Microplastic pollution of the environment from a geoscience perspective

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Part 1

- What is microplastic?
- Brief history of microplastic
- Major sources of microplastic
- Global amount of microplastic
- Problems of microplastic pollution

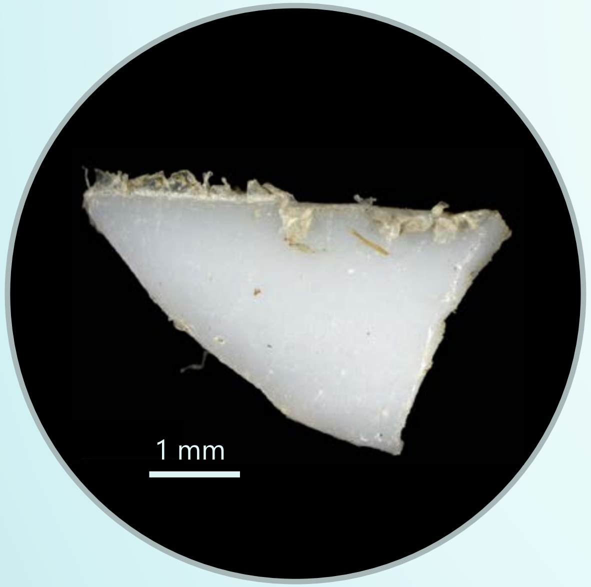
Part 2

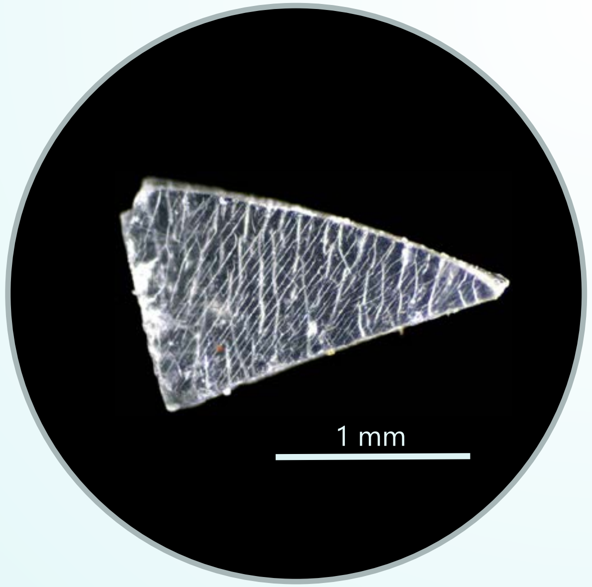
- Microplastic research in Taiwan
- Microplastic in beaches – preliminary results
- Microplastic in rivers – Tamsui River and its tributaries

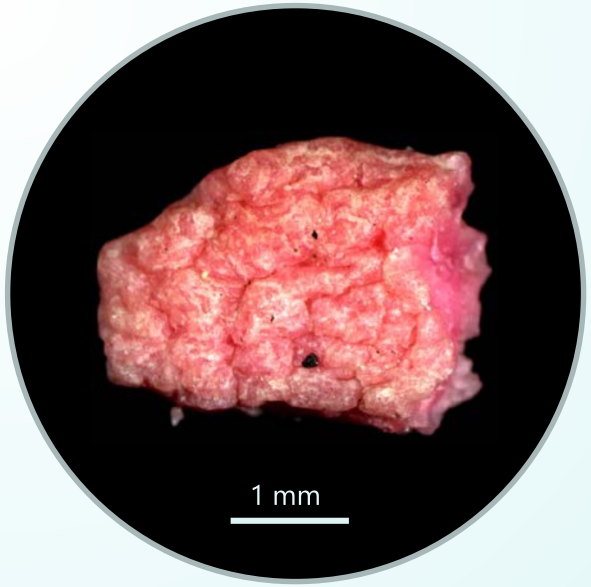
Part 1

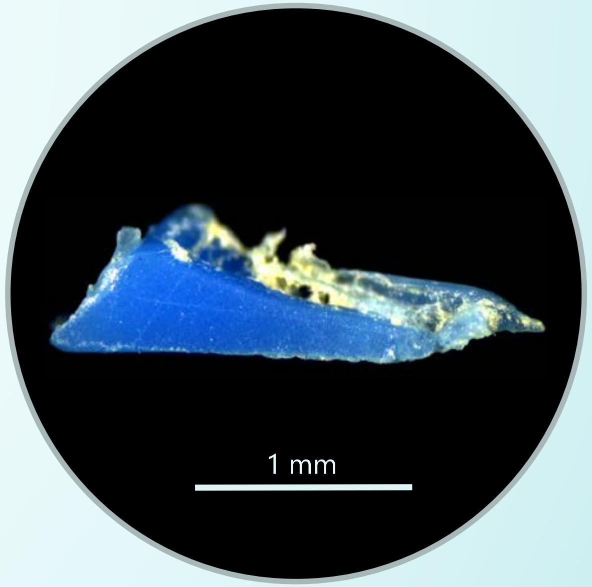
What is microplastic?

- any kind of synthetic polymer or plastic < 5 mm or < 1 mm size
- microplastic = microplastics









What is microplastic?

First description as part of marine litter:

- Cloth
- Glass & Ceramic
- Plastic
- Foamed Plastic
- Metal
- Paper & Cardboard
- Wood
- Other

Subdivided according type or size:

- $>$ 25 mm = macroplastic
- 5-25 mm = mesoplastic
- 1-5 mm = large microplastic
- $<$ 1 mm = microplastic
- $<$ *0.01 mm = nanoplastic*

Size definition was arbitrary and originated mainly from observations during beach cleanings

Subdivision of plastic debris

Macroplastic

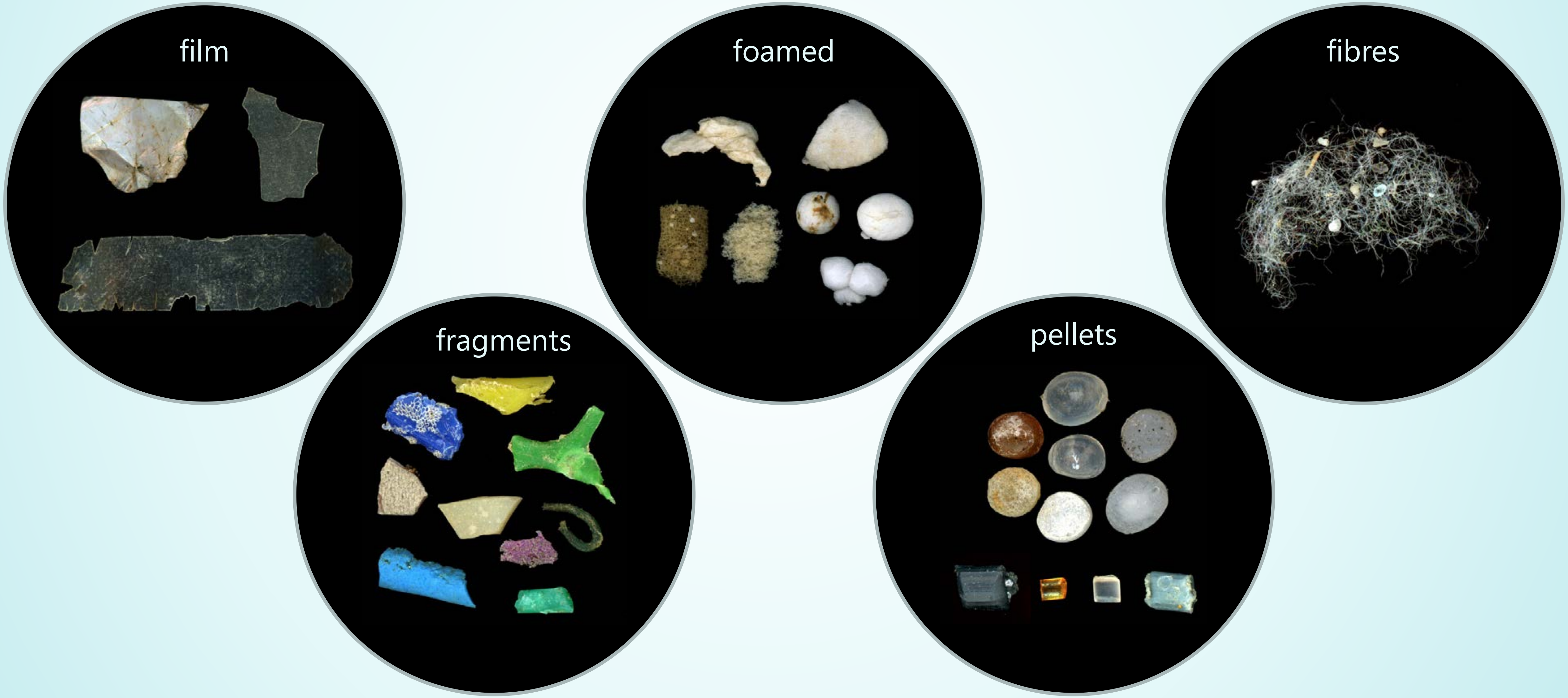
- Bottles
- Bottle caps
- Food containers
- Plastic bags
- Fishing gear
- Syringes
- Plastic buoys
- And many more…

Meso and Microplastic

- Fragments
- Pellets (virgin and weathered)
- Foam (Styrofoam, other foam)
- Fibers
- Fishing lines
- Foil or film
- Other types depending on research question

