Monitoring & Modeling of Ocean microplastics

Atsuhiko Isobe
Research Institute for Applied Mechanics, Kyushu University, JAPAN

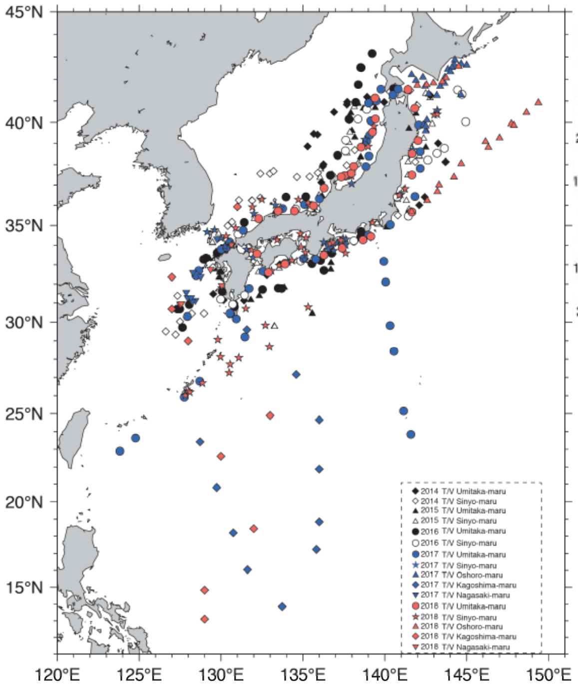
Degradation by sunlight (UV), oxidative breakdown, reaction with water

Fragmentation by mechanical stimulation by waves, friction with sands …

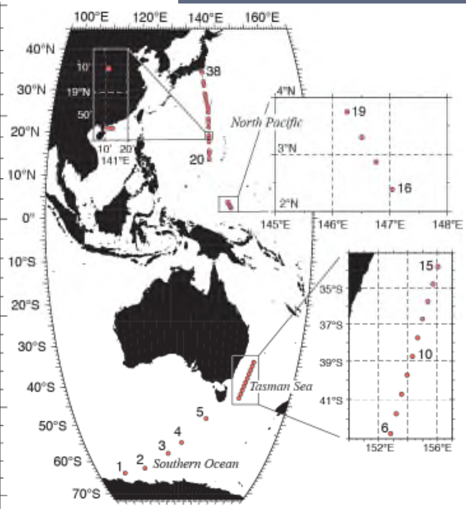
Generation of microplastics especially on beaches

Recent field surveys of meso- and microplastics around Japan

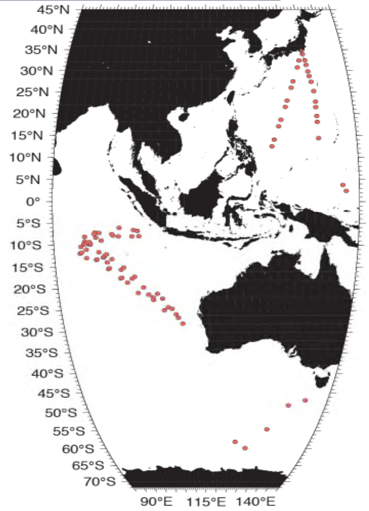
East Asian Seas around Japan (2014-present)
Isobe et al. (2015, MPB), Iwasaki et al. (2017, MPB)



UMITAKA-Maru cruises
Isobe et al., (2017MMPB), Isobe et al, (2019,Nature Comm)



