Selective transport of microplastics by drifting in coastal waters

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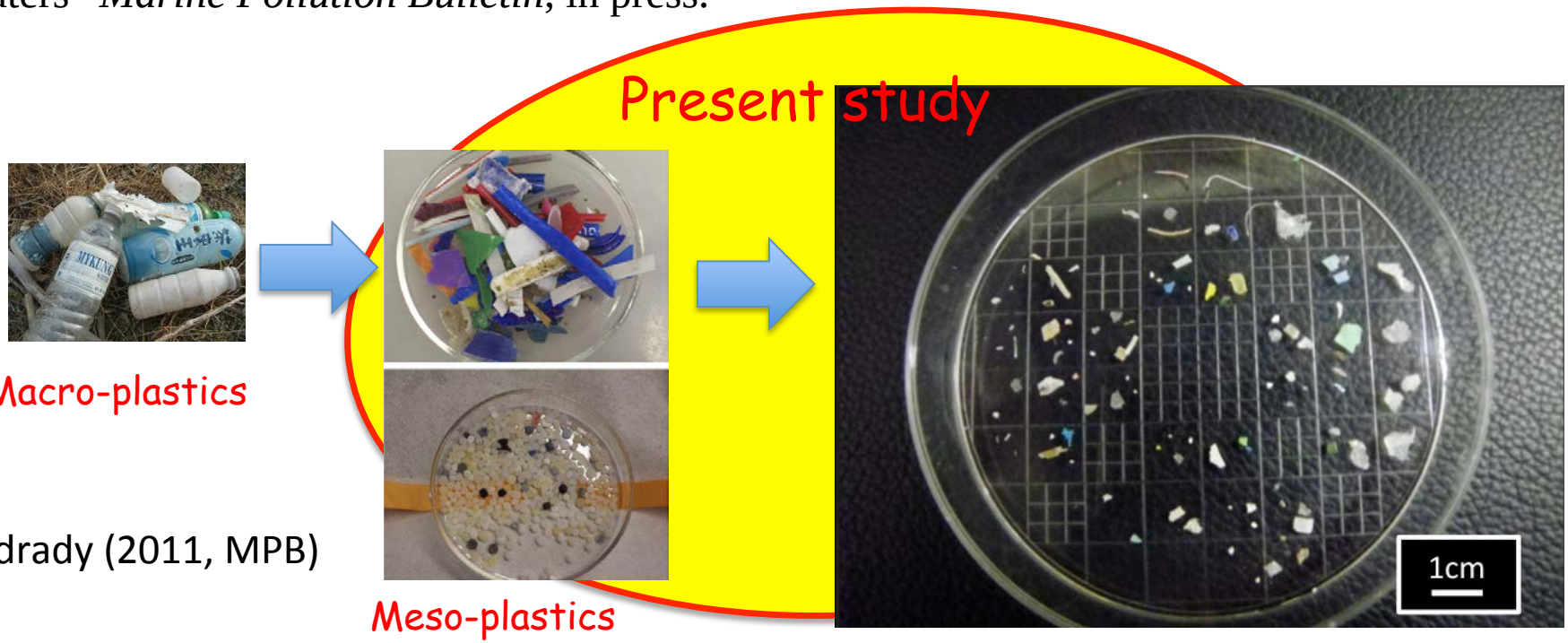
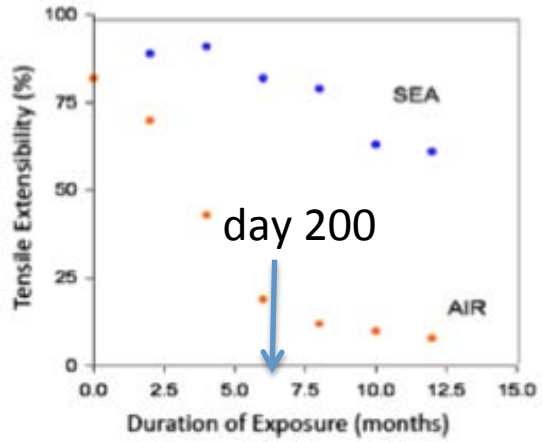
Isobe et al. “Selective transport of microplastics and mesoplastics by drifting in coastal waters” *Marine Pollution Bulletin*, in press.

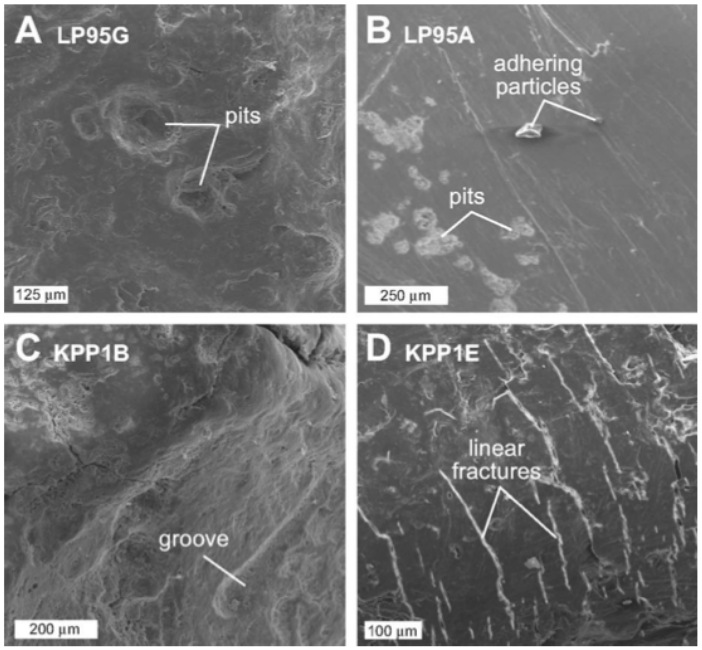


Where does the degradation to microplastics occur in nature?