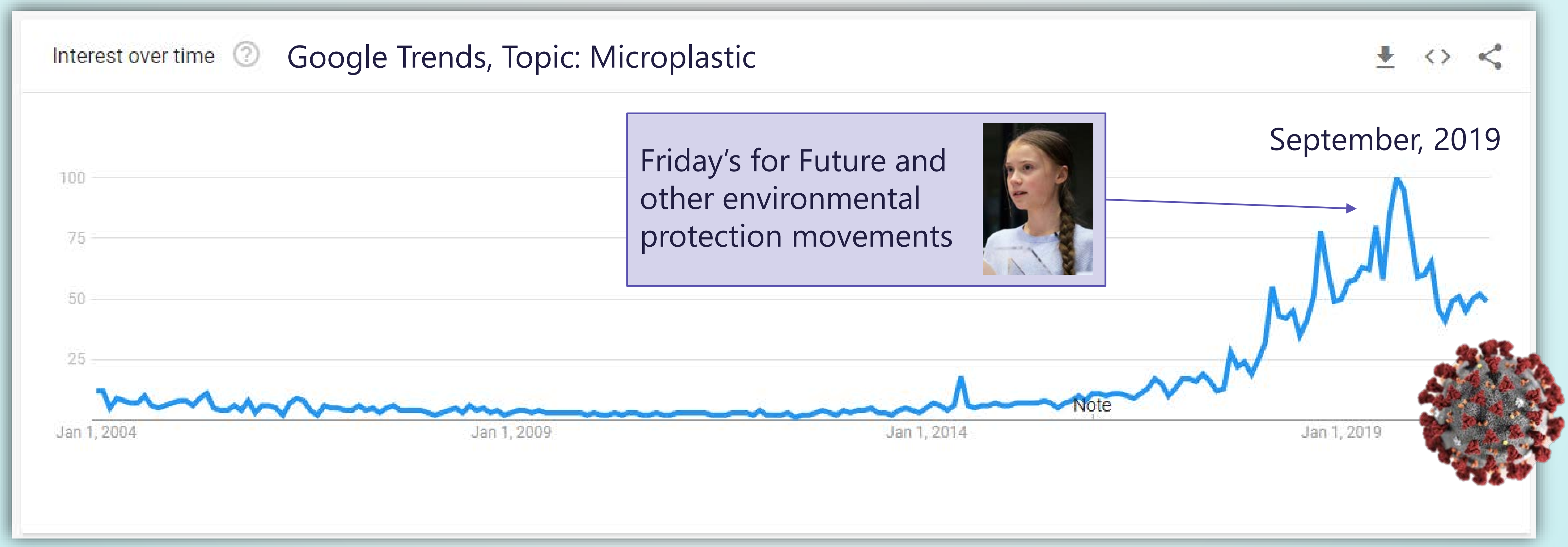
Examples of macroplastic

Microplastic types

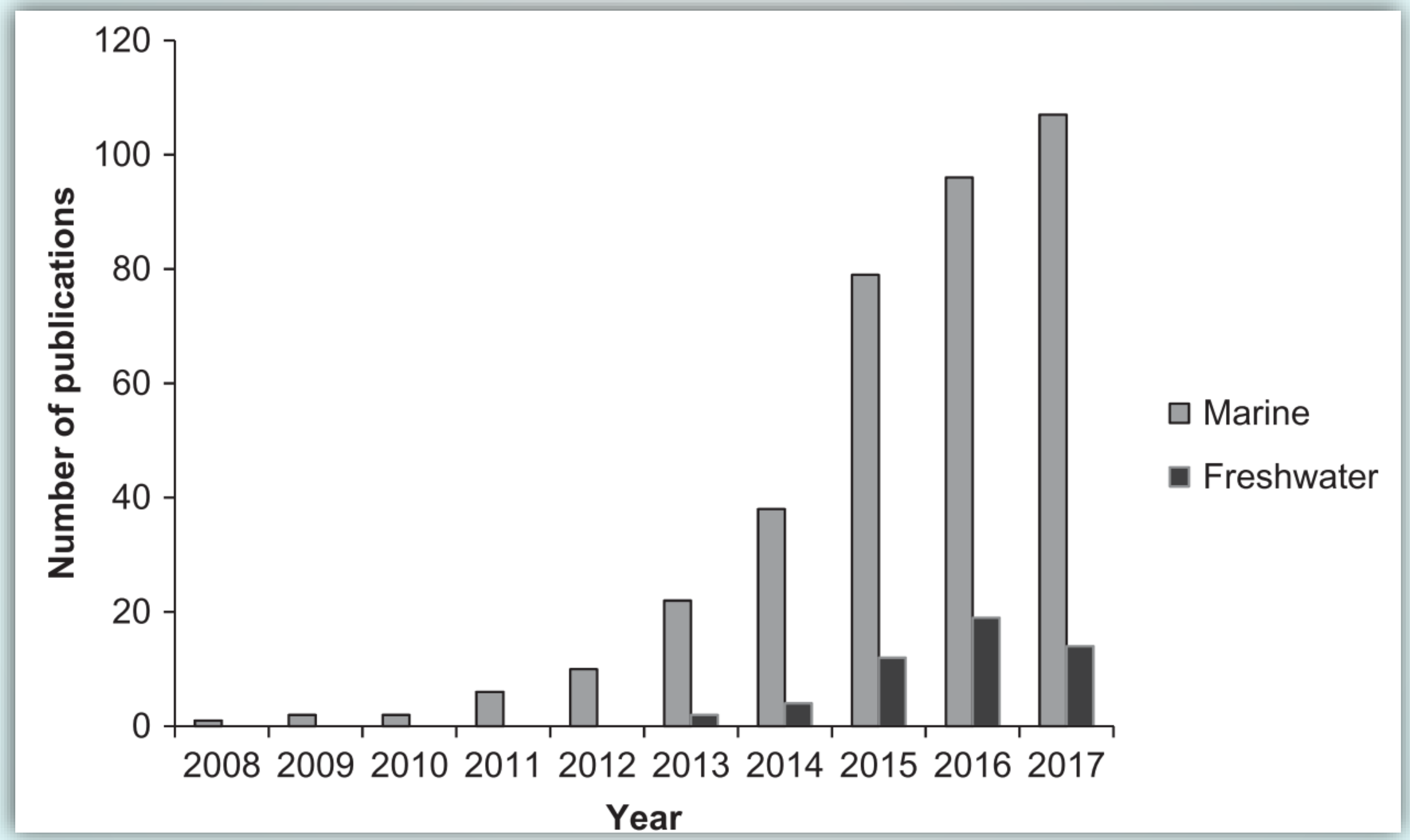


History of microplastic

In the last few years microplastic became a very popular topic in mainstream media and popular science



History of microplastic



Eerkes-Medrano, D. and R. Thompson (2018). Occurrence, Fate, and Effect of Microplastics in Freshwater Systems. Microplastic Contamination in Aquatic Environments**: 95-132.**

History of microplastic

Carpenter & Smith (1972) Science 175 (4027), 1240-1241

Plastics on the Sargasso Sea Surface

Abstract. *Plastic particles, in concentrations averaging 3500 pieces and 290 grams per square kilometer, are widespread in the western Sargasso Sea. Pieces are brittle, apparently due to the weathering of the plasticizers, and many are in a pellet shape about 0.25 to 0.5 centimeters in diameter. The particles are surfaces for the attachment of diatoms and hydroids. Increasing production of plastics, combined with present waste-disposal practices, will undoubtedly lead to increases in the concentration of these particles. Plastics could be a source of some of the polychlorinated biphenyls recently observed in oceanic organisms.*

While sampling the pelagic *Sargassum* community in the western Sargasso Sea, we encountered plastic particles in our neuston (surface) nets. The occurrence of these particles on the sea surface has not yet been noted in the literature [we also collected petroleum lumps, which have received attention (*1*, *2*)].

History

- **1950s** start of mass production
- **1968** first reports about plastic in sea turtles (Mrosovsky et al. 2009)
- **1972** first occurrence of microplastics
- Since **2005** global distribution of microplastic and other plastic waste is documented

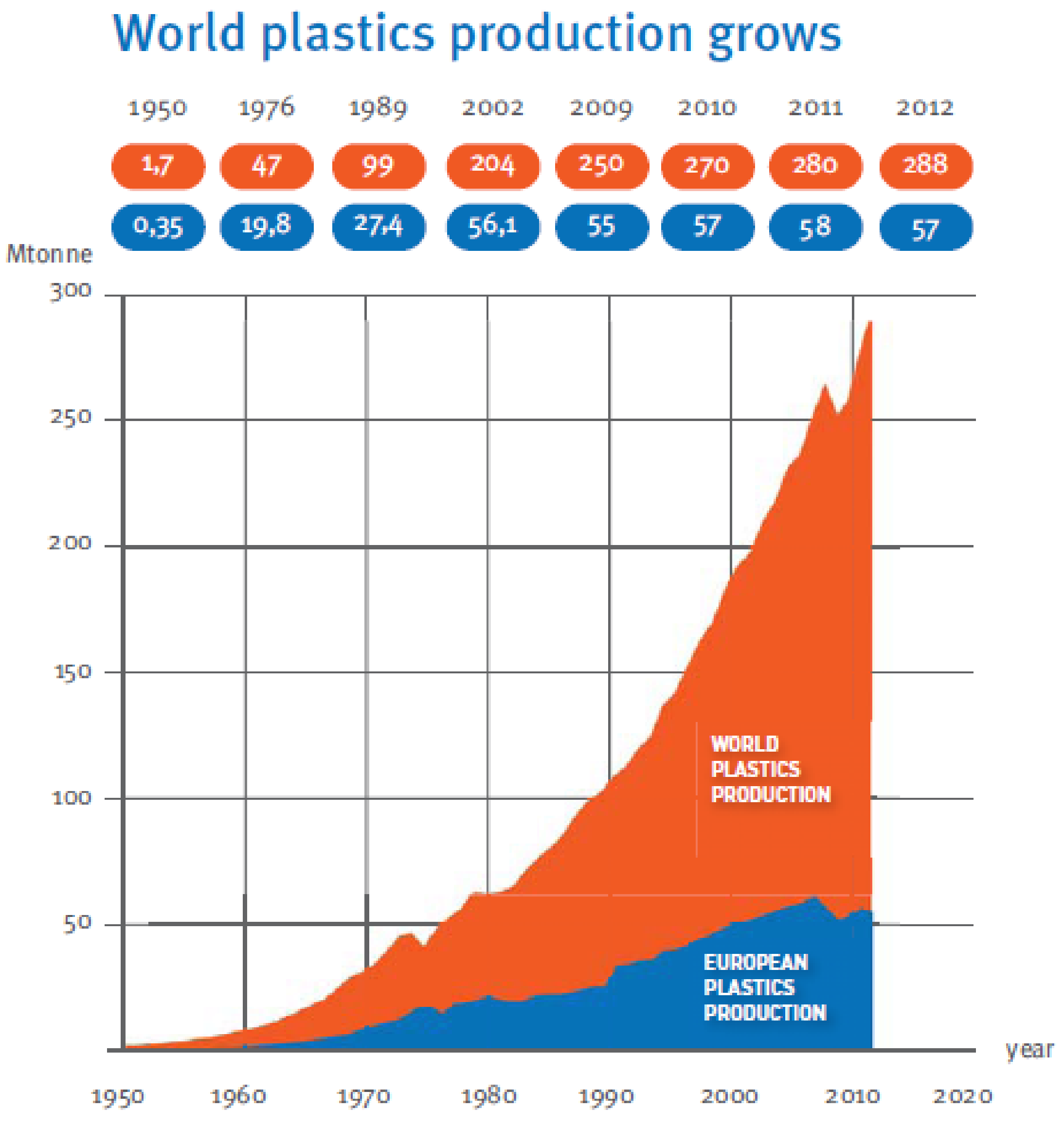


Figure 2: World plastics production 1950-2012
Includes thermoplastics, polyurethanes, thermosets, elastomers, adhesives, coatings and sealants and PP-fibers. Not included PET-, PA- and polyacryl-fibers
Source: PlasticsEurope (PEMRG) / Consultic

10

Mrosovsky, N., et al. (2009). "Leatherback turtles: the menace of plastic." Mar Pollut Bull **58(2): 287-289.**

Sources of microplastic: household

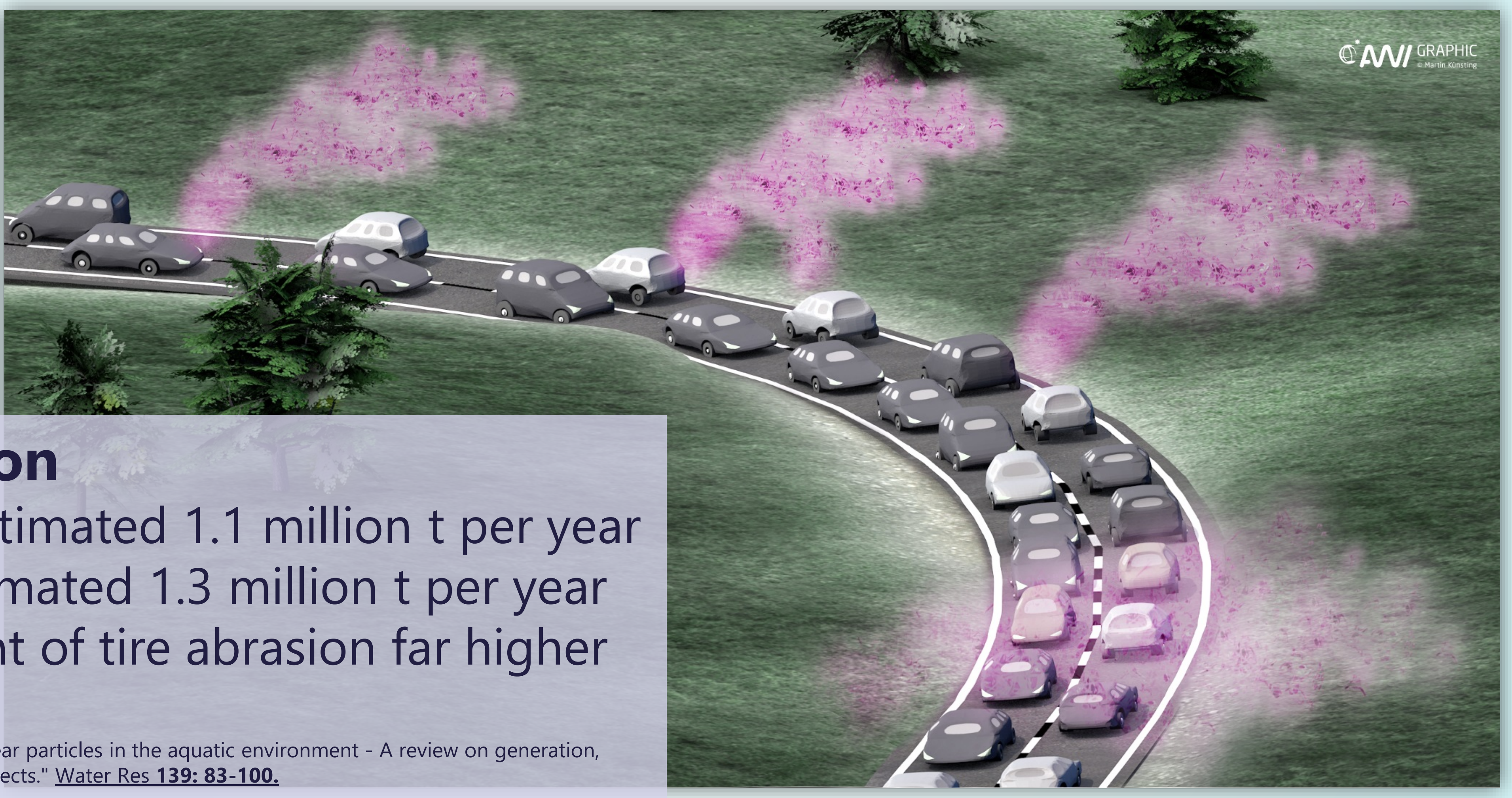
Washing machine: global estimate 12,500 t synthetic fibers per year (Cesa et al. 2020)