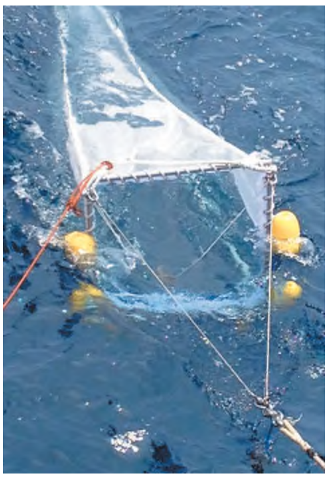
2016



2017

Sampling & analyses

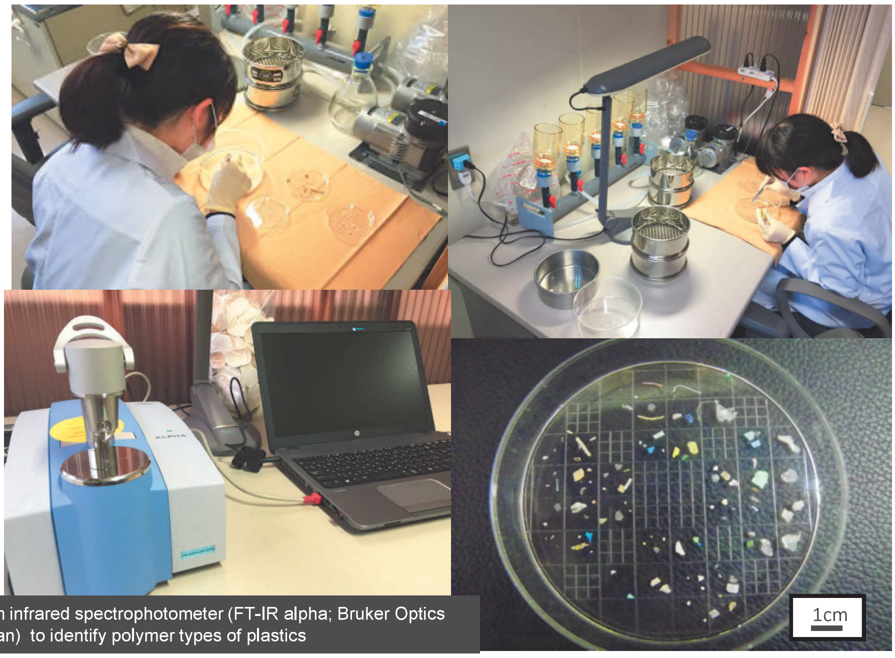
1. Sampling small plastic fragments using neuston net (0.75 x 0.75 m^2, net size of 350 μm) with a flow meter. The net was towed during 15-40 min. by research vessels



We must measure seawater volume passing through the net during each towing; otherwise we cannot compute microplastic number per unit seawater volume.

Sampling & analyses

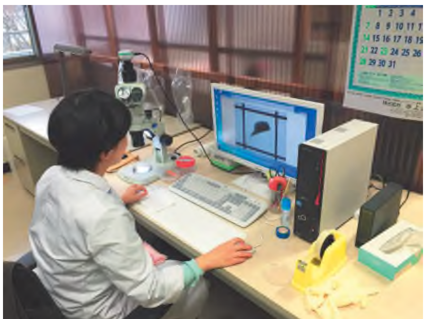
2. Taking pieces of small plastic fragments from sample bottles

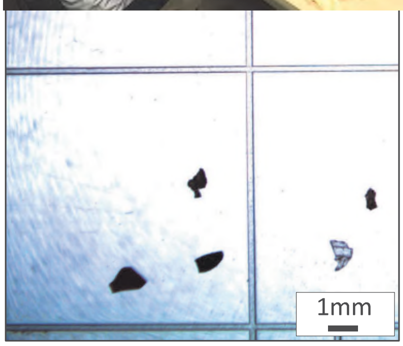


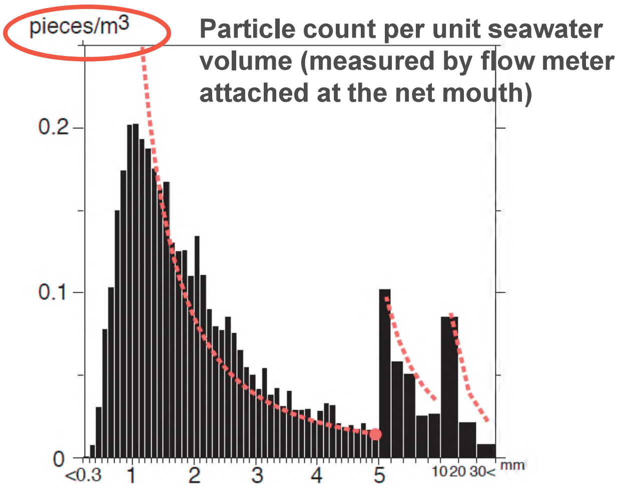
Fourier transform infrared spectrophotometer (FT-IR alpha; Bruker Optics K.K., Tokyo, Japan) to identify polymer types of plastics

