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**Issue of micro plastics in the coastal and marine environment
and 3R solutions**

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Issue of micro plastics in the coastal and marine environment and 3R solutions

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Sources of Microplastics

On global basis, 300 millions tons of plastics are produced annually. Half of them are single-use plastics. Some of them escape from land-based activities and discharged into rivers through surface runoff, and finally into the ocean. The amount of plastics entering into the ocean is estimated at several millions tons per year (i.e., 5 ~13 millions tons/y, Jambeck *et al.*, 2015). During their movement or floating on the sea surface and/or stranding on beaches, they are usually exposed to UV radiation and get fragmented into smaller plastics (Andrady, 2011). Fragments get smaller and smaller and finally they become microplastics (i.e., plastics less than 5 mm in diameter; Fig.1, Fig.2). In addition to fragmentation of plastic products, there are several other origins of microplastics in marine environments, i.e., resin pellets, microbeads in personal care products, chemical fibers from synthetic textile, shavings from sponge of synthetic fibers, etc. One of the oldest examples is plastic resin pellets, which are small granules, generally with shape of a cylinder or a disk (3 to 4 mm diameter) (Fig.3). These plastic particles are usually the industrial feed stock for production of plastic products and are transported to manufacturing sites where they are re-melted and molded into a wide range of final products. Resin pellets can be unintentionally released to the environment, both during manufacturing and transport and carried by surface runoff, streams and river waters eventually leading to the ocean. Their detection in the sea has been reported across the world since 1972 (Carpenter and Smith, 1972).

Smaller plastic particles with ~ hundreds μm are intentionally compounded into personal care products (e.g., facial cleaners) as scrub (Fig.4). Often sewer carries these microbeads to stream, rivers and finally to the sea. Sewage treatment system can remove these plastic particles (Carr *et al.*, 2016; Murphy *et al.*, 2016) with efficiency of 95% – 99 % but it's not 100% as some still escape from the system. More importantly, combined sewer overflow (CSO) occurring during heavy rain even in sewer areas discharges microbeads into the rivers and the sea. Actually, microbeads are found in coastal waters (Fig.5). Sewer carries another microplastics, i.e., lint of chemical fiber found in laundry wastewater. When clothes of chemical fiber such as polyesters are subjected to laundry, lint of chemical fibers are generated and discharged to sewer and finally to the ocean (Browne *et al.*, 2011). They are discovered in marine environments (Fig.6). Similarly, rubbing wastes from sponge of chemical fibers could be a source of microplastics in the sea. As described above, there are several origins of microplastics and all are significant to be regulated, monitored and managed. However, in our observation in microplastics in surface water, pelagic fishes, and coastal sediments, **fragmentation of plastic products is most important source of microplastics in the marine environment, especially in terms of chemical risk.**

Anthropocene : Ubiquitous occurrence of microplastics on earth : Horizontal and vertical dispersion

Plastics are hardly biodegraded and persist in marine environments for a long time. Due to the persistence and lightness, they make long travel, e.g., for thousands of kilometers, even to desert islands (Heskett *et al.*, 2012), and their pollution are dispersed

across the earth from Arctic (Obbard *et al.*, 2014) to Antarctic (Isobe *et al.*, 2016). Microplastics are found on the beaches of remote islands such as Easter Islands, Galapagos Islands, Macquarie Island (Eriksson and Burton, 2003). They are also accumulated in certain parts of open ocean, i.e., gyres (Moore *et al.*, 2001), due to oceanographic conditions (current and wind). Consequently, huge amounts of plastics (i.e., 5 trillions pieces or 270,000 tons of plastics, Cózar *et al.*, 2014; Eriksen *et al.*, 2014) are floating on world ocean (Fig.7 from Dr. Eriksen). Higher abundance of microplastics in western pacific has been recently revealed (Isobe *et al.*, 2015) and this may be related to intensive consumption of plastics in Japan and greater emission of plastic wastes from tropical Asian countries and their transport by the sea current. Rapid economic growth and associated **increase in plastic consumption in the Asian countries and inadequate waste management in those countries has led to the greater emission of waste plastics from land to the sea** (Jambeck *et al.*, 2015).

Plastic and microplastic pollution are dispersed not only horizontally but also vertically in marine environments. Large plastic items such as PET bottles are found on ocean floor (e.g., Galgani *et al.*, 1996). Microplastics are accumulated also in bottom sediments in coastal area (Claessens *et al.*, 2011; Vianello *et al.*, 2013; Matsuguma *et al.*, 2017) to deep sea (Van Cauwenberghe *et al.*, 2013). The amounts of microplastics in bottom sediments are greater than those in surface water and bottom sediments could play as huge sink of microplastics on their global mass balance (Matsuguma *et al.*, 2017). Sediment cores can be utilized as historical archives of marine pollution (Smol 2002). In the sediment cores from Europe (Claessens *et al.*, 2011), Asia and Africa (Matsuguma *et al.*, 2017, Fig.8), increasing trends in microplastics pollution were observed from the deeper (older) to surface (younger) layers. These provide solid evidence of **global increase of microplastic pollution. The results are in accordance with the Anthropocene** being an epoch when human activities significantly impacted Earth's geology, atmosphere and ecosystems (Crutzen and Stoermer, 2000; Waters *et al.*, 2016).

Ingestion of plastics by fish and shellfish: Threat to biodiversity and food security

Plastic fragments in the ocean are ingested by marine organisms of various sizes depending on the sizes of plastic fragments. Ingestion of larger items (e.g., ~ cm) by large marine organisms such as whales, sea turtles, and seabirds (Fig.9) has been often reported since 1970s (e.g., Rothstein, 1973) and reviewed by Ryan (2016). Ingestion rate has been increasing (Fig.10, Yamashita *et al.*, 2016). There are spatial and temporal variations in susceptibility of seabirds to plastic ingestion depending on species and feeding behavior (Ryan, 2016). Wilcox *et al.* (2015) estimated that plastics can be found in stomachs of up to 90 % of seabirds across the world. Plastics were discovered in digestive tracts of sea turtles and whales, too. As of 1997, plastic ingestion was reported for 177 species of marine organisms (Laist, 1997). Physical impacts of plastics on the organisms have been observed (Wright *et al.*, 2013). This implies that **marine plastic pollution may lead to decrease in biodiversity.**

Recently, ingestion of smaller plastics, i.e., microplastics, by smaller organisms, i.e., shellfish (e.g., Van Cauwenberghe and Janssen, 2014; Li *et al.*, 2015) and fish (Lusher *et al.*, 2013; Tanaka and Takada, 2016) was reported. For example, ~ 80 % of anchovies taken from Tokyo Bay, Japan, contained ~ 1 mm microplastics in their digested tracts (Tanaka and Takada, 2016, Fig.11). **This may raise potential threat to food security.** The amounts of plastics in the digestive tract was significant but trivial (2 to 3 pieces per one individual on average) for present (Tanaka and Takada, 2016).

Even if human would consume the fish containing this amount of microplastics in their digestive tracts as food, plastics with these sizes can be excreted and are not expected to be accumulated in specific organs of human. In any way, the presence of microplastics in seafood has become a serious concern. Studies identified microbeads which could be derived from personal care products and chemical fibers in fishes. **However, plastic fragments were predominant** (Fig.12). Predominance of plastic fragments was observed also in surface water (Isobe, 2016). Furthermore, in shellfishes and fishes on a market in Indonesia (Rochman *et al.*, 2015), microplastics were identified and the majority was fragments. **These studies imply that the reduction of plastic wastes from land to sea is one of the top priorities for the regulation.** However, dominance of chemical fibers was reported in the shellfishes and fishes in the market of USA (Rochman *et al.*, 2015) and bivalves from Chinese coast (Liet *et al.*, 2015). More systematic survey together with the assessment of impacts of chemical fiber is necessary.

As larger plastics pose physical impacts on larger marine animals such as seabirds and sea turtles, microplastics may pose physical threat to fish and bivalves. Studies showed that by 2-month-exposure of μm -size polystyrene particles to oysters, significant decrease in their population was observed (Sussarellu *et al.*, 2016). This indicates that microplastics could affect on reproductive system of oyster, though responsible chemicals have not been identified (Sussarellu *et al.*, 2016). Concentration of exposed microplastics seems higher than those present in the environments, though direct measurement of μm -size polystyrene has not been done. We should consider the results of the laboratory experiments as warning bell for the ocean environment as well as our future.

Warning bell of chemical threat of marine plastics and microplastics

In addition to the physical impacts, marine plastics and microplastics may pose chemical or ecotoxicological effects on marine organisms. This is because marine plastics contain various hazardous chemicals as shown in Fig.13. They are categorized into two groups, i.e., additives and chemicals sorbed from the surrounding water. Most of plastic products (i.e., user plastics) contain additives such as plasticizers, antioxidants, UV absorber, flame retardants to maintain their properties. For example, our study demonstrated that even from plastic caps for mineral water bottles, endocrine disrupter nonylphenols were detected (Fig.14). We surveyed 93 caps from 63 brands sold in 18 countries and detected nonylphenols in 44 samples from several countries including the USA, EU countries, and China. We also detected nonylphenols in plastic caps stranded on beaches (Takada, 2013). Nonylphenols in mineral water bottle caps are just a tip of an iceberg, and various hazardous chemicals derived from additives have been detected in various plastic fragments on the beaches (Hirai *et al.*, 2011; Rani *et al.*, 2017). The additives are still retained in microplastics collected from marine environment, even open ocean, though additives, especially hydrophilic ones, are leached out to seawater during floating of the microplastics.

Furthermore, microplastics absorb and accumulate persistent organic pollutants (POPs) from surrounding seawater. POPs are one group of persistent man-made chemicals such as PCBs which is oil used for wide-range of industrial purposes (e.g., lubrication, transformer), DDTs and HCHs both of which are used for pesticides. They are rarely soluble to water and their concentrations in seawater is traceable. However, due to their hydrophobicity, i.e., higher affinity with oily materials, they tend to be partitioned into fatty tissue of marine organisms. This process is so-called bioconcentration. Also in food web, concentrations of POPs are magnified and their

concentrations in higher-trophic-level organisms such as seabirds could reach level where adverse effects may occur with the organisms. Therefore, POPs are regulated by international conventions such as Stockholm Convention. Key property is hydrophobicity. Plastics are very much hydrophobic media and have higher affinity with POPs. In other words, plastics are solid form of petroleum and can dissolve POPs with higher concentrations. Higher affinity of microplastics with POPs have been demonstrated by International Pellet Watch (<http://www.pelletwatch.org/>) (Ogata *et al.*, 2009; Takada and Yamashita, 2016). Distribution of PCBs in pellets is shown in Fig.15. Every single pellet stranded on the beaches in the world contains significant concentrations of PCBs. This means that microplastics accumulate POPs from surrounding seawater. PCBs is just an example, and microplastics accumulate all the hydrophobic chemicals in sea water. Thus, microplastics can be considered as a cocktail of range of hazardous chemicals for the marine organisms.

Because marine organisms ingest plastics and they contain various hazardous chemicals, marine plastics can be considered as potential vector of hazardous chemicals to marine organisms. We have to consider occurrence of the transfer of the chemicals from plastic to the tissue of organisms. There was a need to examine whether the chemicals can be released from plastics to digestive fluid before excretion of plastics and can be transferred of chemicals from the plastics to the tissue of the organisms. Recently, field observation on seabirds (Yamashita *et al.*, 2011; Tanaka *et al.*, 2013; Tanaka *et al.*, 2015), feeding experiment using seabirds (Teuten *et al.*, 2009), and laboratory experiments by using fish (Wardrop *et al.*, 2016) demonstrated that hazardous chemicals were transferred from ingested plastics to the tissue of organisms. However, marine organisms are exposed to hazardous chemicals from natural diet in addition to the ingested plastics, and therefore, evaluation of the contribution of plastic-mediated exposure relative to natural diet is critical. The contribution depends on the background contamination levels of the site and the amount of plastics. In case of additives, plastic-mediated exposure can be more important than the natural path, because some additives are not biomagnified through the food web and their concentrations in higher-trophic-level organisms are low (Fig.16). Regarding sorbed chemicals such as PCBs, in the contaminated areas, contribution from plastic-mediated exposure would be minor. This is because organisms in the contaminated sites are already contaminated with the chemicals. However, in case that contaminated plastic would be transported to remote areas with lower background contamination levels, contribution of plastic-mediated exposure could be important (Fig.17). International Pellet Watch demonstrated that microplastics with sporadically high concentrations of hazardous chemicals are transported to remote islands (Heskett *et al.*, 2012 and Fig.18). For present, the plastic-mediated exposure of hazardous chemicals is minor and no adverse effects have been observed in natural environments. In laboratory experiments, adverse effects (e.g., hepatic stress, liver tumor) caused by chemicals exposed through plastic ingestion have been demonstrated (Browne *et al.*, 2013; Rochman *et al.*, 2013). However, the amounts of plastics exposed to the organisms in the experiments were higher than those observed in natural environments. In future, when the amounts of plastics would increase, contribution from ingested plastics would be greater (Fig.19).

All in all, effects of plastics and microplastics are complicated. We have not seen obvious adverse effects of microplastics and associated chemicals on marine organisms in real world. However, we got some warning bells regarding the chemical impacts on marine organisms, i.e., observed adverse effects in laboratory experiments and long-range transport of contaminated plastics and microplastics to remote areas.

