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Microplàstics com a contaminants emergents: presència en l'ambient i efectes sobre la salut

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Filipines

The Sun



World plastics production* evolution

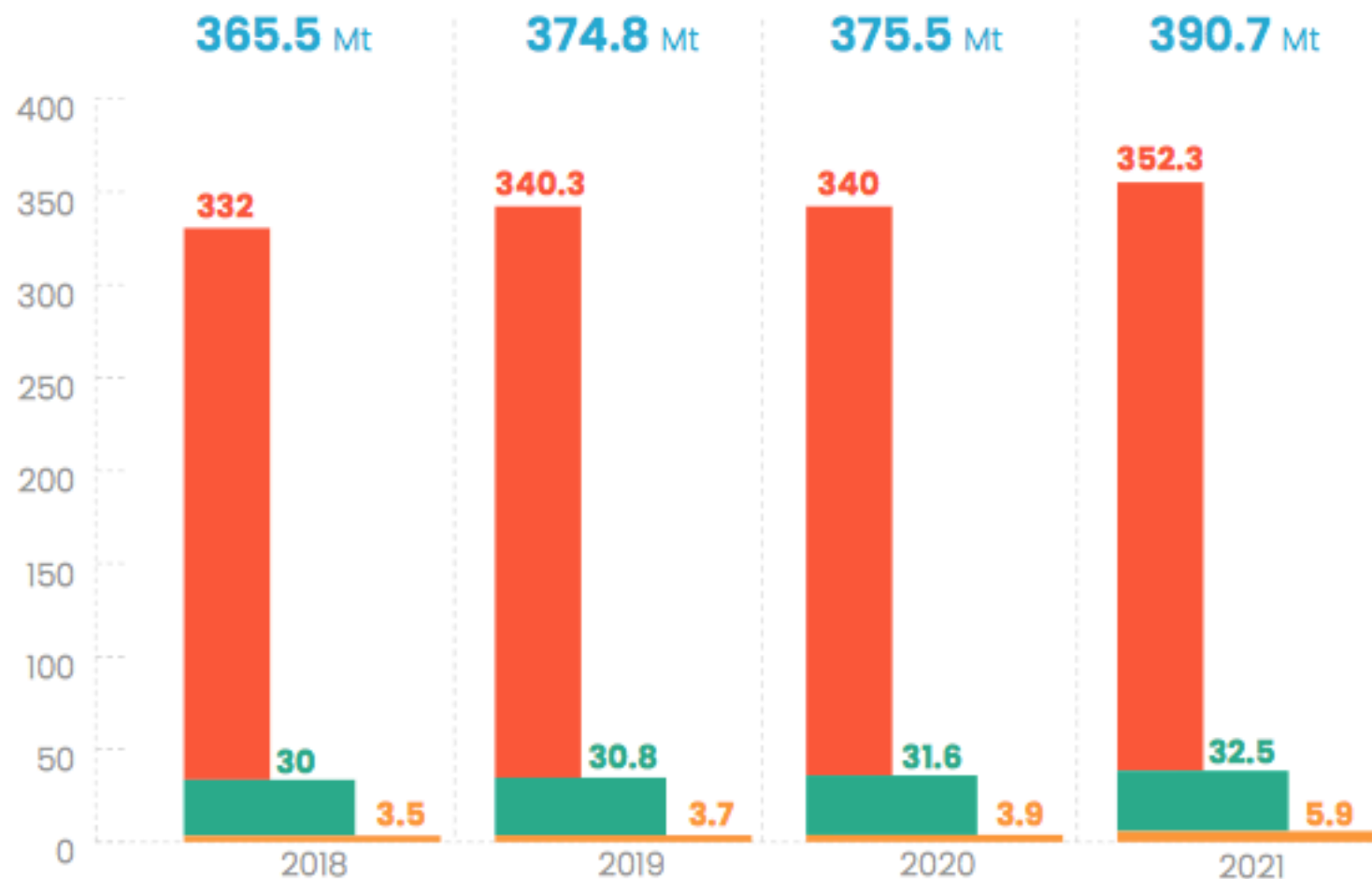
After a stagnation in 2020 due to the Covid-19 pandemic, the global plastics production increased to 390.7 million tonnes in 2021.

in million tonnes

■ Fossil-based plastics¹

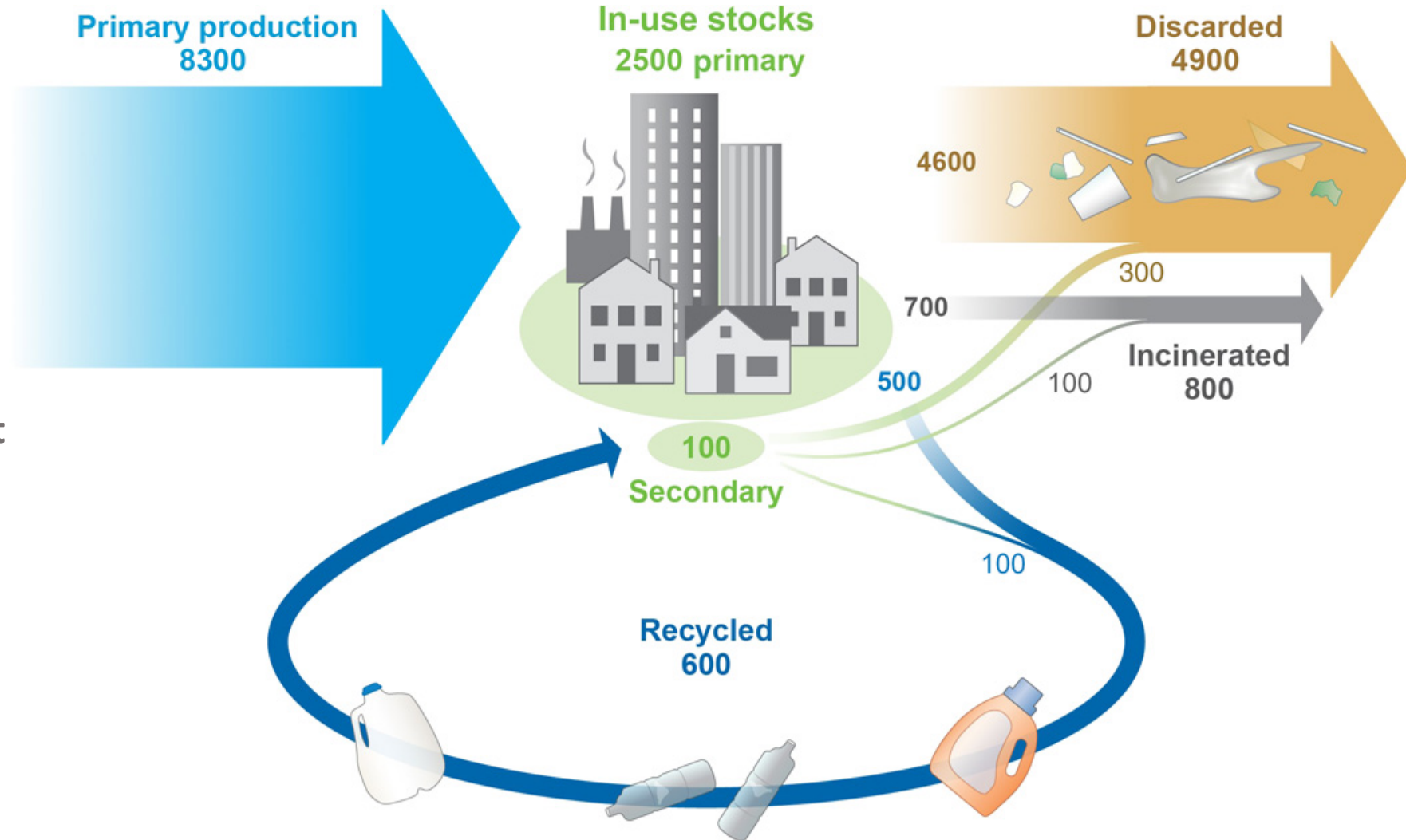
■ Post-consumer recycled plastics²

■ Bio-based plastics (including bio-attributed plastics in 2021 data)³



Cicle de vida del plàstic

- ❖ No compleix l'economia circular
- ❖ Només un 7% del plàstic produït s'ha reciclat i només un 1% s'ha reciclat 2 cops
- ❖ La major part del plàstic es du a l'abocador, s'incinera o acaba en el medi ambient
- ❖ Es probablement el **contaminant xenobiòtic més abundant de la Terra**



Dades en milions de tones

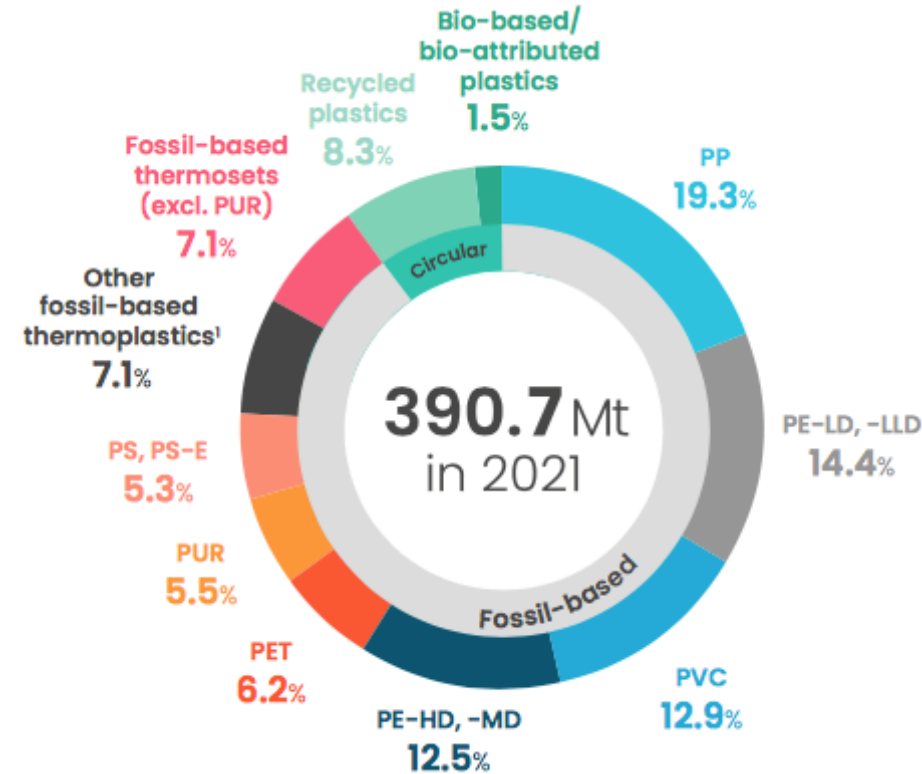
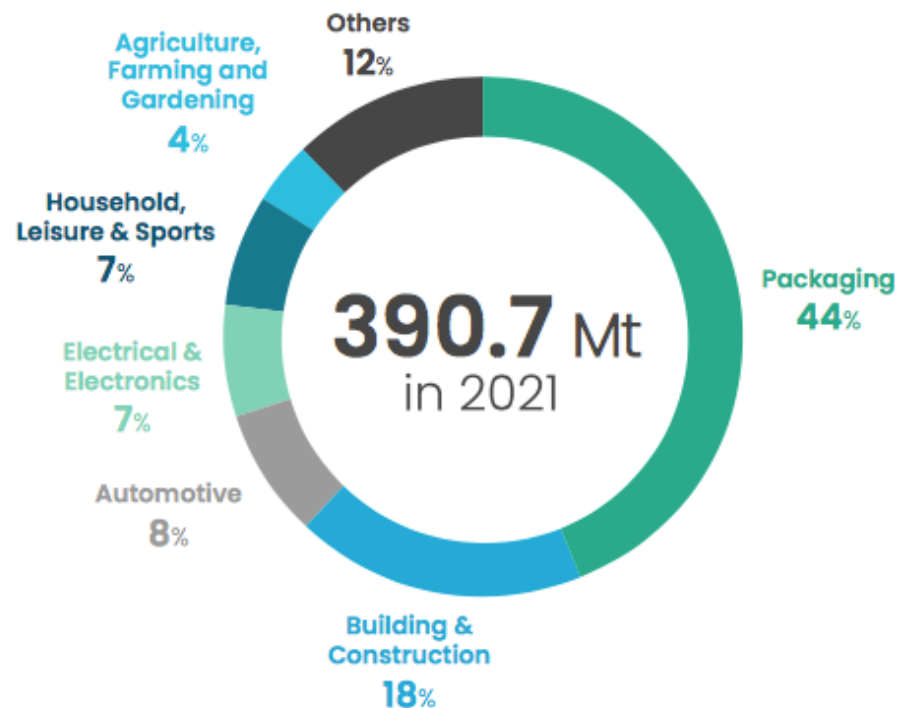
Geyer et al., 2017, *Science Advances*

Distribution of the global plastics production* by type

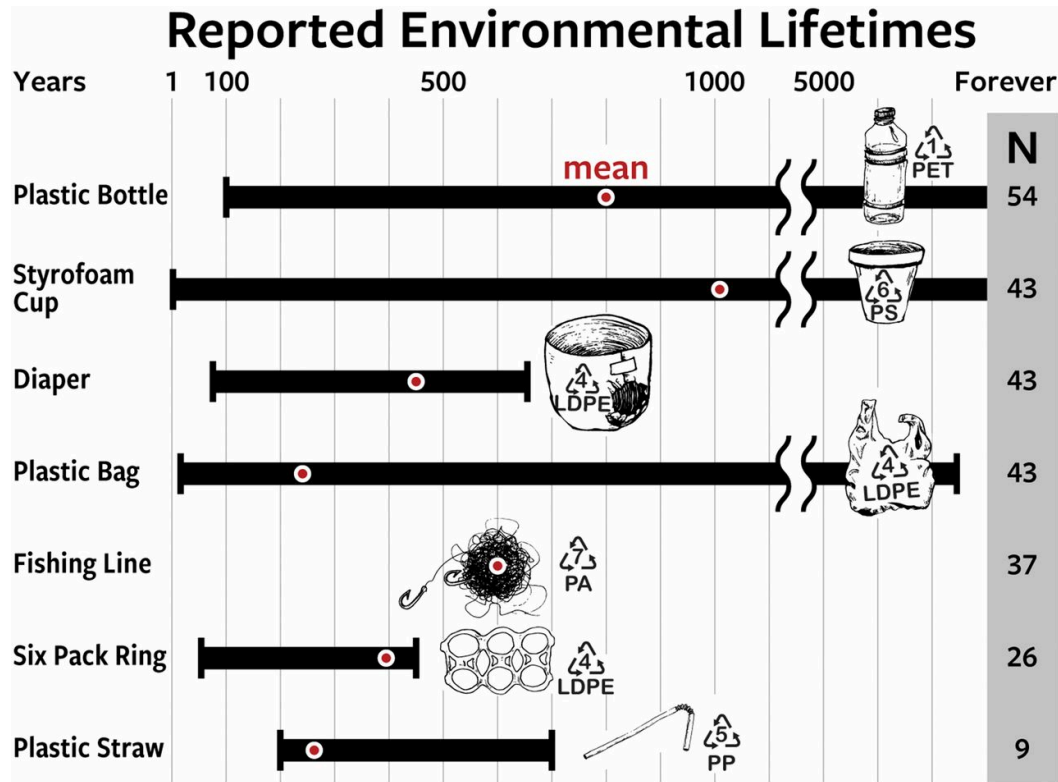
In 2021, circular plastics represented about 9.8% of the world plastics production.

