




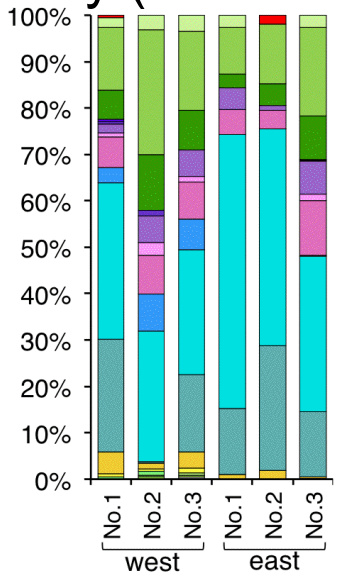


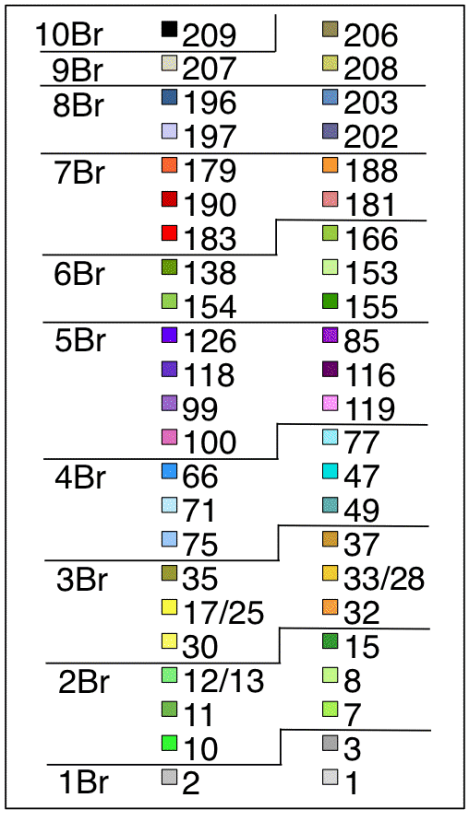
Composition of BDE congeners in seabird adipose, plastics in the stomachs, and their prey.

Abdominal adipose

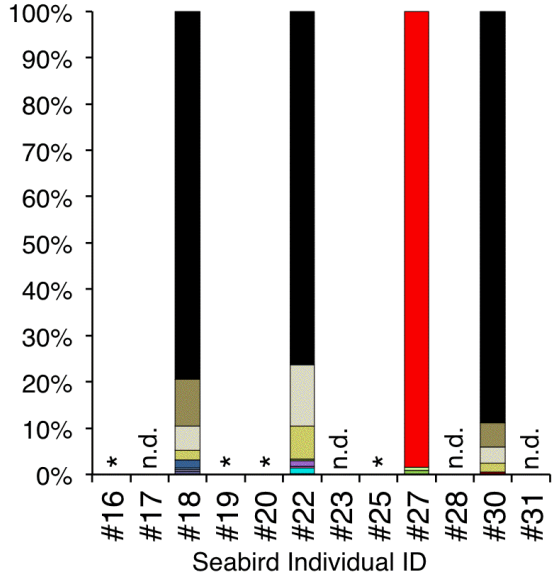


Prey (lantern-fish)





Plastics in stomach



Lower brominated congeners were derived from natural prey, whereas higher brominated congeners were derived from ingested plastics.