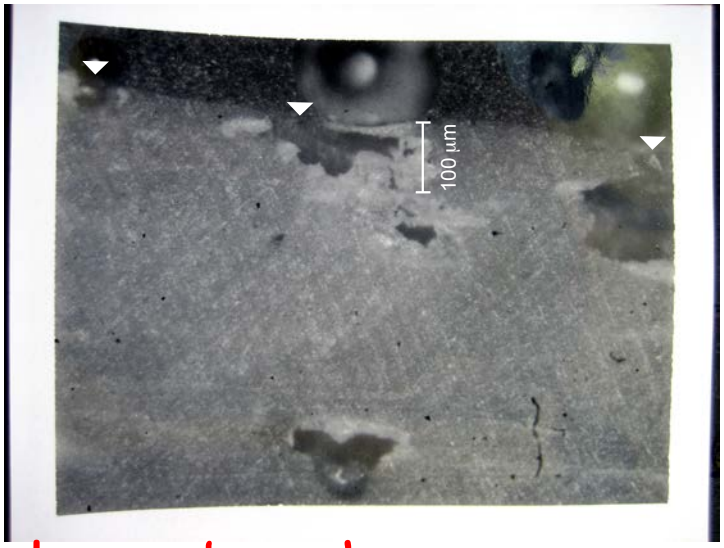


Change of extensibility of plastics in air & in seawater
Andrady (2011, MPB)

exposure to ultraviolet radiation, mechanical erosion, and high temperature



Microscopic images of the surface of marine plastic debris washed ashore on a Hawaiian beach
Corcoran et al. (2009, MPB)

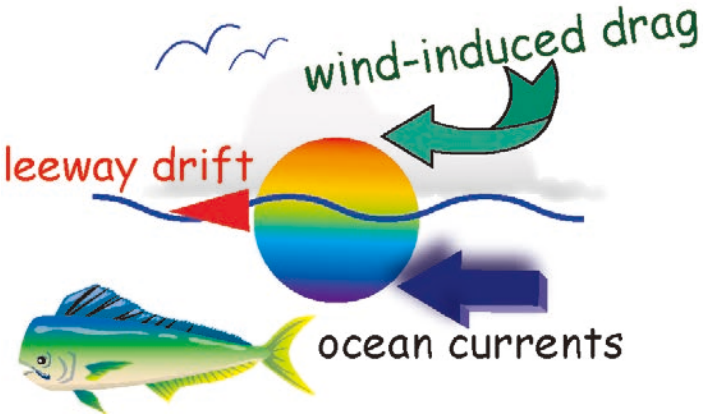


Probably, on beaches

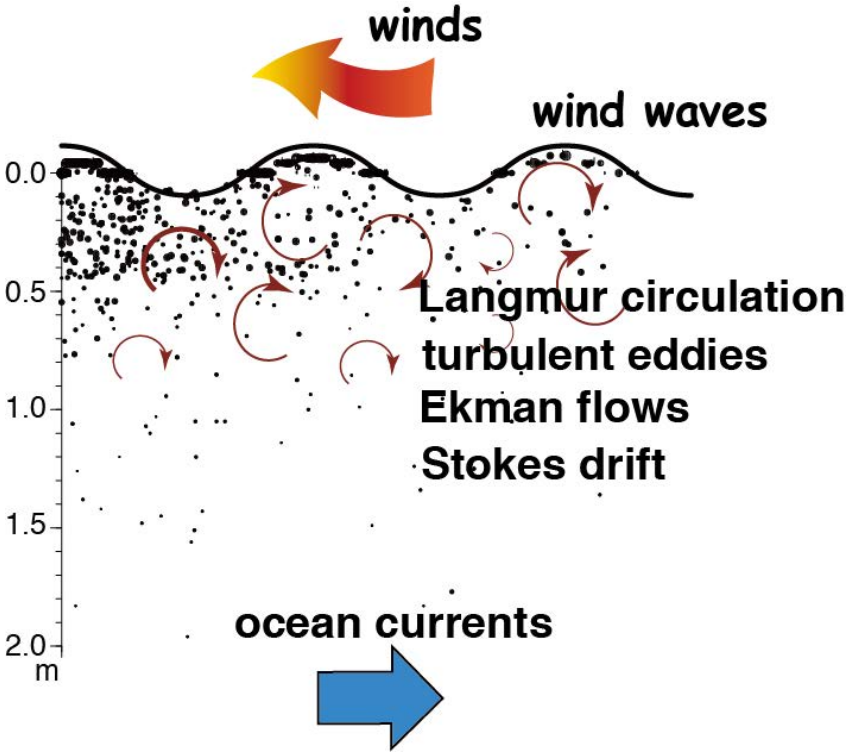
Microscopic images plastic fishery float washed ashore on an Ishigaki-jima beach.
Nakashima et al., (unpublished)

How are meso & microplastics transported in the oceans?