Cosmetic care products: estimated that between 4,594 and 94,500 microbeads could be released in a single use (Napper et al. 2015)

Opening of plastic packing: can generate 0.46–250 microplastic particles/cm (Sobhani et al. 2020)

Cesa, F. S., et al. (2020). "Laundering and textile parameters influence fibers release in household washings." Environ Pollut **257: 113553.**
Napper, I. E., et al. (2015). "Characterisation, quantity and sorptive properties of microplastics extracted from cosmetics." Mar Pollut Bull **99(1-2): 178-185.**
Sobhani, Z., et al. (2020). "Microplastics generated when opening plastic packaging." Sci Rep **10(1): 4841.**

Sources of microplastic: road traffic



Tire abrasion

in the USA estimated 1.1 million t per year

in the EU estimated 1.3 million t per year

global amount of tire abrasion far higher

Wagner, S., et al. (2018). "Tire wear particles in the aquatic environment - A review on generation, analysis, occurrence, fate and effects." Water Res **139: 83-100.**

Sources of microplastic: industry

Spill of pellets at one production site can be between 3 and 36 million pellets annually

Karlsson, T. M., et al. (2018). "The unaccountability case of plastic pellet pollution." Mar Pollut Bull **129(1): 52-60.**

Sources of microplastic: degradation

- 350 million t plastic waste produced in 2014
  - 200 million t in landfill
  - 95 million t incinerated
  - 55 million t recycled
- 4.8 – 12.7 million t released into oceans

=> Macroplastic is basically an endless reservoir for microplastic

Geyer et al. (2017): Production, use, and fate of all plastics ever made. Sci Adv 3 (7), e1700782.
Jambeck et al. (2015): Plastic waste inputs from land into the ocean. Science 347 (6223): 768-771.

Estimated global amount

Floating plastic in world's oceans: 250,000 t

Top 200 m of the Atlantic Ocean: 11.6-21.1 million t

Annual global river discharge of plastic waste: 1.15-2.41 million t

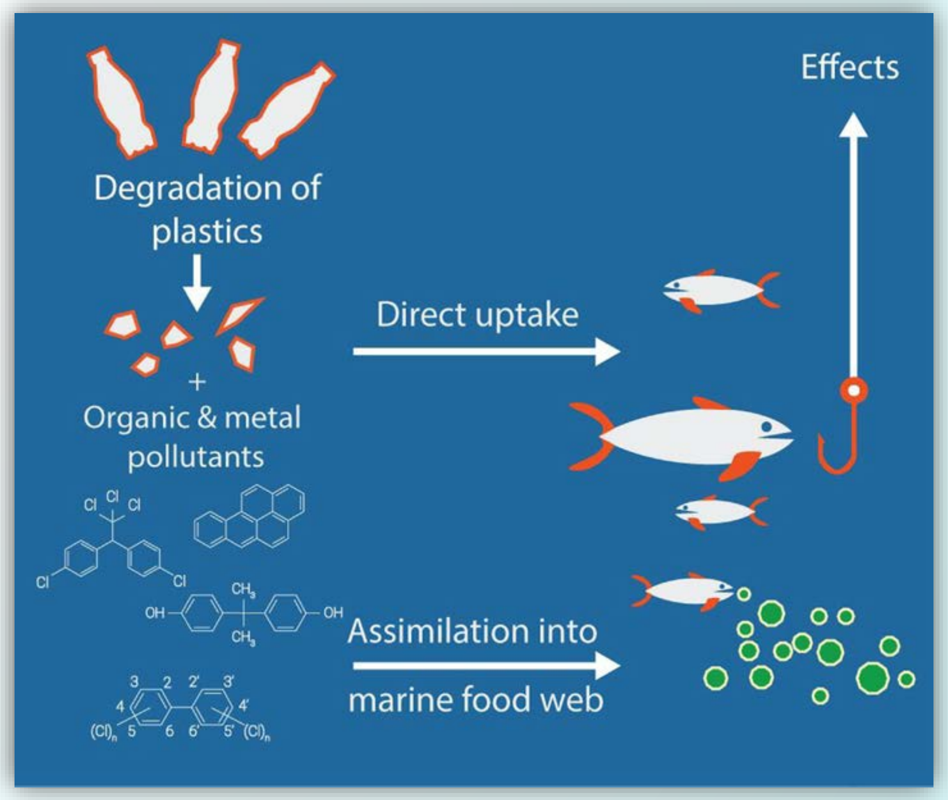
Deep sea sediments: 14 million t

Barrett, J., et al. (2020). "Microplastic Pollution in Deep-Sea Sediments From the Great Australian Bight." Frontiers in Marine Science 7.
Eriksen, M., et al. (2014). "Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea." PLoS One 9(12): e111913.
Lebreton, L. C. M., et al. (2017). "River plastic emissions to the world's oceans." Nat Commun 8: 15611.
Pabortsava, K. and R. S. Lampitt (2020). "High concentrations of plastic hidden beneath the surface of the Atlantic Ocean." Nat Commun 11(1): 4073.

Why is microplastic problematic?

Ingestion causing injury or death

Release and uptake of pollutants



Why is microplastic problematic?

Plastics

Seabirds eat floating plastic debris because it smells like food, study finds

Algae on drifting plastic waste gives off a sulfur compound which smells similar to the krill many marine birds feed on, researchers have discovered

Hannah Devlin Science Correspondent

@hannahdev

Wednesday 9 November 2016 19.00 GMT

Birds and other marine creatures ingest plastic and this can lead to damage to internal organs, gut blockages or chemical build-ups in tissues. Photograph: Dan Clark/USFWS/AP

Seabirds are enticed into eating plastic debris because it smells like their food, according to scientists.

The study found that drifting plastic waste accumulates algae and gives off a smell very similar to the krill that many marine birds feed on. The findings could explain why certain birds - including albatrosses and shearwaters - which rely on their sense of smell for hunting, are particularly vulnerable to swallowing plastic.

SCIENCE ADVANCES | RESEARCH ARTICLE

CHEMICAL ECOLOGY

Marine plastic debris emits a keystone infochemical for olfactory foraging seabirds

Matthew S. Savoca,[1,2]* Martha E. Wohlfeil,[1,2] Susan E. Ebeler,[3] Gabrielle A. Nevitt[1,2]*

Plastic debris is ingested by hundreds of species of organisms, from zooplankton to baleen whales, but how such a diversity of consumers can mistake plastic for their natural prey is largely unknown. The sensory mechanisms underlying plastic detection and consumption have rarely been examined within the context of sensory signals driving marine food web dynamics. We demonstrate experimentally that marine-seasoned microplastics produce a dimethyl sulfide (DMS) signature that is also a keystone odorant for natural trophic interactions. We further demonstrate a positive relationship between DMS responsiveness and plastic ingestion frequency using procellariiform seabirds as a model taxonomic group. Together, these results suggest that plastic debris emits the scent of a marine infochemical, creating an olfactory trap for susceptible marine wildlife.

INTRODUCTION

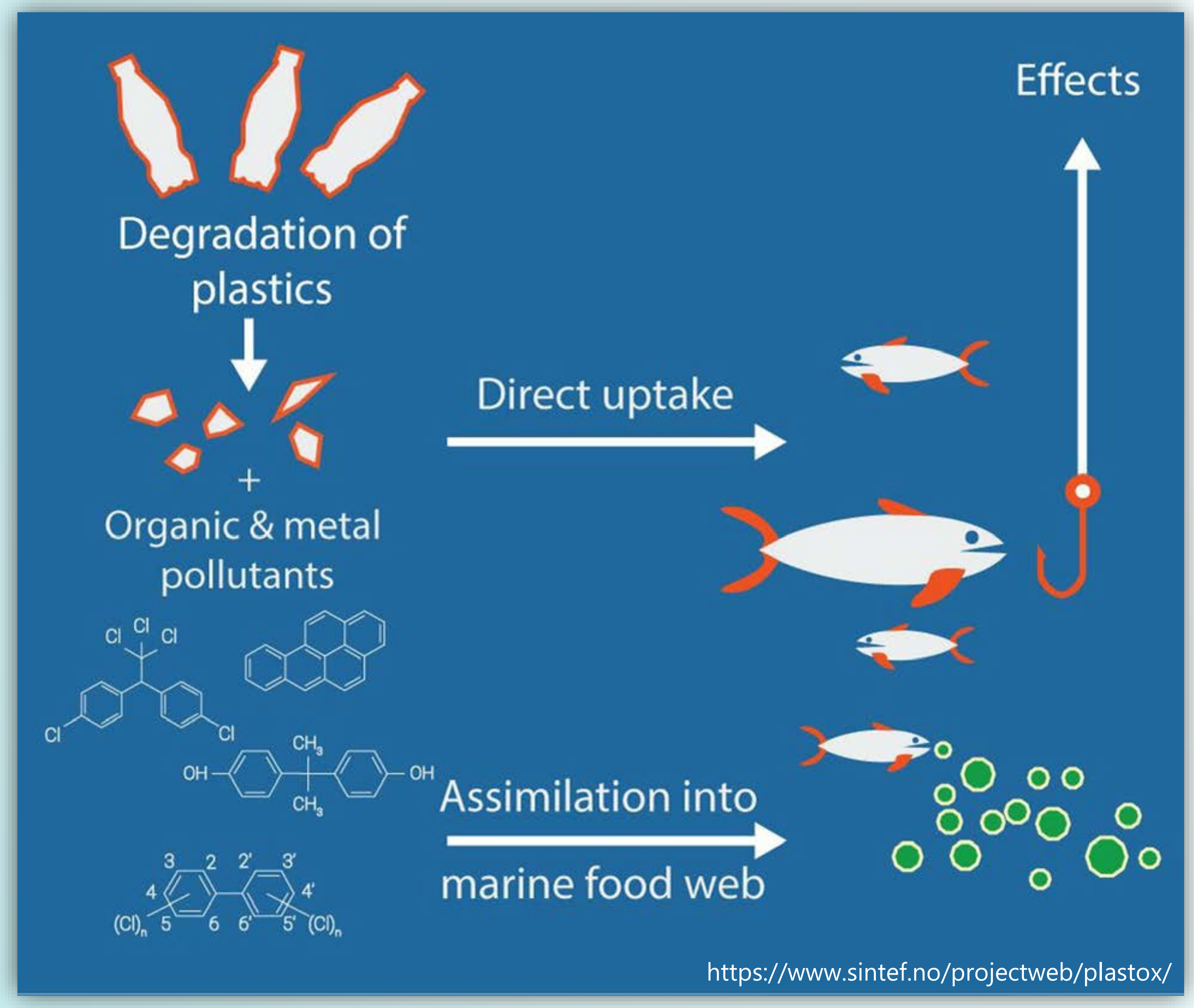
Trophic interactions in the pelagic marine environment are mediated, in part, by infochemicals, including dimethyl sulfide (DMS). DMS and its chemical precursor, dimethylsulfoniopropionate (DMSP), are ideal candidate molecules for this investigation in that they serve as infochemicals for microfauna to macrofauna in foraging cascades (*1–3*) and have also received considerable attention as a potential contributor to global climate regulation (*4*). In pelagic ecosystems, DMS is produced by the enzymatic breakdown of DMSP in marine phytoplankton, which increases during zooplankton grazing (*5*), thus triggering foraging activity in a variety of marine organisms, including tube-nosed seabirds (order: Procellariiformes) (*6*). The procellariiform seabirds include the albatrosses, petrels, and shearwaters; members of this order are highly olfactory, pelagic, and wide-ranging, foraging over vast expanses

genetic group (*6, 9, 21–23*). Moreover, because DMS sensitivity is likely an ancestral trait that coevolved with burrow-nesting behavior (*24*), this relationship allows us to extend our hypothesis to test whether burrow-nesting procellariiforms have a higher incidence of plastic ingestion than surface-nesting species. Our final aim was to use the results of this mechanistic investigation to predict how different species are being negatively affected while accounting for unequal sampling effort to inform future monitoring and conservation efforts.