Topics

- Introduction of plastic pollution and microplastics
- Spread of plastics in marine environments:
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  - Additive chemicals
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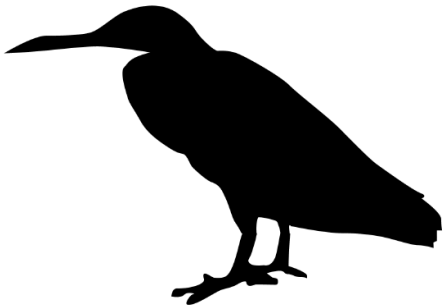
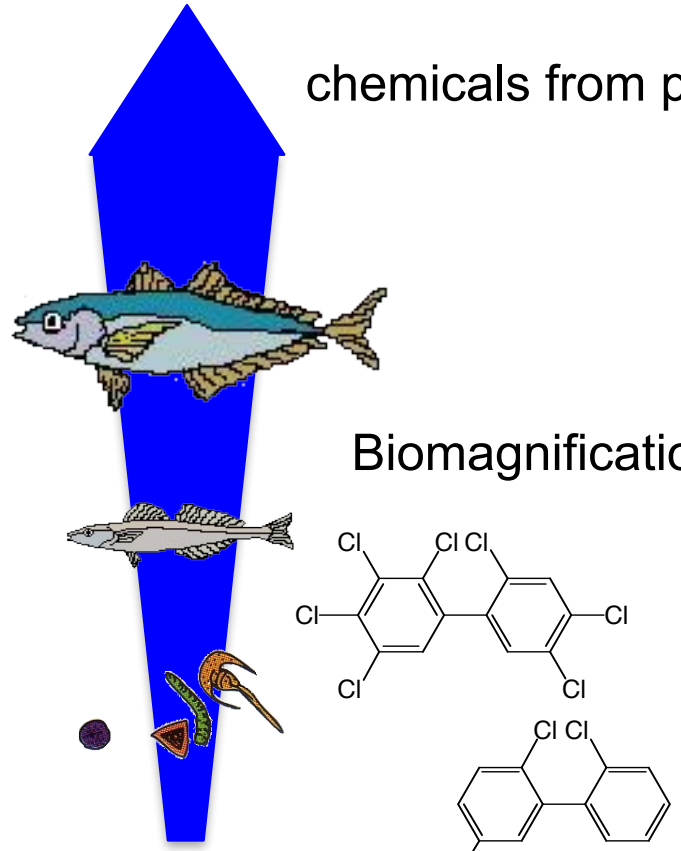
  - Experimental evidences
  - Mechanism
- Significance of the plastics as exposure media : Field observations Higher trophic level organisms
- Lower trophic level organisms
- Effects of the plastic-mediated chemical exposure

Exposure of contaminants both from plastics and prey



Plastic-derived chemicals

chemicals from prey



Biomagnification

POPs in seawater

Significant of ingested plastics as exposure source of chemicals depend on target chemicals, background pollution, study area, and target biota

Summary 1. Plastic contribution to PCBs depends on locations and trophic levels

Location	Animal	Species	Compounds	Significance	
Gough Island	Seabird	Great Shearwater	PCBs	Yes	{Ryan, 1988 #68}
Bering Sea	Seabird	Short-tailed Shearwater	PCBs (LCC)	Yes	{Yamashita, 2011 #453}
Bering Sea	Seabird	Short-tailed Shearwater	PCBs (HCC)	No	{Yamashita, 2011 #453}
Coastal Norway	Seabirds	Northern Fulmars	PCBs, DDTs, PBDEs (LBC)	No	{Herzke, 2016 #654}
Pacific	Seaturtle	olive ridley, loggerhead turtles, blue turtle	PCBs, DDTs, PBDEs	No	{Clukey, 2018 #719}
South Atlantic Ocean	pelagic fish	lantern fish	PCBs, DDTs	No	{Rochman, 2014 #718}
North Pacific Ocean	pelagic fish	lantern fish	PCBs (HCC))	No	{Gassel, 2019 #722}
North Pacific Ocean	pelagic fish	lantern fish	PCBs (LCC)	Yes	{Gassel, 2019 #722}
Remote island, Japan	bivalves	clam	PCBs	Yes	Mizukawa et al., 2019
Remote island, Japan	Crustacea	coenobita	PCBs	Yes	Mizukawa et al., 2019

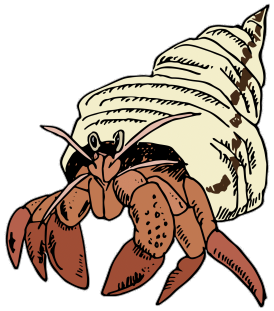
Summary 2. Plastic contribution to BDE209, phthalates, Benzotriazole UV-stabilizers is significant in most cases.