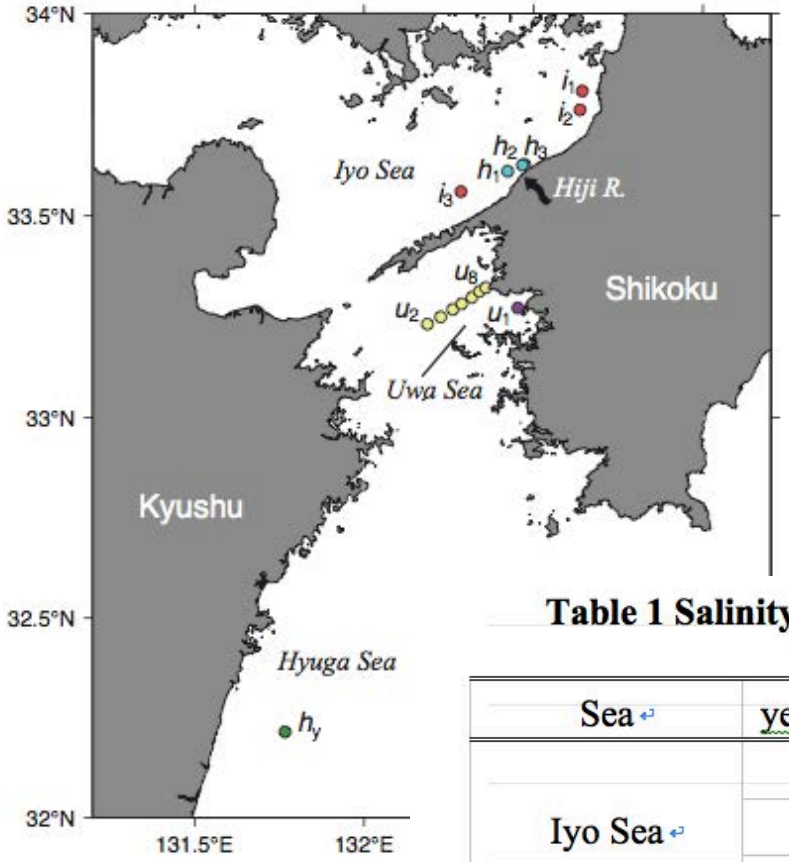
Macro-plastics



Meso & micro-plastics (PP, PE < seawater density) move in the turbid surface "skin layers"



A challenging topic in physical oceanography



Sampling at 15 stations in the Seto Inland Sea, Japan

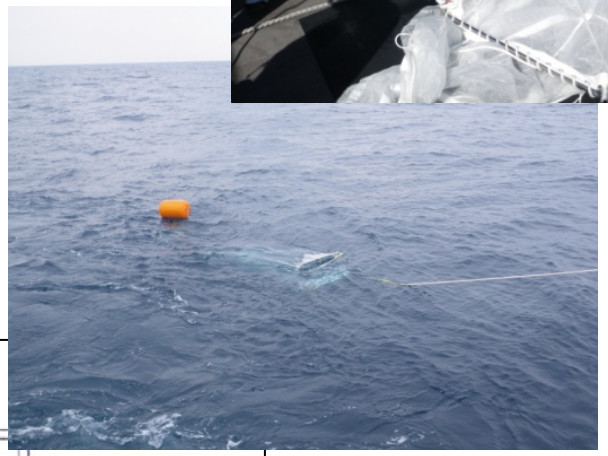
Samplings of meso & microplastics using R/V "Isana" & T/V "Yuge" were conducted from 2010-2012. We first sought oceanic fronts along which plastic debris are accumulated, and thereafter towed a neuston net (350 um)

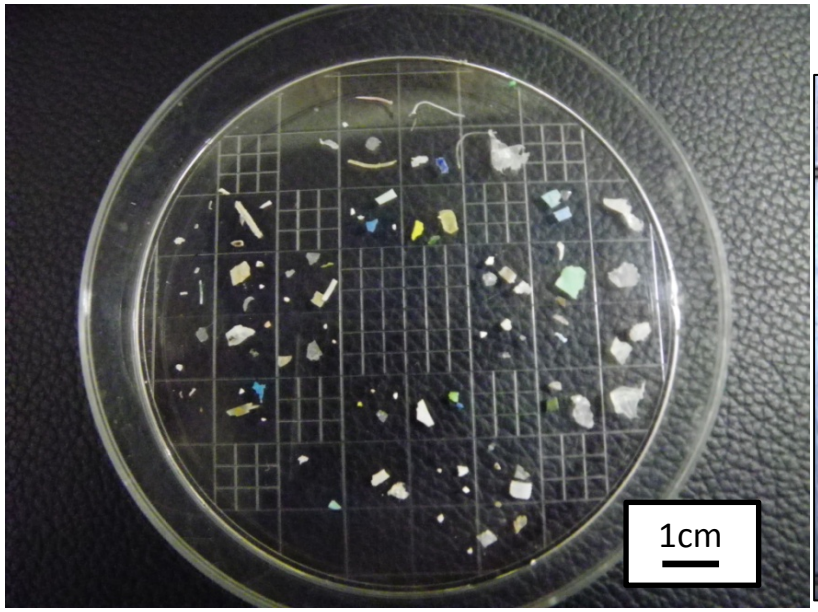
Table 1 Salinity and distance from the nearest coast of the sampling stations

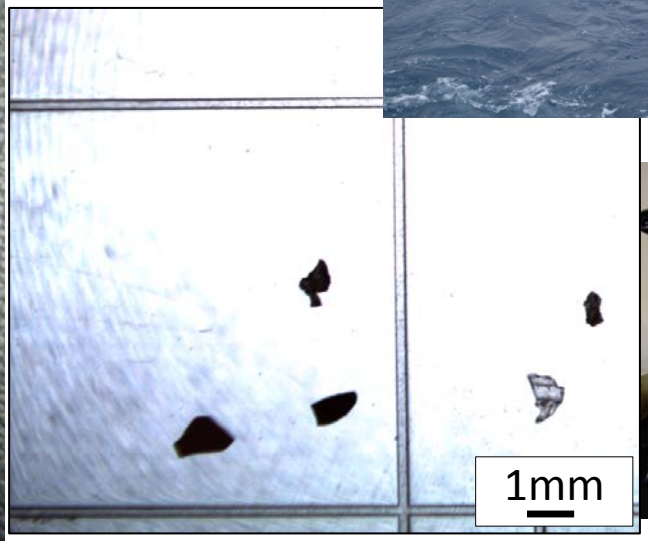
Sea	year/month/date	Stas.	Salinity	Distance (km)
Iyo Sea	2010/06/11	i_1	32.0	4.5
	2010/09/01	i_2	31.4	5.0
	2011/07/14	i_3	31.8	9.5
Hiji R. mouth	2011/07/14	h_1	26.1	1.2
	2011/08/09	h_2	31.2	4.2
	2011/09/13	h_3	30.2	1.6
Hyuga Sea	2011/06/01	hy	32.1	21.6
Uwa Sea	2011/08/09	u_1	31.7	2.2
	2012/05/17	u_2, u_3, u_4	33.4, 32.5, 32.4	19.7, 15.6, 11.6
	2012/05/17	u_5, u_6, u_7	32.4, 32.5, 32.6	5.5, 2.9, 1.1

Sampling & analyses

- The neuston net (0.75 x 0.75 m^2, net size of 350 um) with a flow meter were towed during 15-20 min. by research vessels
- Temperature & salinity were measured every 1 s on board.