Distribution of the global plastics use by application

In 2021, packaging and building & construction applications were the two largest world plastics markets.



El problema de los plàstics actuals és la seva baixa biodegradabilitat (persistència)



Ward & Reddy, 2020. *PNAS*

Plastics					
C-C backbone				Heteroatoms in backbone	
PE 	PP 	PS 	PVC 	PET 	PU
29.6	18.9	7.1	10.4	6.9	7.4
fraction of total European demand [%]					

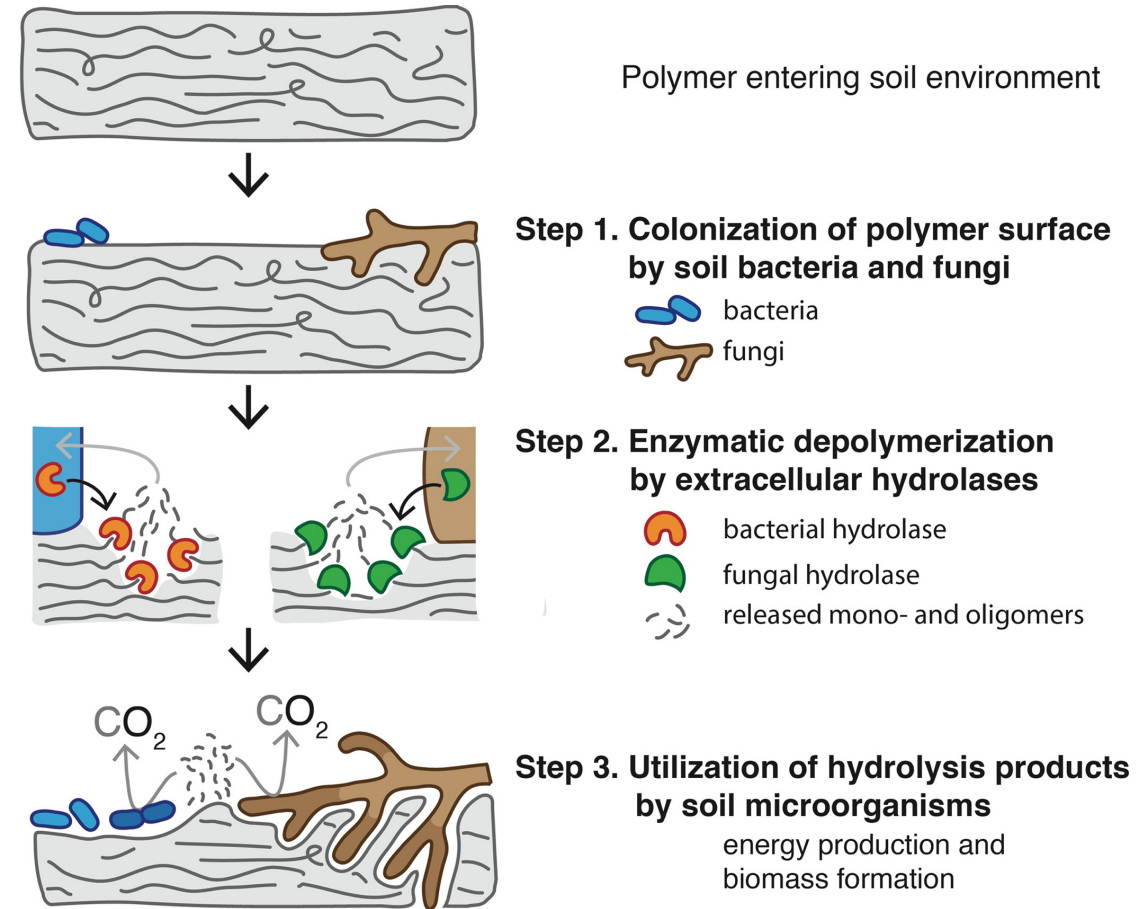
Gewert et al., 2015, *Environ.Sci: Processes Impacts*

- ❖ Elevat pes molecular (milions de grams per mol)
- ❖ Esquelet de la cadena aporta hidrofobicitat (lipofília)
- ❖ Additius els fan més resistents
- ❖ Resistents a la hidròlisi
- ❖ Resistents a l'oxidació
- ❖ Resistents a l'atac enzimàtic
- ❖ Cristalinitat aporta més resistència que el plàstic amorf

Etales necessàries per (bio) degradar un plàstic

Per haver-hi biodegradació real calen 3 etapes:

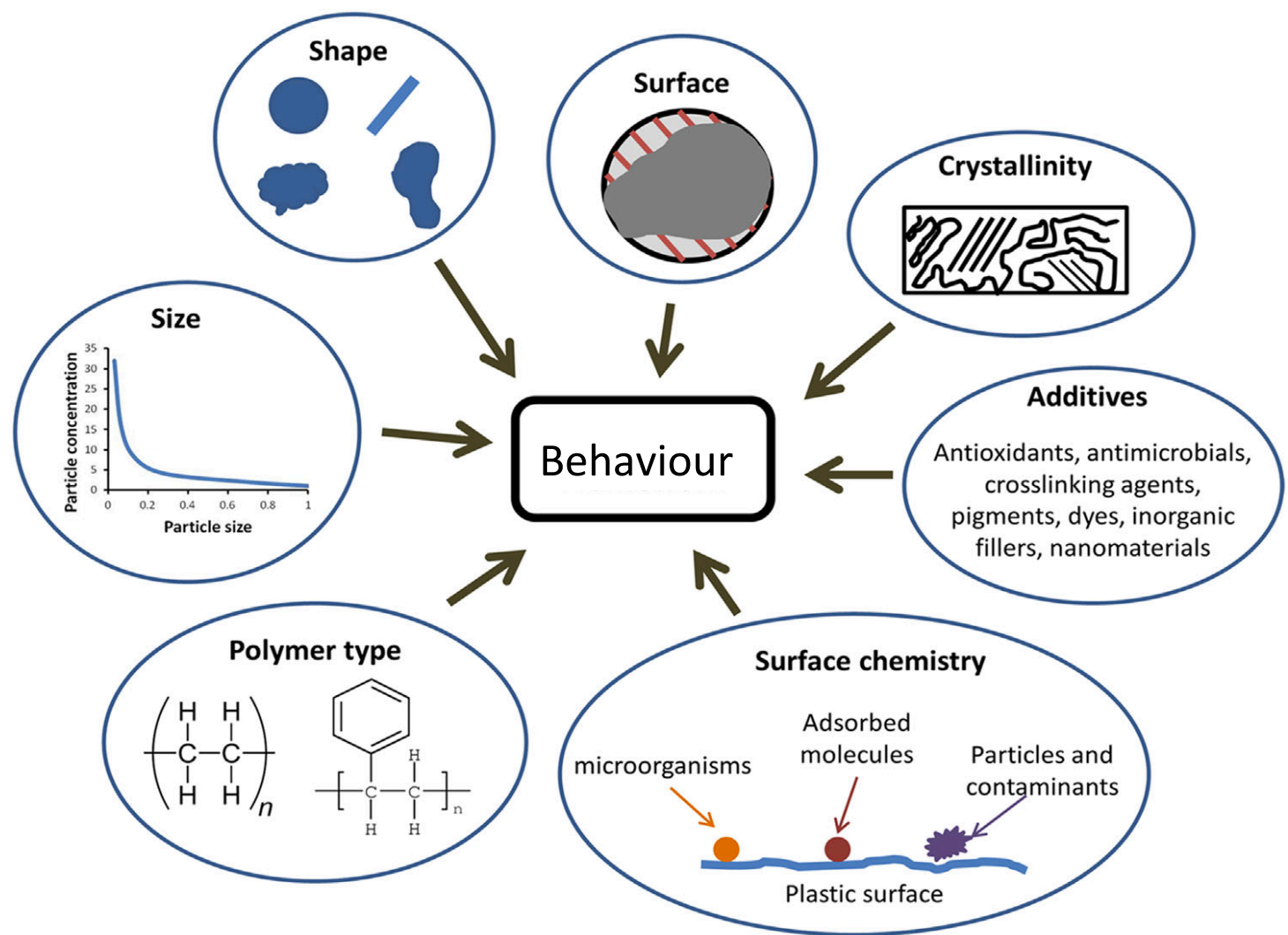
- ❖ (Bio)deterioració: fragmentació del plàstic gràcies a factors abiòtics (llum, temperatura...) + biòtics (biofilms)
- ❖ Despolimerització: trencar molècules polimèriques (hidròlisi, oxidació...) per l'acció d'agents catalítics (**enzims**, radicals lliures...) de microorganismes
- ❖ Assimilació i mineralització de les molècules simples per part dels microorganismes



Sander, 2019; *Environ. Sci. Technol.*

1 pellet >>> 2.000.000 MP (20 μm diàmetre) >>> $1,5 \times 10^{13}$ NP (0,1 μm diàmetre)

Factors que condicionen el comportament ambiental dels MP



Polymer	Density (g cm ⁻³)
PP	0.9–0.91
PE	0.92–0.97
PA	1.02–1.05
PS	1.04–1.1
Acrylic	1.09–1.20
PMA	1.17–1.20
PU	1.2
PVC	1.16–1.58
PVA	1.19–1.31
Alkyd	1.24–2.10
Polyester	1.24–2.3
PET	1.37–1.45
POM	1.41–1.61

El plàstics en ambients marins



Accumulation of debris in deep sea environments. Submersible observations in Mediterranean canyons (*a* and *b*: plastic bottles at 1000 m depth at two different locations in the Marseille canyon, 43°03'00" N, 05°00'00" E) and above the polar circle, under ice floe (*c* and *d*: individual plastic bags, 2200–2600 m depth at Hausgarten, Fram strait, 79°03'80" N, 04°11'60" E).

Classificació dels MP

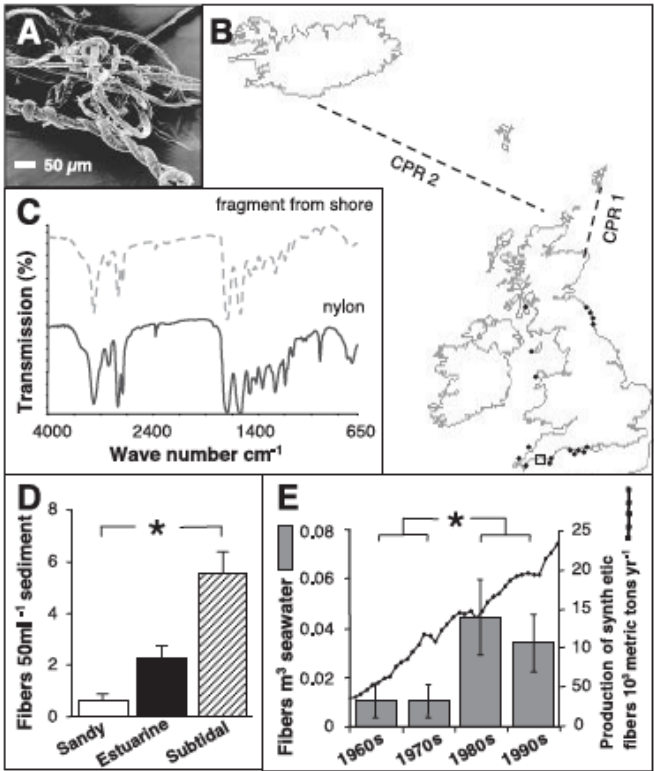
- ❖ **Primaris** (fabricats expressament d'aquesta mida: pellets, cosmètics, fibres...)
- ❖ **Secundaris** (formats a partir de la fragmentació de plàstics més grans)

Nano <1µm	Micro <5mm	Meso <2.5cm	Macro <1 m	Mega >1m
• Nanofibres from clothing • Rubber dust from tyre wear • Nanoparticles in products and pharmaceuticals.	• Microbeads from personal care products • Fragmentation of existing (plastic) products • Polystyrene • Plastic from blasting in shipyards • Particulates from waste incineration	• Bottle caps • Cigarette filters and butts • Plastic pellets • Windblown/storm-washed waste	• Beverage bottles and cans • Plastic bags • Food & other packaging • Disposable tableware / cutlery • Beer-ties • Fishing lines, floats & buoys • Tyres • Pipes • Balloons and toys • Textiles	• Abandoned fishing nets and traps • Rope • Boats • Plastic films from agriculture • Construction PVC (Polyvinyl chloride)

Source: adapted from Watkins et al., 2016.

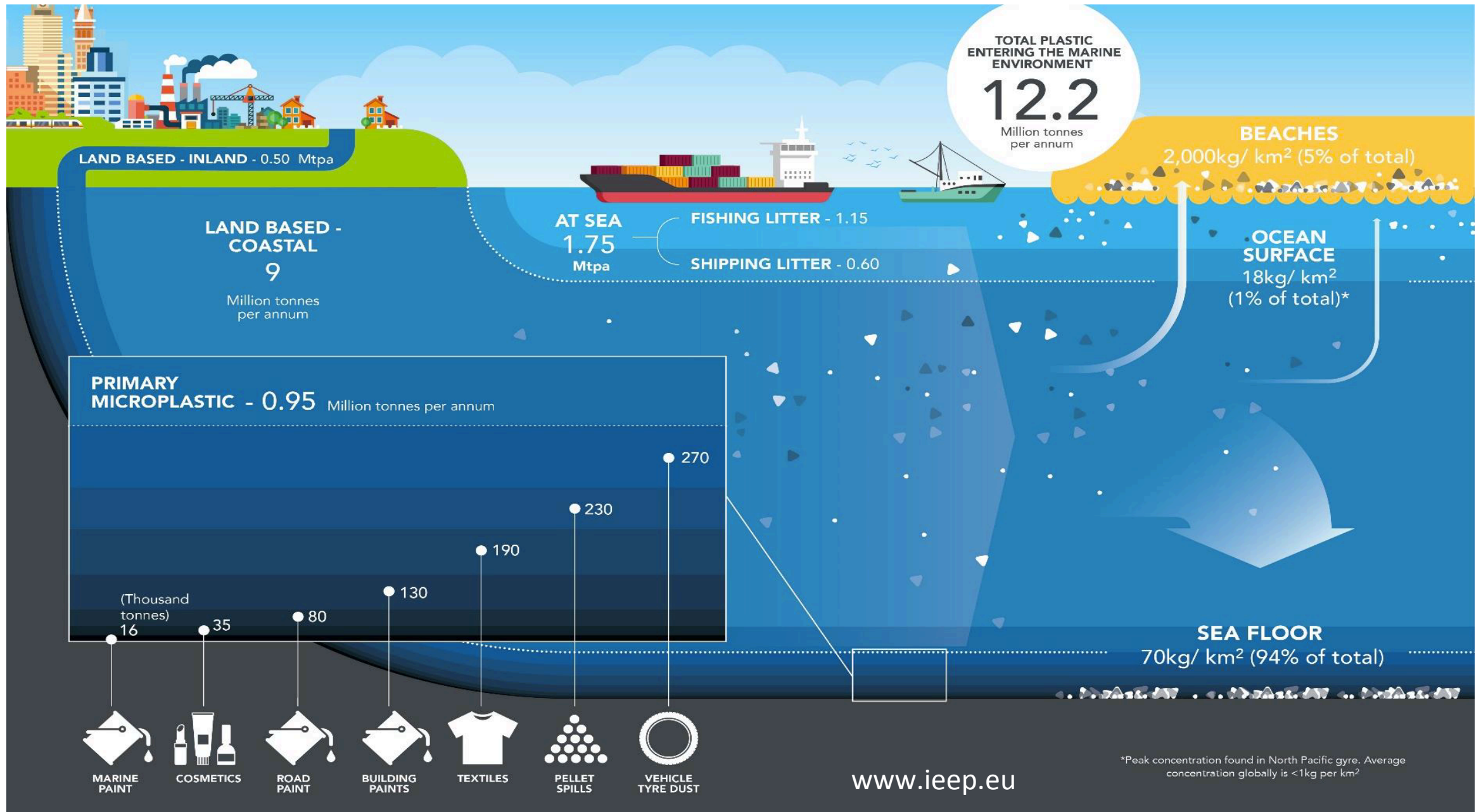
Lost at Sea: Where Is All the Plastic?