Sampling & analyses

3. Measuring particle count by each size bin of small plastic fragments





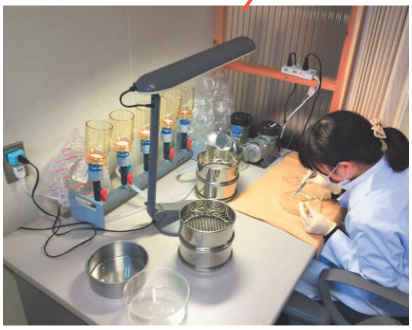


Sizes and numbers per unit volume of plastic fragments (identified by eyes and FT-IR) were measured in the laboratory.

Japan’s efforts in standardization/harmonization of microplastic surveys & monitoring

Isobe et al., (2019, MPB)

Probably one of the most time-consuming and error-generated processes in MP measurement is the extraction of MPs from seawater sample bottles.



Researcher	Organization
Chavanich, Suchana (Viyakarn, Voranop)	Chulalongkorn University (Thailand)
Hagmann, Pascal	Association Oceaneye (Swiss)
Hinata, Hirofumi	Ehime University (Japan)
Isobe, Atsuhiko	Kyushu University (Japan)
Kozlovskii, Nikolai	Pacific Institute of Geographical (Russian)
Lusher, Amy	Marine Pollution Norwegian Institute for Water Research (NIVA, Norway)
Marti, Elisa (Cózar, Andrés)	University of Cadiz (Spain)
Mu, Jingli (Zhang, Weiwei)	National Marine Environmental Monitoring Center, SOA (China)
Shim, Wonjoon	Korea Institute of Ocean Science and Technology (Republic of Korea)
Uchida, Keiichi	Tokyo University of Marine Science and Technology (Japan)
Vasilenko, Katerina (Peter, Ross)	Vancouver Aquarium Marine Science Centre (Canada)
(Delorenzo, Marie)	National Oceanic and Atmospheric Administration (NOAA, United States)

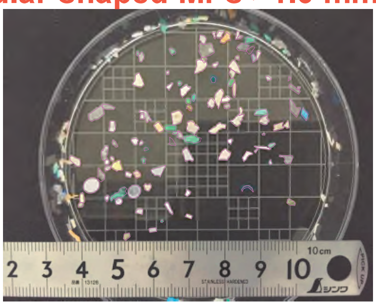
We conducted an “interlaboratory comparison (**ILC**) experiment” for measuring the abundance of microplastics in standard seawater samples.

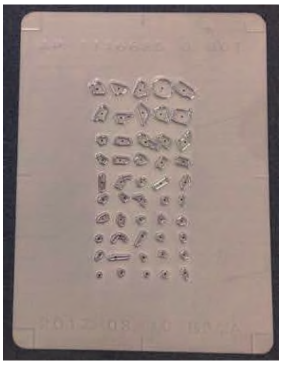
Seawater sample bottles with man-made MPs were sent to 12 laboratories over the world to compare microplastic numbers extracted in each laboratory.