Location	Animal	Species	Compounds	Significance	
Bering Sea	Seabirds	Short-tailed Shearwater	BDE209	Yes	{Tanaka, 2015 #612}
South Atlantic Ocean	pelagic fish	lantern fish	BDE209	Yes	{Rochman, 2014 #718}
Coastal Australia	Seabirds	short-tailed Shearwater/wedged-tailed shearwater	Phthalates (DEHP)	Yes	{Hardesty, 2015 #643}
Hawaii	Seabirds	Black footed albatross, Laysan albatross	UV-stabilizer (UV-326, UV-328)	Yes	{Tanaka, 2019 #715}
Mediterranean	basking shark	Cetorhinus maximus	MEHP	Yes	{Fossi, 2014 #610}
Remote island, Japan	Crustacea	coenobita	PBDEs	Yes	Mizukawa et al., 2019
Coastal Norway	Seabirds	Northern Fulmars	BDE209	Yes	{Herzke, 2016 #654}
Pacific	Seaturtle	olive ridley, loggerhead turtles, blue turtle	BDE209	No	{Clukey, 2018 #719}


remote island in Okinawa
Control beach

remote island in Okinawa

Microplastics in digestive tract of Hermit Crab

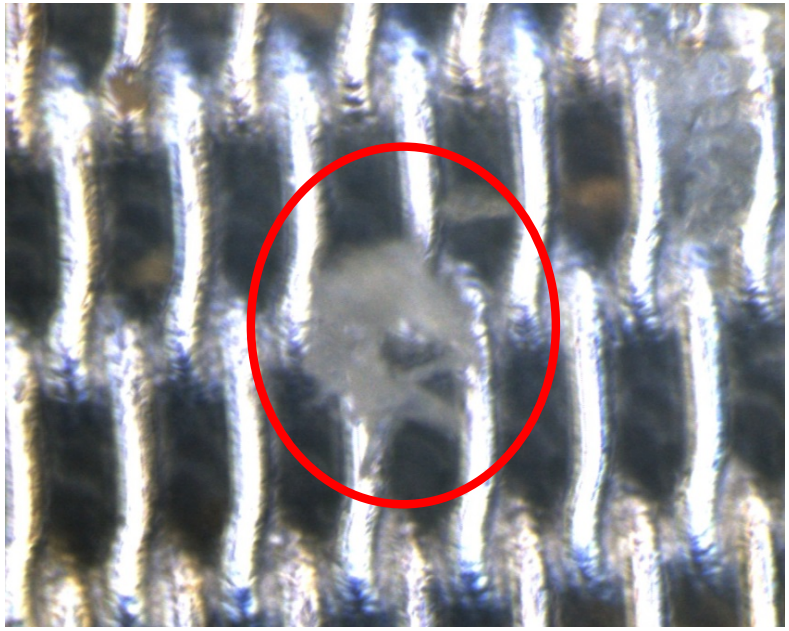


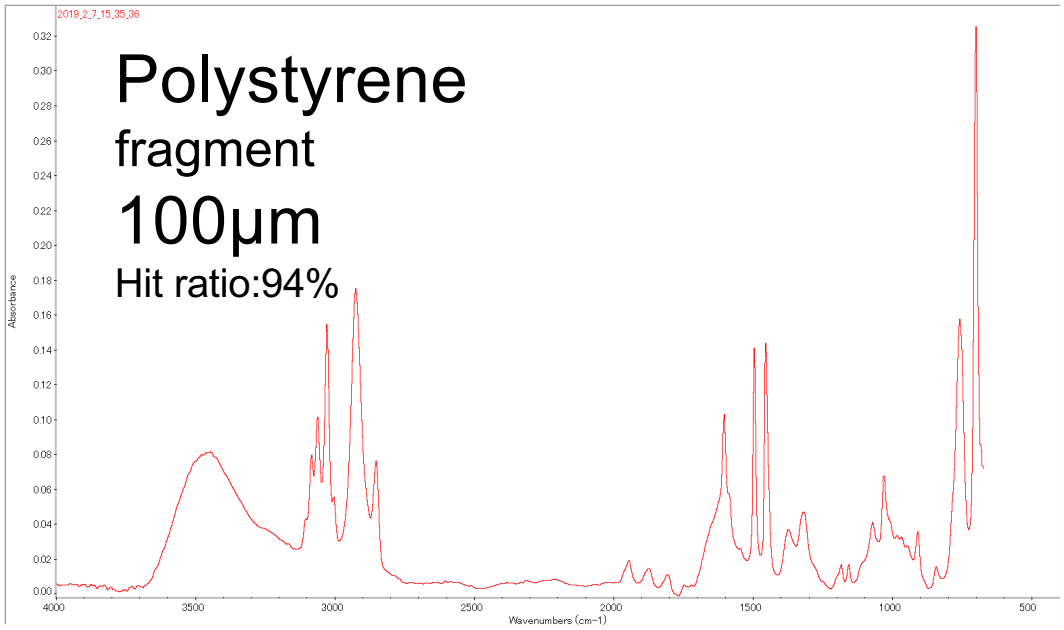
0 – 13 pieces/g-wet

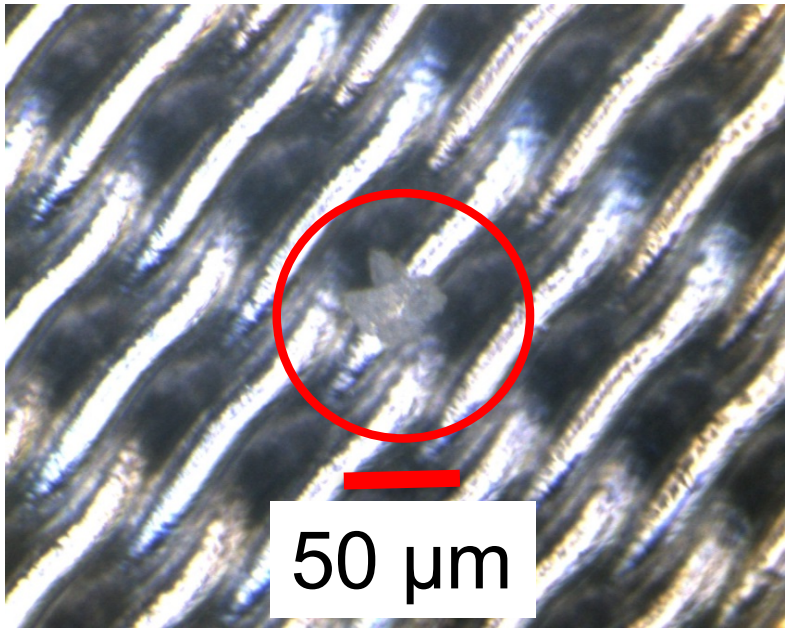
Control
beach

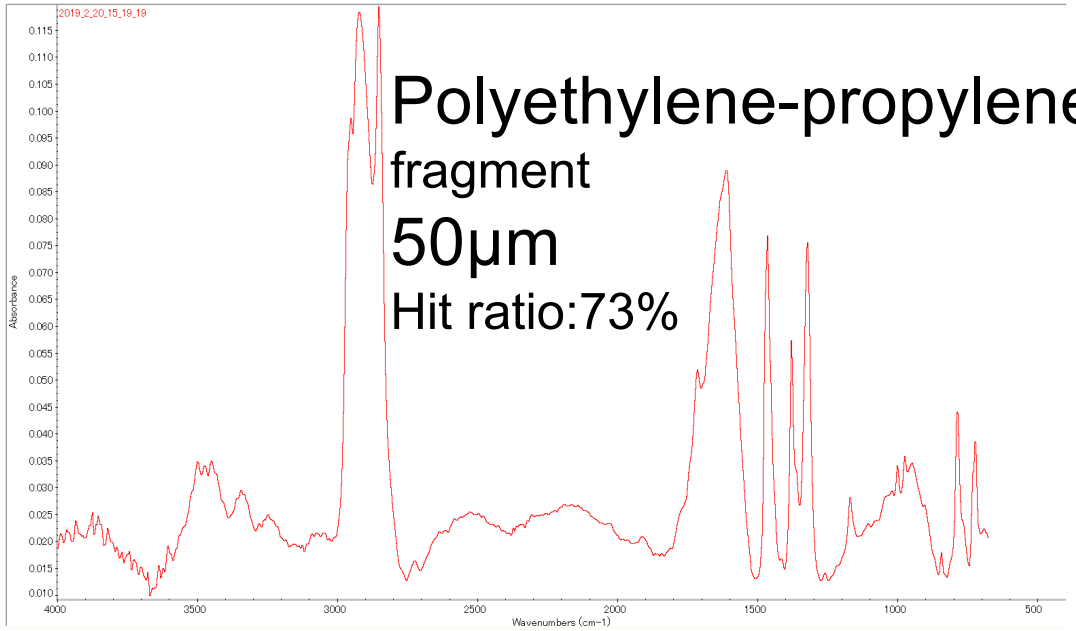
293 - 482 pieces/g-wet

Plastic
contaminated
beach



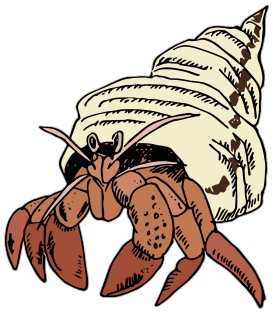


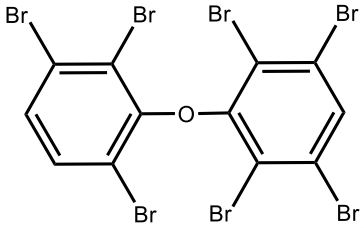