Richard C. Thompson,^{1*} Ylva Olsen,¹ Richard P. Mitchell,¹ Anthony Davis,¹ Steven J. Rowland,¹ Anthony W. G. John,² Daniel McGonigle,³ Andrea E. Russell³

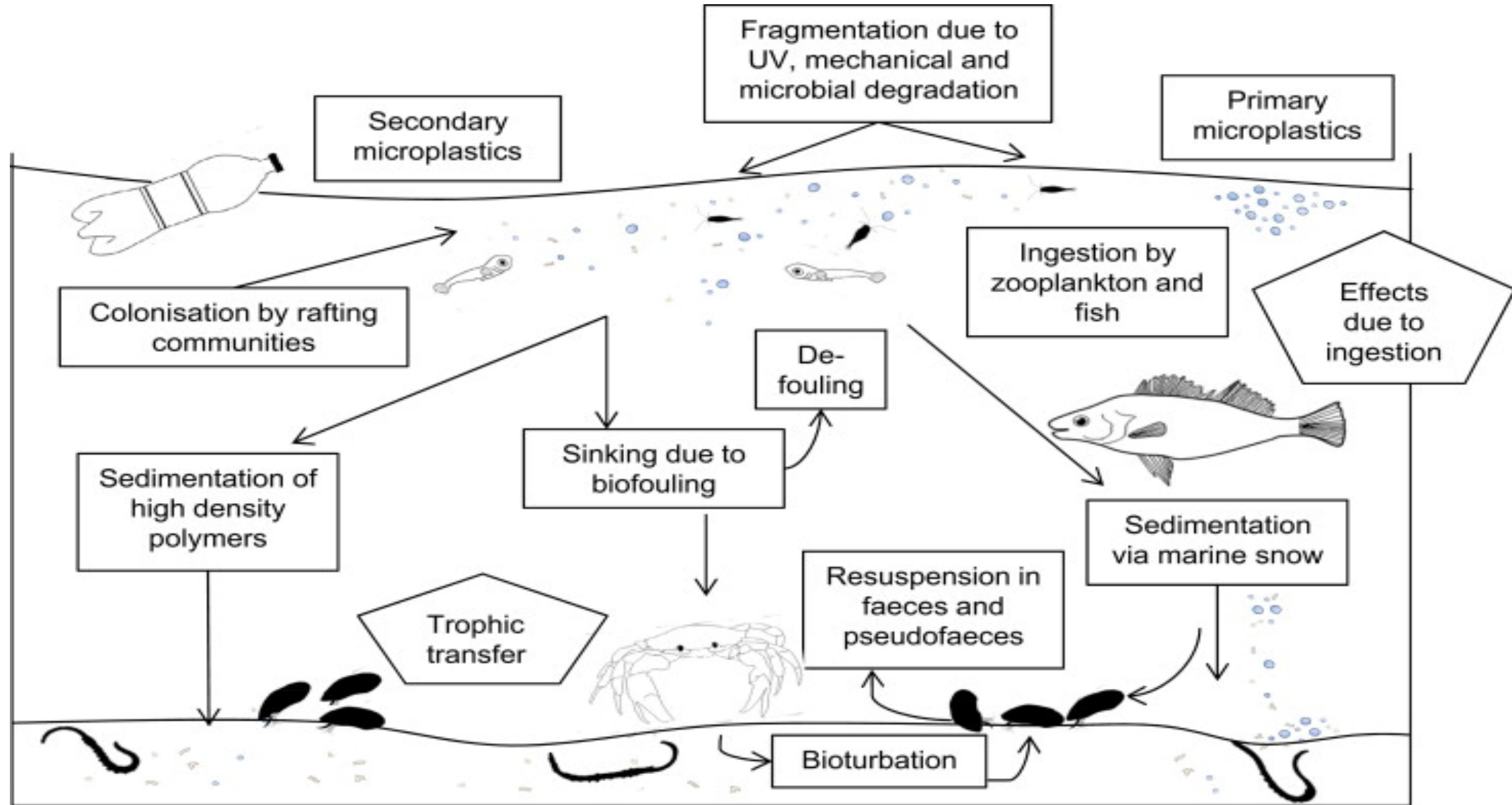


El plàstics en ambients marins

Dades en milions de tones/any

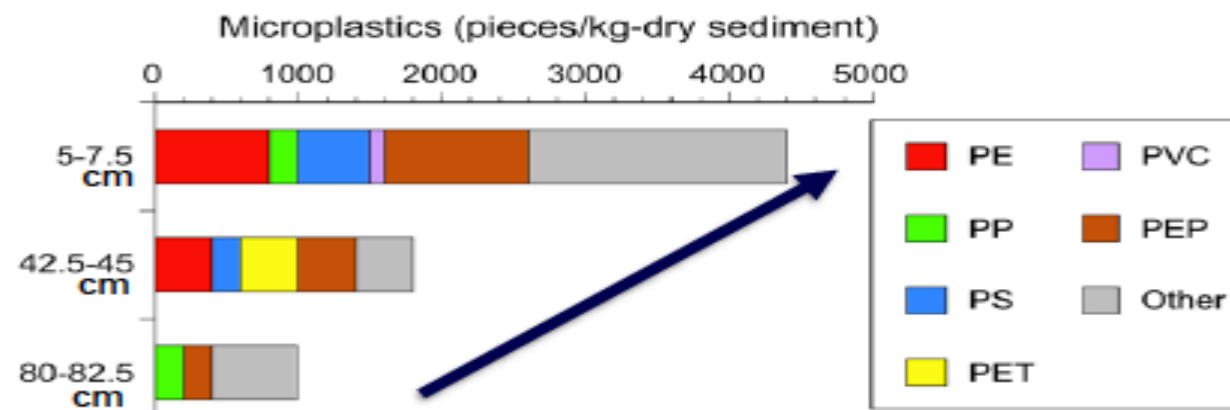
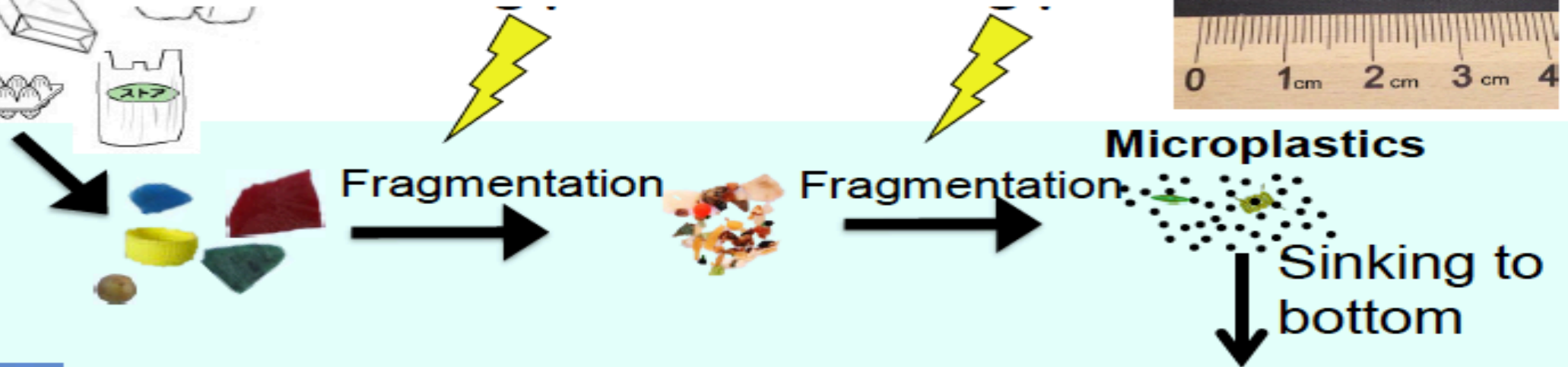
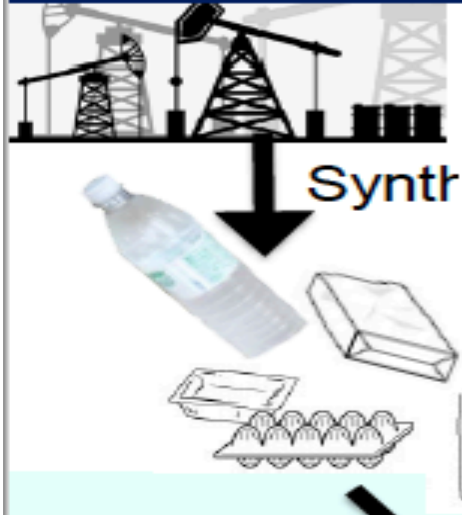


El plàstics en ambients marins



Increasing trend : Microplastic pollution is getting serious

Anthropocene : an epoch when human activities significantly impacted Earth's geology, atmosphere, and ecosystems

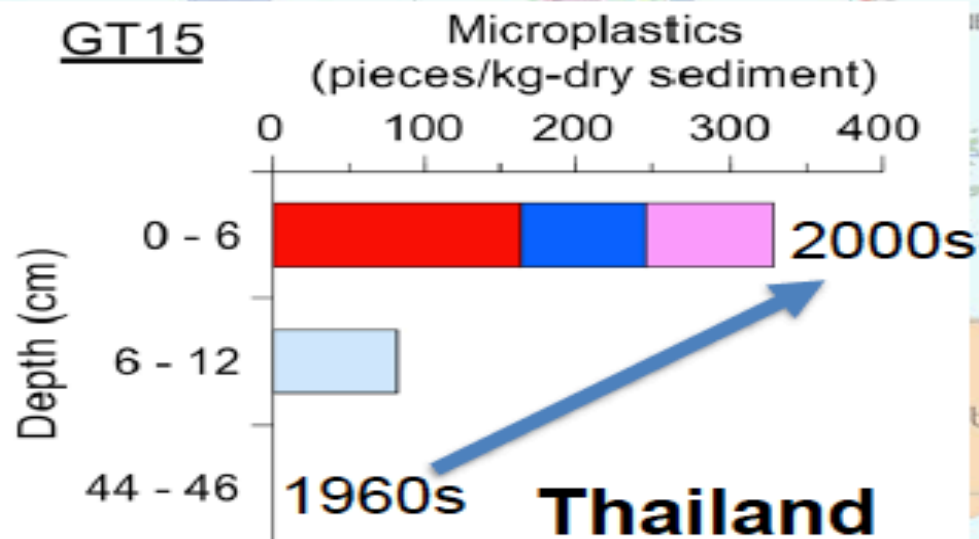
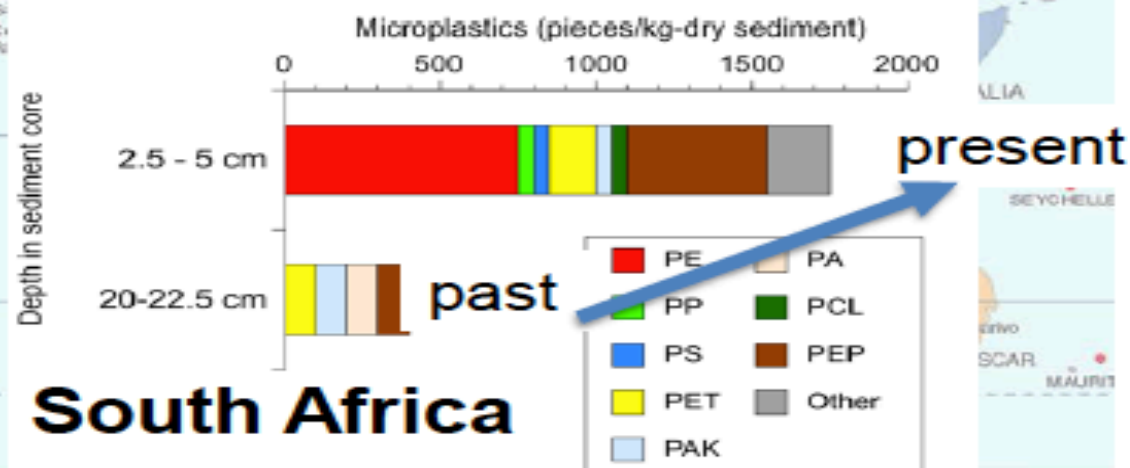
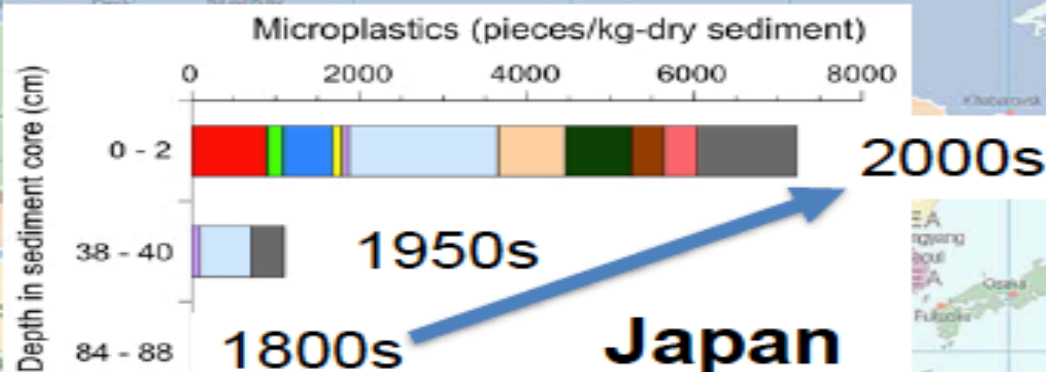


Cosmopolitan phenomena : increasing trend in microplastics in sediment cores from Asian and African waters