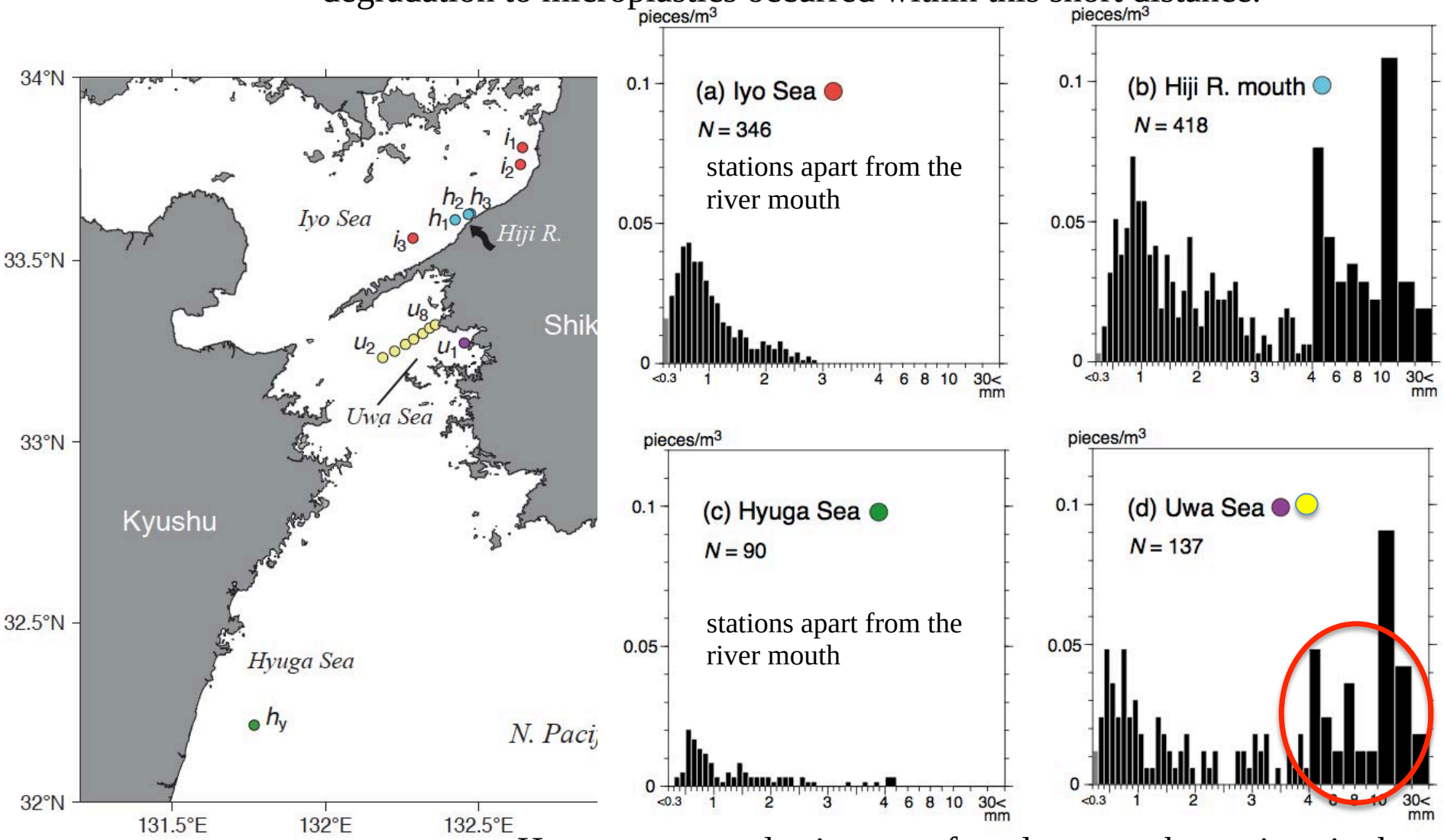




- Sizes and numbers per unit volume of plastic fragments (identified by eyes and FT-IR) were measured in the laboratory.