Isobe et al., (2019, MPB)

Three types of man-made MPs prepared for ILC experiment

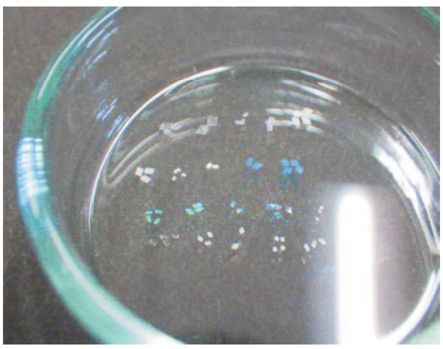
Irregular-shaped MPs >1.0 mm





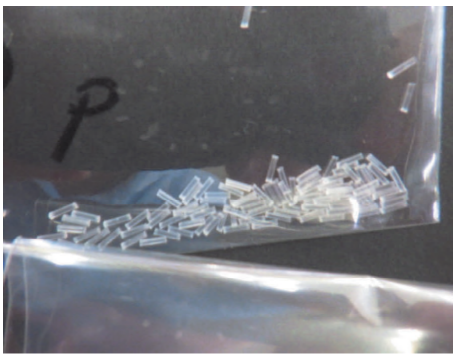
The shapes of these man-made microplastics were predetermined by two metallic molds on which microplastics collected from the actual ocean around Japan were reproduced.

0.3 mm < rhombic MPs <1.0 mm



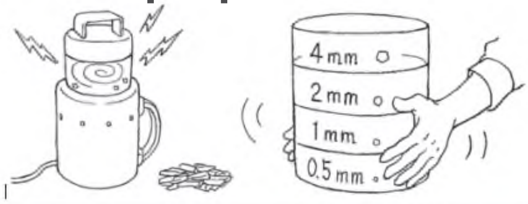
Rhombic fragments made by cutting plastic sheets.

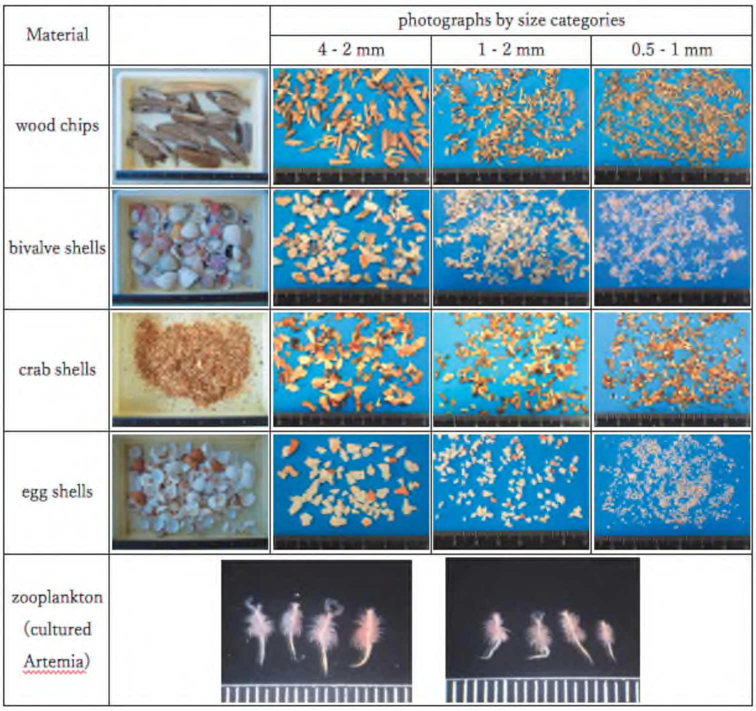
Fibers



Fibrous microplastics were reproduced by cutting plastic fibers with various length.