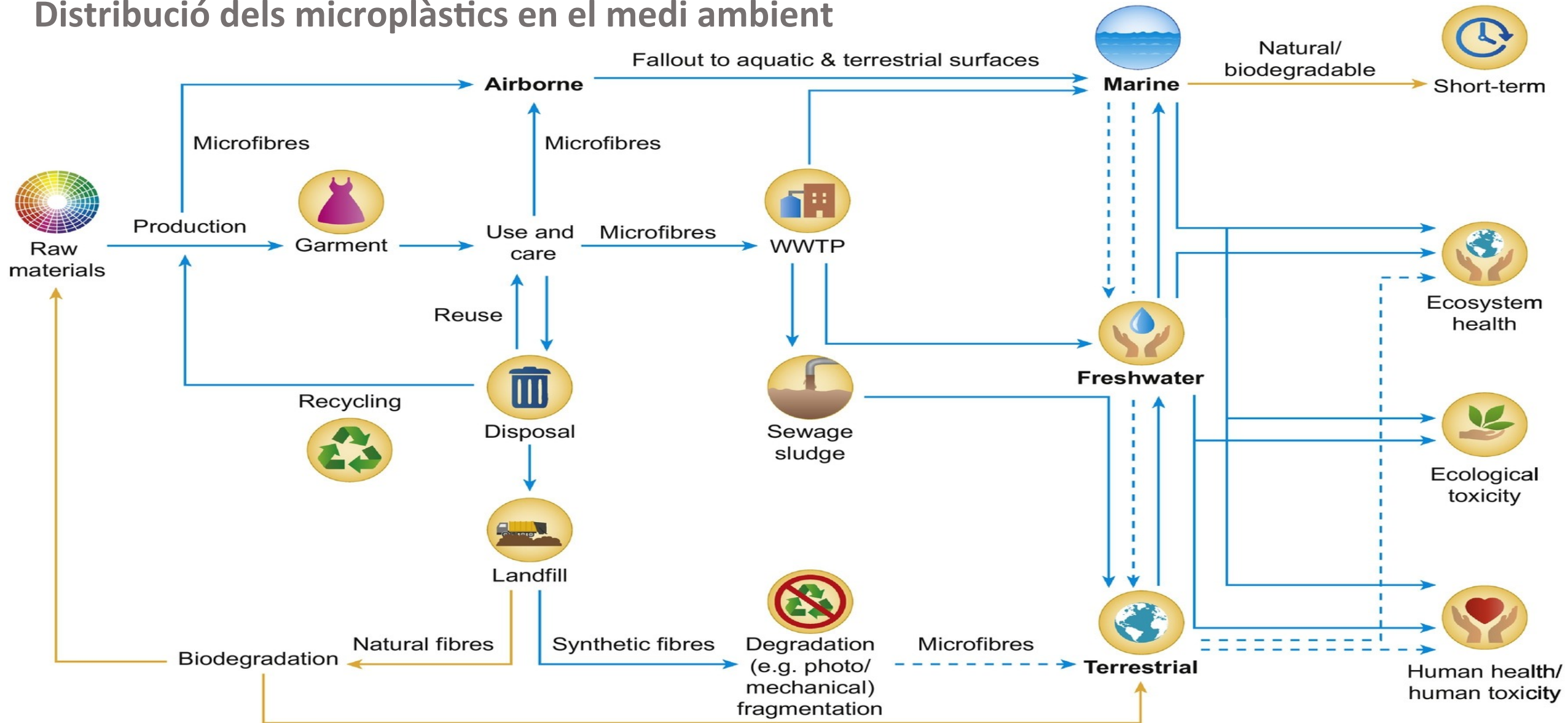
Vertical profiles of microplastics in sediment cores from Asian and African waters.

After Matsuguma et al. (2017)

Archives of Environ. Contam. Toxicol.



Distribució dels microplàstics en el medi ambient



PLASTIC POLLUTION

HOW MICROFIBERS ARE
CONTAMINATING OCEANS &
THE FOOD CHAIN



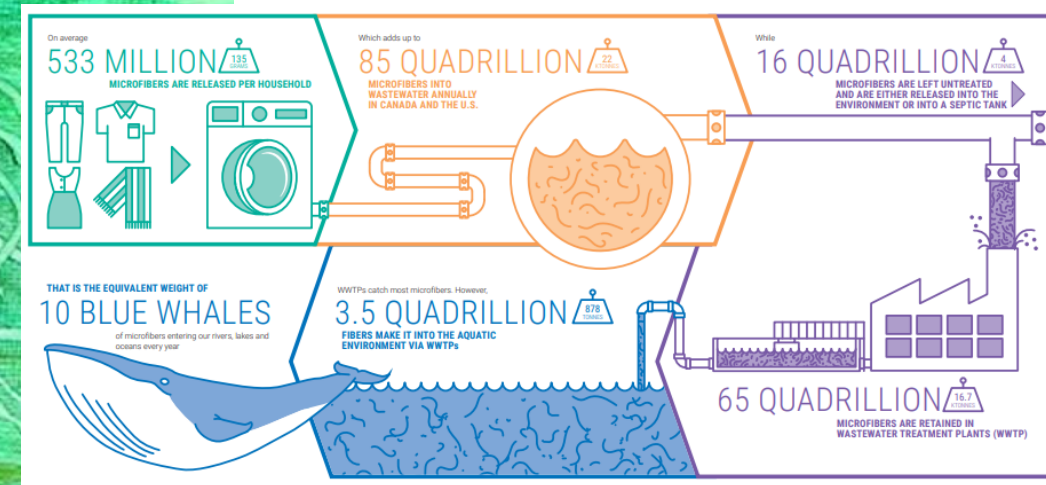
Illustration by Laszlo Kubinyi

'Fast Fashion' Is Polluting The Oceans With Microfibers

by Luana Steffen · February 25, 2020

A cada rentada s'alliberen entre
9.777 i 4.315.371 microfibras (9.6 mg
a 1,240 mg) per kg de roba nova

(una rentadora admet entre 5 i 12 kg
de roba)



Microplàstics en aigües potables

Mostra d'aigua	V analitzat (L)	Fragments/L	Fibres/L	MP/L
Aigua de mar	45000	0,001	0,002	0,003
Aigua de Riu LL	360	1,0	3,2	4,2
Aigua residual (entrada EDAR)	1	334	666	1000
Fuente Primavera	30	0,3	1,4	1,70
<u>Solan de Cabras</u>	30	0,2	1	1,20
Font Vella	30	0,2	0,9	1,10
Font Agudes	30	0,3	0,5	0,80
Aixeta (URV)	32	0,09	0,09	0,18
Potabilitzadora LL	965	0,05	0,02	0,07
<u>Dessalinitzadora LL</u> (sortida planta)	250	0,03	0,1	0,13
<u>Dessalinitzadora LL</u> (òsmosi inversa)	3500	0,0008	0,0008	0,0017

MP en
aigües
marines

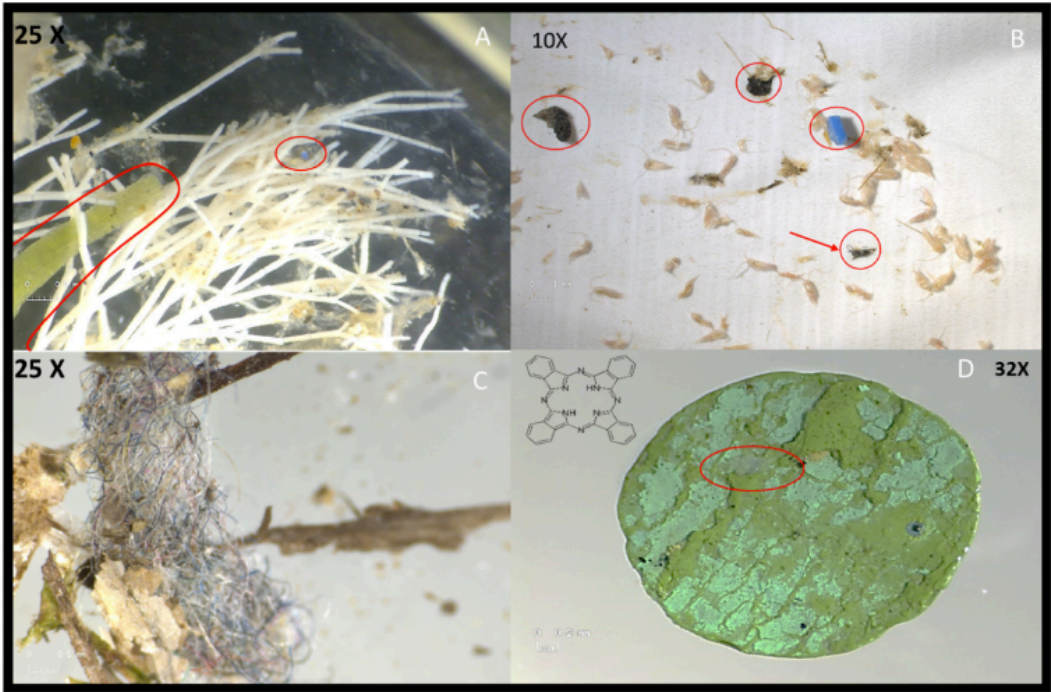


Fig. 3. Microplastics associated to environmental samples. A: Microplastics associated with algae aggregations. B: Microplastics associated with plankton. C: Fibres ball associated with marine sediments and algae organic remains. D: Microplastic weathered with biofilm attached.

Lodo Espesado 1 <X< 2 mm. Aumento 10x



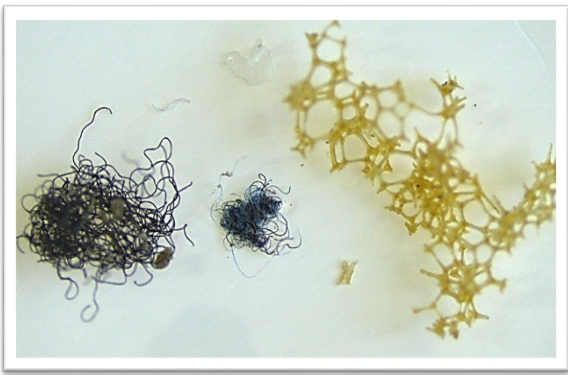
Lodo Espesado 0,5 <X< 1 mm. Aumento 16x



Lodo Deshidratado 0,5<X<1 mm. Aumento 16 X



Lodo Deshidratado 1<X<2 mm Aumento 12,5 X



MP en aigües residuals/fangs depuradora

MP en aigües potables

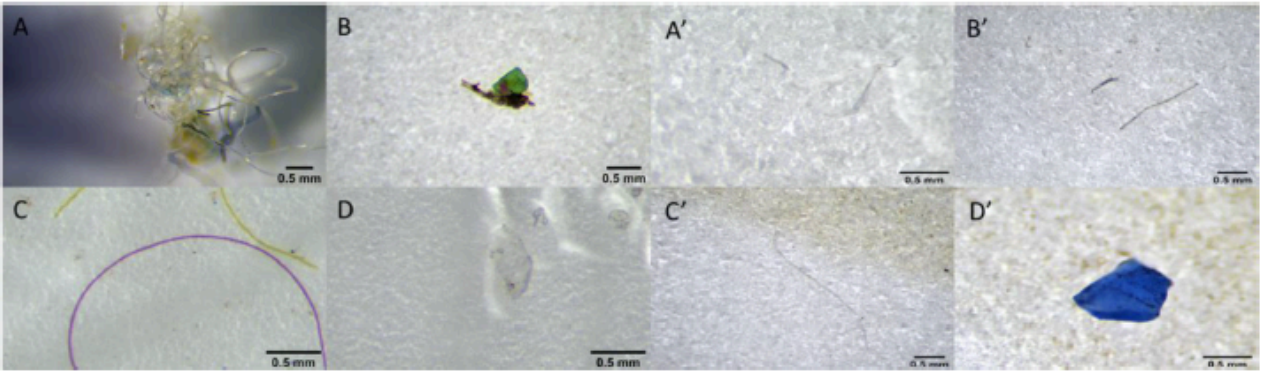
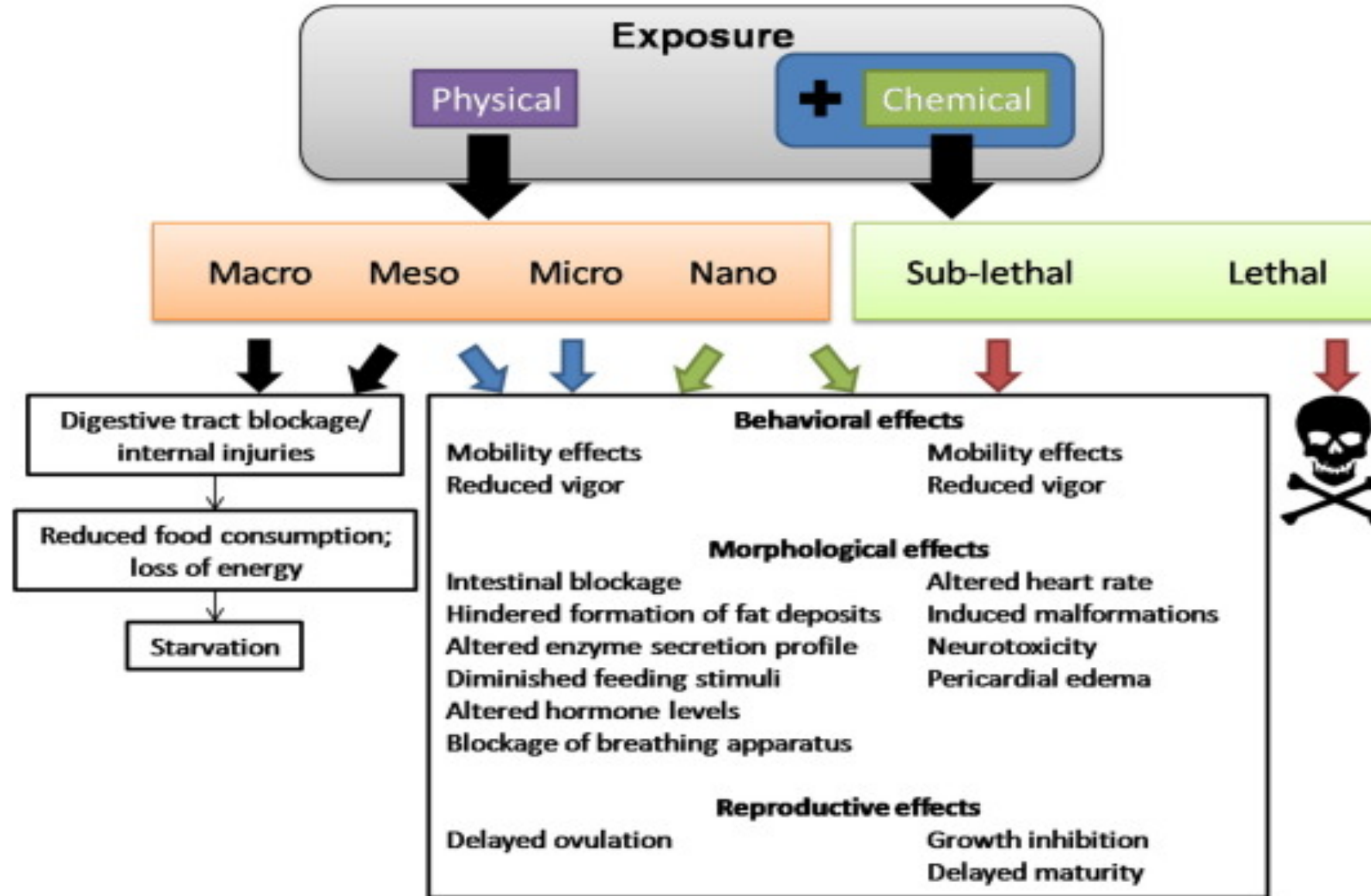


Fig. 4. MPs detected in influent: (A) group of fibers (B) fragment (C) individual fibers (D) films and effluent of DWTP: A'. film and fiber B'. fibers C'. fiber D'. fragment with 50–80 x magnification.