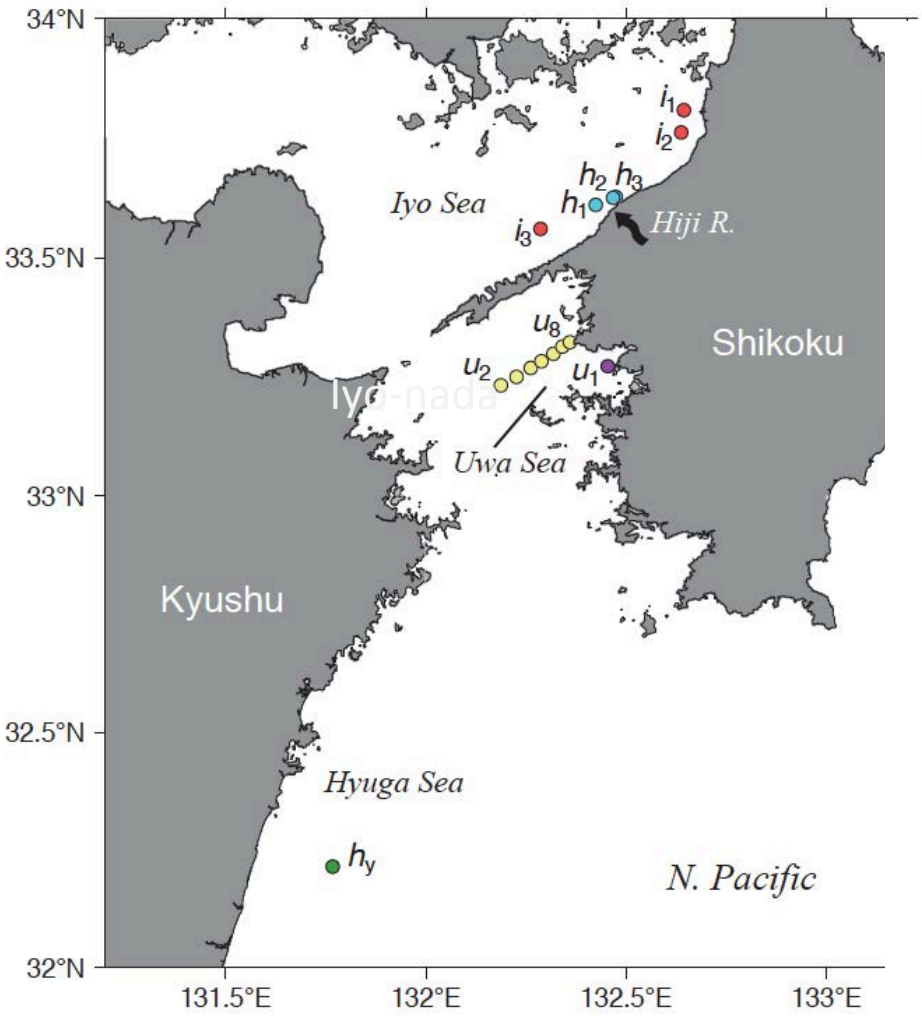
Results

Mesoplastics appeared at the river mouth. It is therefore likely that they were supplied from the river. The mesoplastics disappeared at the stations apart from the river mouth (10 km from the mouth). It is therefore considered the degradation to microplastics occurred within this short distance.

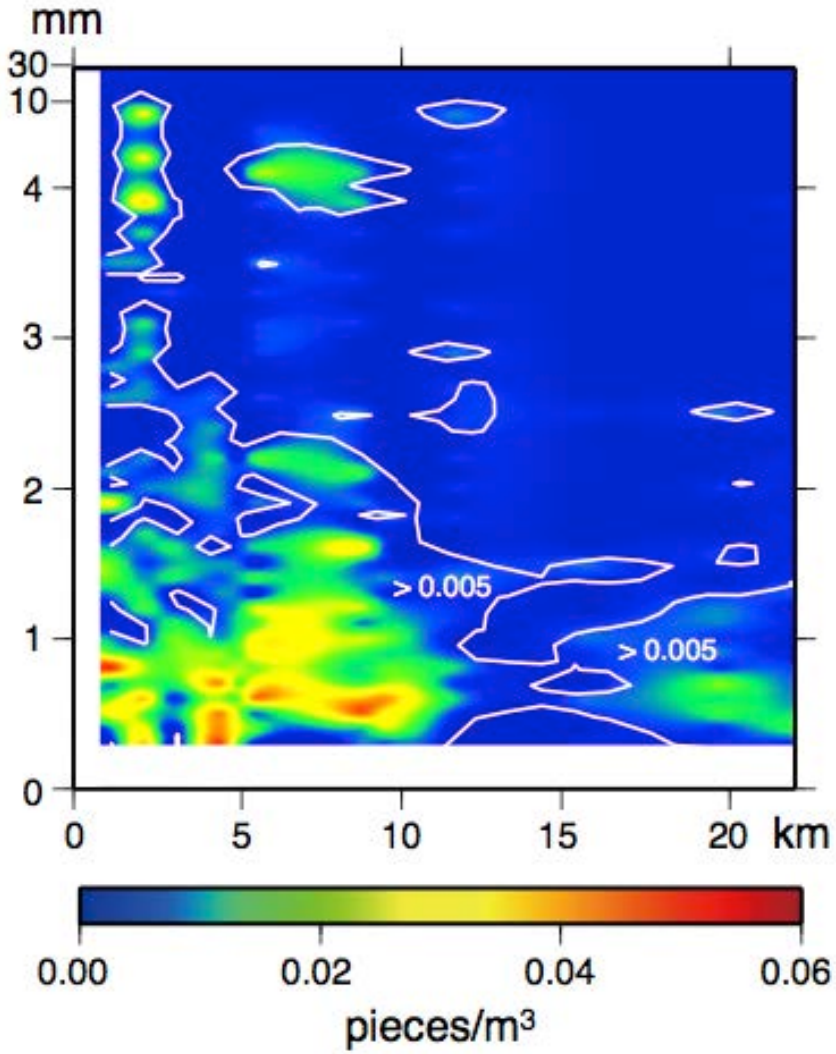


However, mesoplastics were found even at the stations in the sea without river mouths…???