Images and FTIR spectrum of microplastics found in stomach of Hermit Crab

PBDEs (Additives : Brominated flame retardants) in hepatopancreas of Hermit Crab





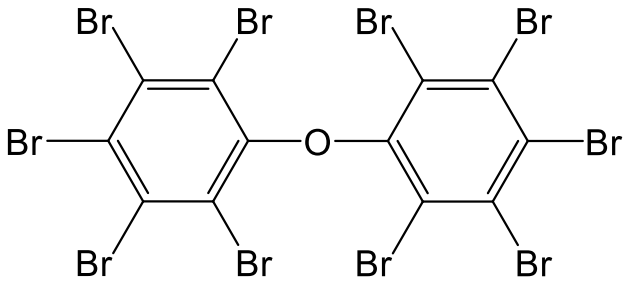
Control beach

Plastic contaminated beach

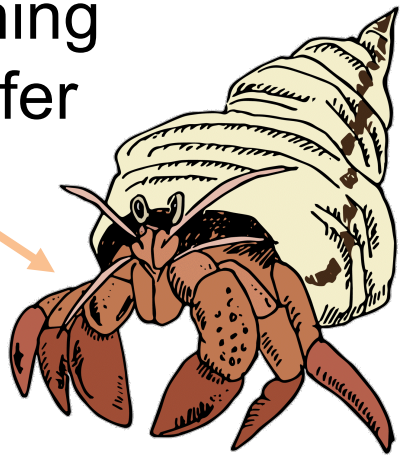
Mizukawa et al.

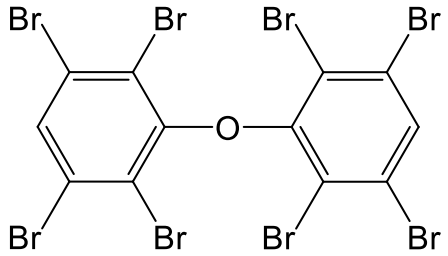
BDE209 was transferred to internal metabolic system and debrominated

BDE 209



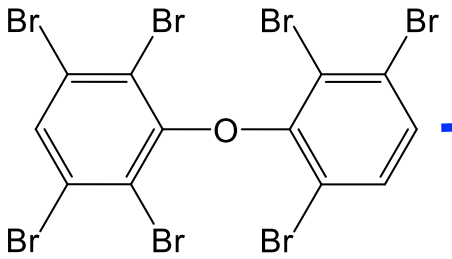
fragmentation
leaching
transfer



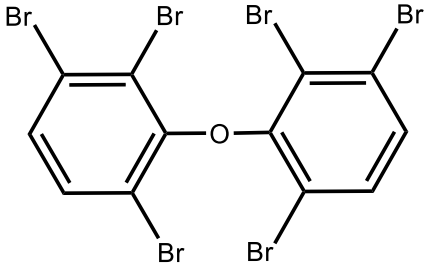


202

meta-debromination



179



136

Mizukawa et al.