RESULTS

We first examined whether exposure to the photic zone changes the sulfur signature of plastic beads (diameter, 4 to 6 mm) made from the three most common types of microplastic and mesoplastic debris: high-density

Microplastic and pollutants

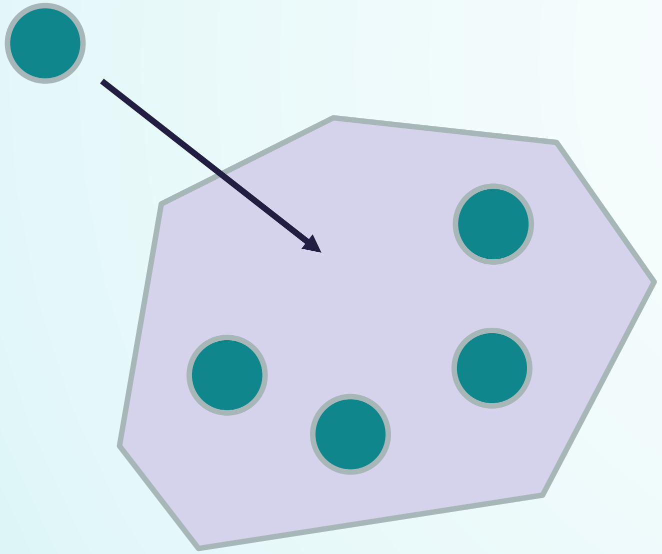


https://www.sintef.no/projectweb/plastox/

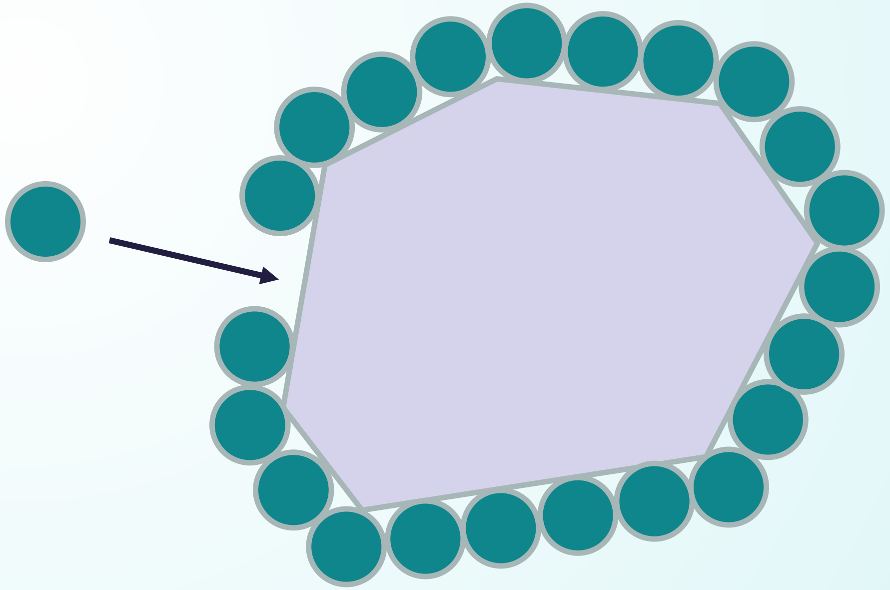
POP	Usage	Health effects
Chlordane*	pesticide	carcinogenic
DDT*	pesticide	chronic health effects
HCH*	pesticide	toxic
Perfluoro-alkylates	repellent	neurotoxic effects
Phtalates	softener in plastic	hormonal effects (?)
PAHs	fuel, oil, …	carcinogenic
PBDEs	flame retardant in plastic	toxic, hormonal effects
PCBs*	dielectric and coolant fluid	toxic, carcinogenic, immune deficiency

POPs love microplastic

- many POPs are hydrophobic and plastic offers a chance to leave the water



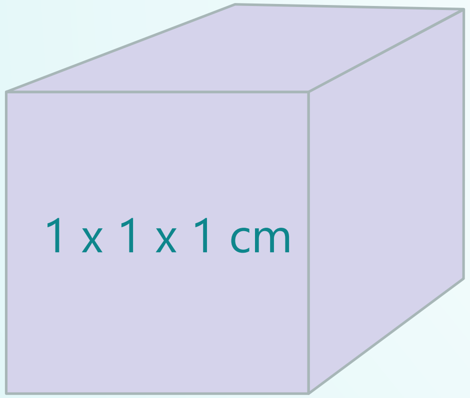
Absorption



Adsorption

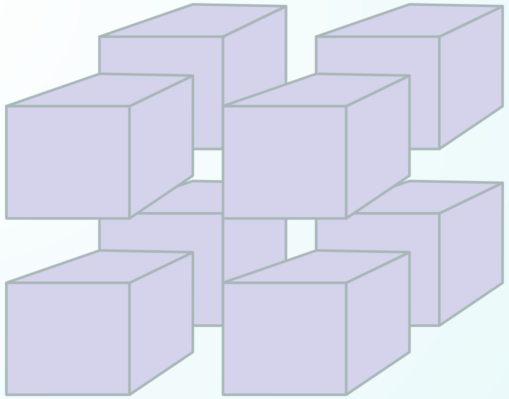
Microplastic and POPs

- Breakdown of plastic into smaller pieces creates more surface area for POPs, also small particles more likely to be eaten.



Volume = 1 cm^3
Surface = 6 cm^2

0.5 x 0.5 x 0.5 cm



Volume all cubes = 1 cm^3
Surface all cubes = 12 cm^2

Why is microplastic problematic?

- Plastic particles or chemicals from plastic particles enter the food chain and end up in humans

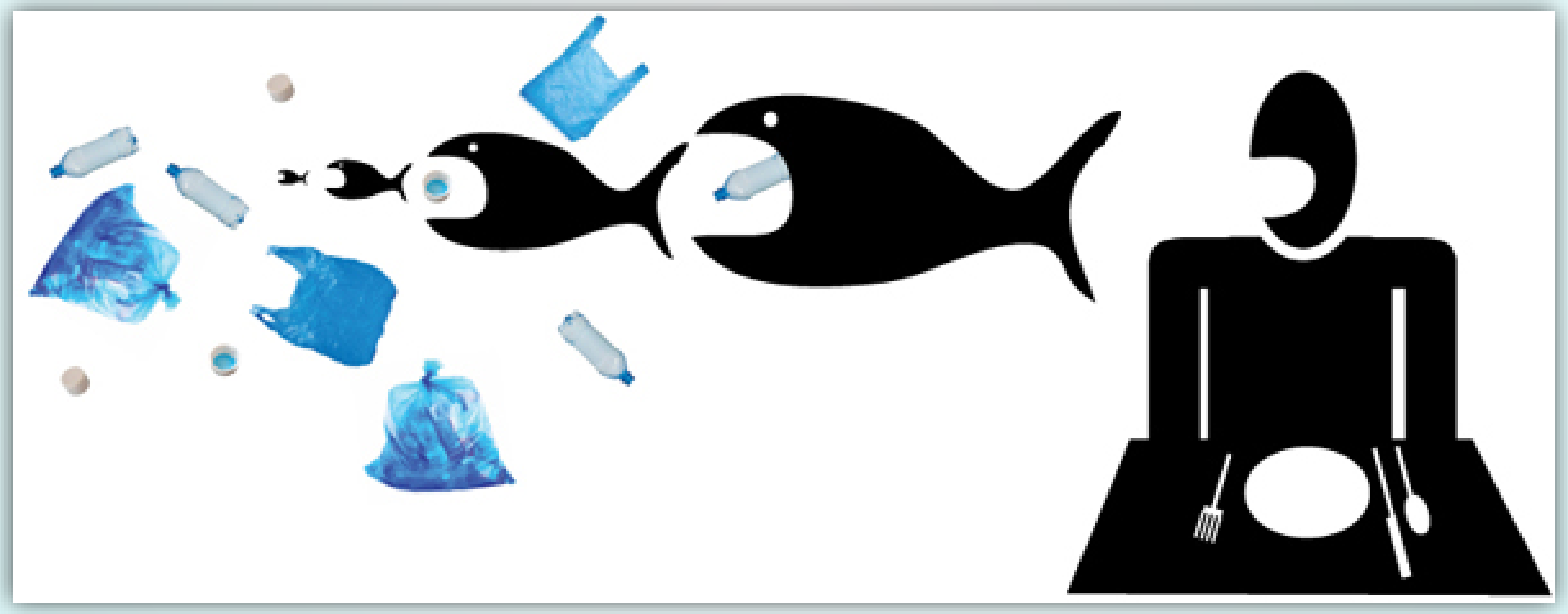
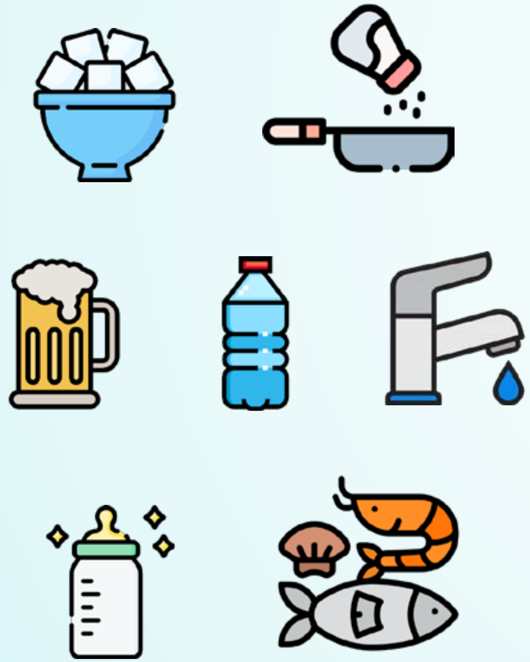


Image: https://plastictides.wordpress.com/2014/07/08/microplastic-ingestion/

Human consumption of microplastic

Estimated 106-142 particles per day



Estimated 97-170 particles per day

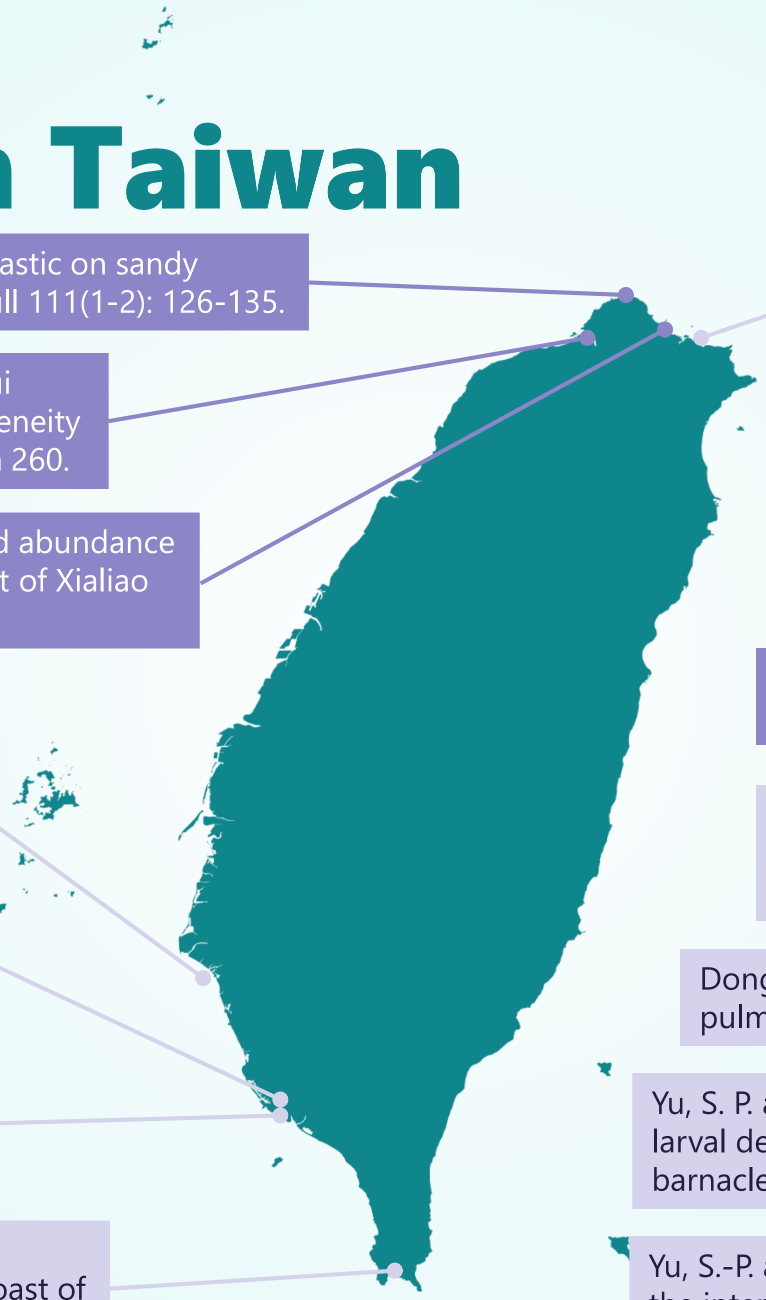
Amount varies depending on lifestyle, region, age, gender.