When the amounts of microplastics would increase in future, we may encounter adverse effects on marine organisms and eventually on human. Microplastics disperse in surface and subsurface layers of seawater together with natural planktons. It is impossible to remove only microplastics without taking the natural planktons by our current technology. Therefore, prevention of plastics waste, including microplastics, in marine environment is very important. Another point to emphasize is that plastics are persistent in marine environments and their amounts have been steadily increasing. Actually we have observed increasing trend in plastics and microplastics in marine environments. That is, our measurement of microplastics in sediment cores from Asia and Africa demonstrated the increasing trend in microplastic pollution (Fig.8). Some model calculation also indicates that amounts of plastics in the ocean would be 10 times than the present amounts in coming 20 years if we will not take any action (Jambeck *et al.*, 2015). Thus, as a precautionary principle, we should reduce and stop the input of plastics into marine environments.

3R (reduce, reuse, recycle) : Key of solution of marine plastics and microplastic pollution

Sources of marine plastics are primarily land-based single-use plastics. Jambeck *et al.* (2015) estimated that annually 5 to 13 millions tons of plastic wastes enter into the ocean on global basis. Their estimation based % mismanaged plastic wastes. This means that waste management as well as amounts of plastic waste control the plastic inputs to the ocean. For example, Japan generate 7.15×10^6 tons of plastic wastes annually. This is the third in the world next to USA and China. However, plastic wastes are relatively well managed and only 0.7 % is mismanaged and consequently 35×10^3 tons of plastic wastes are estimated to enter into the ocean. This amount is 30th in world. On the other hand, Southeast Asian countries poorly manage plastic wastes and they discharge large amounts of plastic wastes to the ocean. For example, Indonesia generates 3.89 millions tons of plastic wastes annually. Percent mismanage of plastic wastes is 30.2 % and, consequently 804×10^3 tons of plastic wastes are estimated to enter into the ocean. This amount is 2nd in world. These indicate waste management together with generation of plastic wastes on land is critical to control the inputs of plastics into the sea.

Collection of waste is important and critical step to reduce the littering of plastic wastes on land. Littered plastic wastes are carried by surface runoff to find their way to the ocean. For example, Japan has established an excellent system of waste collection which reduces the littered plastics and finally reduce the amounts of plastics to the sea. Next concern is treatment of the collected plastic wastes. Landfill of waste is common practice of waste-management in many countries. However, we have limited area for landfill on global basis. Furthermore, based on our studies in landfill sites (Teuten *et al.*, 2009; Kwan *et al.*, 2013), landfill leachate discharge toxic chemicals to rivers and groundwater (Fig.20). Dumped plastics (additives, monomers, and oligomers) are major sources of the toxic chemicals in the leachate. To decrease the toxicity of landfill leachate, sorting of plastic wastes from organic wastes (food waste, kitchen waste and so on) is important, because dumping of organic wastes cause anaerobic conditions where some plastic additives could be converted to toxic chemicals (Kwan *et al.*, 2013). Thus, segregation of waste together with collection of waste are recommended to reduce the problems associated with plastic wastes.

Incineration is another option of waste-management. For example, 68 % of plastic wastes generated in Japan is incinerated. However, incineration of plastics produces toxic products such as dioxin and polycyclic aromatic hydrocarbons. We can

prevent the emission of the toxic chemicals from the treatment facilities by using sophisticated technology. However, huge cost involved to construct the facilities and to maintain their performance (e.g., replacement of expensive filters) and risk associated with accident are always big challenges. For example, construction of a modern incinerator with negligible dioxin emission covering 400 thousands inhabitants takes 100 millions USD and running cost is 2 millions USD per year. Because its life time is 30 years, 100 millions USD must be prepared for every 30 years. It seems not sustainable. In addition, ultimate discard of expired treatment facilities, which contain extremely large amounts of hazardous materials, could place a heavy financial burden on the future generations. Fundamentally, incineration of plastic waste is not sustainable and not circular and not consistent with Paris Agreement on Climate Change. As plastic is a solid form of petroleum, incineration of plastics emits CO₂ and would not be in consistent with the Paris Agreement. Production of plastics utilizes 8 % of global oil production. As it can be seen from the global carbon cycle (Fig.21), combustion of fossil fuel is not circular. Fossil fuel is generated from dead organisms in the past and formation of fossil fuel in the crust takes more than millions years. Thus, once fossil fuel is combusted, it would take millions years or more until the fossil fuel is again generated.

As we discussed above, landfill and incineration are not clean and sustainable option for the treatment of plastic waste. We need to minimize the amounts of plastic wastes to be landfilled or incinerated. Toward zero landfill and incineration, key is 3R (reduce, reuse, recycle). Among 3R, reduction has priority from the view point of prevention of microplastic pollution and reduction of CO₂ emission. Good example is regulation of plastic shopping bags. More than 24 countries, usage of plastic shopping bags is banned, charged, or taxed (Table 1). In 2014, EU headquarters ordered the member states to have regulatory options to reduce by 40 plastic shopping bags per person per year. Plastic shopping bags are normally made of polyethylene (PE) which has highest affinity with POPs. PE is lighter than water and float on sea and can make a long travel. Thin nature of the shopping bag facilitates their fragmentation, i.e., their turning to microplastics. Thus, plastic shopping bags are reasonable target of the regulation. The regulation should be facilitated more in many other countries and globally by international architecture such as convention. Regulation on plastic food containers and beverage bottles is another good example. In France, a law to regulate the plastic containers and bottles for food and drinks has been established in September 2016 and regulation will be starting in 2020. In these contexts, regulation on single-use plastics, especially plastic bags, could be considered as a useful option for SDG 14.

Even after through reduction, we would need to use single-use plastics for many aspects of our daily life. There are several options to mitigate the impacts of such plastics. Recycling of plastics is third option next to reduction and reuse of plastics. For example, material recycle and chemical recycle represent 26 % of material flow of plastic waste in Japan. Recycle also should be facilitated. However, recycling takes energy and cost. For example, just for transport of PET bottles from collection points to recycling factories in a city with 220 thousands inhabitants, it takes one million USD per year. Thus, we should reduce and reuse first. Also replacement of plastics with biomass-based materials (i.e., paper and wood) is important and promising option, especially in tropical countries where biomass is rich. For example, companies of wooden lunch boxes, which is replacement of widely used plastic disposable lunch boxes, have been expanding their business in Japan, though it's still minor in share of lunch boxes. Development of biomass-based materials is demanding option. Lowering their cost is also important. When we promote the biomass-based replacement

or alternative, we should be careful with conflict with food production. Application of “biodegradable” plastic is another option. However, their degradability depends on environmental conditions and normally degradation of biodegradable plastics is slow in marine environment because bacteria in soil is responsible bacteria and their density is low in marine environments. We should treat biodegradable plastics in a closed degradation system such as incubator before they would be discharged to the environments.

As discussed above, there are several options for citizens to conduct to reduce plastic pollution in the sea (i.e., 3R and alternative materials). For the facilitation, increase in the awareness of the problems is necessary. In that aspect, beach-clean-up is good tool for the public awareness.

Recommendation

Based on the discussion above, the followings are recommended to reduce the inputs of plastic waste to the sea.

General concept : Promotion of waste management based on 3R (Reduce > Reuse > Recycle). All options should follow circular economy.

Specific solution options :

- Regulation of single-use plastics, especially plastic shopping bag.
- Establishment of social system and increase public awareness to efficiently collect and segregate garbage.
- Product and package design to facilitate reuse and recycle.
- Promotion of utilization of biomass and biomass-based plastics.
- Establishment of social system to facilitate the recycling of plastics.
- Development of biodegradable plastics together with their treatment system.
- Activating beach-cleanup
- Increasing public awareness on plastic pollution

There is no single solution to address the issues of plastic waste but smart combination of these measures are necessary for individual countries depending on their prevailing conditions and economy. Among the options, promotion of 3R, especially source reduction, is the key.

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Microplastics

< 5mm

Fig. 1 Microplastics collected in western Pacific

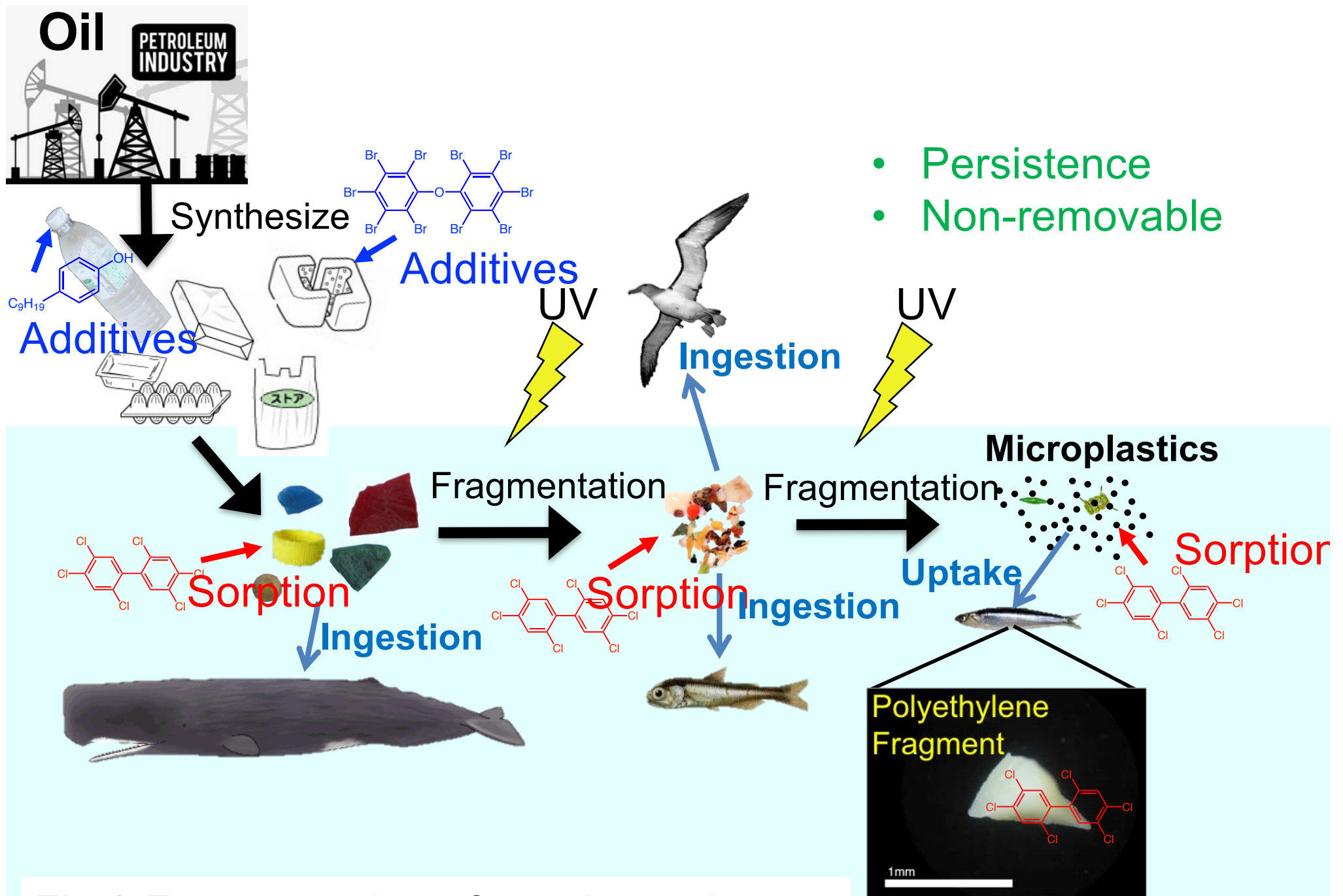


Fig.2 Fragmentation of plastic products and formation of microplastics.