Topics

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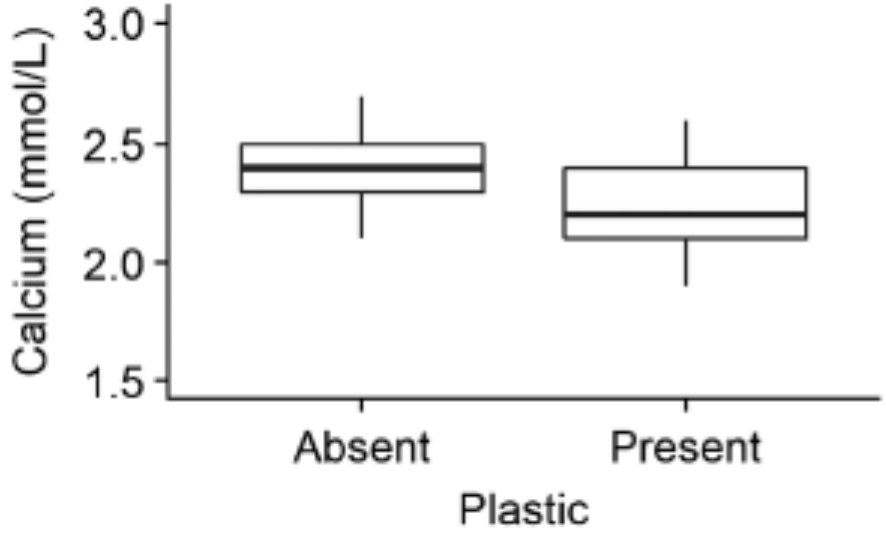
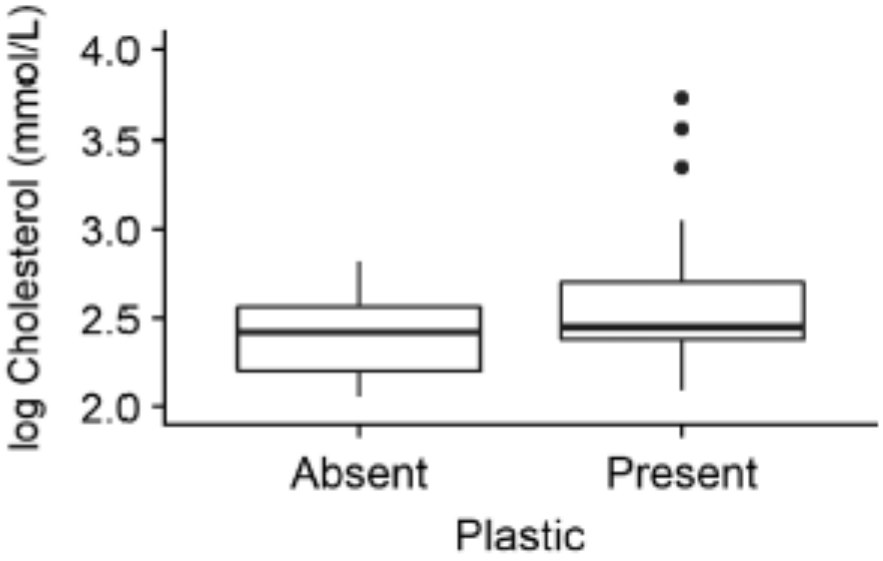
  - Mechanism
- Significance of the plastics as exposure media : Field observations
- Effects of the plastic-mediated chemical exposure

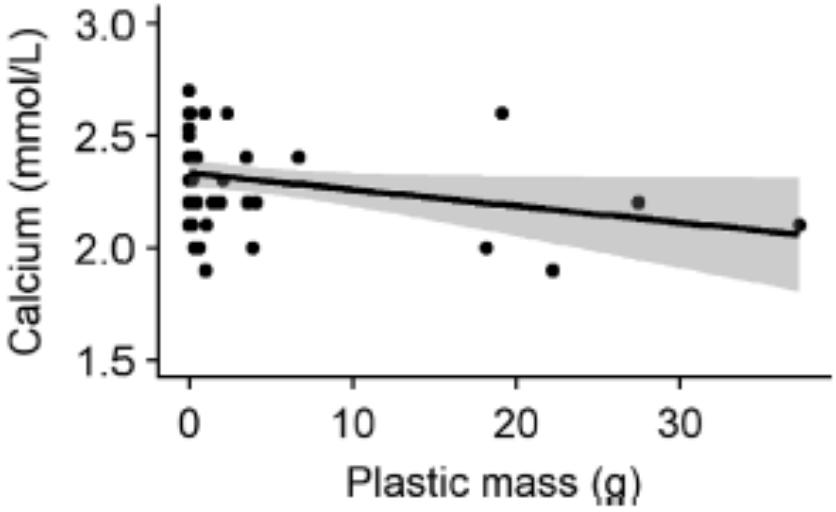
Environ. Sci. Technol. XXXX, XXX, XXX–XXX