20 particles per 10 g of stool

Cox et al. 2019: Human Consumption of Microplastics. Env. Sci. Tec. 53: 7068-7074.
Schwabl et al. 2019: Detection of Various Microplatics in Human Stool. Ann. Int. Med. 1.October 2019

Part 2

Research in Taiwan



Kunz, A., et al. (2016). "Distribution and quantity of microplastic on sandy beaches along the northern coast of Taiwan." Mar Pollut Bull 111(1-2): 126-135.

Wong, G., et al. (2020). "Microplastic pollution of the Tamsui River and its tributaries in northern Taiwan: Spatial heterogeneity and correlation with precipitation." Environmental Pollution 260.

Bancin, L. J., et al. (2019). "Two-dimensional distribution and abundance of micro- and mesoplastic pollution in the surface sediment of Xialiao Beach, New Taipei City, Taiwan." Mar Pollut Bull 140: 75-85.

Davidson, T. M. (2012). "Boring crustaceans damage polystyrene floats under docks polluting marine waters with microplastic." Mar Pollut Bull 64(9): 1821-1828.

Liu, T. K., et al. (2013). "Influence of waste management policy on the characteristics of beach litter in Kaohsiung, Taiwan." Mar Pollut Bull 72(1): 99-106.

Chen, C. F., et al. (2020). "Microplastics and their affiliated PAHs in the sea surface connected to the southwest coast of Taiwan." Chemosphere 254: 126818.

Chen, M.-C. and T.-H. Chen (2020). "Spatial and seasonal distribution of microplastics on sandy beaches along the coast of the Hengchun Peninsula, Taiwan." Marine Pollution Bulletin 151.

Kuo, F. J. and H. W. Huang (2014). "Strategy for mitigation of marine debris: analysis of sources and composition of marine debris in northern Taiwan." Mar Pollut Bull 83(1): 70-78.

Walther, B. A., et al. (2018). "Type and quantity of coastal debris pollution in Taiwan: A 12-year nationwide assessment using citizen science data." Mar Pollut Bull 135: 862-872.

Lee, H., et al. (2019). "Microplastic contamination of table salts from Taiwan, including a global review." Sci Rep 9(1): 10145.

Chen, J. Y.-S., et al. (2020). "Microplastic Contamination of Three Commonly Consumed Seafood Species from Taiwan: a Pilot Study." Preprints 2020090694.

Dong, C. D., et al. (2020). "Polystyrene microplastic particles: In vitro pulmonary toxicity assessment." J Hazard Mater 385: 121575.

Yu, S. P. and B. K. K. Chan (2020). "Effects of polystyrene microplastics on larval development, settlement, and metamorphosis of the intertidal barnacle Amphibalanus amphitrite." Ecotoxicol Environ Saf 194: 110362.

Yu, S.-P. and B. K. K. Chan (2020). "Intergenerational microplastics impact the intertidal barnacle Amphibalanus amphitrite during the planktonic larval and benthic adult stages." Environmental Pollution 267.

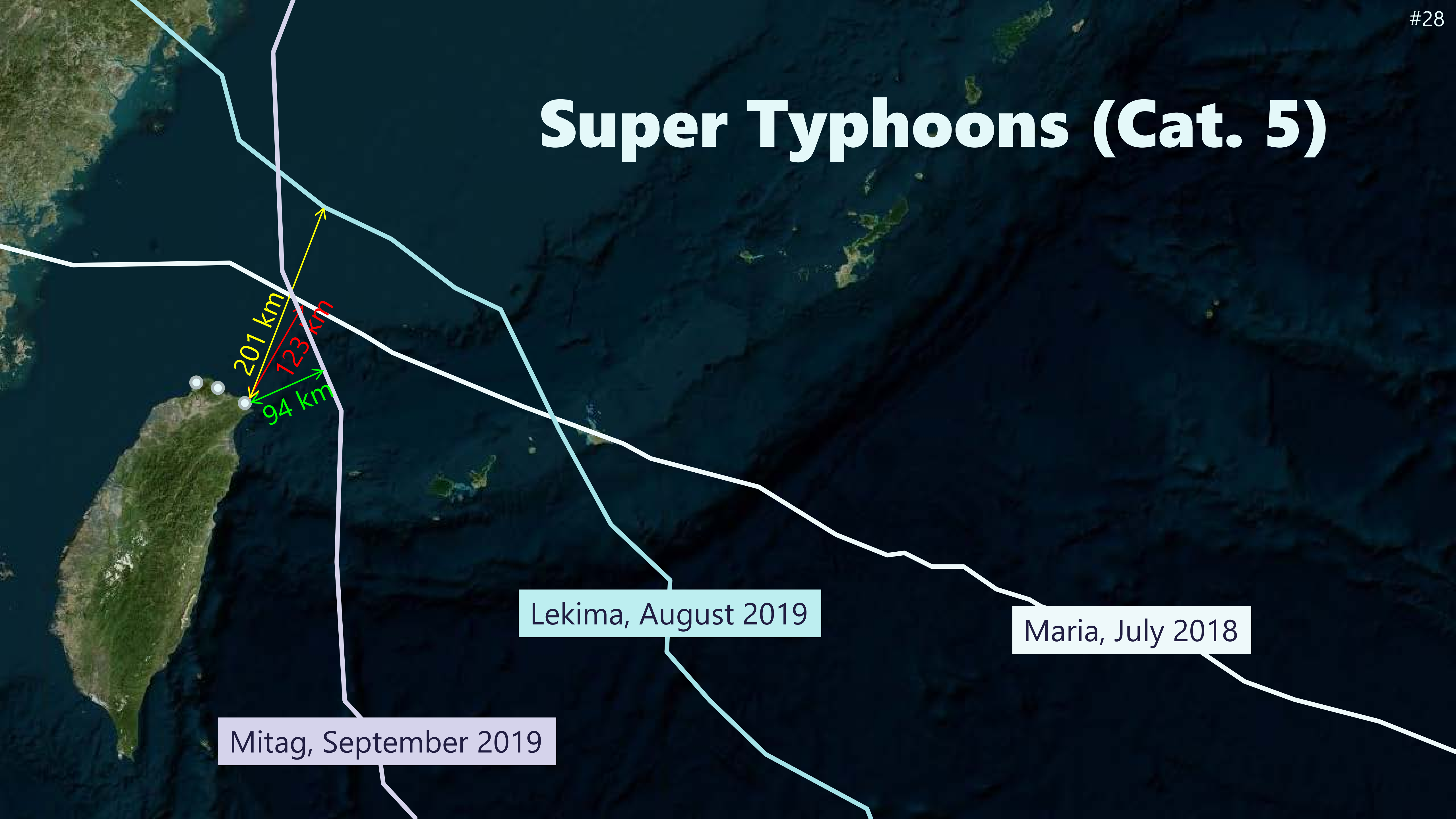
Microplastic in beaches

- April 2018 – November 2019
- Microplastic distribution before and after typhoon
- Depositional dynamics

- 1520 samples collected = 1863.6 kg beach sand

- 12,980 mesoplastic particles (5-25 mm)
- 14,088 microplastic particles (1-5 mm)
- still counting

Super Typhoons (Cat. 5)

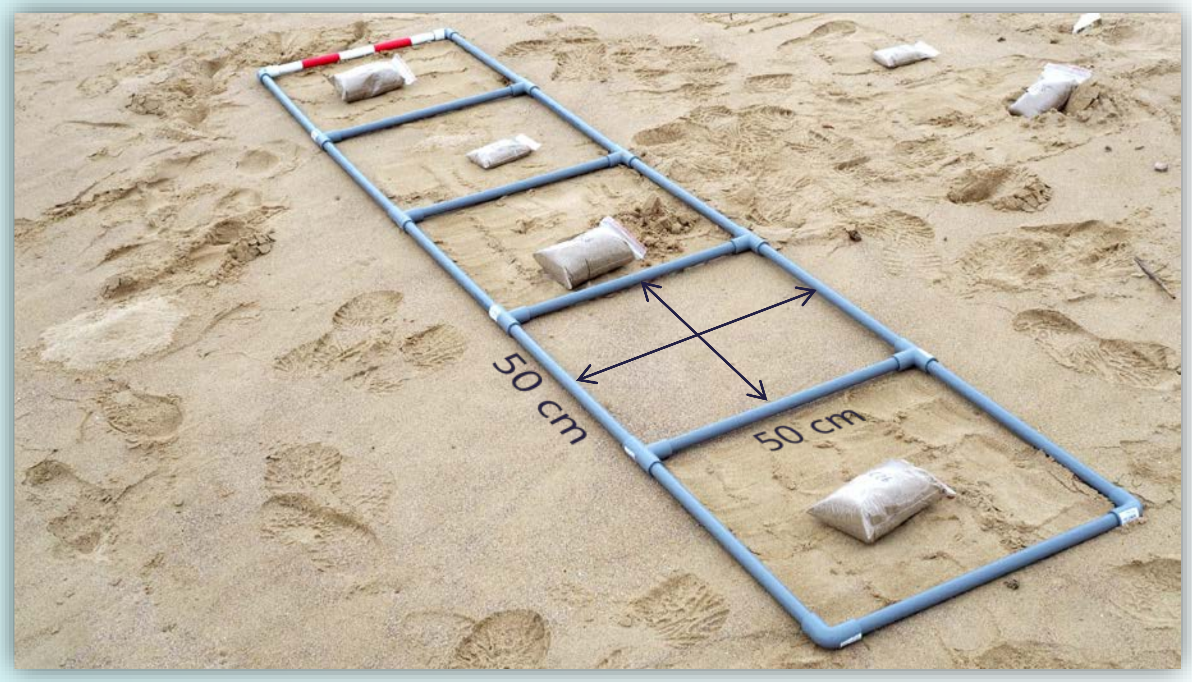


Zhouzhiwan Beach near Danshui

Xialiao Beach in Jinshan

Longmen Beach in Gongliao

Beach sampling



- Sand from surface
- Three parallel transects
- Sample distance 1 m
- Sampled area 0.25 m^2
- Sampling on random days during non-typhoon season
- Sampling immediately after typhoon

Beach sampling

Microplastic distribution (pcs/0.25 m^2)