man-made SPMs prepared for ILC experiment





seawater samples including man-made MPs and SPMs prepared for ILC experiment

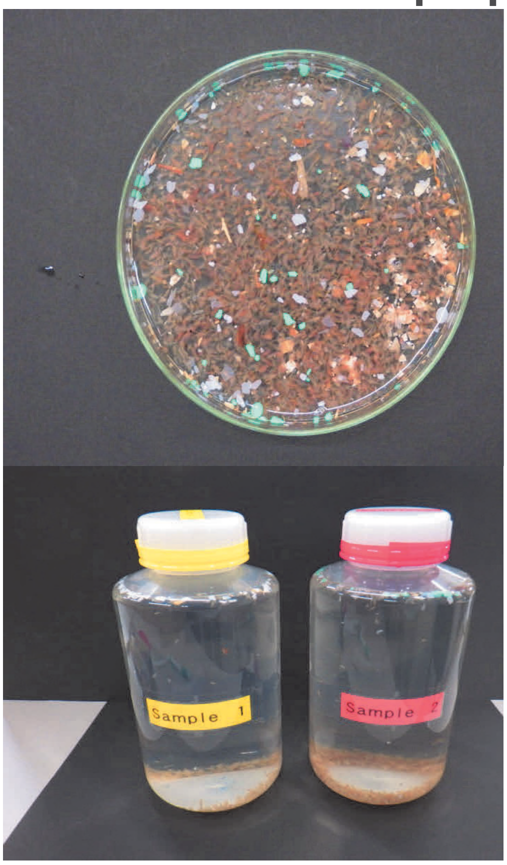


Table 2

Standard sample 1: particle count (pieces $2L^{-1}$)				
Size categories	Irregular-shaped	Rhombic	Fibrous	Total
$\delta < 1$ [mm]	0	26	8	34
$1 < \delta < 2$	34	11	5	50
$2 < \delta < 3$	66	0	4	70
$3 < \delta < 4$	26	0	2	28
$4 < \delta < 5$	48	0	1	49
$5 < \delta$	26	0	0	26
Total	200	37	20	257

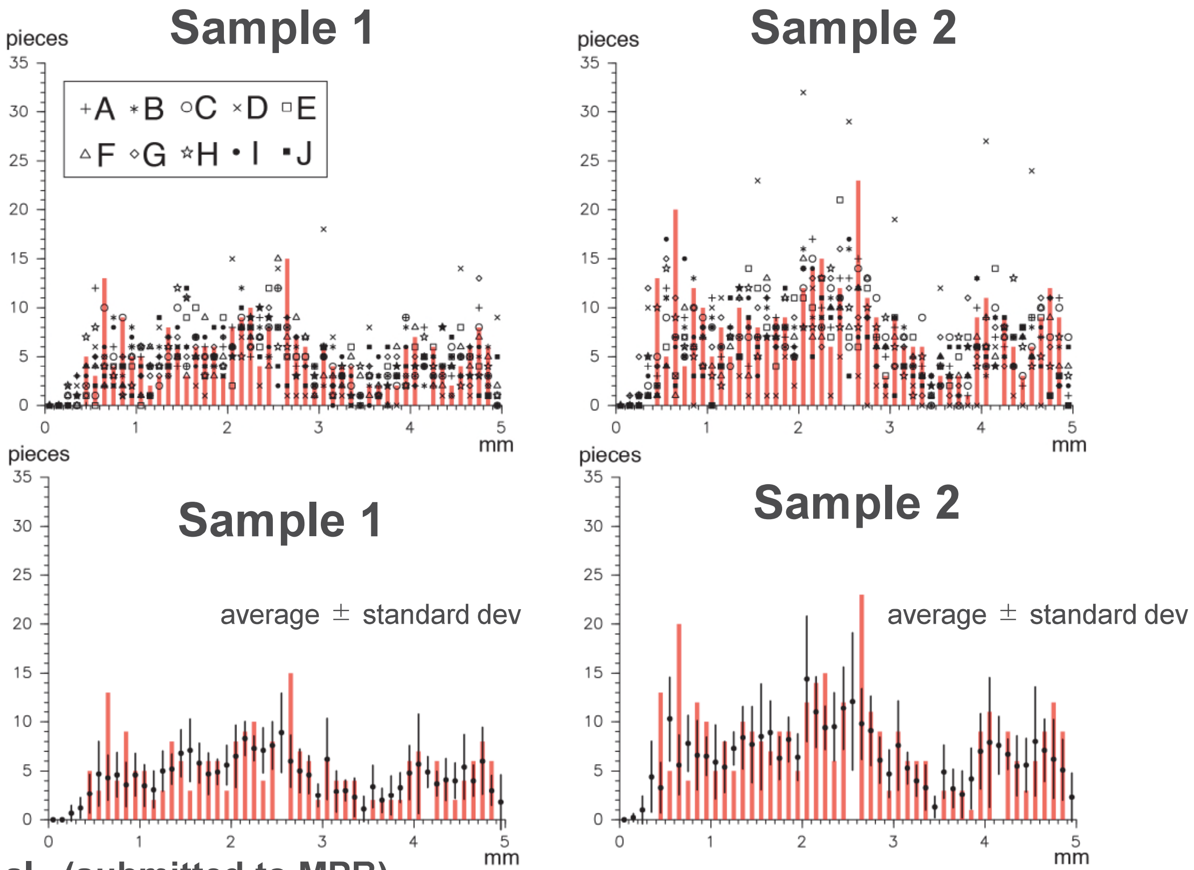
Standard sample 2: particle count (pieces $2L^{-1}$)				
Size categories (mm)	Irregular-shaped	Rhombic	Fibrous	Total
$\delta < 1$	0	44	10	54
$1 < \delta < 2$	51	19	10	80
$2 < \delta < 3$	99	0	8	107
$3 < \delta < 4$	39	0	1	40
$4 < \delta < 5$	72	0	2	74
$5 < \delta$	39	0	3	42
Total	300	63	34	397