Els efectes dels plàstics



Els efectes dels plàstics



Northern gannet entanglement. On a nest on Helgoland, Germany (top), on a beach on Texel, The Netherlands (bottom left) and with fishing nets wrapped around the neck (bottom right) (Photos: J.A. van Franeker (1, 2) and S. Kühn (3), IMARES)



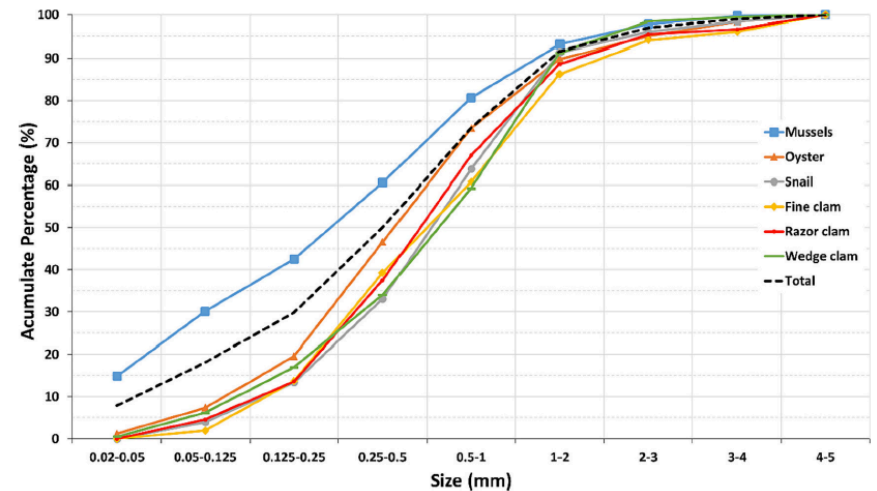
Els efectes dels plàstics



Dead whale 'had 40kg of plastic in its stomach'

A dead whale has been found washed up in the Philippines with a stomach filled with 40kg of plastic.

The map displays the study area in the Iberian Peninsula, specifically the Bay of Biscay and the Atlantic Ocean. Sampling locations are marked with yellow dots and labeled CAT1-01 through CAT1-23. Stations are marked with orange circles and labeled WC, M, S, and BO. The map includes an inset of the Iberian Peninsula, a north arrow, and the Google Earth logo. The text 'M, FC, RC, S, BO' is highlighted in a red box at the bottom.



Occurrence of microplastics in possible atmospheric depositions^a.

Locations	Size (µm)	Abundance (items·m ⁻² ·d ⁻¹) ^b	Shapes	Extraction	Identification	MP en aire
<i>Atmospheric fallout</i>						
Dongguan, China	200–700	175–313	Fiber: 80%; Foam and film	Filtration (φ1.0 µm)	Microscopy, µ-FTIR	(Cai et al., 2017)
Ho Chi Minh City, Vietnam	300–5000	71–917	Fragment; Fiber	Filtration (φ1.6 µm)	Microscopy	(Dris et al., 2015)
Paris, France	100–5000	29–280; mean:118	Fiber: > 90%	Filtration (φ1.6 µm)	Microscopy	(Dris et al., 2015)
Paris, France	50–500: 3%; 200–600: 42%; 600–1400: ~40%	2.1–355.4	Fragment: ~10% Fiber	Filtration (φ1.6 µm)	Microscopy	(Dris et al., 2015)
<i>Atmospheric deposition</i>						
Guangzhou, China	50–5000	51–178	Fibers, fragments, films and microbeads	Filtration (φ0.45 µm)	Microscopy, µ-FTIR	(Huang et al., 2021a)
Hamburg, Germany	< 63: ~60%; 63–300: ~30%; > 300: ~20%	275 (Range 136–512)	Fragment: 90% Fiber:10%	Staining (Nile Red)	Microscopy, µ-Raman	(Klein and Fischer, 2019)
Pyrenees moutains, Europe	100–300	Fragment: 249; Film: 73; Fiber: 44	Fragment: 68%; Film: ~20%; Fiber:12%	Filtration (φ0.45 µm)	Microscopy, µ-Raman	(Allen et al., 2019)
Yantai, China	23–500: > 50%	Fiber: 115–602; Others: 40	Fiber: 95%; Film and foam	Filtration (φ1.0 µm)	Microscopy, µ-FTIR	(Cai et al., 2017)
<i>Suspended atmospheric microplastics</i>						
Shanghai, China	23–500: > 50%	0 ~ 4.18 items·m ⁻³	Fiber: 67% Fragment: 30%	Filtration (φ1.6 µm)	Microscopy, µ-FTIR	(Liu et al., 2019)
<i>Dust (including urban and rural dust)</i>						
House dust, Australia	200–400	22–6169	Fiber	Filtration (φ0.6 µm)	Microscopy,	(Soltani et al., 2021)

Balanç de MP en una EDAR

MP 20-5000 µm

Caudal: 37916 m³/día
Concentració: 1058 MPs/L
Flujo MPs: 4,01x10¹⁰ MPs /día

100 %

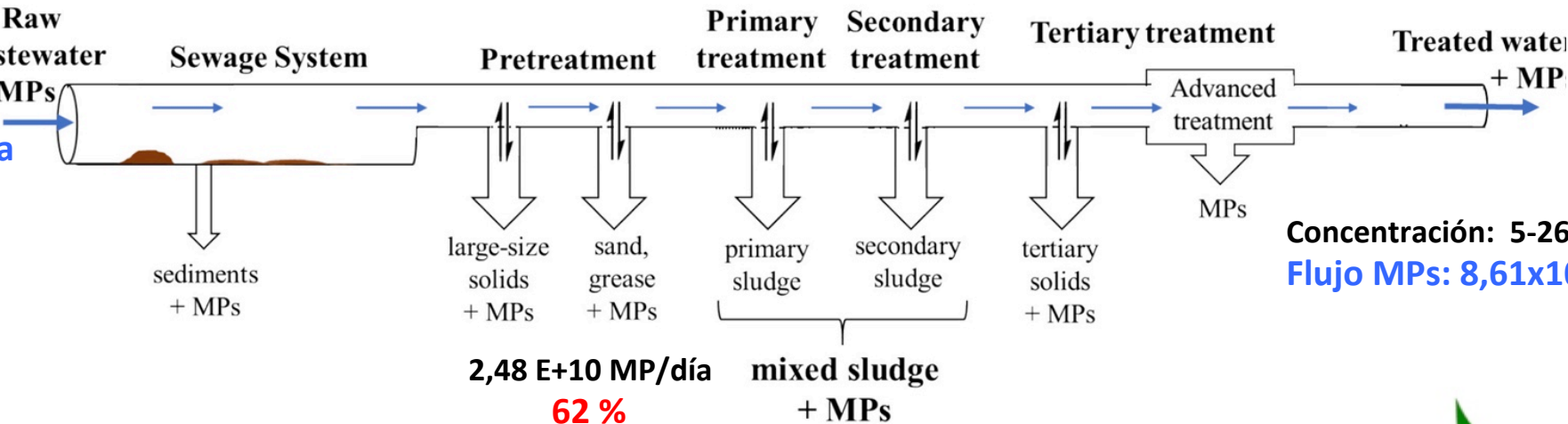
Concentració: 403 MPs/L
Flujo MPs: 1,53x10¹⁰ MPs /día

Concentració: 134 MPs/L
Flujo MPs: 5,1x10⁹ MPs/día

78 – 98%
MPs removal

7 – 20%
MPs removal

≤ 7% MPs removal



Producció : 25093 kg/día
Concentració: 50000-133200 items/kg
Flujo MPs: 3,30x10⁹ MPs /día

8,2 %

Estabilizació



Caudal 40.000 m³/día, 360.000 hab

Masiá, et al., 2020. *Marine Poll Bull.*
Dronjak et al., 2023 In press (Tecnatox)

Arribada de MPs al medi ambient: Ecosistemes Terrestres vs Aquàtics

Entre 473,000 i 910,00 t/any entren als ecosistemes terrestres de l'EU. Això és entre 4 i 23 vegades més que l'abocament a l'oceà

Horton, et al., 2017. Sci. Total Env.

Waste management data and estimates of plastic waste released to terrestrial and fresh-water (continental) environments, based on figures for the European Union. Rows highlighted in grey are those directly related to plastic within continental environments.

Plastic handling/disposal	Plastic million metric tonnes/year
Plastic production (EU total, 2014) ^d	59
Plastic waste (EU total, 2014) ^d	25.8
Managed plastic waste (– 2% mismanaged waste) ^b	25.28
Landfill (EU total) ^{a,d}	8
Recycling (EU total) ^{a,d}	7.6
Energy recovery (EU total) ^{a,d}	10.2
Mismanaged plastic waste (2% of plastic waste in the EU) ^b	0.52
Plastic in sewage sludge (EU total) ^e	0.063–0.43
Ocean input (EU total) ^f	0.04–0.11
Total mismanaged plastic waste remaining in continental environments (EU) ^c	0.47–0.91

^a Values for specific waste management practises do not account for mismanaged waste.

^b Managed and mismanaged waste figures are calculated based on the proportion of waste categorised as managed or mismanaged in the United States: 2% (Jambeck et al., 2015).

^c Values are calculated based on mismanaged waste to include plastics within sewage sludge, minus plastic that is transported to the oceans. Some sources, such as atmospheric fallout have not been considered due to the limited data available.

^d PlasticsEurope (2015).

^e Nizzetto et al. (2016b).

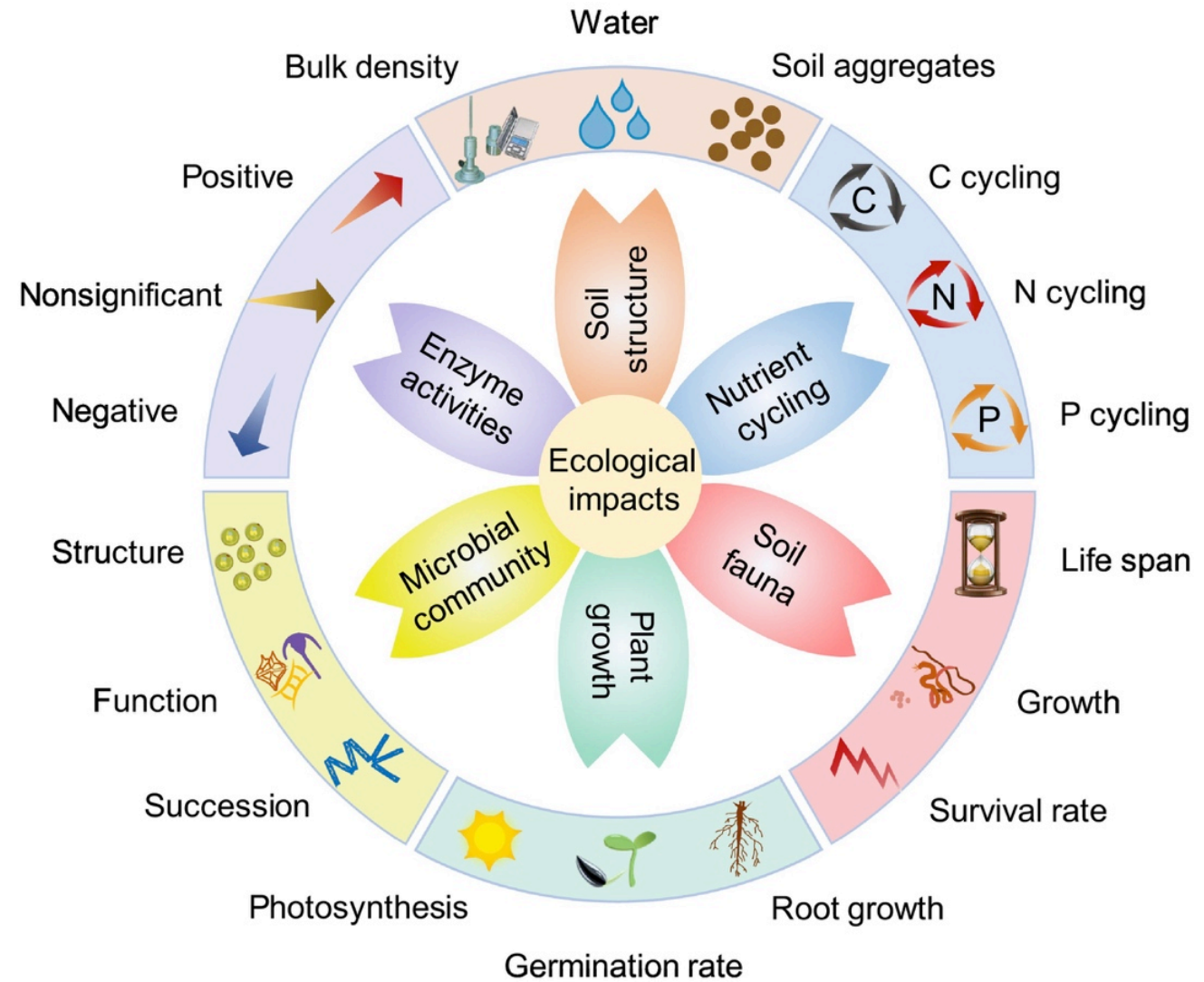
^f Jambeck et al. (2015).

Efectes sobre el sòl

El sòl és una matriu ambiental molt complexa:

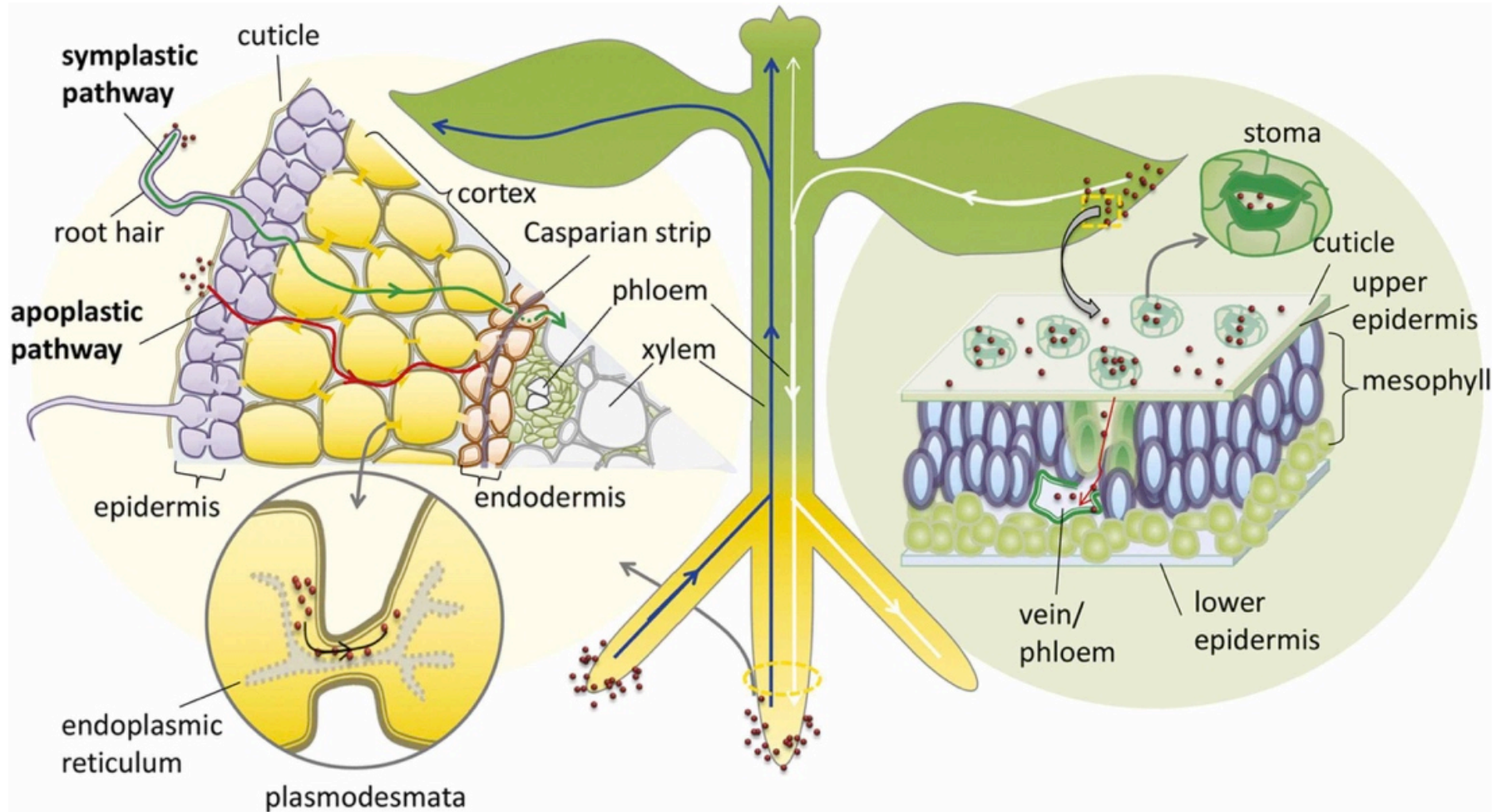
- ❖ Propietats físiques
- ❖ Propietats químiques
- ❖ Propietats biològiques (flora, microbiota, mesofauna...)
- ❖ Funcions del sòl: hàbitat organismes (alta biodiversitat), provisió aliments, segrest de C, purificació de les aigües, regulació del clima i inundacions, cicles biogeoquímics (C, N, P...), depurador natural d'aigües i aire, reserva genètica i de productes interès, suport d'infraestructures.