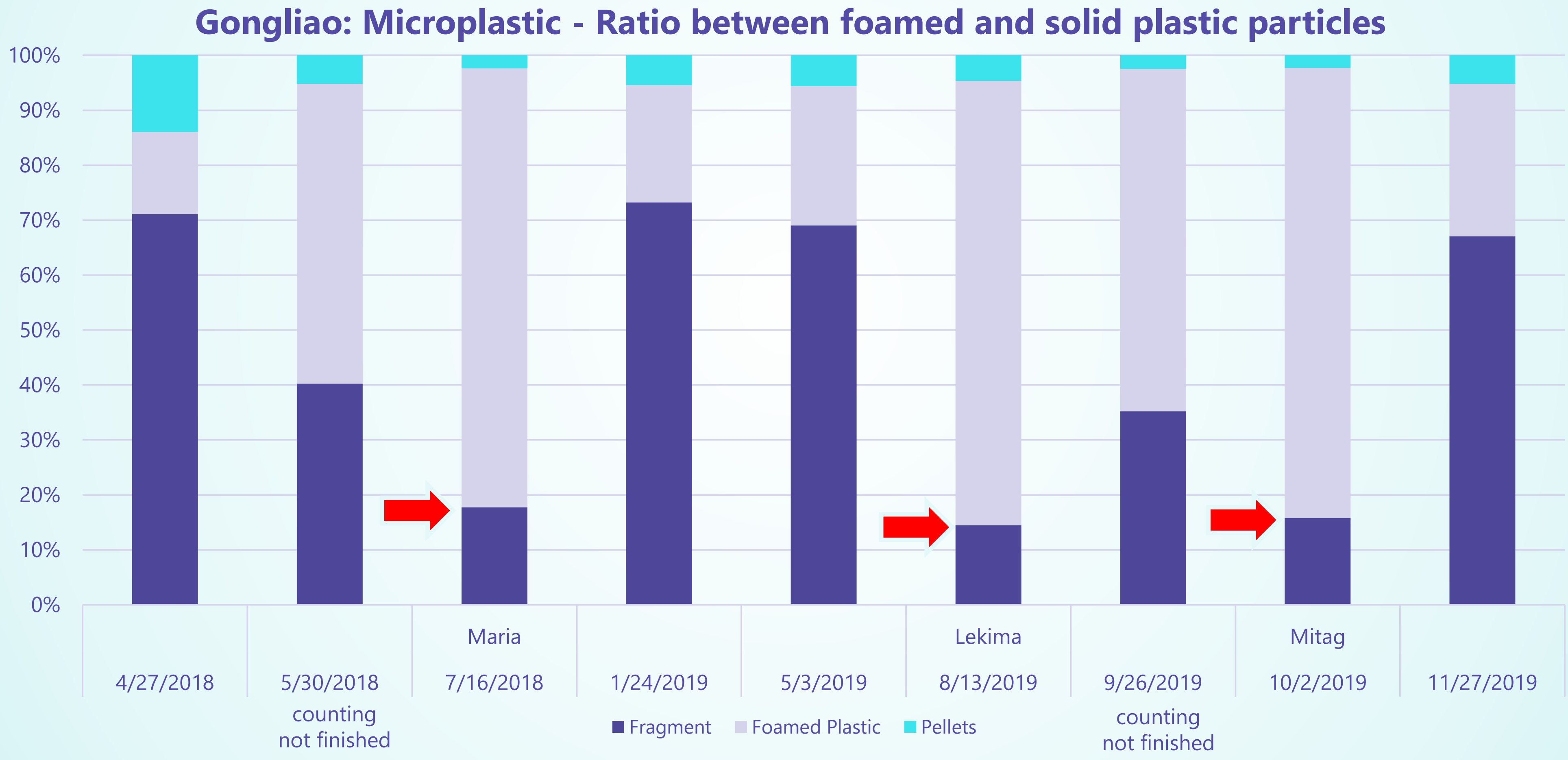
IT	HTD	supra littoral						recent stormline				backshore					old stormline				backshore		dune			
2	67	3	2	13	3	19	19	22	72	8	2	0	6	33	10	10	44	6	3	5	13	12	11	16	8	7
3	20	5	1	11	35	5	13	25	1	4	3	8	7	16	21	18	39	7	13	12	16	2	6	3	9	12
1	9	1	2	2	1	1	4	12	18	1	3	5	8	16	13	10	8	11	12	12	6	7	3	3	3	1

Microplastic distribution (pcs/0.25 m²)

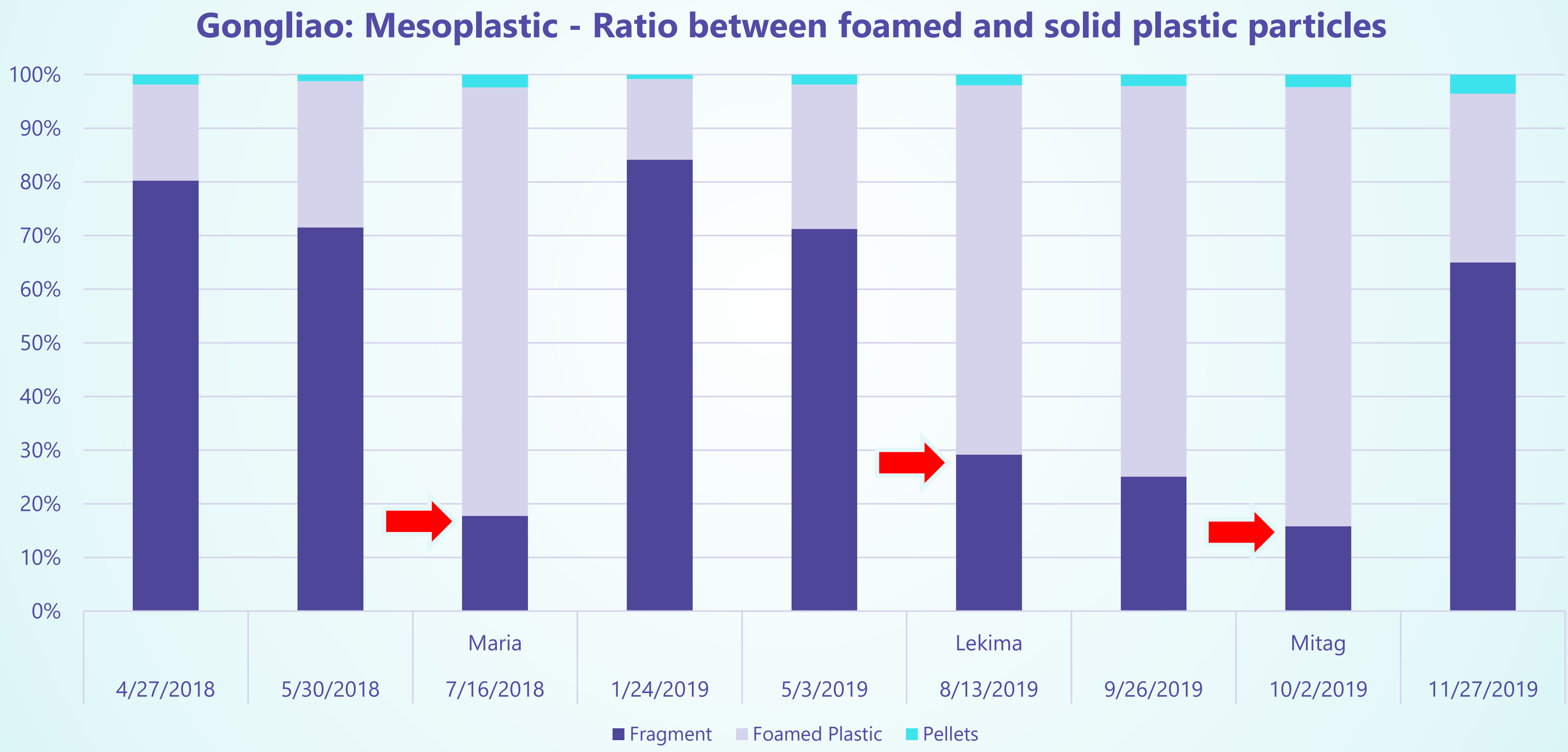
July 2018 after typhoon Maria

intertidal			high tide line			"supra littoral"																storm line from typhoon					dune	
2	0	5	1	2	7	1	2	5	3	4	1	10	3	3	1	7	2	8	3	2	2	25	16	277	12	341	10	21
1	2	0	2	3	2	1	6	1	11	1	3	4	3	0	3	5	11	4	0	1	3	11	1	47	1	82	30	6
1	2	1	2	3	0	2	2	2	5	2	19	2	3	3	1	2	1	8	2	1	5	60	15	21	25	407	27	11

Shape assemblages



Shape assemblages



Shape assemblages

Why after typhoon more foamed plastic?

- Foamed plastic 10 times lighter than fragments.
- During typhoon wave energy is higher.
- Could expect more heavy material on the beach.
- During typhoon wind is much stronger.
- Light particles should be blown beyond the dunes.
- Does foamed plastic come from further offshore?
- Do undercurrents remove heavy particles?

Preliminary results summary

01

Strong impact from typhoon

- Increased amount of microplastic
- Change in shape assemblages and deposition patterns

02

High dynamic

- After few weeks distribution patterns change strongly

03

Deposition follows wave energy

- Most microplastic deposited at stormline
- Second most at high tide line

04

Probably reflect depositional processes

- Microplastic as indicator for wind or wave energy
- Needs more research

Microplastic Pollution of the Tamsui River

Wong, G., Löwemark, L., Kunz, A.* (2020): “Microplastic pollution of the Tamsui River and its tributaries in northern Taiwan: Spatial heterogeneity and correlation with precipitation”
Environmental Pollution 260: 113935.

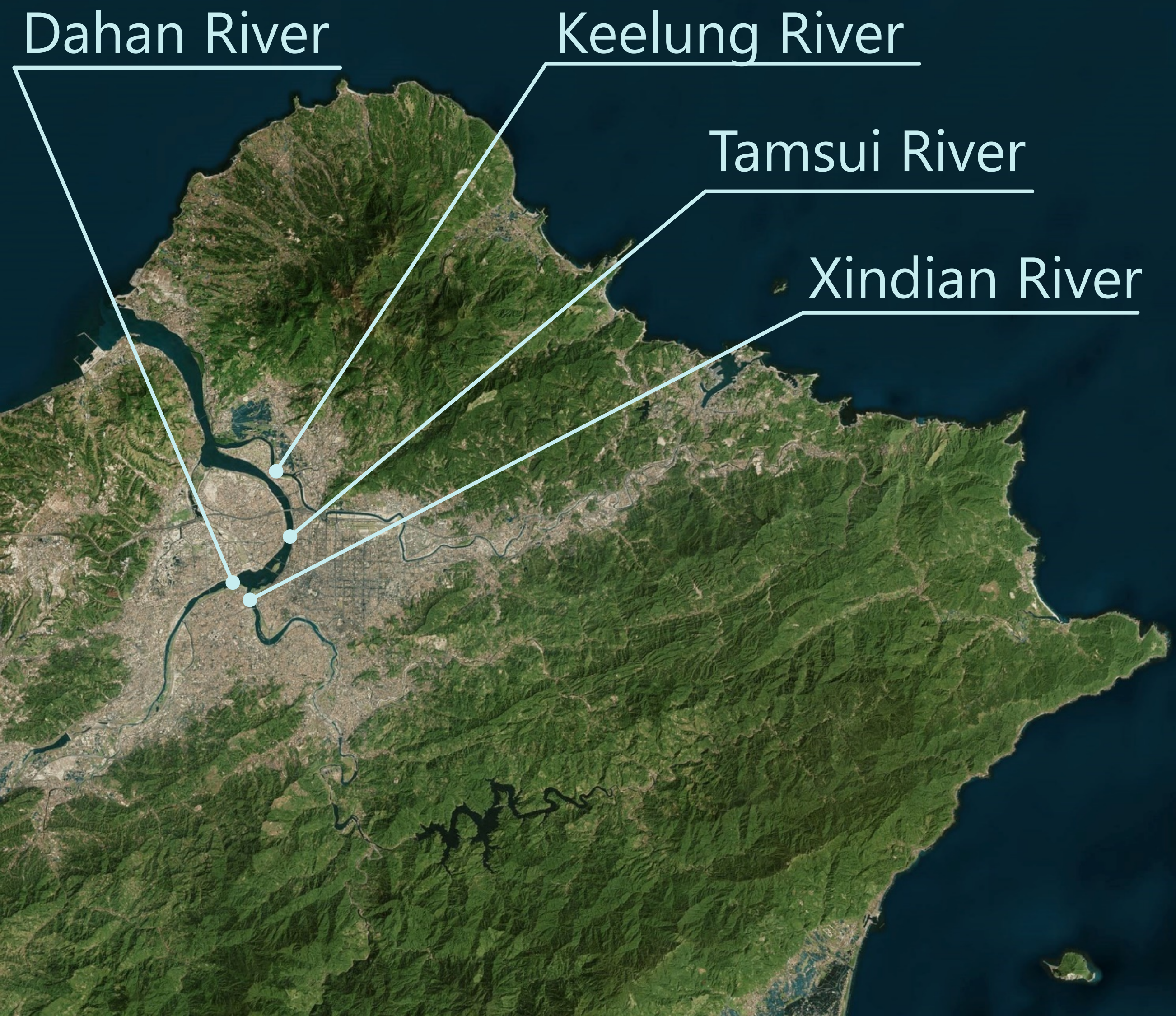
Microplastic in rivers

- Major contributor to plastic pollution in the oceans
- Important source for fresh water and drinking water

- Tamsui River in the top 20 most polluting rivers (Lebreton et al. 2017)
- Need real field data about microplastic pollution

Lebreton, L. C. M., et al. (2017). "River plastic emissions to the world's oceans." Nat Commun 8: 15611.