Isobe et al., (2019, MPB)

The weight ratios between MPs and SPMs were adjusted to those actually observed around Japan.

RESULTS

10 of 12 laboratories were used for plotting because they provided numbers by each 0.1-mm interval. MP numbers measured were roughly consistent with the correct numbers (red bars) in each bin, but were dispersed largely.



Isobe et al., (submitted to MPB)

RESULTS

Isobe et al., (2019, MPB)

Percentages of MP numbers counted in the laboratories to true numbers in each 1-mm bin of sizes. Left (right) bars denote the measurements with (without) the items of each panel. Black bars means the difference was statistically significant. Red lines denote the standard deviations of which deference was statistically significant.

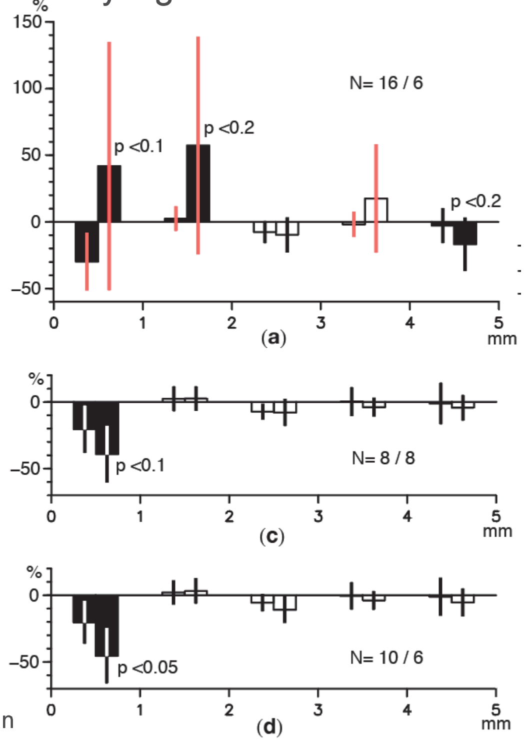
FTIR/ no FTIR

FTIR (or Raman spectrometer) was efficient to identify MPs <2 mm. FTIRs are required to identify plastics smaller than 2 mm.

Chemical treatment

All experiments in these panels used FTIR. Chemical treatment to remove the organism on MP surface and/or density separation in the measurement were effective to identify MPs < 1mm.