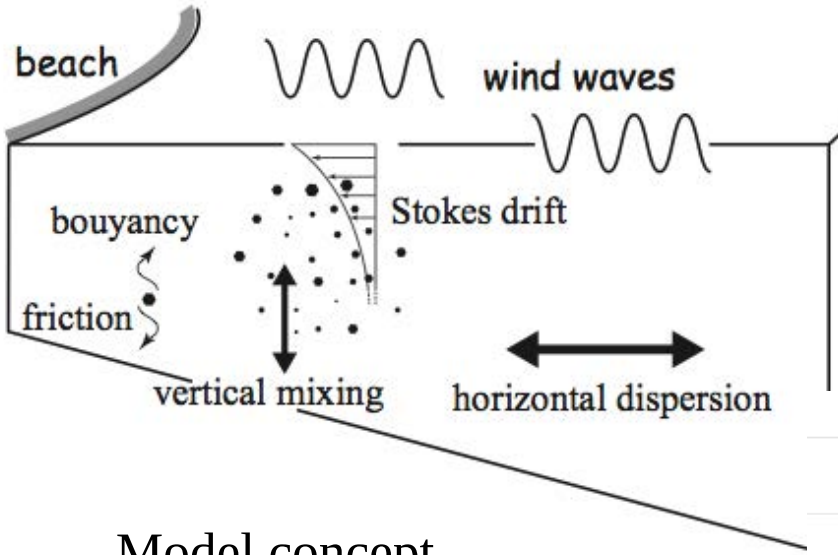
The size and quantity of mesoplastics gradually increased close to the coast, while microplastics were more dominant as we moved further offshore.



Drift density (colors) of plastic fragments as a function of their size and distance from the nearest coast. The samples near the river mouth(h1-3) are NOT used in depicting this figure.



Transport model of meso & microplastics



Model concept

particle tracking model on vertical 2D plain

$$\mathbf{x}(t+\Delta t)=\mathbf{x}(t)+\mathbf{u}\Delta t, \qquad (1)$$

$$u=-\frac{a^2\sigma k\cosh\{2k(h+z)\}}{2(\sinh kh)^2}+\frac{R\sqrt{2K_h\Delta t}}{\Delta t}, \qquad (2)$$

The horizontal motion is governed by random walk (ocean currents & turbulence) and Stokes drift generated by wind waves.

$$w=\frac{d^2(\rho-\rho')g}{18\eta}+\frac{R\sqrt{2K_z\Delta t}}{\Delta t}, \quad R_e<1, \qquad (3)$$

$$w=0.223d\left\{\frac{(\rho-\rho')^2g^2}{\rho\eta}\right\}^{1/3}+\frac{R\sqrt{2K_z\Delta t}}{\Delta t}, \quad 1\le R_e\le 100, \qquad (4)$$

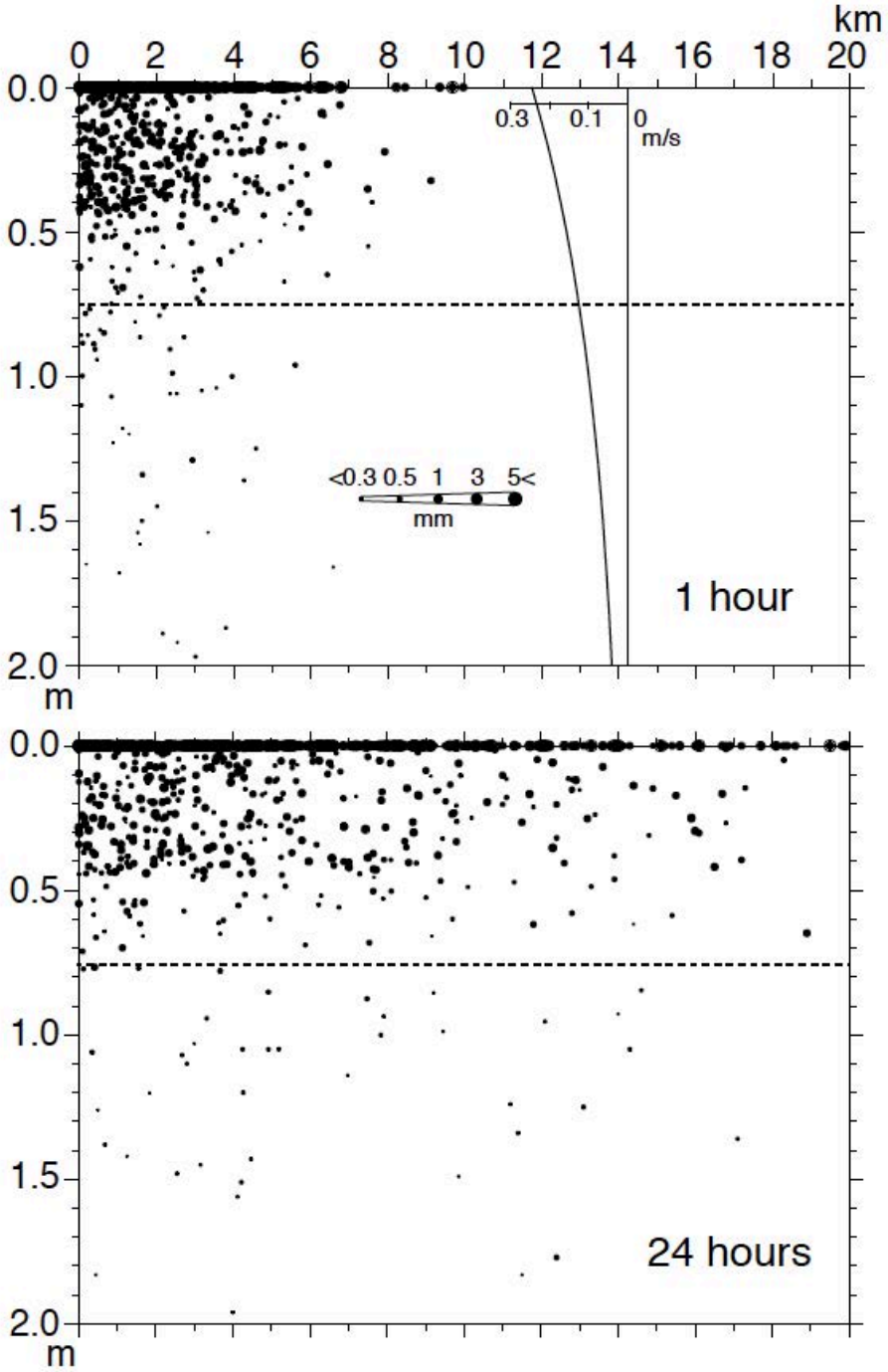
$$w=1.82\left\{\frac{(\rho-\rho')gd}{\rho}\right\}^{1/2}+\frac{R\sqrt{2K_z\Delta t}}{\Delta t}, \quad 100<R_e, \qquad (5)$$