Microplastic in rivers

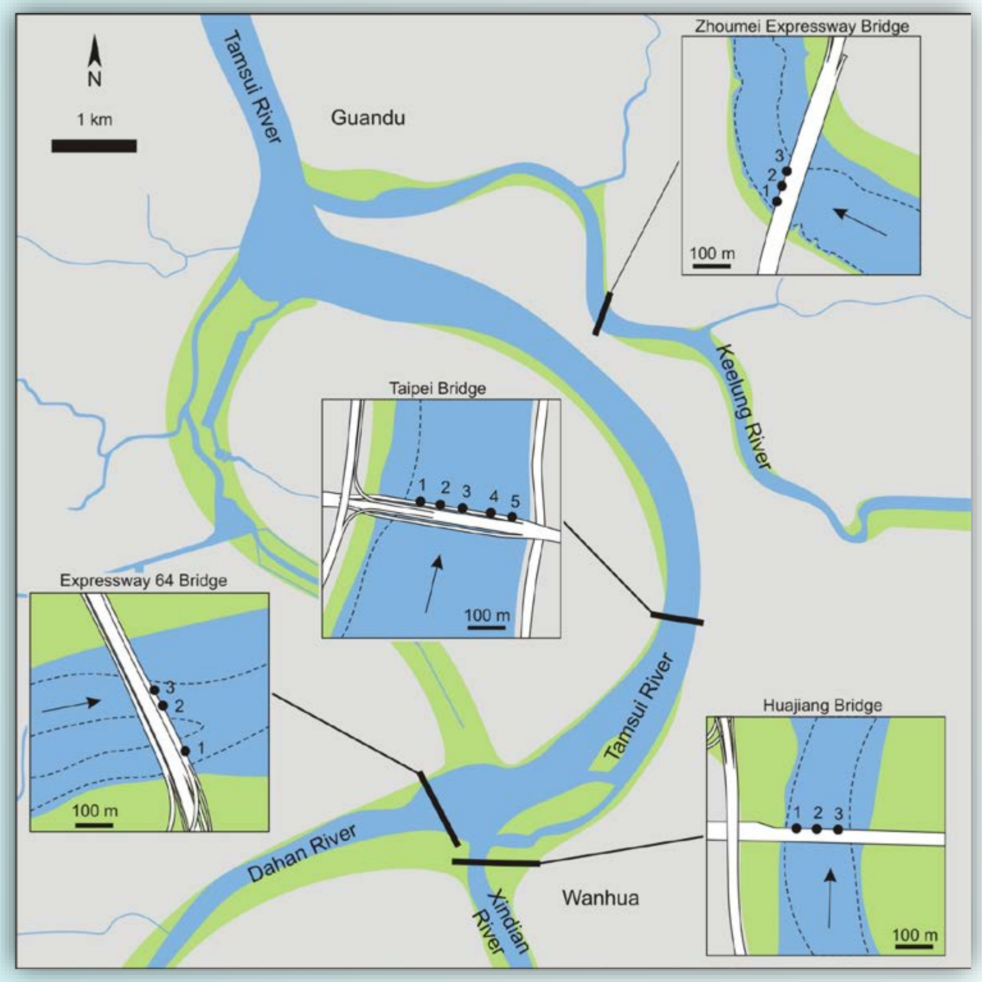


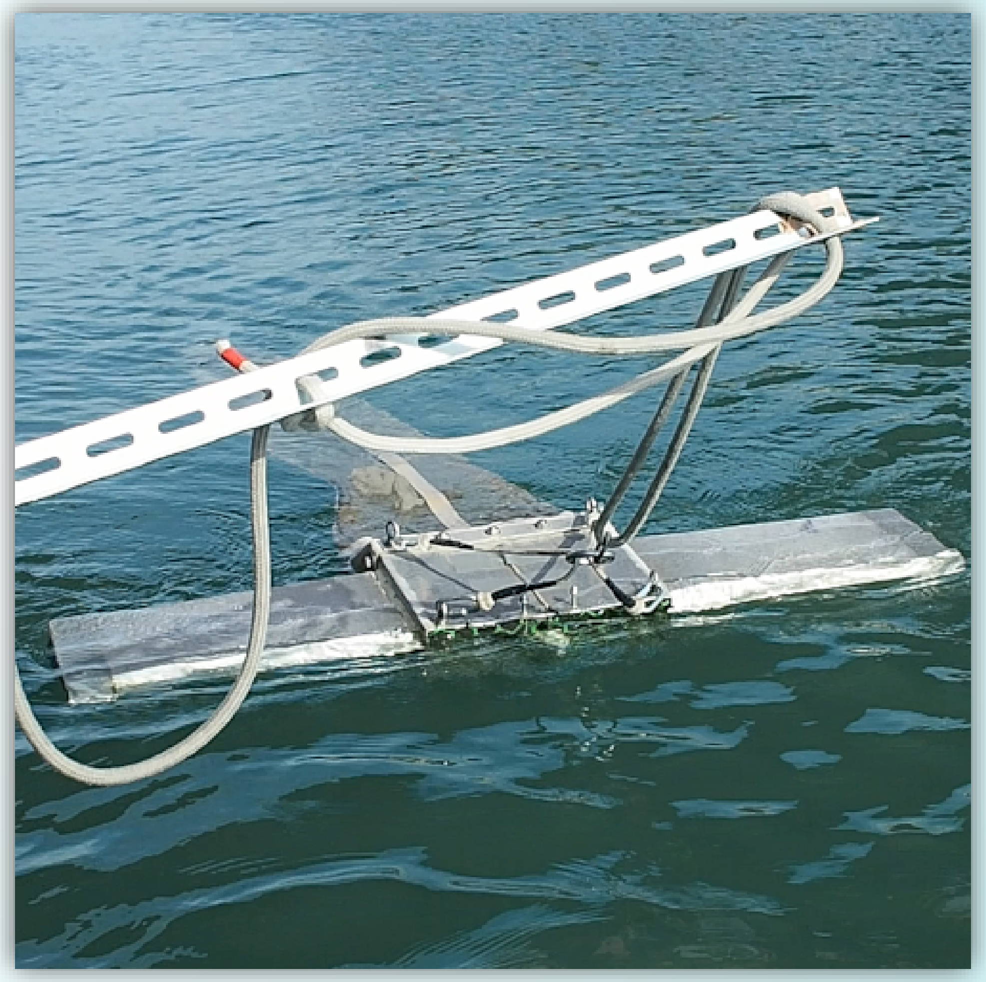
- Every two weeks sampling for three months
- Amount of microplastic
- Temporal trends
- Mass balance

- 680.5 m^3 = 680,500 liters river water

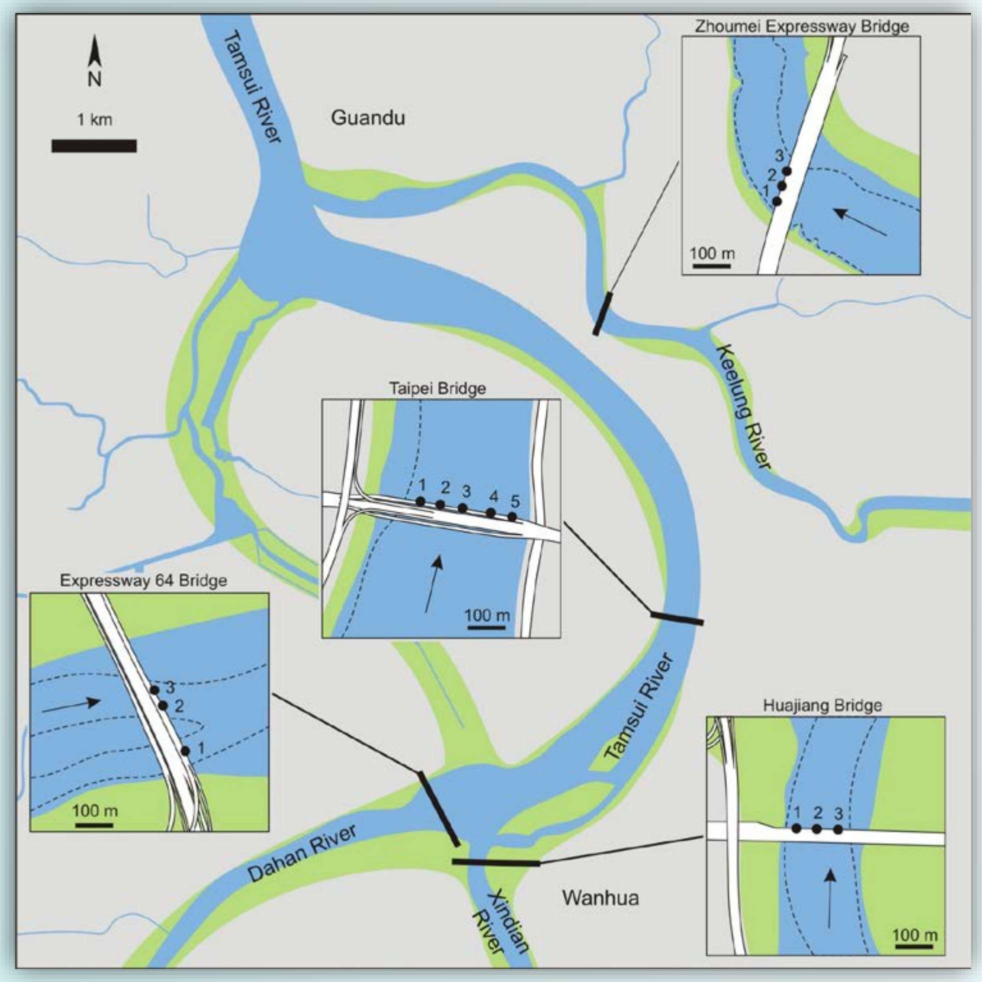
- 16,776 microplastic particles (0.3 to 5 mm size)

Sampling in rivers





Microplastic in rivers



Keelung River:
from 2.8 ± 1.2 pcs/m^3
to 64.4 ± 76.2 pcs/m^3

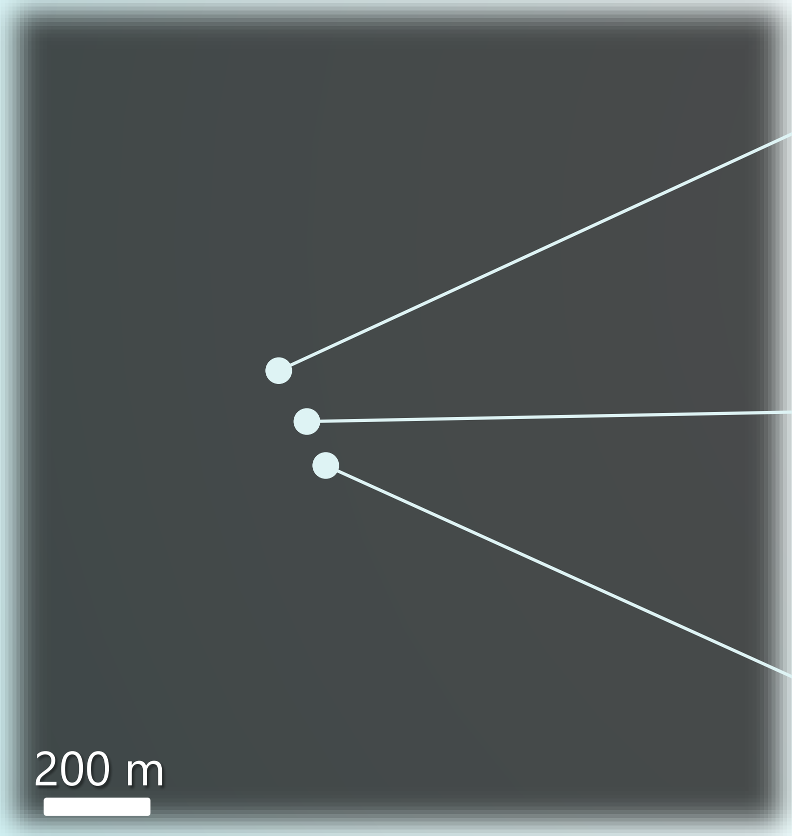
Tamsui River:
from 10.1 ± 5.1 pcs/m^3
to 70.5 ± 30.6 pcs/m^3