Fig.3 Plastic Resin Pellets

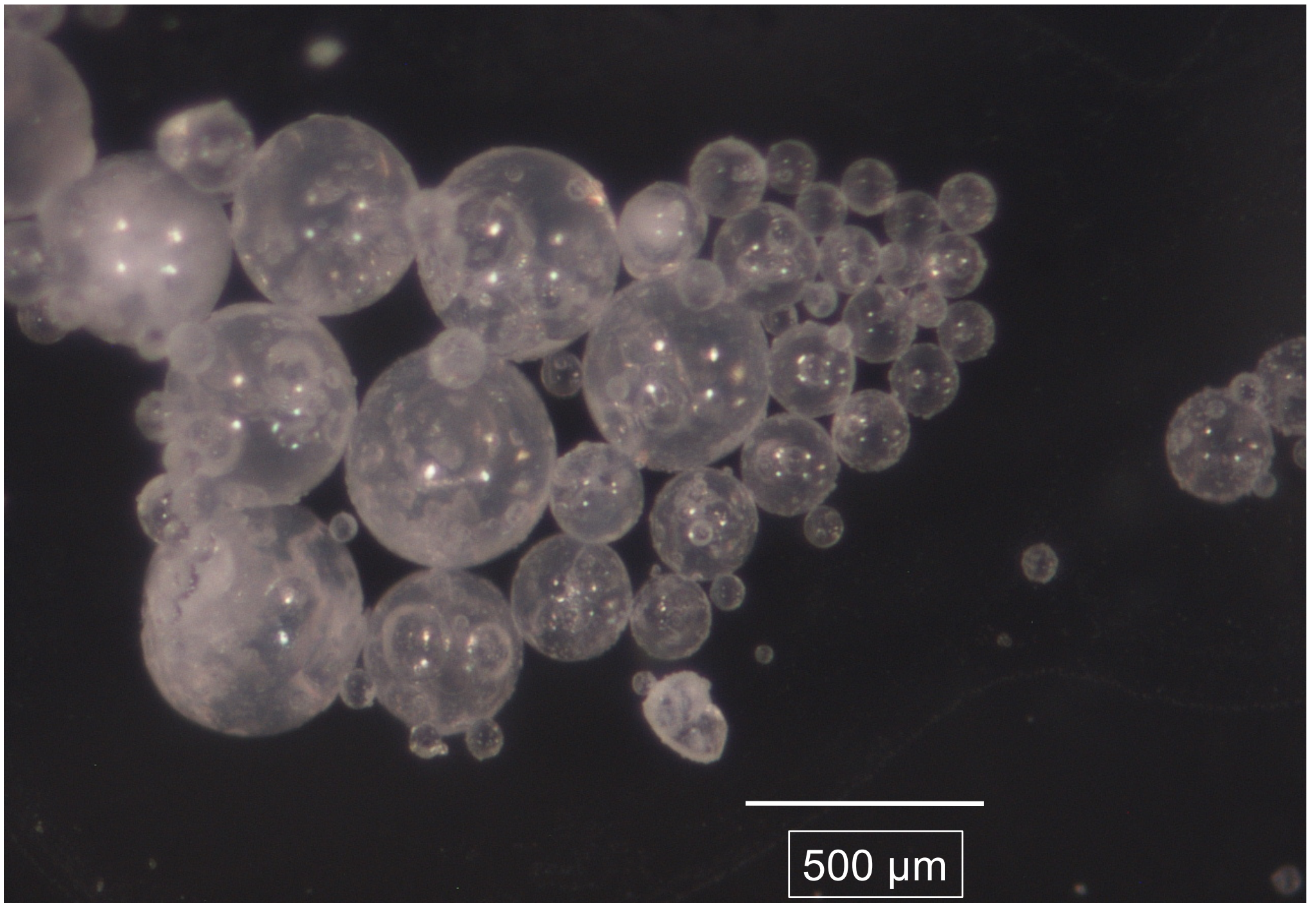


Fig.4 Plastic beads in facial cleaner

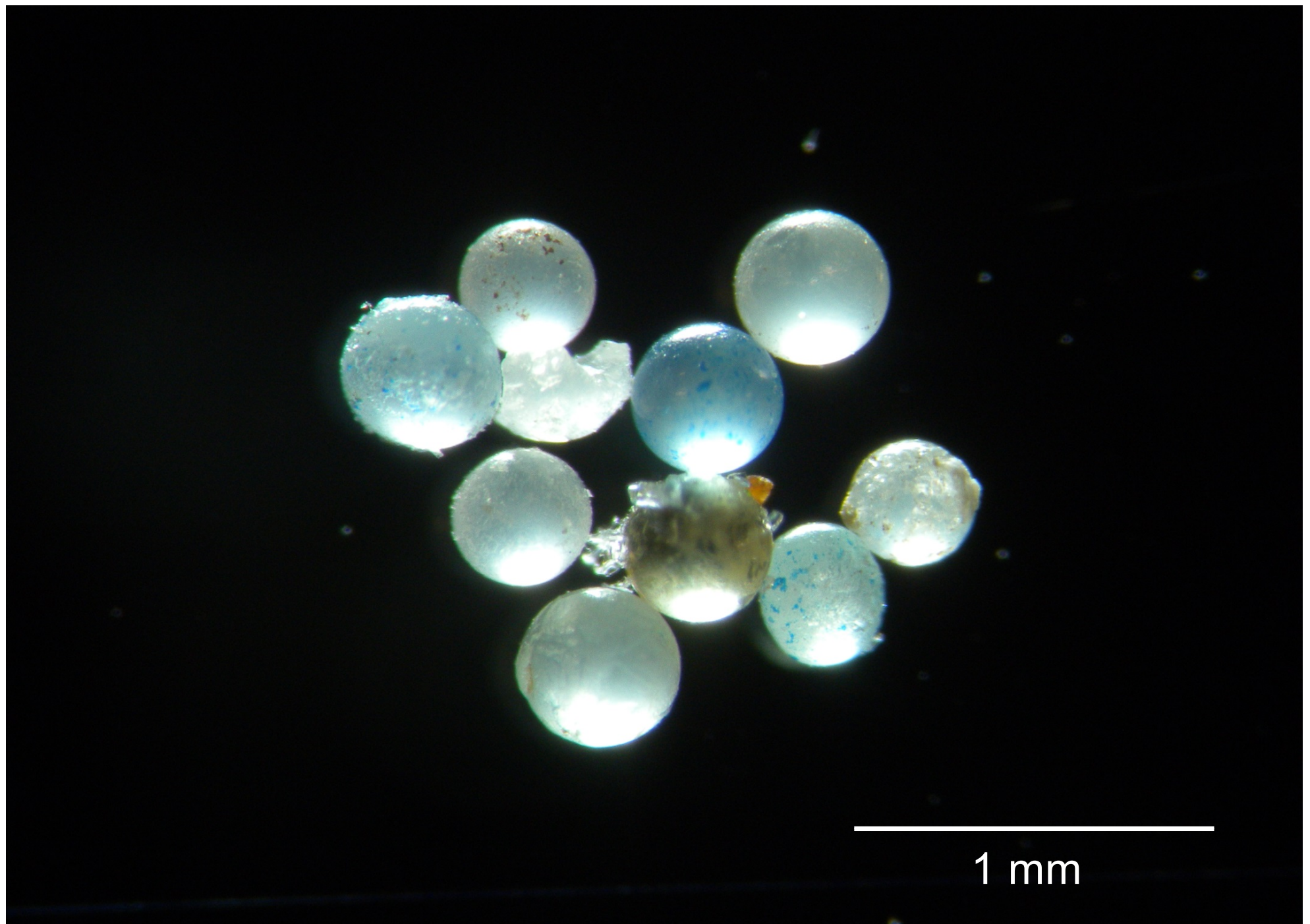


Fig. 5. Micorbeads collected from water in Tokyo Bay

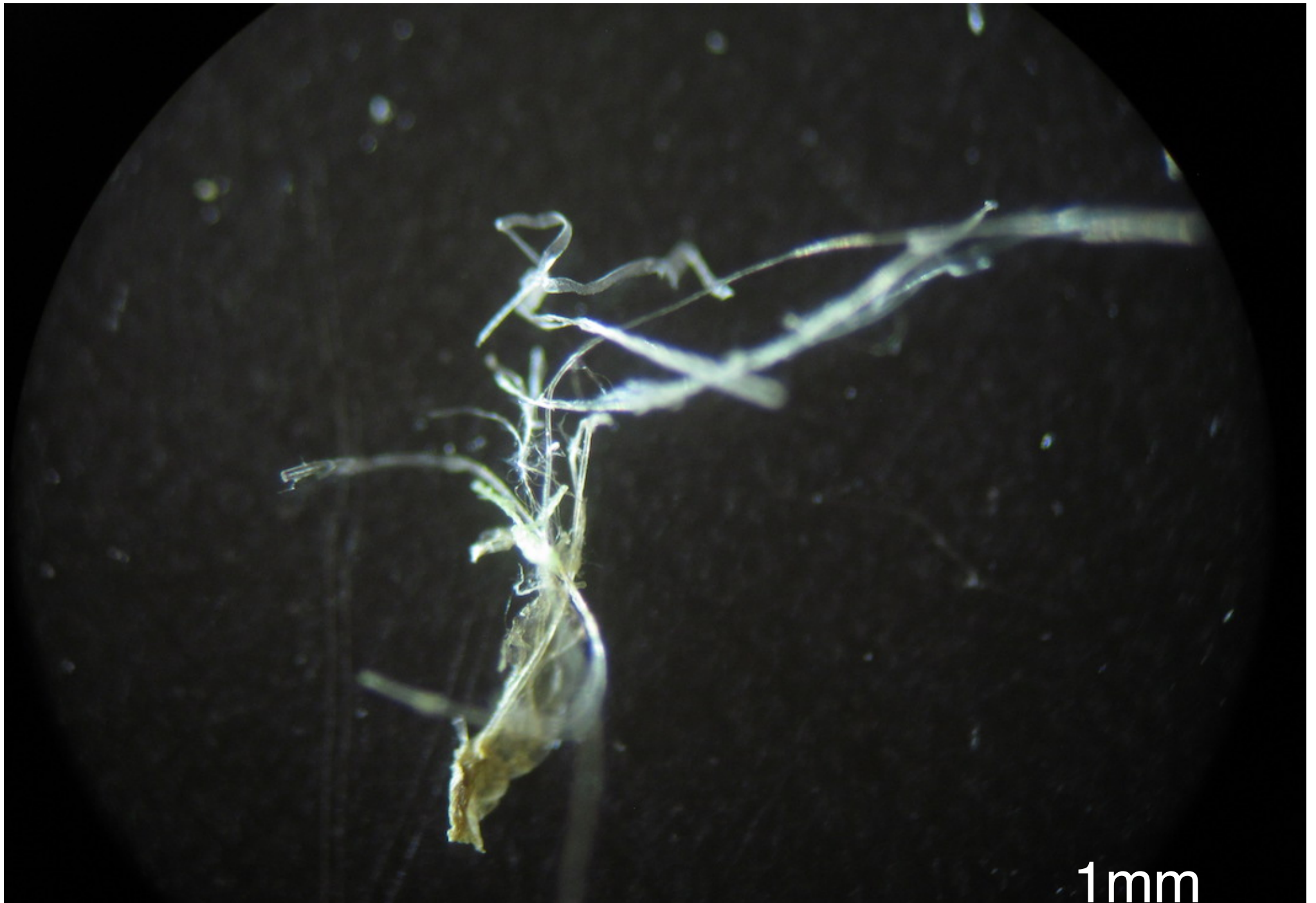
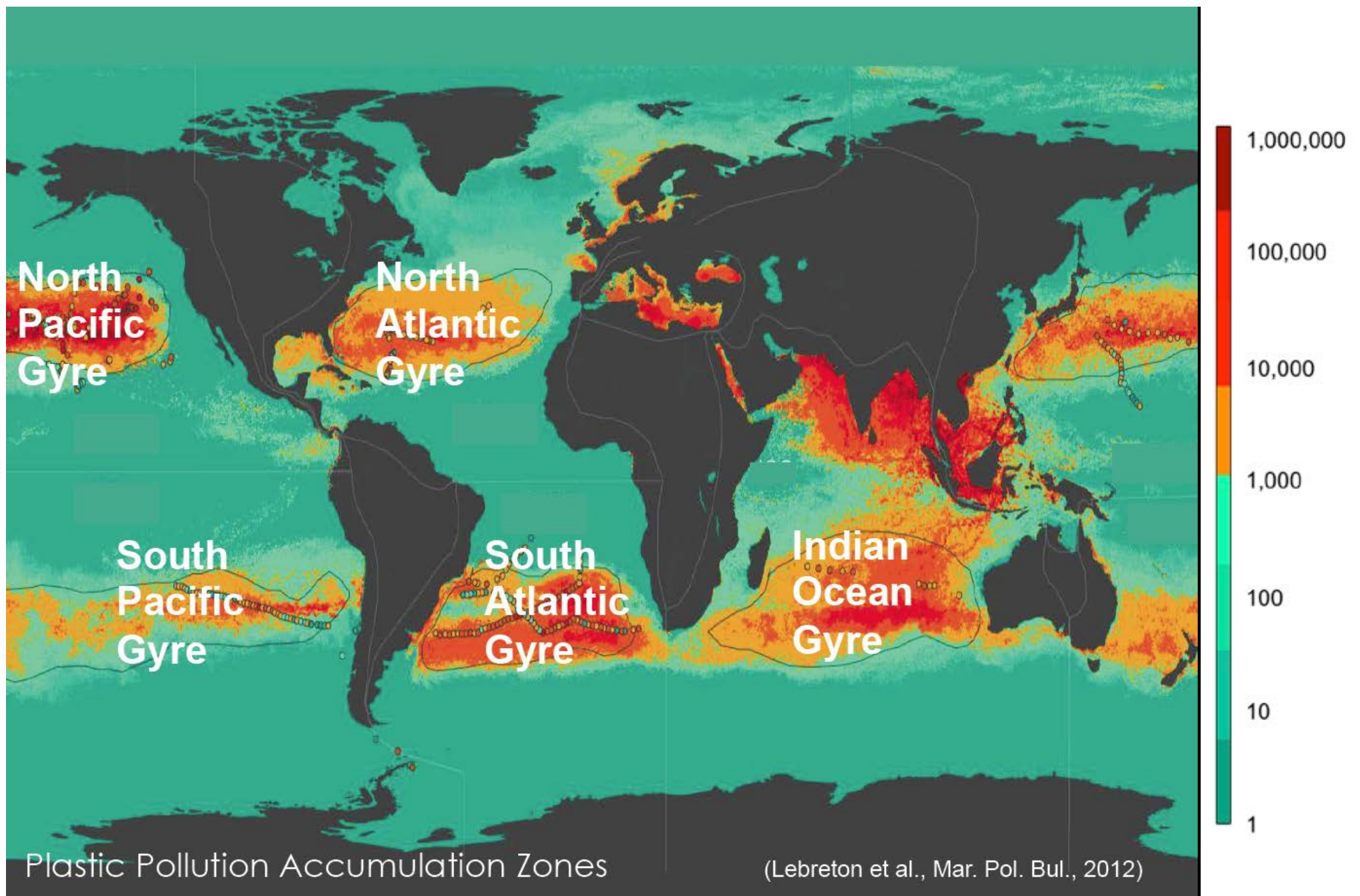