Clinical Pathology of Plastic Ingestion in Marine Birds and Relationships with Blood Chemistry

Jennifer L. Lavers,*,† Ian Hutton,‡ and Alexander L. Bond†,§







Conclusions

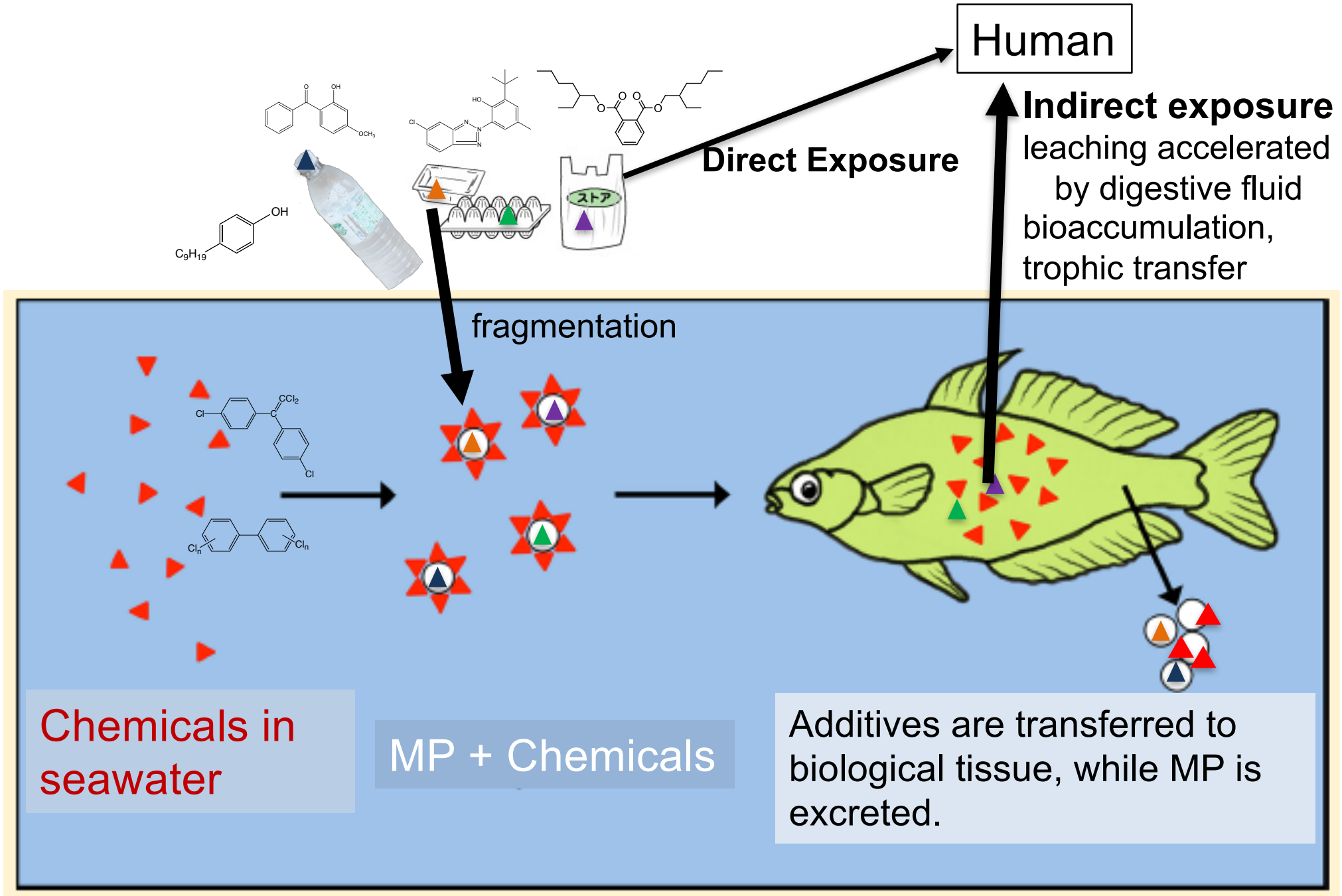
1. Both sorption- and additive-derived chemicals were retained in microplastics (PCBs, BDE209; 0.3 mm – 5mm).