Dahan River:
from 6.7 ± 2.4 pcs/m^3
to 83.7 ± 70.8 pcs/m^3

Xindian River:
from 2.5 ± 1.8 pcs/m^3
to 66.6 ± 58.0 pcs/m^3

Large variation within river …

… but not within replicates. Dahan River as example



21.2 pcs/m³
18.0 pcs/m³
24.6 pcs/m³

21.3 ± 3.3 pcs/m³

12.1 pcs/m³
11.6 pcs/m³
9.5 pcs/m³

11.1 ± 1.4 pcs/m³

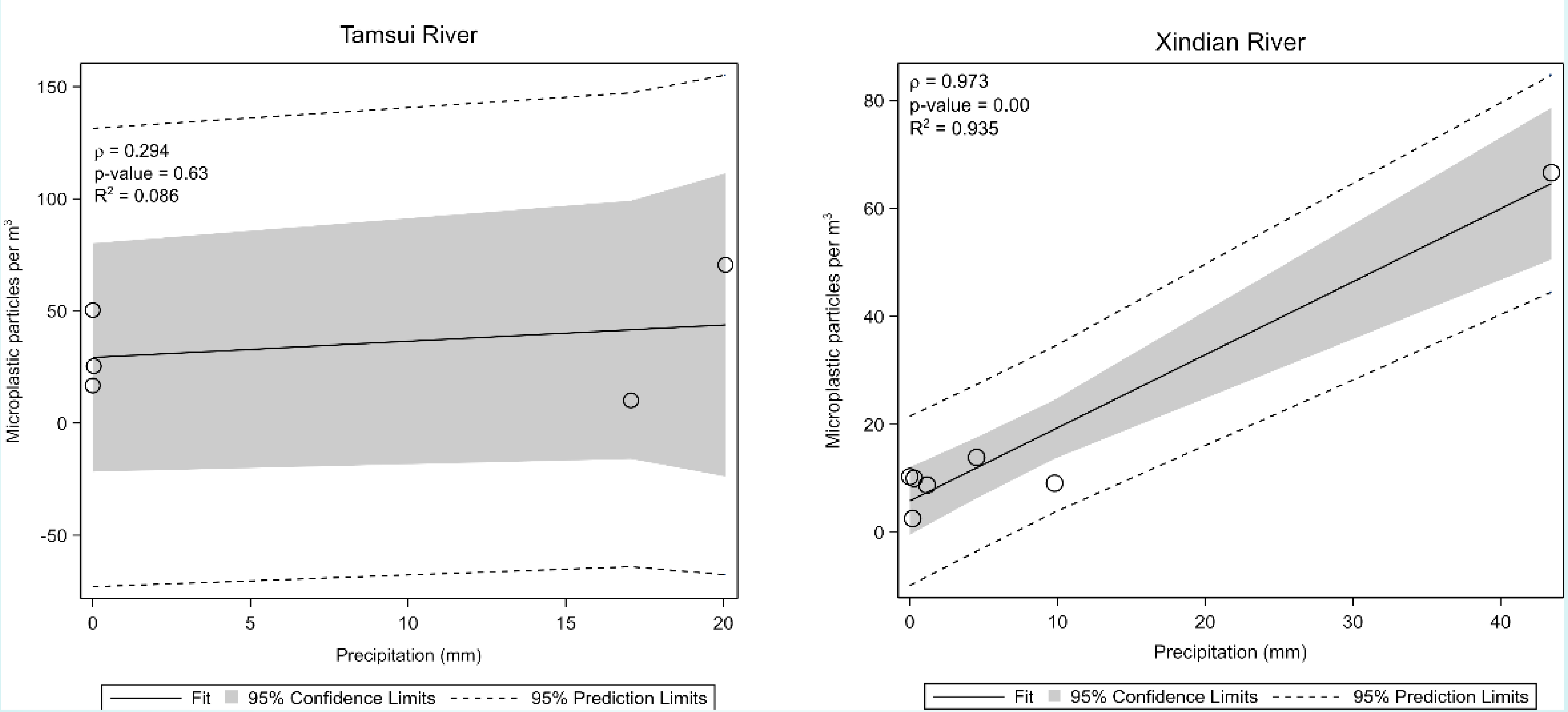
7.6 pcs/m³
6.8 pcs/m³
6.0 pcs/m³

6.8 ± 0.8 pcs/m³

13.1 ± 6.7 pcs/m³

Correlation with precipitation

Correlation strongly depends on sampling position across the river

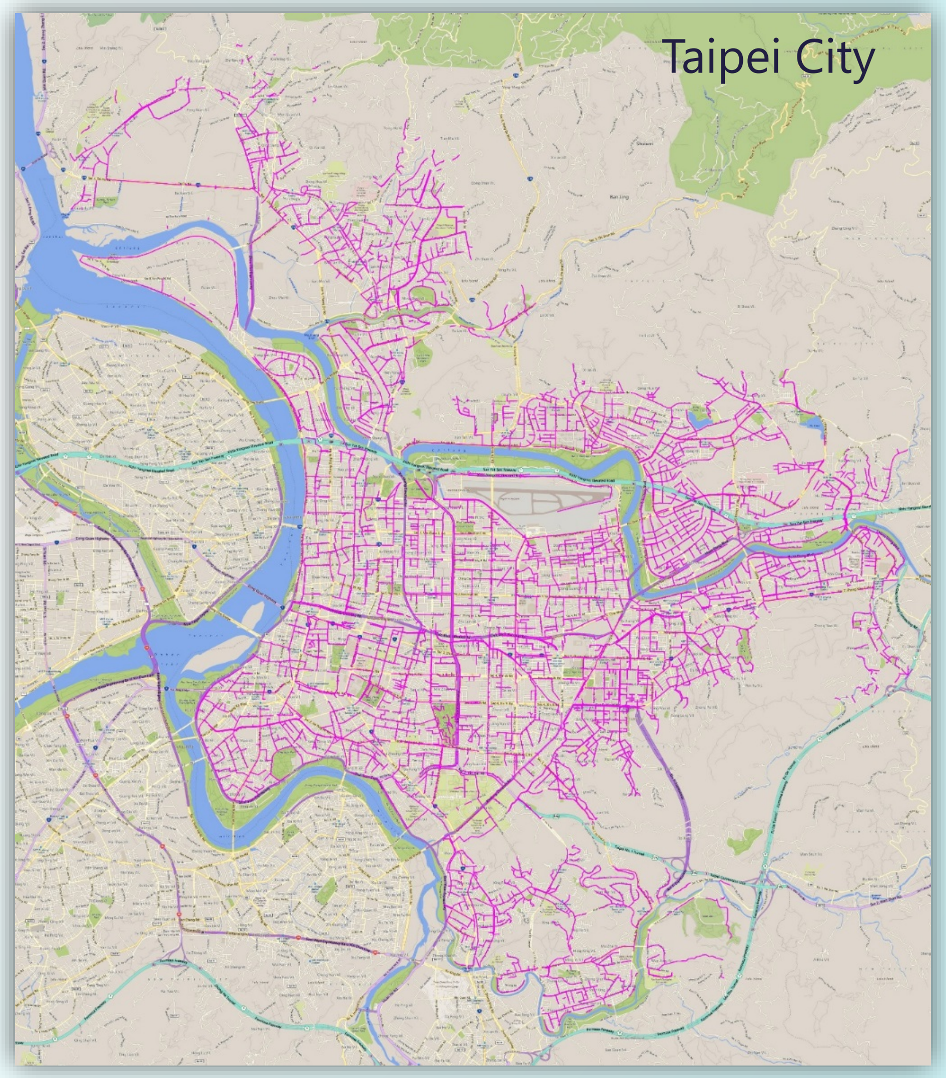


Origin of microplastic

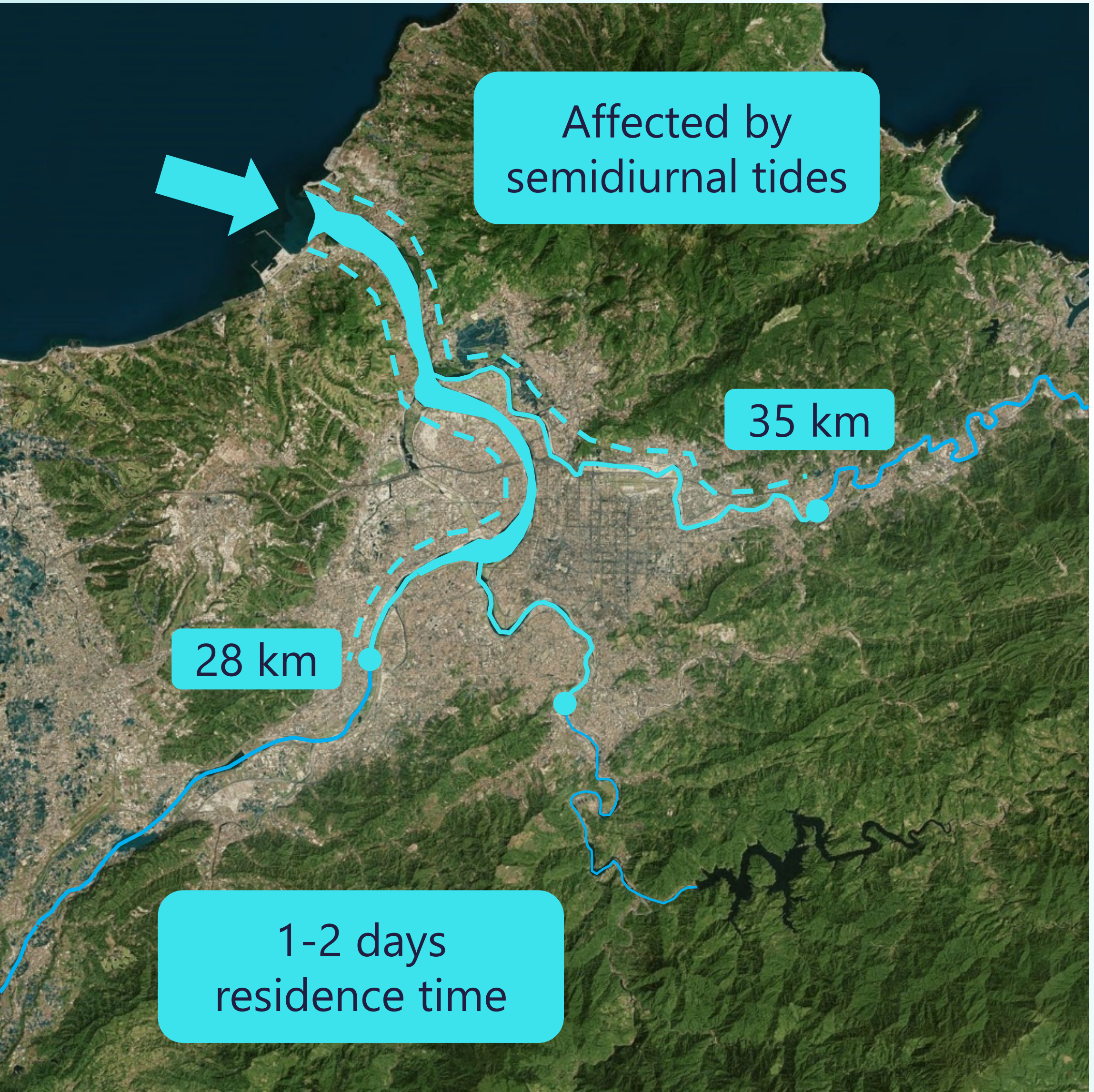
- Rivers are very short:

  Keelung River = 96 km
  Xindian River = 81 km
  Dahan River = 135 km long
  Tamsui River = 23 km long
- Travel time source to mouth 2-28 days
- No time for plastic to disintegrate
- Probably microplastic is produced on land

Storm sewer as a source?



Ocean as a source?



More research on the way

Spatial distribution in 3D

Identify land-based sources

Tidal input

Realistic estimate of microplastic in the Tamsui River

Microplastic in the environment

01 ubiquitous

Occurs in all environments, as well as living organisms and food.

02 heterogeneous

Neighboring samples can have large variation in particle numbers.

03 variable

Large spatial and temporal variation in the amount of particles.

04 inaccurate

Numbers are mostly estimates or snapshots in time and space.

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