Fig. 6. PET Fiber in Tokyo Bay sediment



After Dr. Marcus Eriksen (pieces/km²)

Fig.7. Distribution of microplastics in world ocean

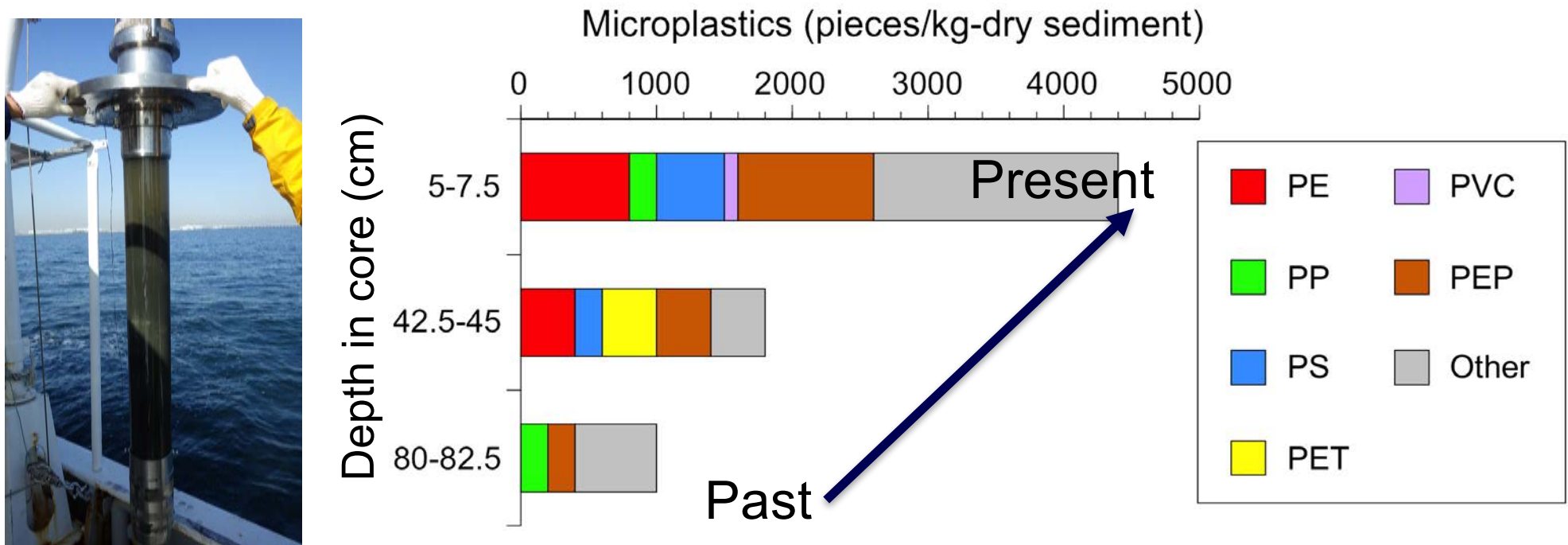


Fig. 8 (a). Vertical profile of microplastics in sediment core from Tokyo Bay, Japan

Tokyo, Japan, Moat of Imperial palace

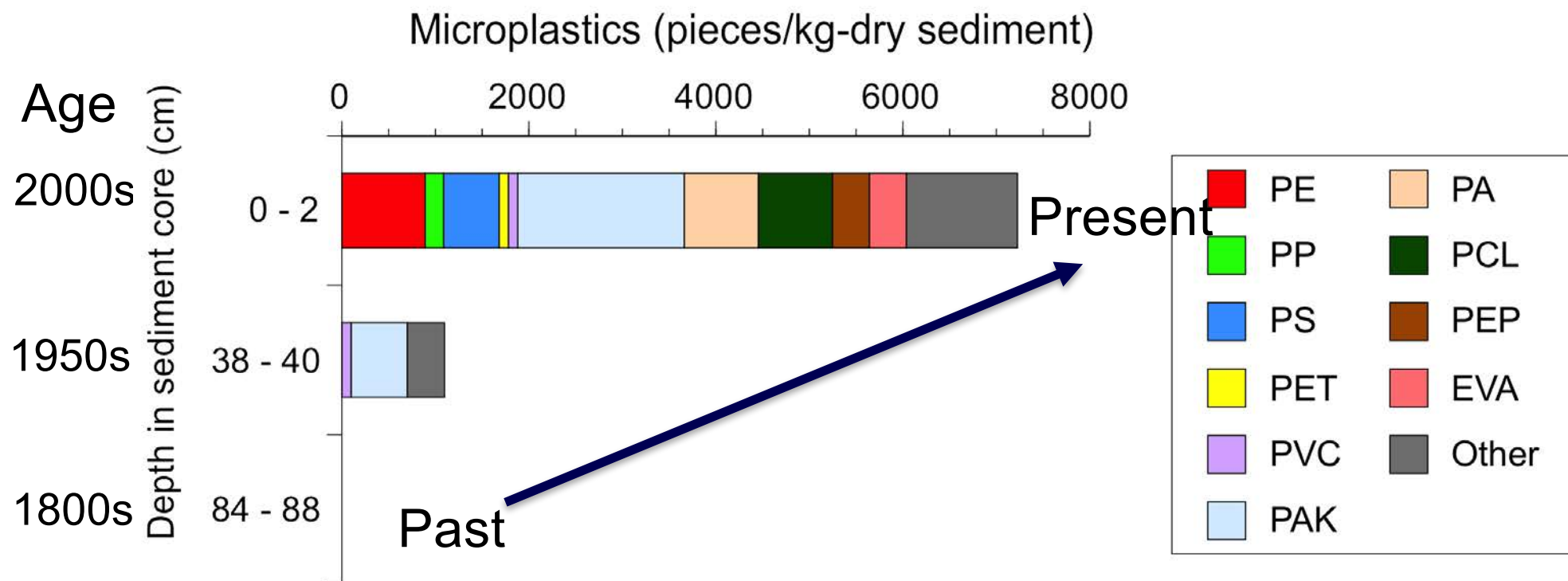
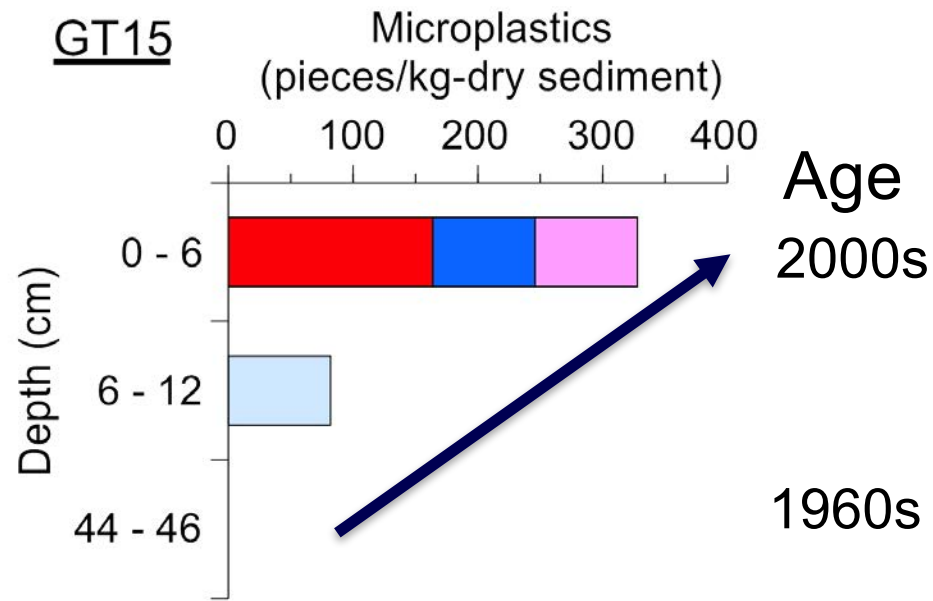


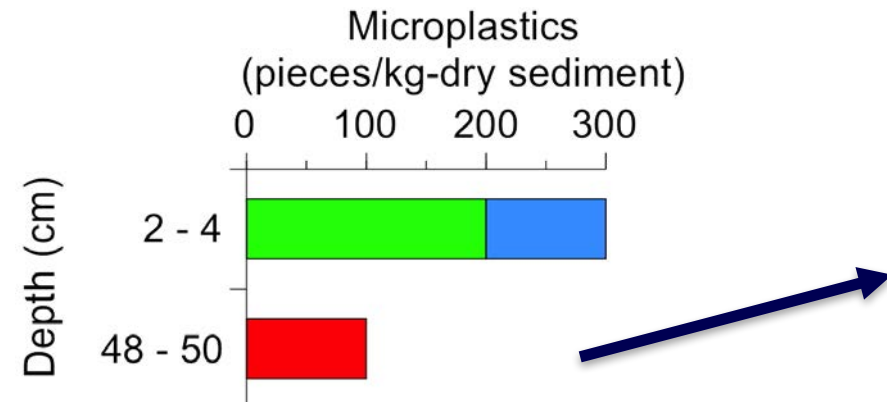
Fig. 8 (b). Vertical profile of microplastics in sediment core from the Imperial moat located in downtown Tokyo, Japan

After Matsuguma et al. (in press in *Arch. Environ. Contam. Toxicol.*)

Thailand (Gulf of Thailand)



Malaysia



South Africa

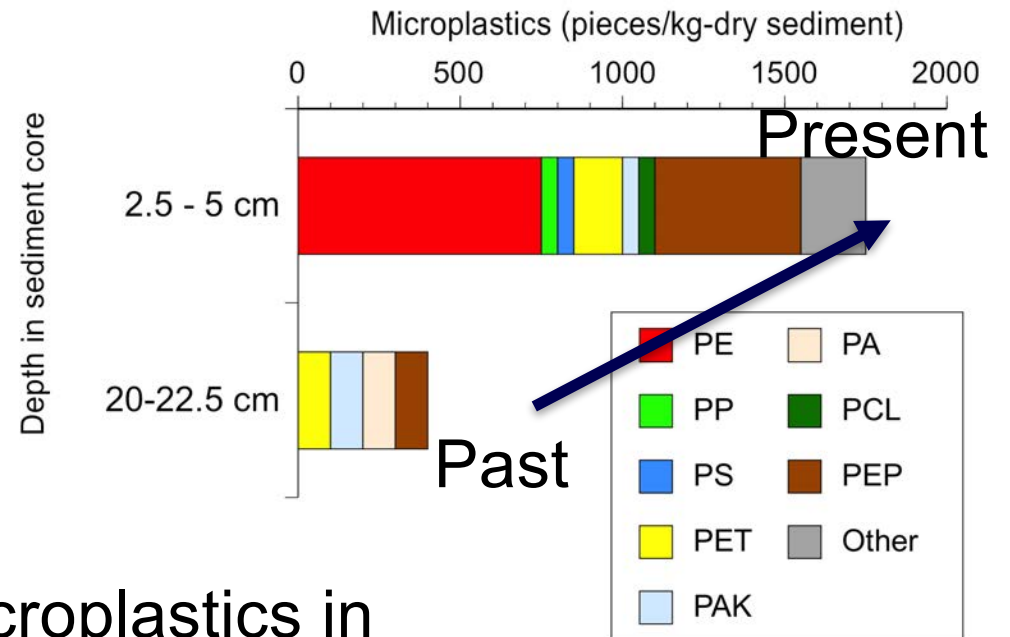
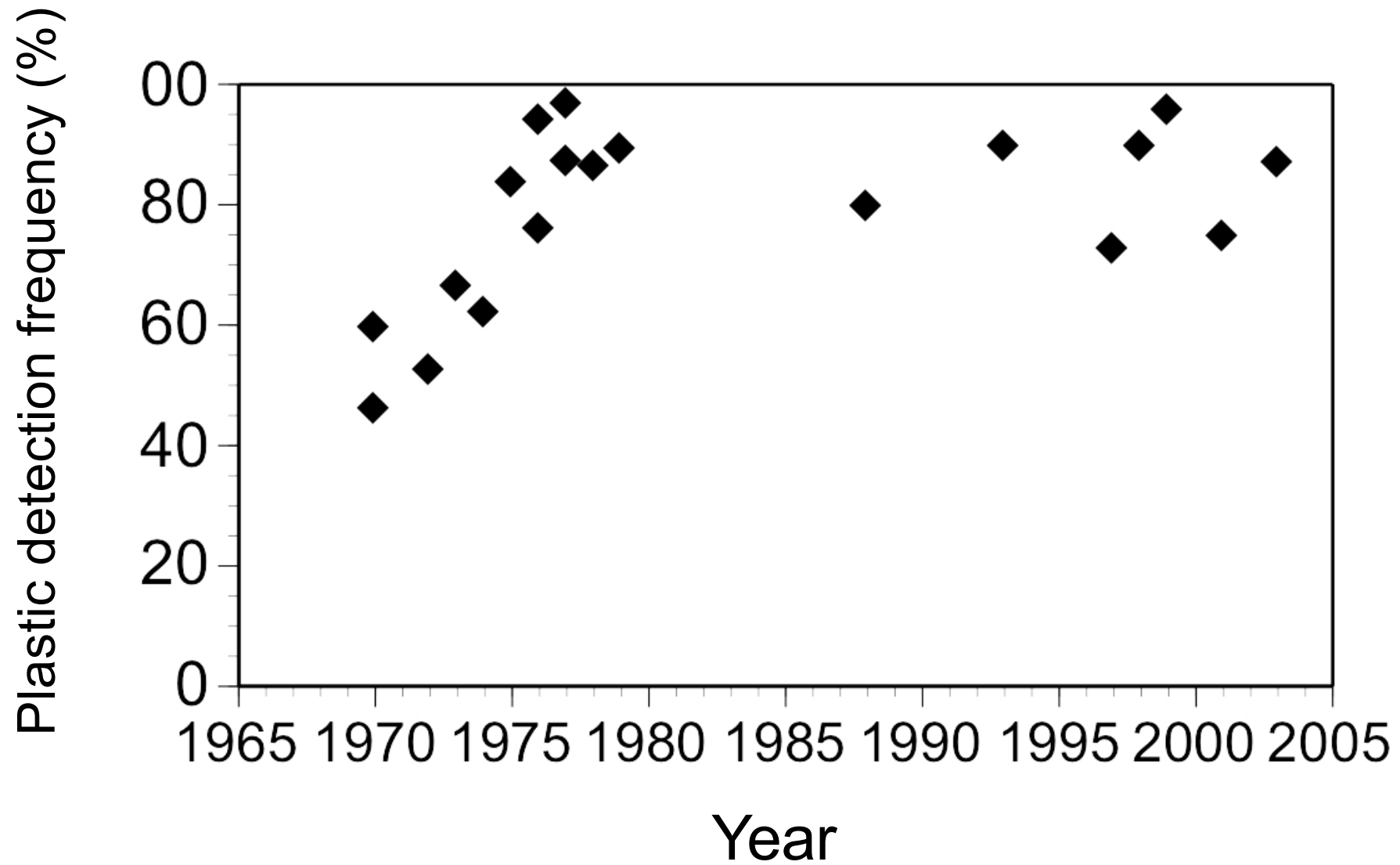