2. Sporadic occurrence of microplastics with high concentrations of additives and sorbed chemicals were observed. Their exposure to remote ecosystem was suggested.

3. Transfer of hydrophobic additives to internal tissue of marine organisms was confirmed and it is facilitated by oily components in digestive fluid.

4. Plastic-mediated chemical exposure does occur and its significance depends on locations, background pollution, chemicals, species of biota, especially trophic levels.

Microplastic pollution : Acceleration of exposure of additives to human



Human Reproduction Update, Vol.23, No.6 pp. 646–659, 2017
Advanced Access publication on July 25, 2017 doi:10.1093/humupd/dmx022

human reproduction update

Temporal trends in sperm count: a systematic review and meta-regression analysis

Hagai Levine [1,2,*], Niels Jørgensen [3], Anderson Martino-Andrade[2,4], Jaime Mendiola[5], Dan Weksler-Derri[6], Irina Mindlis[2], Rachel Pinotti[7], and Shanna H. Swan[2]

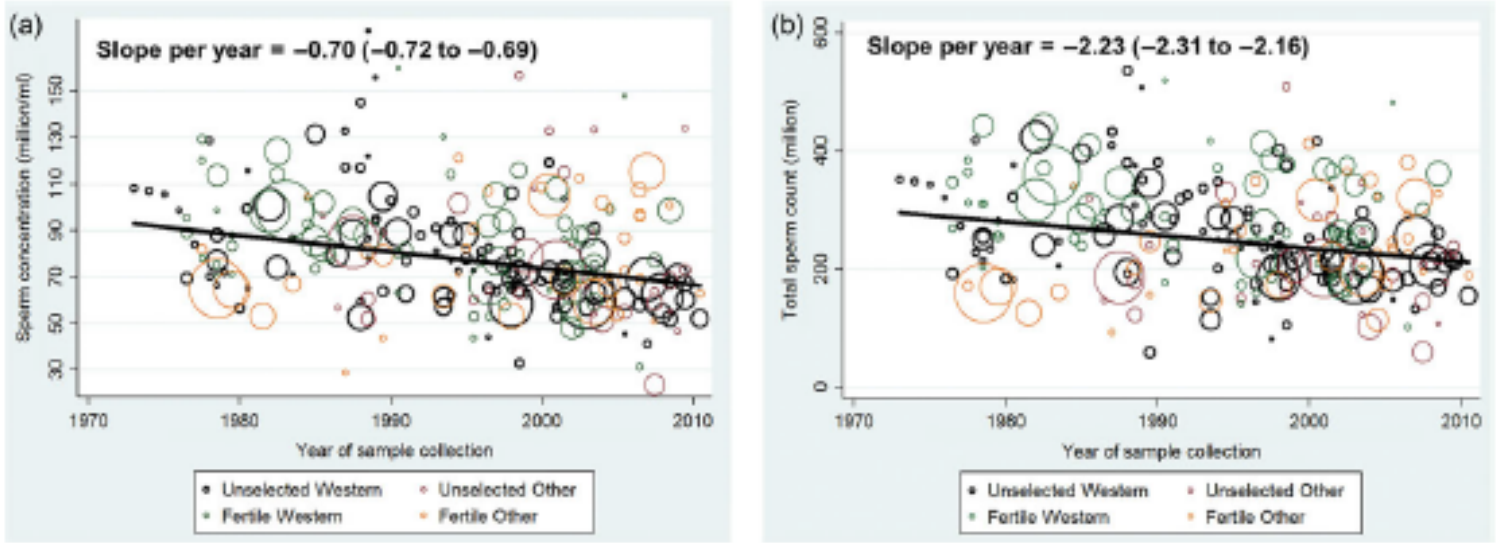


Figure 2 (**a**) Mean sperm concentration by year of sample collection in 244 estimates collected in 1973–2011 and simple linear regression. (**b**) Mean total sperm count by year of sample collection in 244 estimates collected in 1973–2011 and simple linear regression.

Direction of future efforts

Methodology to detect insidious biological effects on the field and by epidemiological survey

Endocrine disruption of variety of additives

Fate of additives

- Leaching from μm-size plastics
  transfer to lower trophic level organisms, biomaginification
- More field observations

Nano-size plastics

- Measurement
  biological effects

Yo-yo-effects of microplastics and legacy pollution

Acknowledgement