The vertical motion is governed by terminal velocities dependent on Reynolds number (determined by particle sizes)

Transport model of meso & microplastics

Variables	Physical quantities	Equations	Values
Δt	time increment	(1), (3)-(5)	10 s
a	wave amplitude	(2)	0.5 m
σ	wave frequency	(2)	2.2 s^{-1}
k	wave number	(2)	0.45 m^{-1}
h	ocean depth	(2)	20 m
K_h	horizontal diffusivity	(2)	4000 m^2s^{-1}
ρ	seawater density	(3)-(5)	1025 kg m^{-3}
ρ'	particle density	(3)-(5)	950 kg m^{-3}
η	viscosity of seawater	(3)-(5)	1.025×10^{-3} kg $m^{-1}s^{-1}$
g	gravitational acceleration	(3)-(5)	9.8 m s^{-2}
K_z	vertical diffusivity	(3)-(5)	0.01 m^2s^{-1}

Parameters required for the computation were chosen by climatologically averaged wind-wave data actually observed in the Seto Inland Sea, Japan. Particle densities used for the computation of terminal velocities are equal to PE (dominant in the present case) .

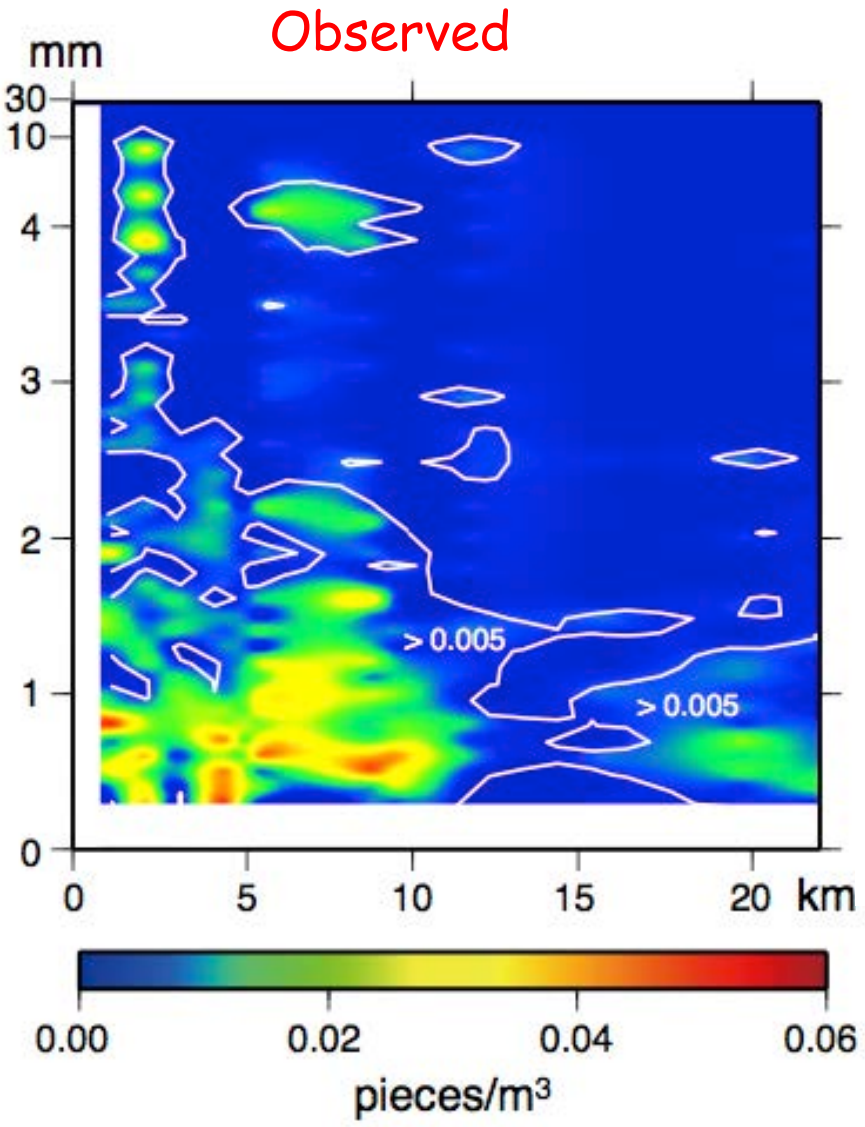


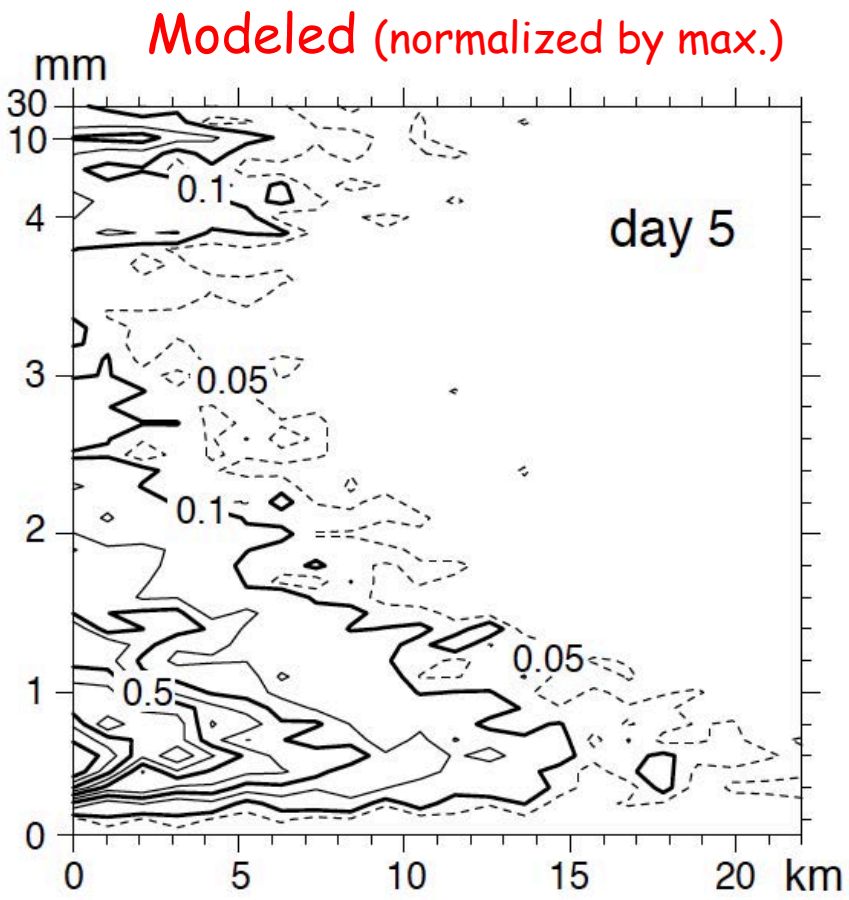
Procedures

- 10,000 particles were first released at x=0 km, z=0 m (upper left), and thereafter we compute the motions of all particles until an equilibrium state was reached (5 days).