Fig. 8 (c). Vertical profiles of microplastics in sediment cores from Asian and African waters

After Matsuguma et al. (in press in *Arch. Environ. Contam. Toxicol.*)

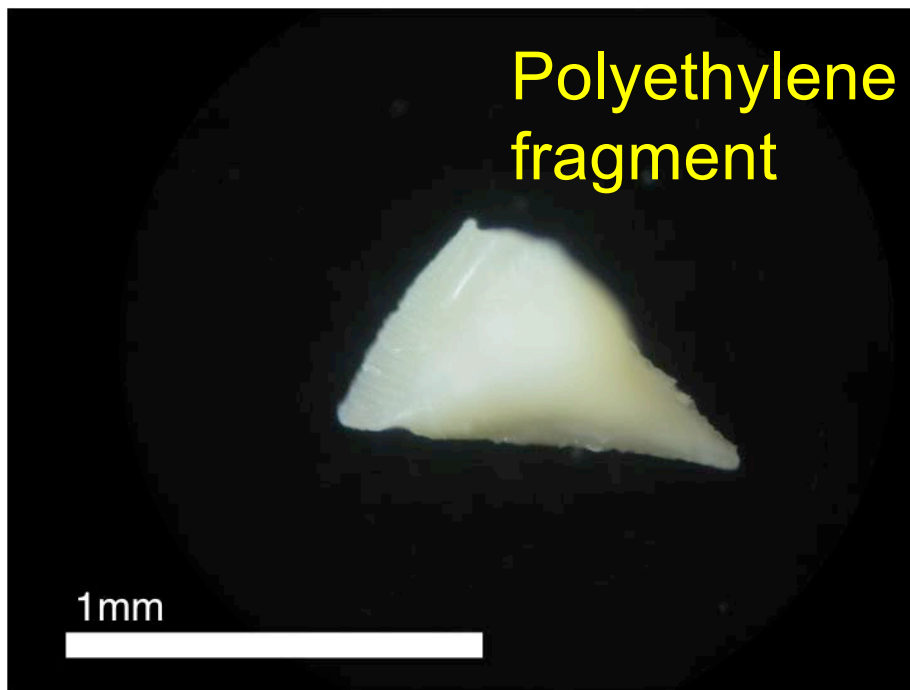


Fig.9 Plastics detected in digestive tract of short-tailed shearwater



After Yamashita et al. (2016)

Fig. 10. Temporal increasing trend in plastic ingestion by short-tailed shearwater



**49 detected
of 64 examined**

80% detection

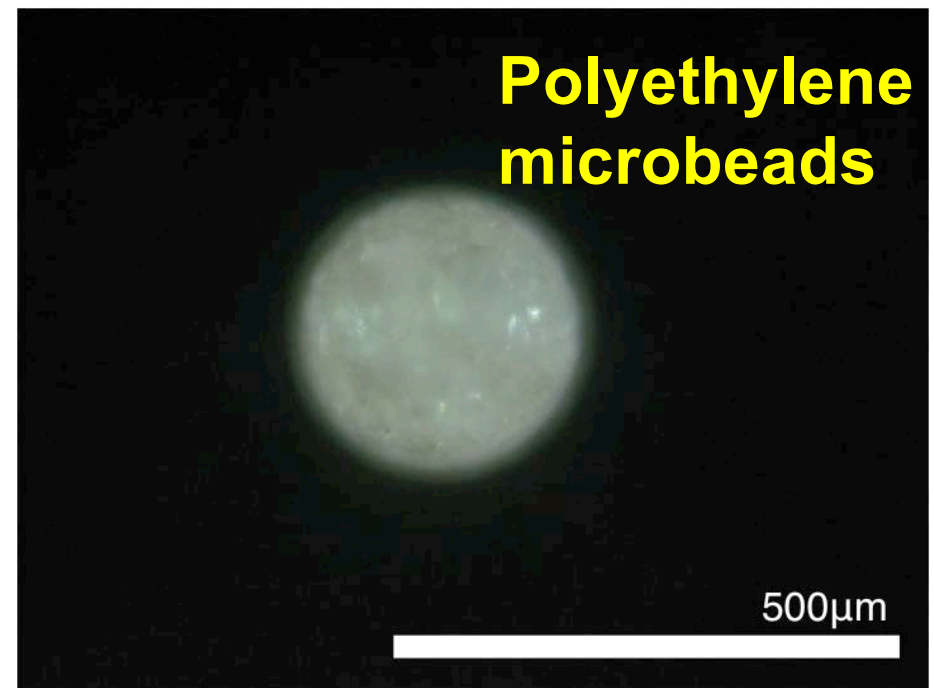
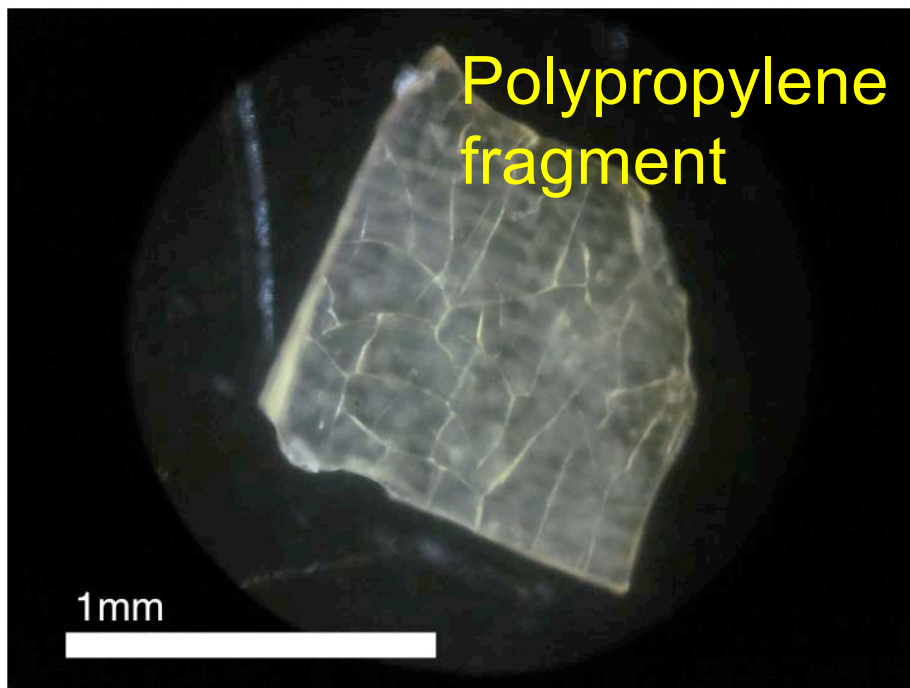
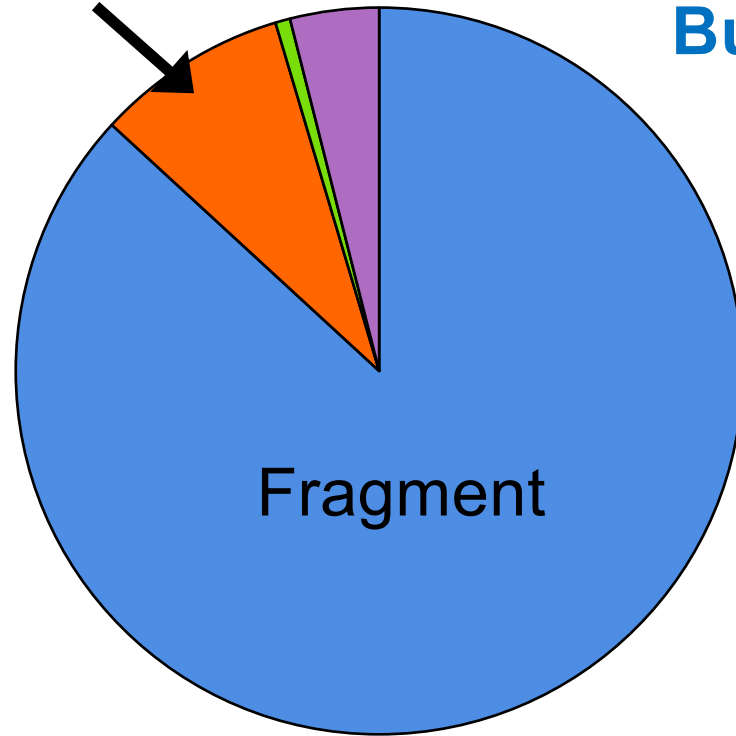


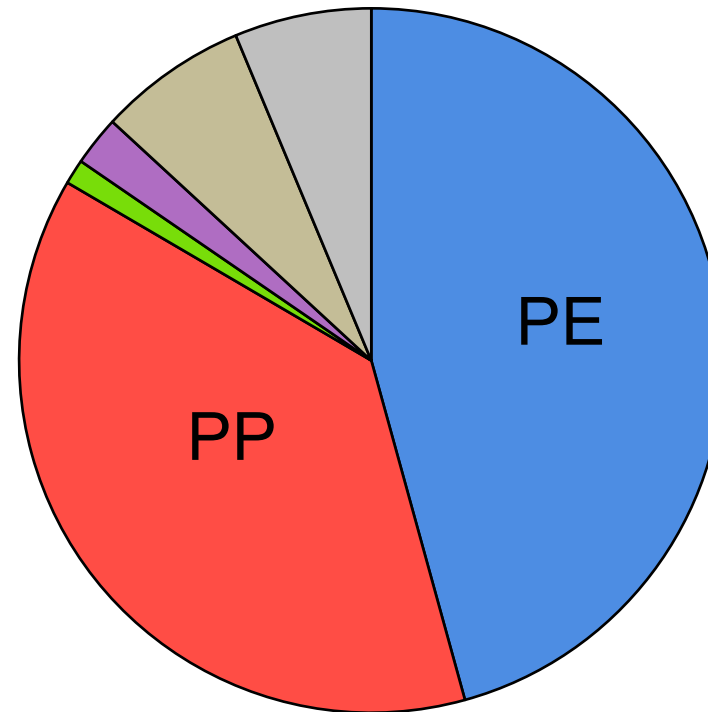
Fig. 11. Plastic fragments and microbeads detected in digestive tracts of anchovy (after Tanaka and Takada, 2016)

Microbeads

Microbeads were significant.
But, micro fragments were dominant.