FAO, 2015. Dia mundial
del suelo 5 dic



Zhao, et al., 2022 *Applied Soil Ecology*

Hi ha absorció de microplàstics per part del vegetal? Sí, hi ha bioacumulació



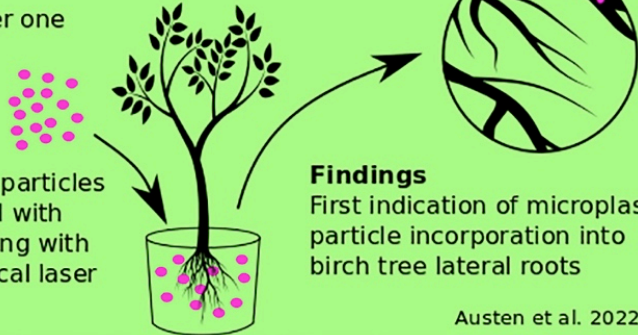
Huang, et al., 2022. *J. Hazardous materials*

Bioacumulació de micro- i nanoplàstics en vegetals

Microplastic inclusion in birch tree roots

Birch trees cultured over one growing season in soil containing labelled microplastic particles

Polyamide microplastic particles (5-50 μm) were labelled with iDye Poly Pink for imaging with fluorescence and confocal laser scanning microscopy

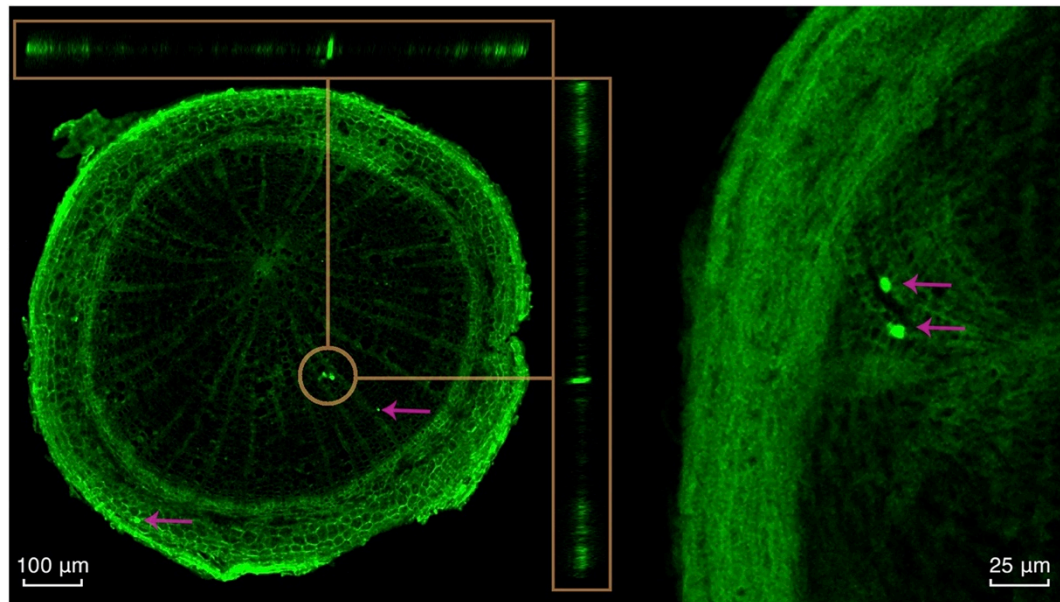


Findings

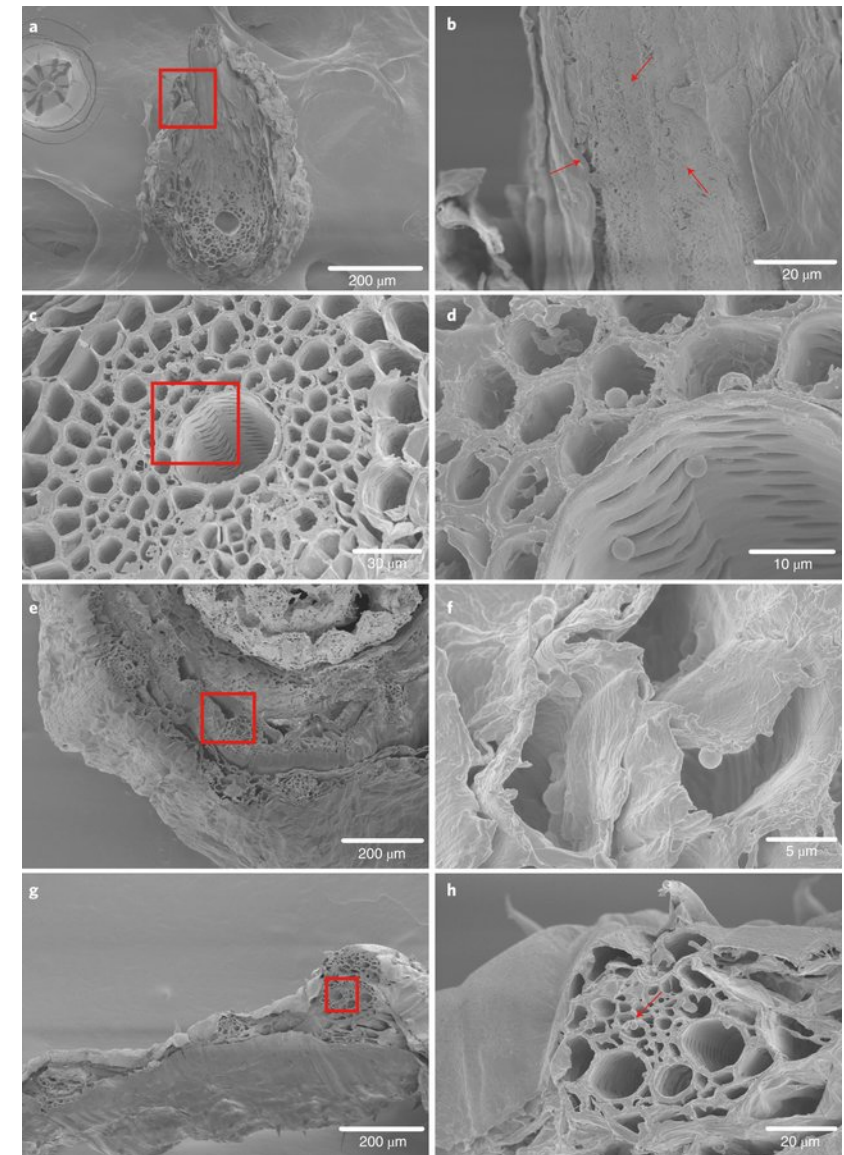
First indication of microplastic particle incorporation into birch tree lateral roots

Austen et al. 2022

Partícules entre 0,2-10 μm s'absorbeixen a través de les arrels (bedoll, blat, enciam...)



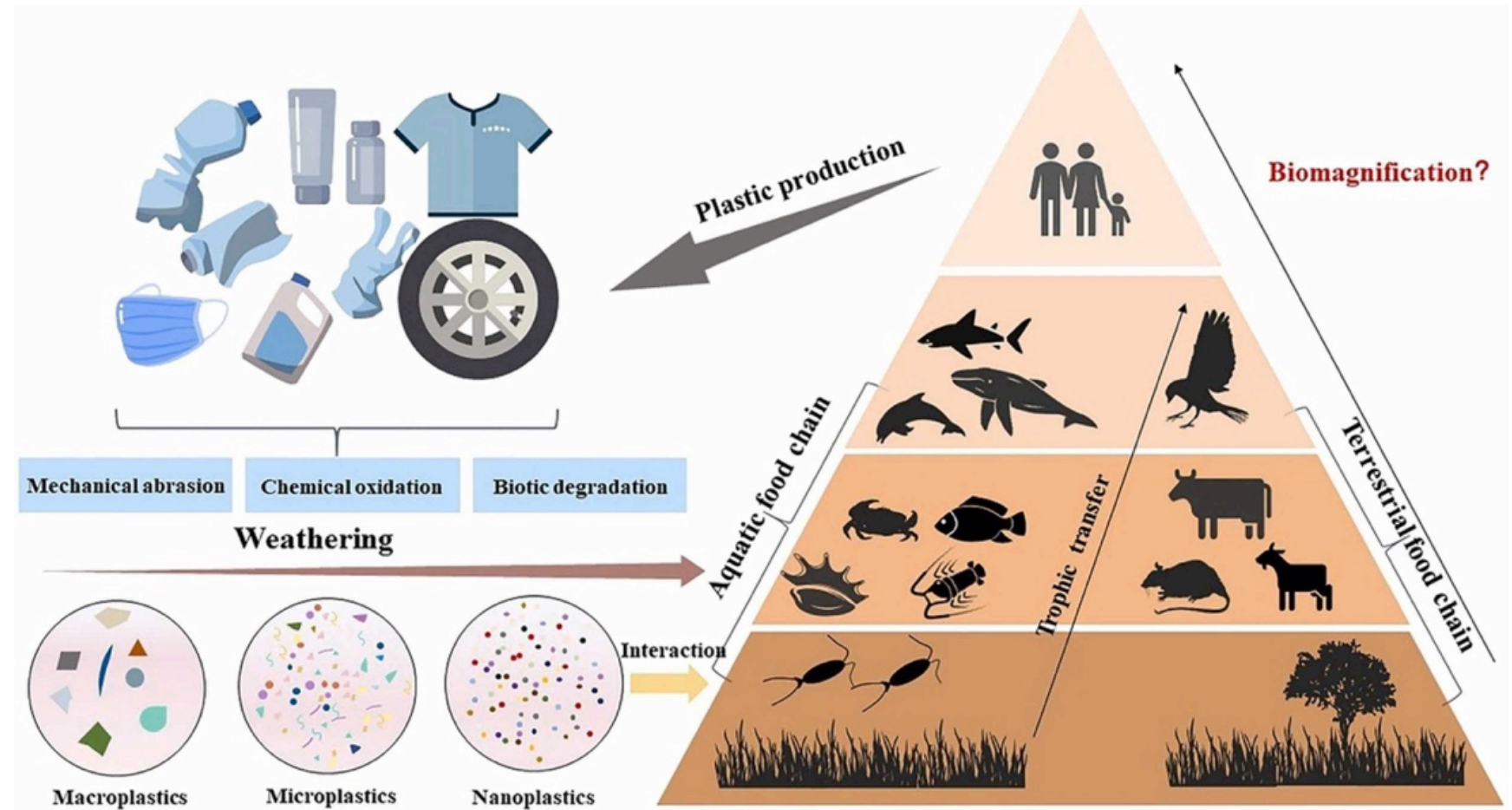
Austen, et al., 2022. *Sci. Total Env.*



Li, et al., 2020. *Nature sustainability*

Existeix bioacumulació de microplàstics, però ¿hi ha biomagnificació?

- ❖ Bioacumulació és el pas d'un contaminant del medi ambient a la biota
- ❖ Biomagnificació és quan un contaminant es bioacumula en major concentració en els organismes de nivells tròfics superiors (p.e. Hg, DDT...)
- ❖ **No s'ha demostrat la biomagnificació de micro- i nanoplàstics**



Huang, et al., 2022. *J. Hazardous materials*

Ingesta estimada pels humans

Estimated average number of microplastic particles ingested (ANMP_{ingested}) per person per year.

Source of particles	The estimated average number of particles/ person/year		Sample size n
	Minimum	Maximum	
Shellfish	2602	16,288	24
Fish	339	3005	6
Salt	41	1088	13
Honey	57	107	2
Sugar	0.1	8211	1
Beer	177	869	6
Tap water	16,265	68,331	12
Bottled water	346	292,251	10
Drinking water ^a	9029	174,959	22

^a Drinking water includes both tap water and bottled water to provide a global representation of water ingested.

Uncertainties in mass estimates for consumable categories based on Monte Carlo simulation results (g/year) of estimated mean mass and 95% confidence intervals of microplastics <1 mm ingested per person per year using 3 scenarios.

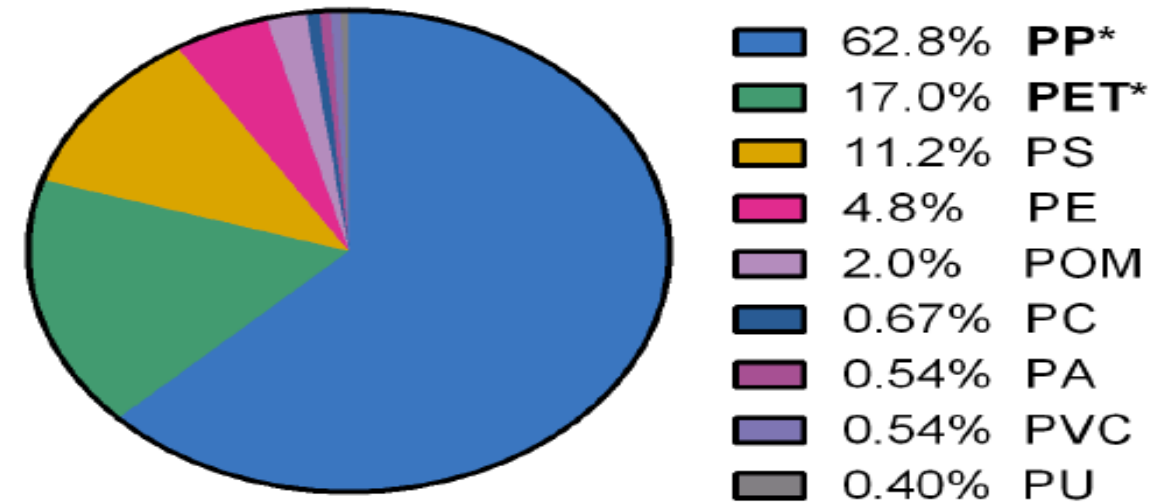
Source of particles	Monte Carlo simulation of mean mass consumed (g/person/year) [95% confidence interval]		
	Scenario 1: Assuming aquatic particle (size 0–1 mm) ^a	Scenario 2: Assuming sphere (diam 0 – 1 mm) ^b	Scenario 3: Assuming cube (length 0–1 mm) ^b
Shellfish	36.0 [4.7,84.8]	8.9×10^{-05} [1.2×10^{-05} , 2.1×10^{-04}]	1.7×10^{-04} [2.3×10^{-05} , 4.0×10^{-04}]
Salt	2.3 [0.2, 5.6]	10.8 [0.7, 26.0]	20.8 [1.4, 50.9]
Beer	1.9 [0.3, 4.5]	0.3 [0.05, 0.8]	0.6 [0.098, 1.5]
Drinking water	372.6 [28.1, 906.4]	0.06 [0.004, 0.1]	0.1 [0.008, 0.3]
TOTAL	412.8 [63.4, 948.8]	11.2 [1.1, 27.0]	21.6 [2.1, 51.7]
TOTAL (g/ week)	7.9 [1.2, 18.2]	0.22 [0.02, 0.52]	0.42 [0.04, 0.99]

^a Particle size based on aquatic particle size data from literature reviewed.
^b Particle size based on PSDs specific to each category of consumable.