- The size composition used for the modeled particles were consistent with those observed in the actual ocean
- The drift density was examined in the upper 0.75 m, which is the same as the neuston net size used in the present study

Particle locations in the 2D plain at 1 hour after (upper) and 24-hours after the beginning of the computation.

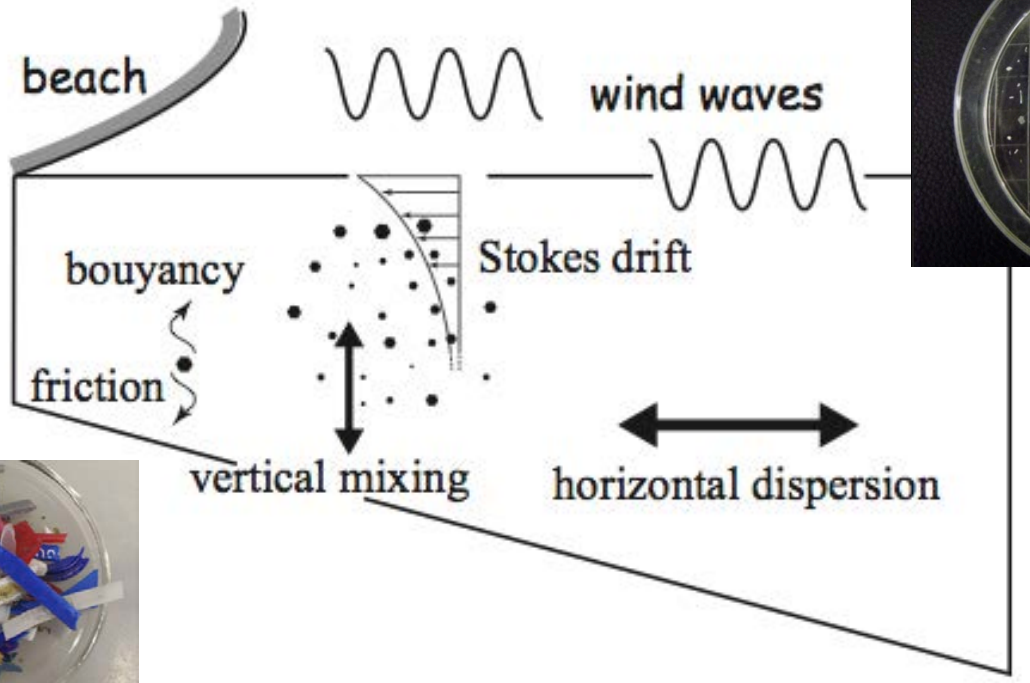
Drift density (colors) of plastic fragments as a function of their size and distance from the nearest coast.

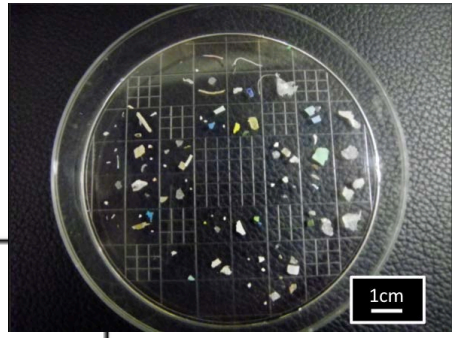


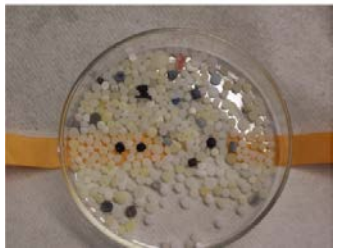


The model including Stokes drift, random walk, and terminal velocities well reproduces the situation that mesoplastics disappear in the offshore.

Conclusion The mesoplastics are selectively conveyed onshore by a combination of Stokes drift and terminal velocity, dependent on fragment sizes. It is suggested that mesoplastics washed ashore on beaches degrade into microplastics, and that the microplastics, which are free from near-shore trapping, are thereafter spread offshore in coastal waters.







Coastal waters have an effective "function" for changing mesoplastics to microplastics.