■ Fragment
■ bead
■ sheet
■ line

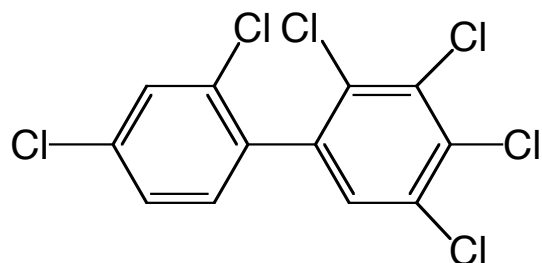


■ Polyethylene
■ Polypropylene
■ Polystyrene
■ Other plastics
■ Others
■ Not identified

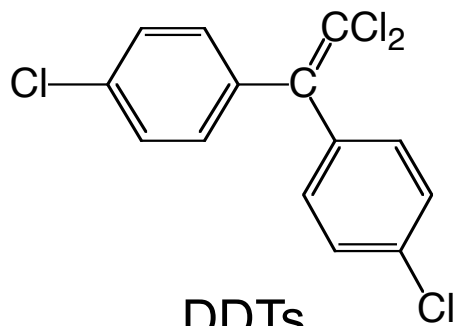
Fig. 12. Proportion of polymer shapes and types of microplastics detected in anchovies

Sorption from ambient seawater

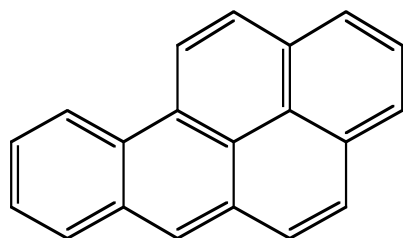
Additive-derived chemicals



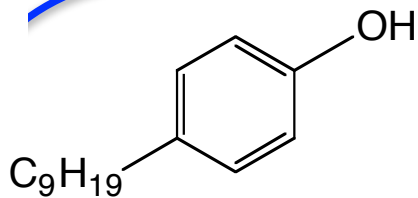
Polychlorinated biphenyl (PCBs)



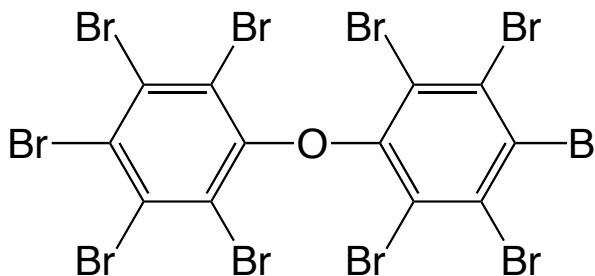
DDTs



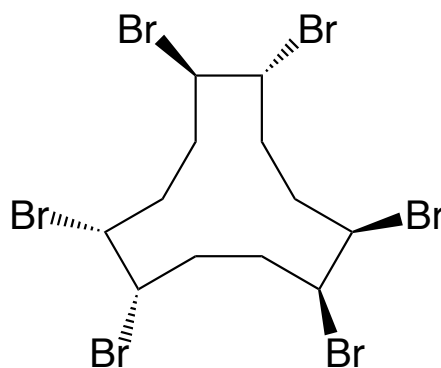
Polycyclic aromatic hydrocarbons (PAHs)



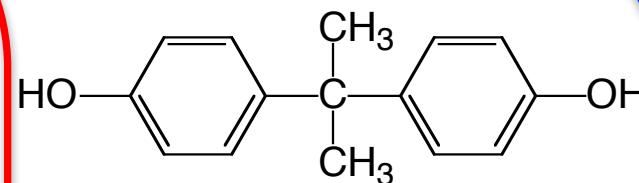
Nonylphenol



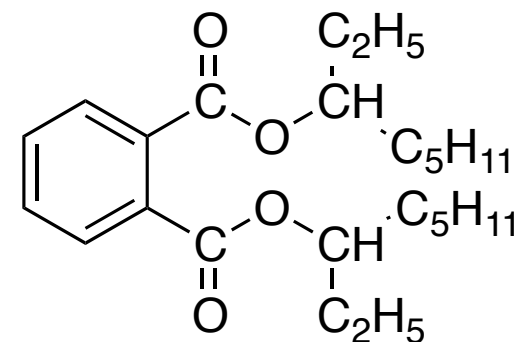
Polybrominated diphenyl ethers (PBDEs)



Hexabromocyclododecanes (HBCDs)



Bisphenol A



Phthalates (DEHP)

Fig. 13. Chemicals found in marine plastics

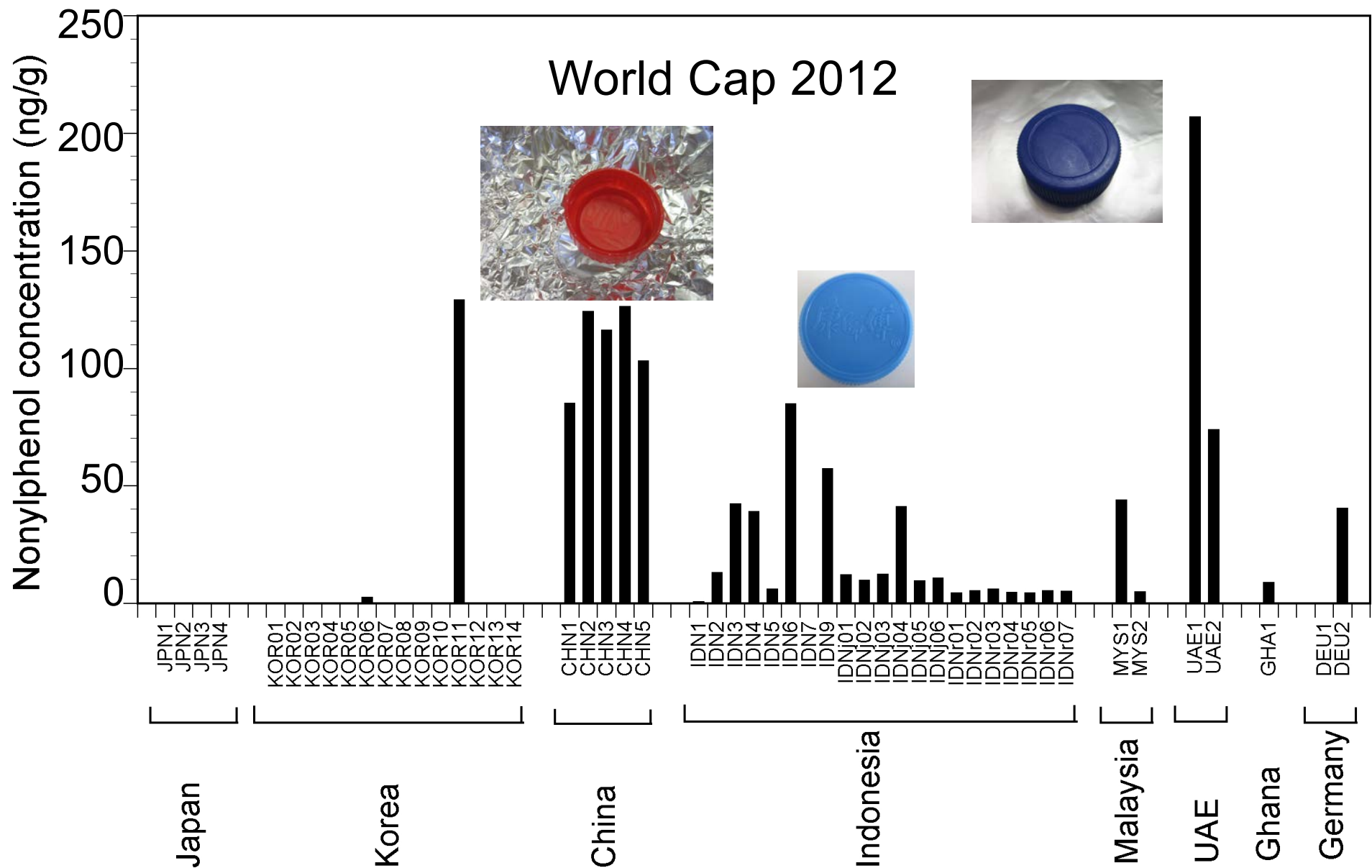
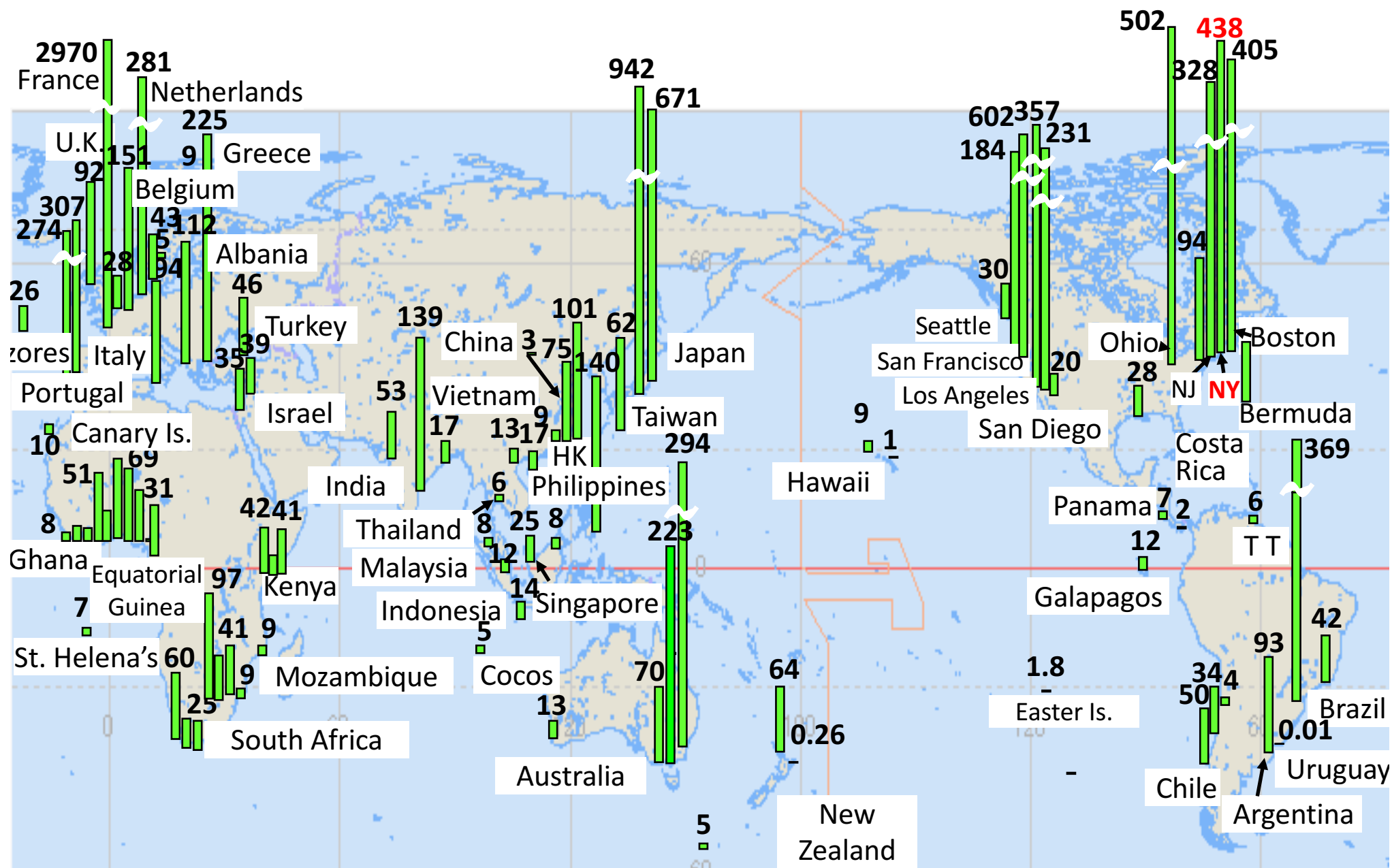


Fig. 14. Endocrine disrupting chemicals detected in plastic caps of mineral water bottles



Lower brominated
congeners ($\text{Br}_1 - \text{Br}_6$)

Higher brominated
congeners ($\text{Br}_7 - \text{Br}_{10}$)