MPs en fientes humaines

❖ Stool weight:	34 [8-39] g
❖ Positive samples:	8/8
❖ Microplastic particles / 10g stool:	20 [18-172] particles
❖ Particle size:	50-500 µm
❖ Plastic types detected:	9/10 (3-7 types /sample)

Schawbl, et al., 2019. *Annals of internal medicine*



*PP and PET were found in all 8/8 samples

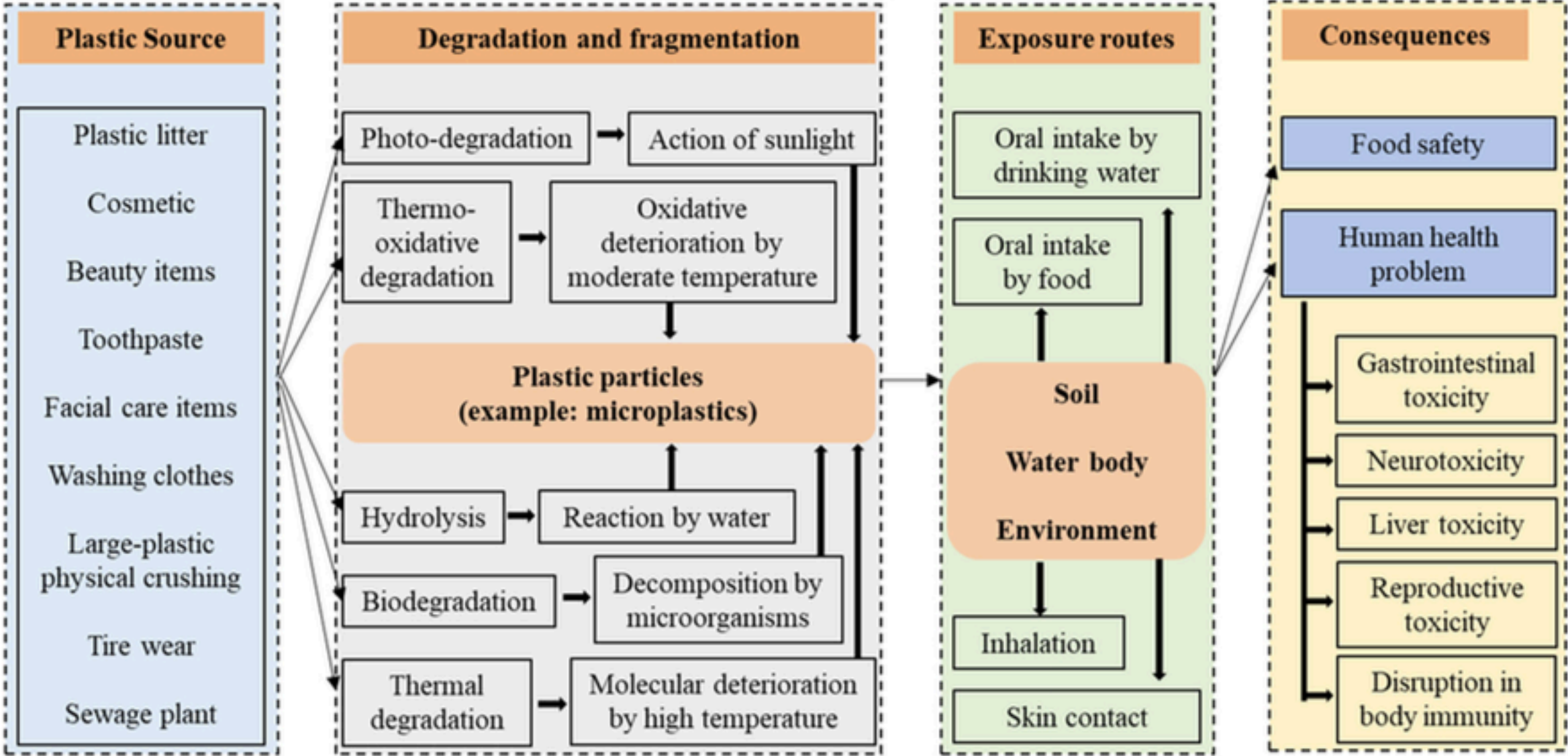


Plasticenta: First evidence of microplastics in human placenta

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Particle	Placenta Portion	Microparticles			Pigment		HQI
		Size	Color	Polymer matrix	Generic name	Molecular formula and IUPAC name	
#1	FS	~10 μm	Orange	n.d.	Iron hydroxide oxide yellow (Pigment Yellow 43; C.I. Constitution 77492)	$\text{FeO}(\text{OH})$ iron(III) oxide hydroxide	89.97
#2	CAM	~10 μm	Blue	Polypropylene	Copper phthalocyanine (Pigment Blue 15; C.I. Constitution 74160)	$\text{C}_{32}\text{H}_{16}\text{CuN}_8$ (29H,31H-phthalocyaninato(2-)-N29,N30,N31,N32)copper(II)	82.86
#3	FS	~10 μm	Blue	n.d.	Phthalocyanine Blue BN (Pigment Blue 16; C.I. Constitution 74100)	$\text{C}_{32}\text{H}_{18}\text{N}_8$ 29H,31H-phthalocyanine	89.16
#4	MS	~10 μm	Dark blue	n.d.	Violanthrone (Pigment Blue 65; C. I. Constitution 59800)	$\text{C}_{34}\text{H}_{16}\text{O}_2$ Anthra[9,1,2-cde]benzo[rst]pentaphene-5,10-dione	86.44
#5	MS	~5 μm	Blue	Polypropylene	Copper phthalocyanine (Pigment Blue 15; C.I. Constitution 74160)	$\text{C}_{32}\text{H}_{16}\text{CuN}_8$ (29H,31H-phthalocyaninato(2-)-N29,N30,N31,N32)copper(II)	86.15
#6	MS	~10 μm	Red	n.d.	Diiron trioxide (Pigment Red 101/102; C.I. Constitution 77491)	Fe_2O_3 Oxo(oxoferriooxy)iron	83.65
#7	MS	~10 μm	Red	n.d.	Diiron trioxide (Pigment Red 101/102; C.I. Constitution 77491)	Fe_2O_3 Oxo(oxoferriooxy)iron	89.80
#8	CAM	~5 μm	Dark blue	n.d.	Pigment Direct Blue 80	$\text{C}_{32}\text{H}_{14}\text{Cu}_2\text{N}_4\text{Na}_4\text{O}_{16}\text{S}_4$ Dicopper,tetrasodium,3-oxido-4-[[2-oxido-4-[3-oxido-4-[(2-oxido-3,6-disulfonatophthalen-1-yl)diazenyl]phenyl]phenyl]diazenyl]naphthalene-2,7-disulfonate	84.55
#9	CAM	~10 μm	Dark blue	n.d.	Ultramarine Blue (Pigment Blue 29; C.I. Constitution 77007)	$\text{Al}_6\text{Na}_8\text{O}_{24}\text{S}_3\text{Si}_6$ Aluminium Sodium orthosilicate trisulfane-1,3-diide	91.96
#10	FS	~10 μm	Blue	Polypropylene	Copper phthalocyanine (Pigment Blue 15; C.I. Constitution 74160)	$\text{C}_{32}\text{H}_{16}\text{CuN}_8$ (29H,31H-phthalocyaninato(2-)-N29,N30,N31,N32)copper(II)	80.60
#11	FS	~10 μm	Violet	Polypropylene	Hostopen violet (Pigment Violet 23; C.I. Constitution 51319)	$\text{C}_{34}\text{H}_{22}\text{Cl}_2\text{N}_4\text{O}_2$ 8,18-Dichloro-5,15-diethyl-5,15-dihydrodiindolo(3,2-b:3',2'-m)tri-phenodioxazine	80.92
#12	FS	~10 μm	Pink	n.d.	Novoperm Bordeaux HF3R (Pigment Violet 32; C.I. Constitution 12517)	$\text{C}_{27}\text{H}_{24}\text{N}_6\text{O}_7\text{S}$ 4-[(E)-2-[2,5-dimethoxy-4-(methylsulfamoyl)phenyl]diazen-1-yl]-3-hydroxy-N-(2-oxo-2,3-dihydro-1H-1,3-benzodiazol-5-yl)naphthalene-2-carboxamide	84.57

Fonts de contaminació, dinàmica en l'ambient, rutes d'exposició i efectes



Overview of the potential interactions of microplastics with environmental health on different levels of biological organization.

Level of biological organization	Biological effects	Species	Reference
Chemical level	IL-6 gene↑, IL-8 gene↑	human gastric adenocarcinoma cells	(Forte et al., 2016)
	IL-8 gene↑	A549 epithelial cells	(Brown et al., 2001)
	SOD3↑, Casp3↑, Tp53↑, CXCR5↑	fish, the sheepshead minnow (<i>Cyprinodon variegatus</i>).	(Choi et al., 2018)
	Oxidative stress responses↑, anti-oxidant↑, glutathione-related enzymes↑	marine mussels <i>Mytilus</i> spp.	(Paul-Pont et al., 2016)
	transcription of genes involved in energy metabolism and development	pacific oyster <i>Crassostrea gigas</i>	(Sussarellu et al., 2016)
	DNA damage↑	<i>Daphnia magna</i> and shrimp <i>Neocaridina davidi</i>	(Berber, 2019)
	Genotoxic↑		
	ROS↑		
Cellular level	Endocytosis	A549 cells;	(Salvati et al., 2011)
	intracellular endocytotic pathway by accumulating in lysosomes	endothelial cell line EAhy926;	(Fröhlich et al., 2012)
		primary human renal epithelial cells	(Monti et al., 2015)
	neurotoxic effects and oxidative stress ↑	epithelial human cells	(Schirinzi et al., 2017)
	intracellular ROS ↑	human colonic epithelial cells CCD841CoN and small	(Zhang et al., 2022)
	oxidative stress ↑	intestinal epithelial cells HIEC-6	
	mitochondrial depolarization ↑		
	neurotoxic effects and oxidative stress ↑	marine planktonic crustaceans	(Gambardella et al., 2017)
Tissue level	immunomodulation, apoptosis ↑	marine bivalve <i>Mytilus</i>	(Canesi et al., 2015)
	MAPKs signaling related inflammation and apoptosis↑	monogonont rotifer (<i>Brachionus koreanus</i>)	(Jeong et al., 2016)
	Energy deficiency: ATP↓	mice	(Deng et al., 2017)
	Lipid metabolism disturbance: total T-CHO↓, TG↓		
	Oxidative stress: GSH-Px↑, SOD↑, CAT↓		
	Neurotoxic responses: AChE activity ↑		
	histopathological changes: tissue alterations, occurrence of neutrophils	adult zebrafish	(Limonta et al., 2019)
Organ level	structural changes and necrosis	Mediterranean mussels (<i>M. galloprovincialis</i>)	(Bråte et al., 2018)
	strong inflammatory responses and tissue alterations	the blue mussel <i>Mytilus edulis</i>	(Von Moos et al., 2012)
	Histopathological change: inhaled fibres in histopathology slides	human lung tissues	(Pauly et al., 1998)
	Translocation across membranes ↑	rats	(Kreyling et al., 2009)
	Bioaccumulation of nanoplastics and microplastics	mice	(Meng et al., 2022)
	Kidney damage and nephrotoxicity		
	Penetrate the BBB	fish, Crucian carp, <i>Carassius carassius</i>)	(Mattsson et al., 2017)
	Oxidative stress and damage in liver ↑	crab <i>Dicentrarchus labrax juveniles</i>	(Barboza et al., 2018b)

Table 1
Overview of the potential interactions of microplastics with environmental health on different levels of biological organization.

Level of biological organization	Biological effects	Species	Reference
Digestive system	Nine plastic types of microplastics were found	human stool	(Schwabl et al., 2019)
	Microplastics were detected in eleven colectomy samples	human colectomy specimens	(Ibrahim et al., 2021)
	iron absorption↑	chicken	(Mahler et al., 2012)
	remodeling of the intestinal villi		
	Gut microbiota dysbiosis↑, hepatic lipid metabolism disorder↑	mice	(Lu et al., 2018)
	the secretion of mucin in gut↓		
	gst-4 expression↑	zebrafish <i>Danio rerio</i> , nematode <i>Caenorhabditis elegans</i>	(Lei et al., 2018)
	intestinal Ca2 + ↓		
	Microbiota dysbiosis and inflammation in the gut	zebrafish	(Jin et al., 2018a)
	Microflora dysbiosis:	crab Juvenile <i>Eriocheir sinensis</i>	(Liu et al., 2019c)
Respiratory system	fusobacteria↑, proteobacteria↑		
	fimicutes↓, bacteroidetes↓		
	Oxidative stress: ROS↑	normal human lung epithelial BEAS-2B cells	(Dong et al., 2020)
	α1-antitrypsin↓, transepithelial electrical resistance by depleting zonula occludens proteins↓		
	CXCL5↑, G-CSF↑	cystic fibrosis mouse model	(Geiser et al., 2014)
Endocrine system	15-HETE↓		
	TGF-β↑, TNF-α↑	Sprague-Dawley rats	(Lim et al., 2021)
	liver enzymes GGT↑	human urine	(Lang et al., 2008)
Reproductive System	Body mass index↑, waist circumference↑	human urine	(Do Minh et al., 2017)
	Microplastics were detected	human placenta	(Ragusa et al., 2021)
Immune system	Ovarian response↓, number of fertilized oocytes↓, blastocyst formation↓	Human	(Vandenberg et al., 2009)
	Birth weight in offspring↓	human	(Miao et al., 2011)
	Oocyte number↓, diameter↓, sperm velocity↓	oysters	(Sussarellu et al., 2016)
	Feeding capacity↓, reproductive output↓	pelagic copepod <i>Calanus helgolandicus</i> .	(Cole et al., 2015)
	Impaired development and reproduction↑	pacific oysters <i>Crassostrea gigas</i>	(Tallec et al., 2018)
	Fertilization success↓		
	ROS generation↑, endoplasmic reticulum stress↑	human lung epithelial (BEAS-2B) cells	(Chiu et al., 2015)
	Complement system genes (cfhl3, cfhl4, cfb and c9) ↑	zebrafish larvae	(Veneman et al., 2017)
	PRRs and AMPs family↑	edible mussel <i>Mytilus galloprovincialis</i> .	(Détrée and Gallardo-Escárate, 2018)
		crab Juvenile <i>Eriocheir sinensis</i>	(Liu et al., 2019c)
	Caspase↑, MyD88↑		
	haemocyanin (Hc)↓, alkaline phosphatase (AKP)↓, phenoloxidase (PO)↓, lysozyme (LSZ)↓, acid phosphatase (ACP)↓		