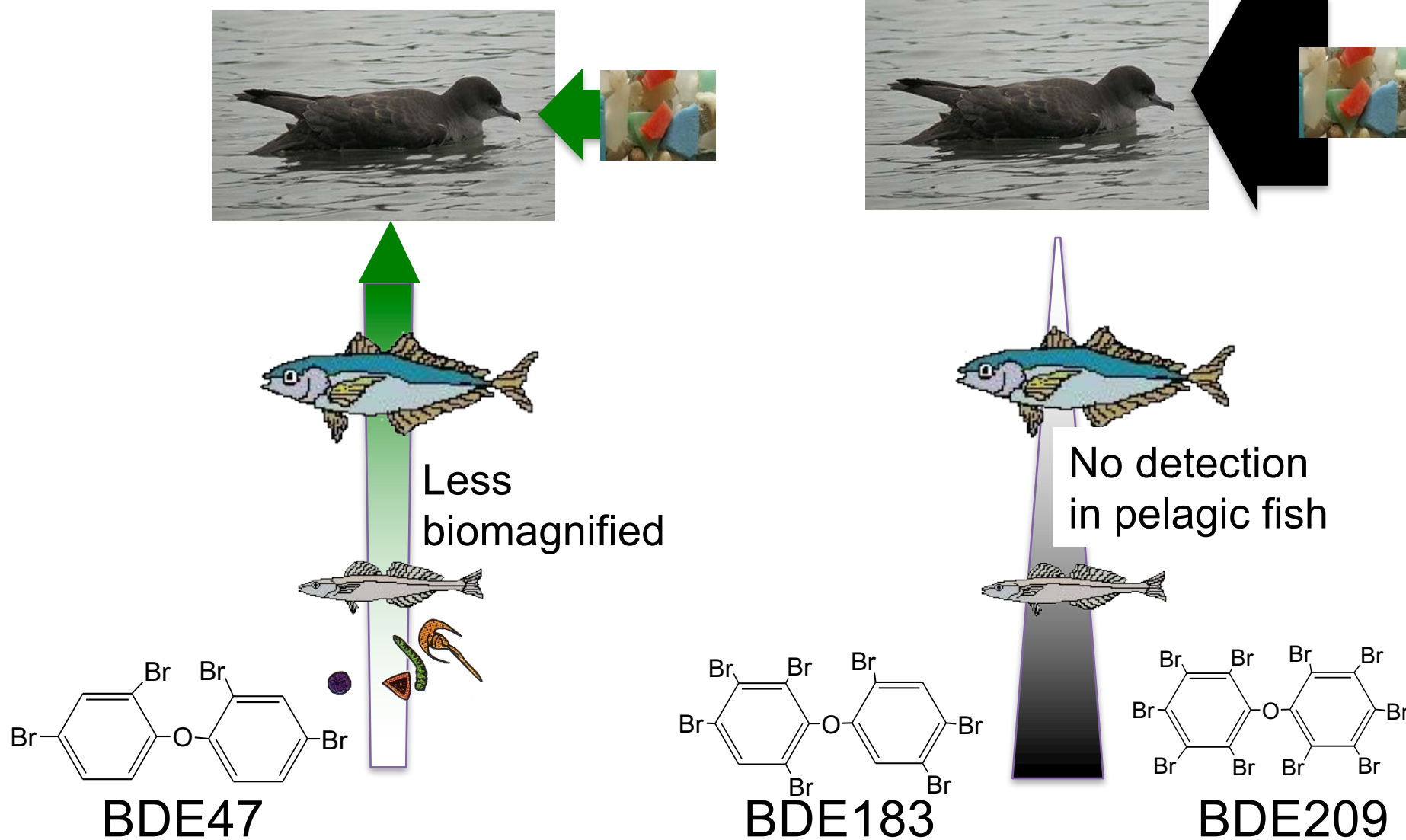
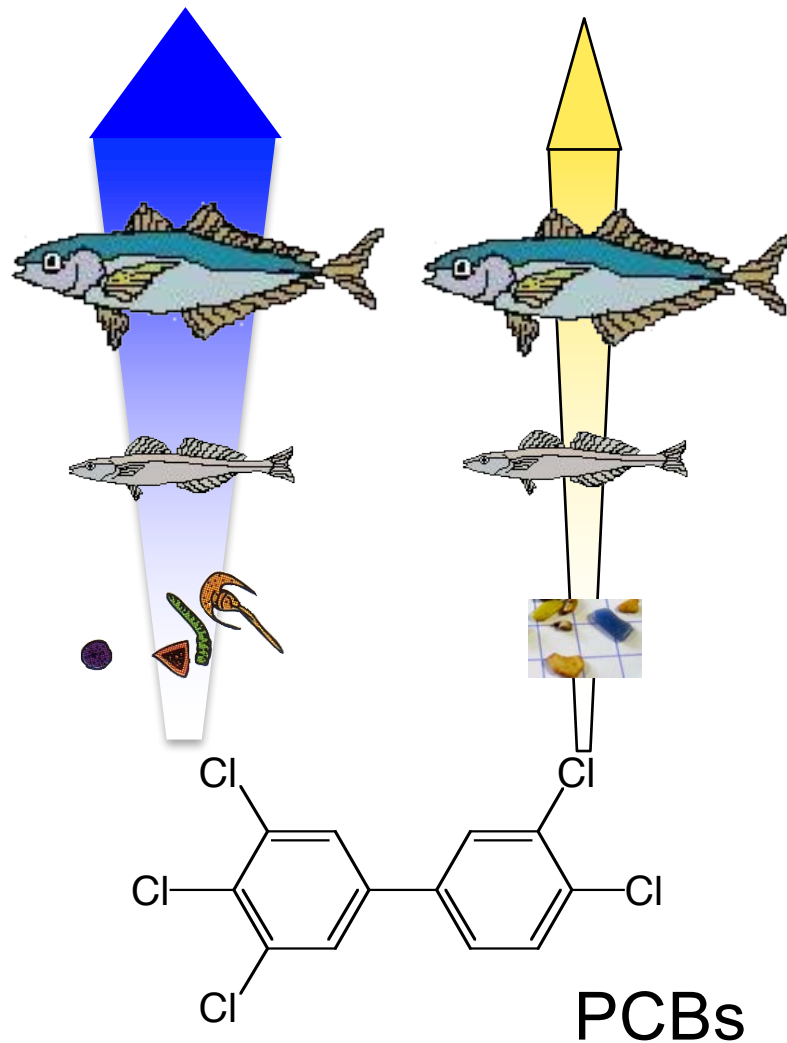


Fig. 16. Model of exposure of additives (PBDEs)

Human



At present,
plastic-mediated exposure
of hazardous chemicals is
minor compared with prey-
mediated exposure.
However, in future

Fig. 17. Model of exposure of sorbed chemicals (PCBs) : Present

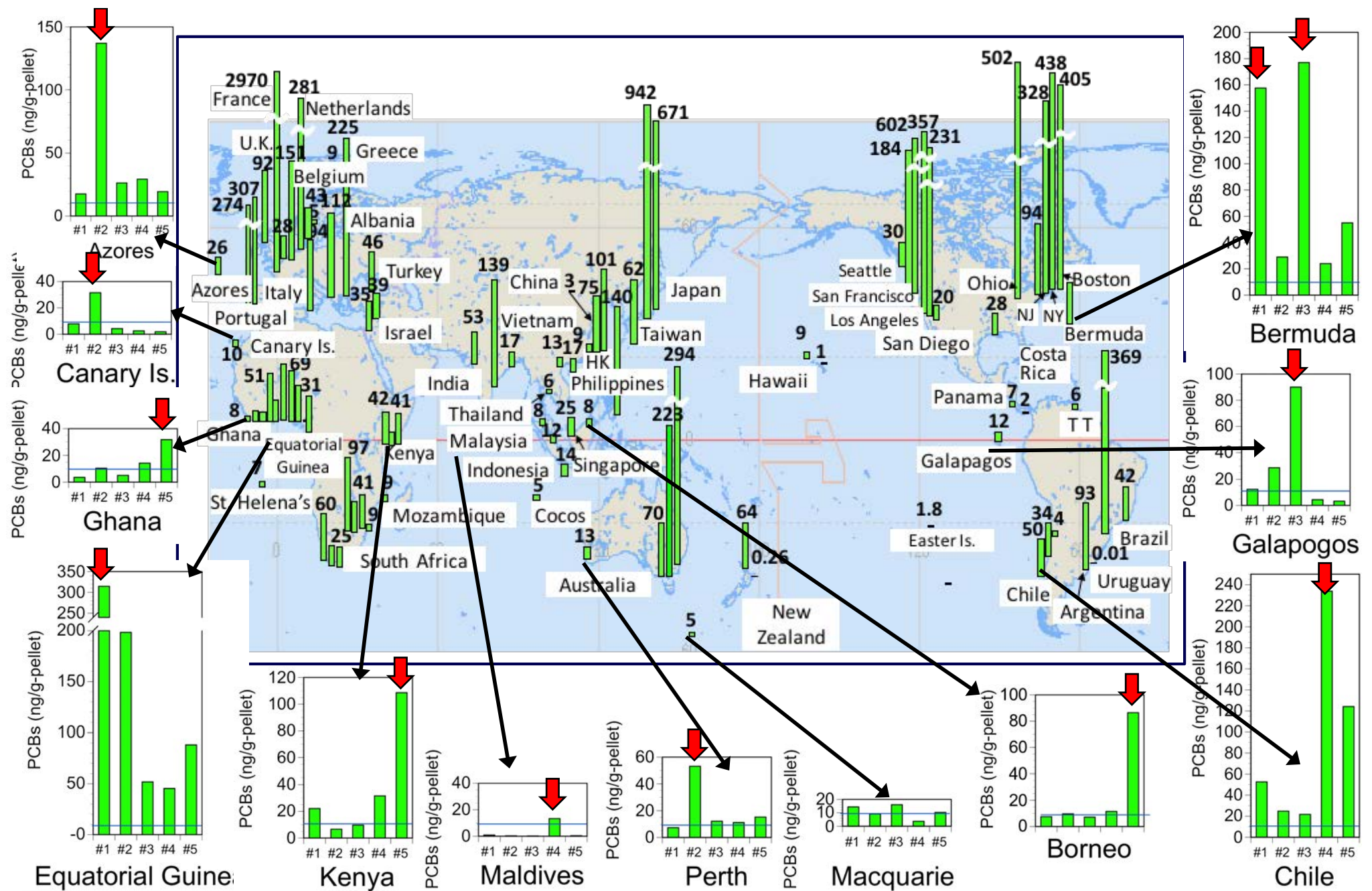
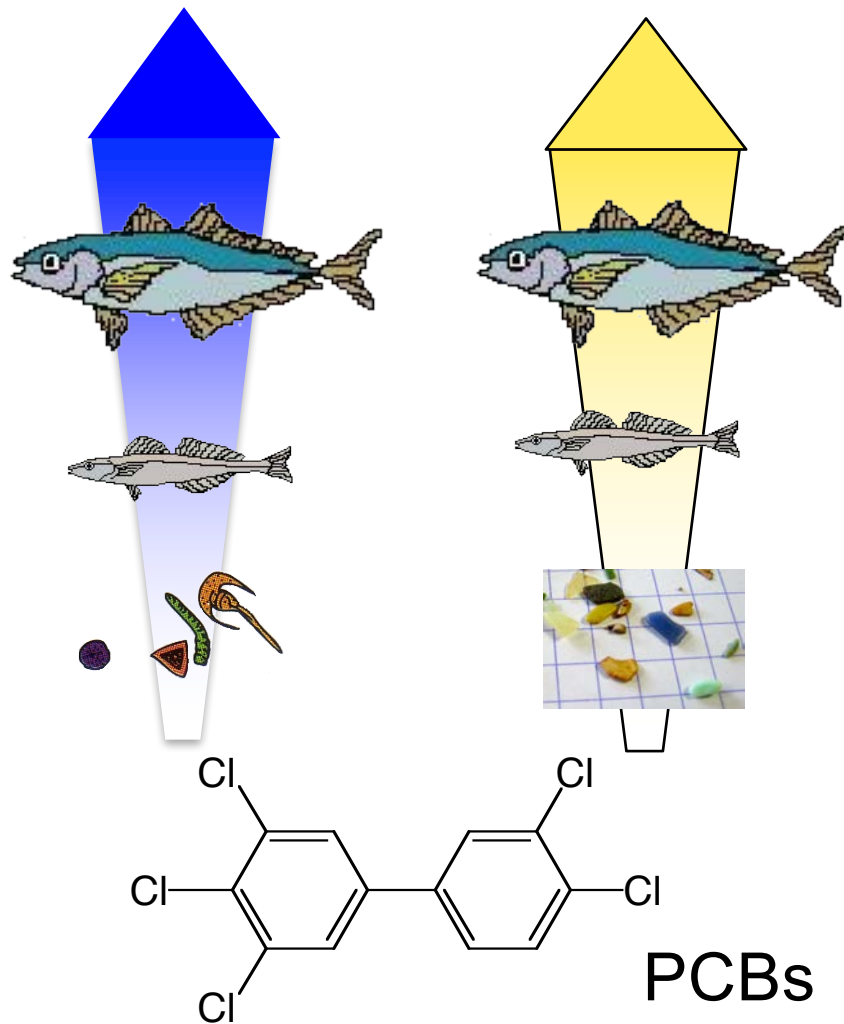


Fig. 18. PCB concentrations in pellets from remote islands and remote areas

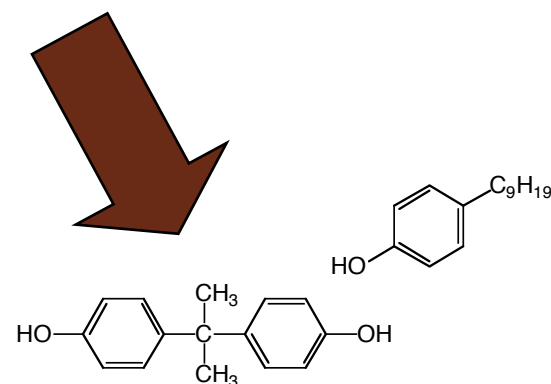
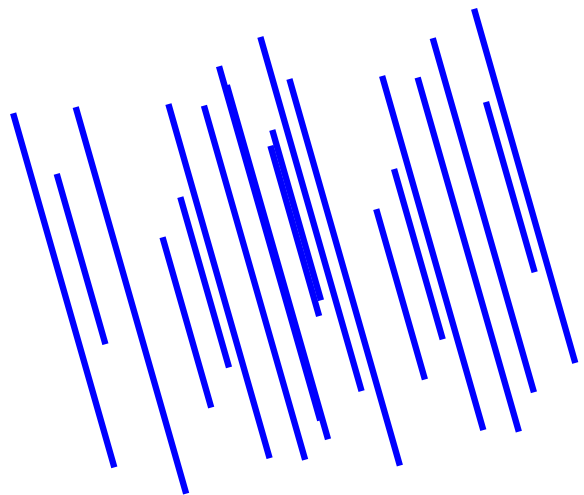
Human



We have to take action to reduce the inputs of plastics from land to the sea.