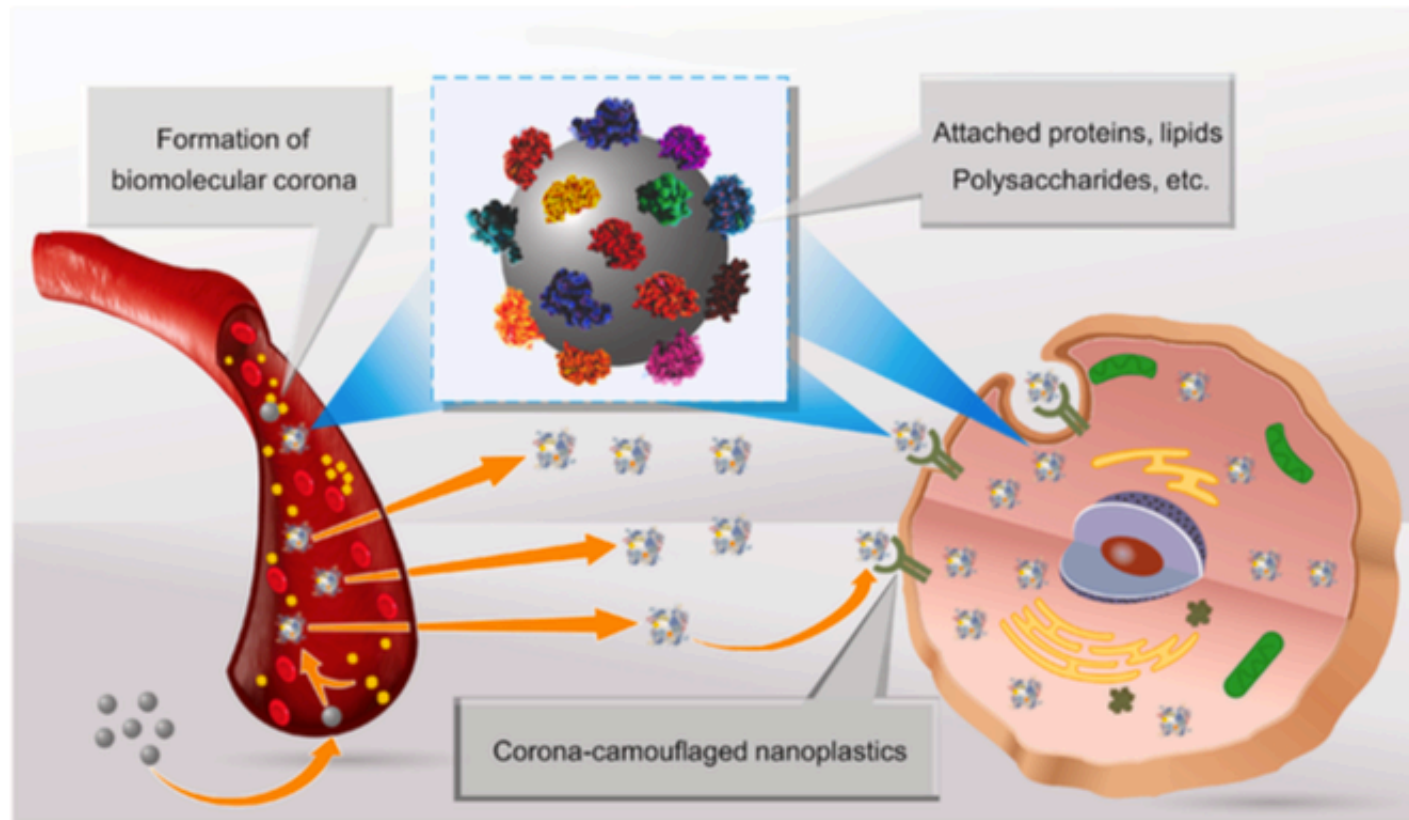


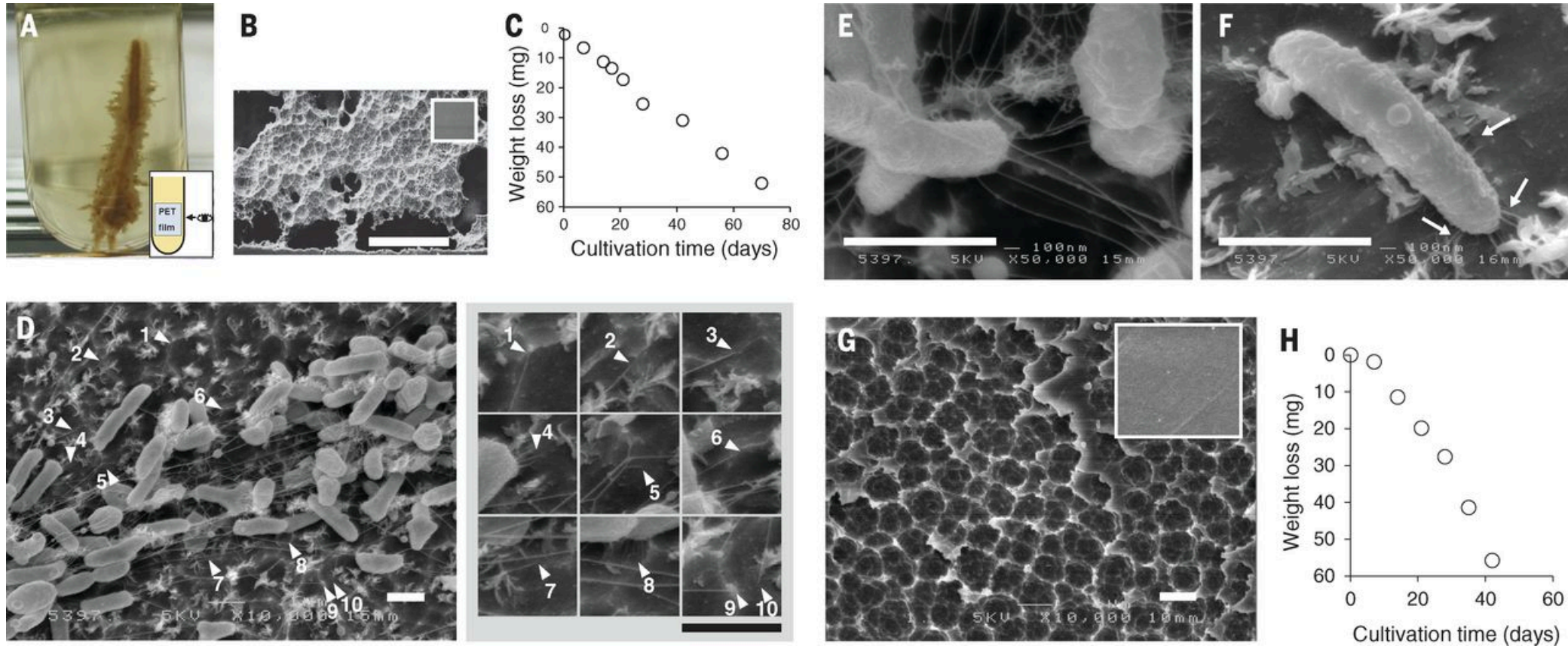
Fig. 4. The formation of biomolecular corona on NPs. The NP surface interacts with various molecules and is rapidly coated by the proteins (protein-corona), as well as other biomolecules, including proteins, polysaccharides, lipids, etc., to form a biomolecule corona. The corona critically affects the interactions between NPs and living systems, such as camouflaging the foreign particles to enter or cross cells. These mixtures of adsorbed molecules further alter the persistence, bioavailability, and ecotoxicity of NPs.

Algunes mesures preventives i correctores

- ❖ Prohibir els MP en productes de consum (Europa 42,000t, EU Draft, 2022)
- ❖ Apostar pels nous plàstics realment biodegradables (baix pes molecular) sobretot per a usos temporals (no per a material de construcció)
- ❖ Introduir sistemes de retenció de fibres a les rentadores domèstiques i/o ús de roba amb fibres naturals
- ❖ Millorar el pretractament de les EDAR (flotació, floculació-sedimentació, tamització...60%>>99%), el fang generat va abocador/incineració
- ❖ Millorar tractaments terciaris (micro, ultra, nanofiltració...) per evitar la contaminació d'aigües
- ❖ Millorar els sistemes d'estabilització del fang de depuradora perquè els MP es (bio) degradin
- ❖ Promoure l'estudi d'enzims (despolimeritzadors), aïllament de microorganismes i ús de l'enginyeria genètica per desenvolupar microorganismes capaços de degradar MP en condicions ambientals o a escala real
- ❖ Hipòtesi: l'evolució natural de les espècies aconseguirà organismes capaços de degradar els MP però no a escala de temps humana
- ❖ ...

Exemples esperançadors

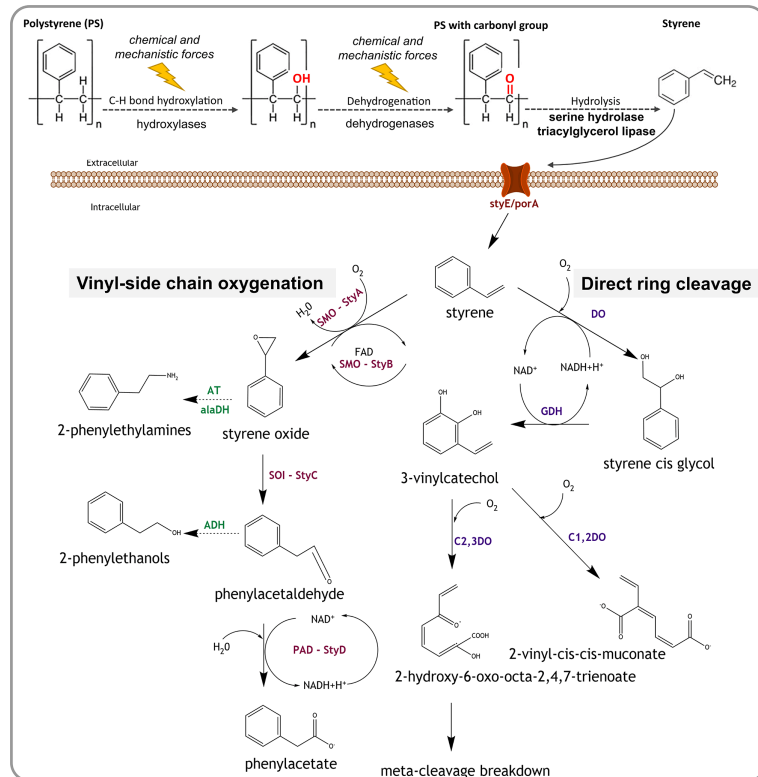
- ❖ D'una planta de reciclatge de plàstic aïllen un bacteri, *Ideonella sakaiensis*, que té enzims (PETasa i MHETasa) capaços d'usar com a font de carboni (degradar) film de Tereftalat de polietilè (PET)



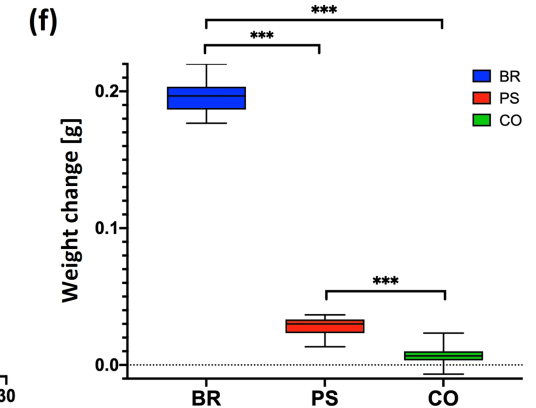
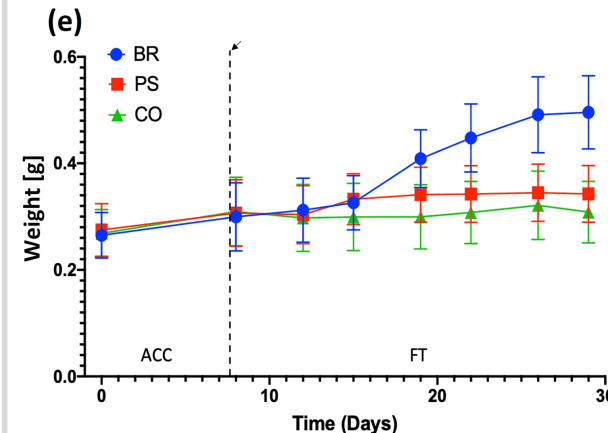
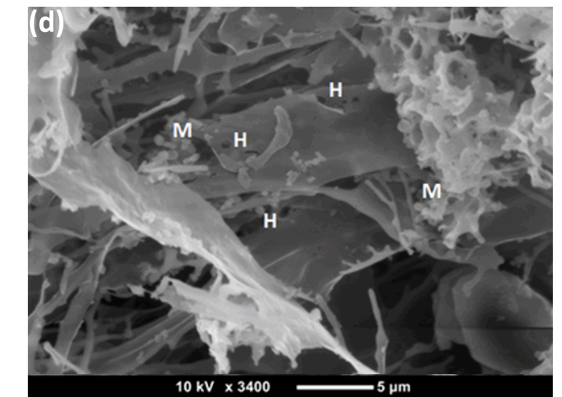
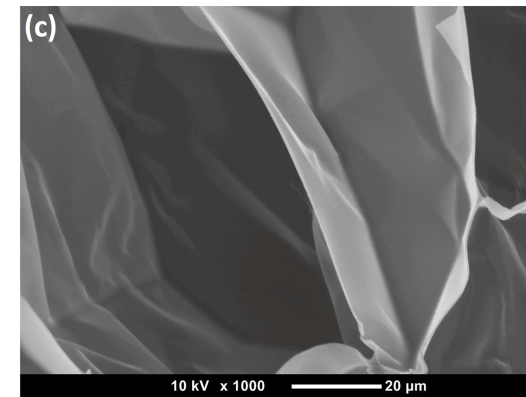
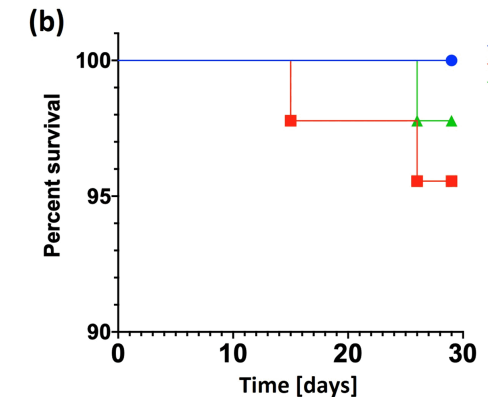
Yoshida, et al., 2016. *Science*

Exemples esperançadors

- ❖ Larves d'un escarabat (*Zophobas morio*) conegudes com a cuc de la farina
- ❖ Guanyen una mica de pes i completen el seu cicle
- ❖ Espècies identificades de *Pseudomonas*, *Rhodococcus* i *Corynebacterium* al seu intestí tenen enzims capaços de degradar el poliestirè



BR: alimentació normal
 PS: només amb poliestirè
 CO: en dejú





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