Key is promotion of 3R, especially, reduction of single-use plastics.

Fig. 19. Model of exposure of sorbed chemicals (PCBs) : Future



Plastic-derived chemicals

Fig. 20 (a) Hazardous chemicals released from dumped plastics at landfill sites

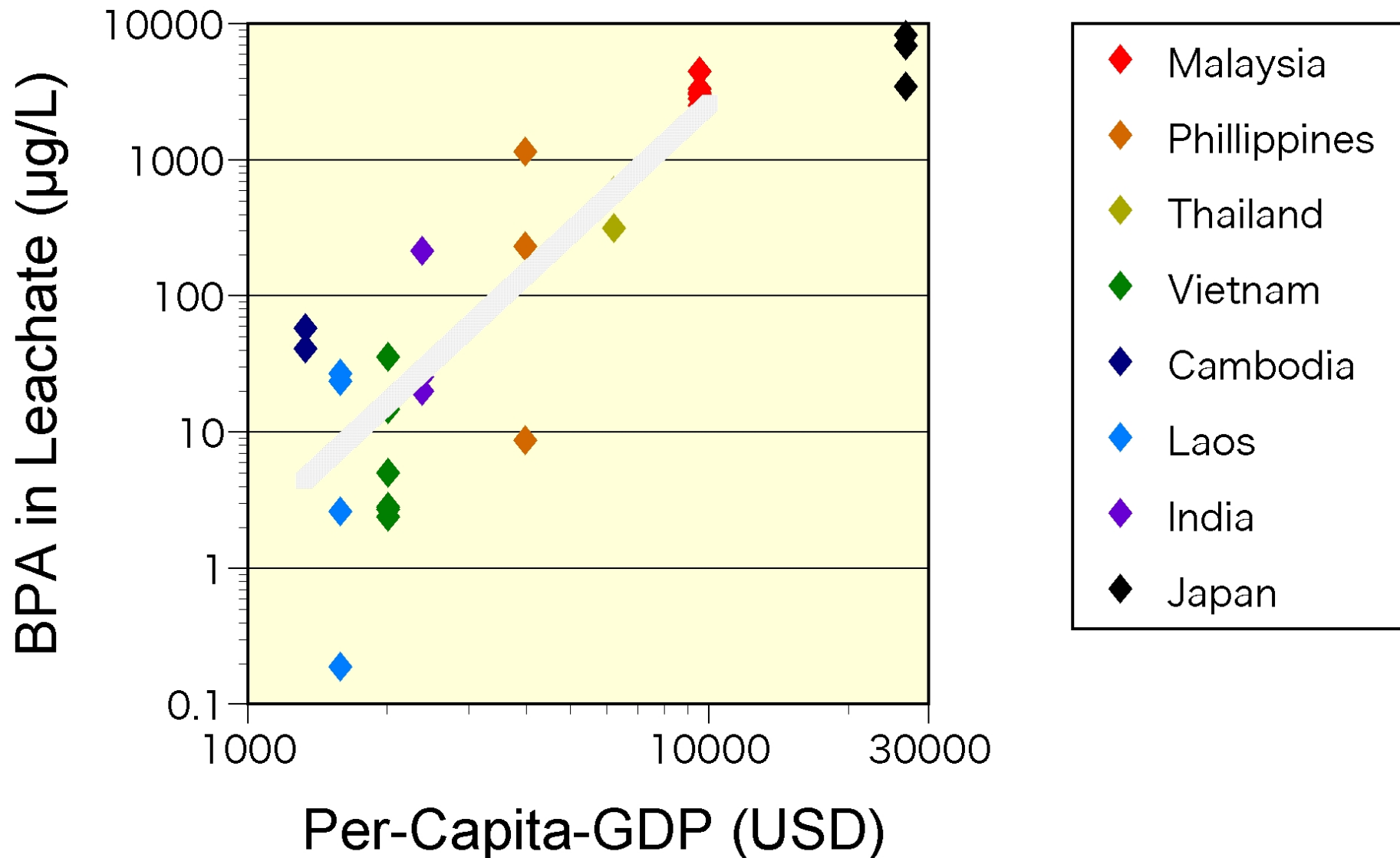


Fig.20(b) Endocrine disrupter BPA concentrations in leachates from landfill sites in connection with economic status

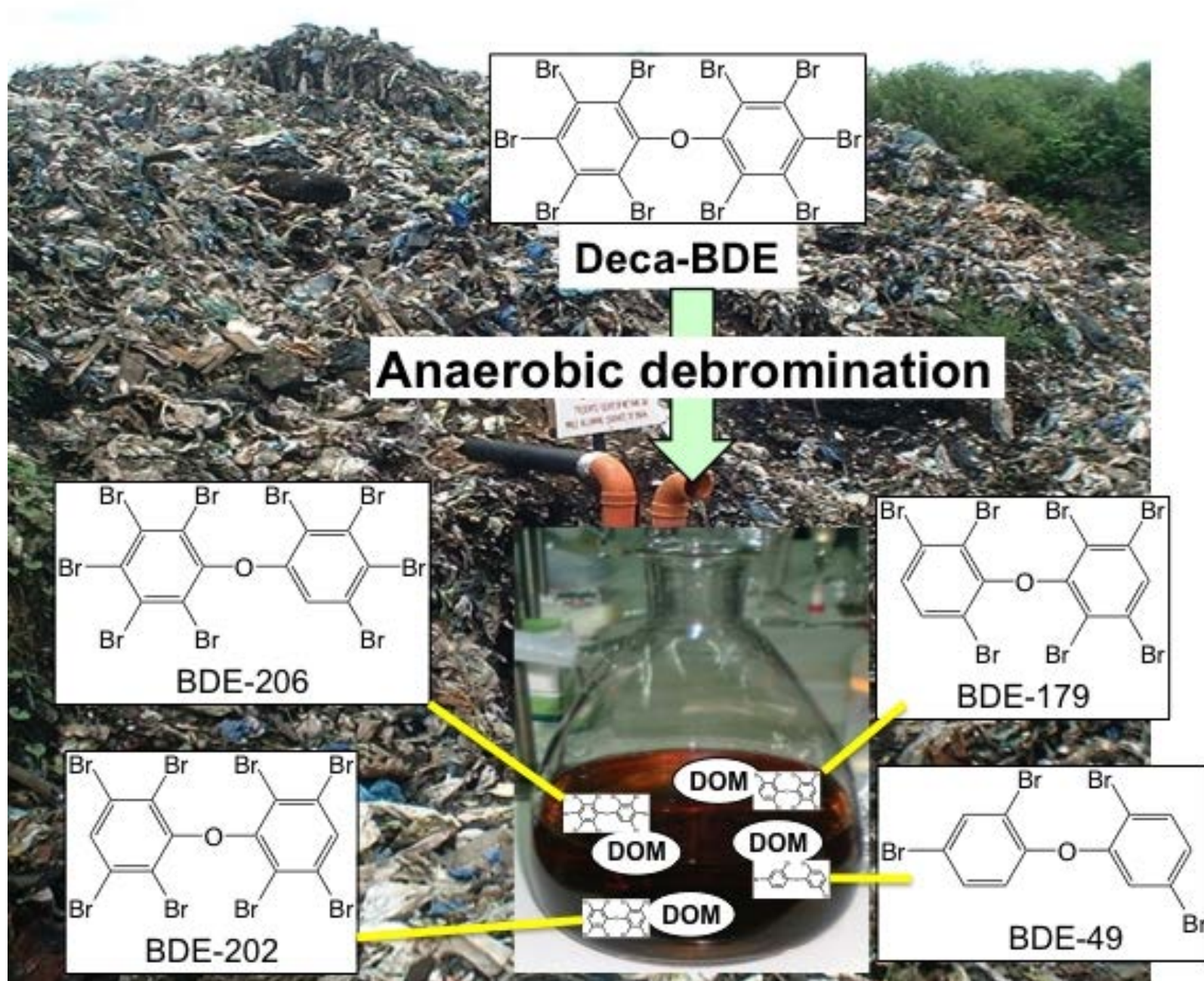


Fig. 20 (c). Increased toxicity of additive chemicals in anaerobic condition in landfill sites

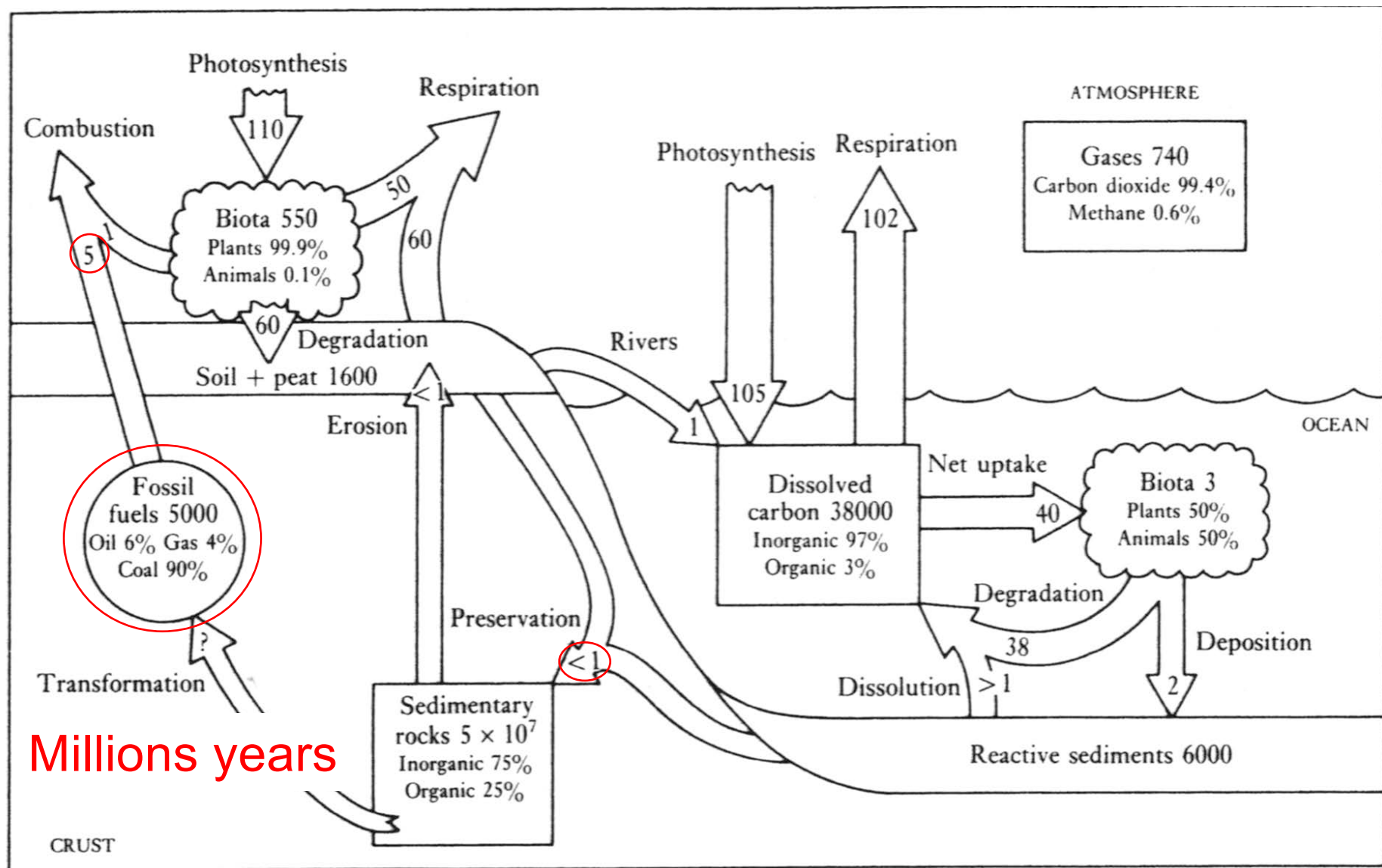


Figure 1.1 Summary of the global carbon cycle, showing sizes of main reservoirs (boxes of various shapes) and annual fluxes (arrows) in units of Gt (10⁹ t or 10¹⁵ g) of carbon. (After several sources, including Bolin et al., 1979, 1983; Kempe, 1979; Mopper and Degens, 1979; De Voys, 1979; NERC, 1989.)

Fig. 21. Global carbon cycle and formation of petroleum

(After "An Introduction to Organic Geochemistry" by Killops and Killops, 1993)

Table 1. Regulation on plastic shopping bags in the world

	Ban		Charge		Tax
	France		Sweden		Denmark
	Italy		Finland		Belgium
	Eritrea		The Netherlands		Luxembourg
	Rwanda		Germany		Iceland
	Bhutan		Australia		Ireland
	Bangladesh		Spain		Kenya
	Cameroon		Botswana		
			South Africa		
			Korea		
			China		
			UK		