Density separation

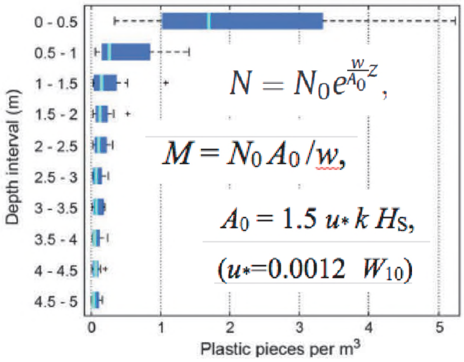


Chemical treatment is considered to be more effective than suggested in the present experiment, because the MPs in the nature have more organisms than man-made MPs.

Three units (metrics) of quantifying microplastic (<5 mm) abundance

1. **Particle count per unit seawater volume (N_0; pieces/m^3)** directly observed by towing neuston net with a flowmeter

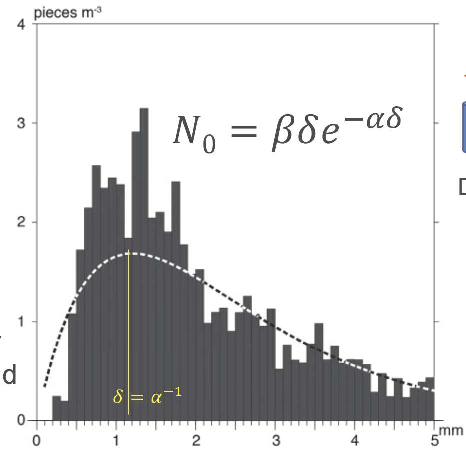
2. **Total particle count over the water column (M; pieces/km^2)**

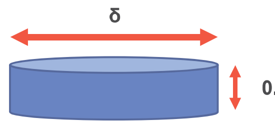


Kukulka et al. (2012), Reisser et al. (2015)

Vertically integrating ***N*** over the entire water column yields ***M*** using **wave height** (*H*s) and **wind speed** (W_{10}) both measured onboard.
Wind/wave correction

3. **Weight per unit seawater volume (W; mg/m^3)**

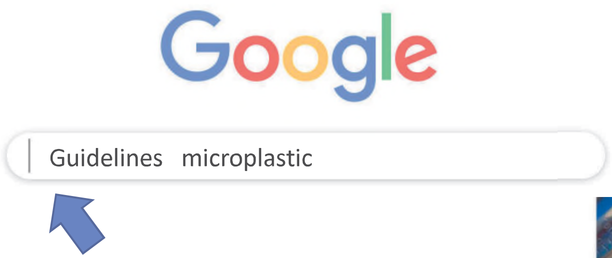




Density (ρ)~1.0 g/m^3 for PE & PP

Assuming the size distribution by the function in the panel, and assuming a flat cylinder for the shape of macroplastics, we can convert ***N*** to ***W***.

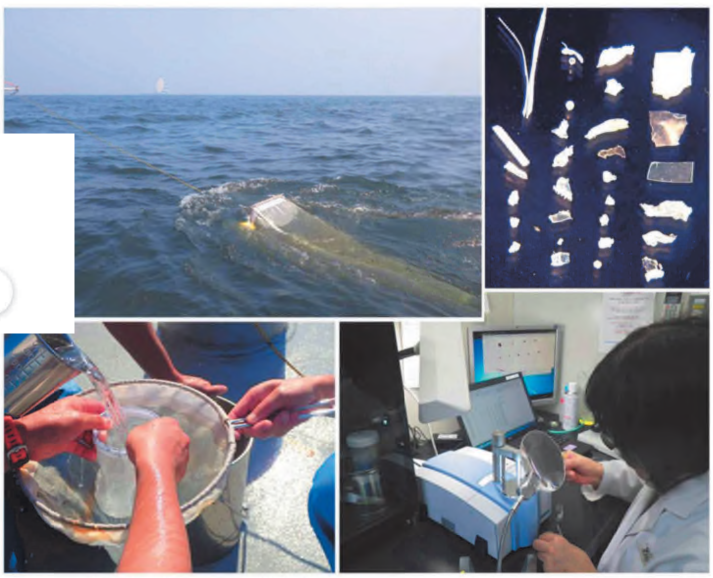
Japan's efforts in standardization/harmonization of microplastic surveys & monitoring



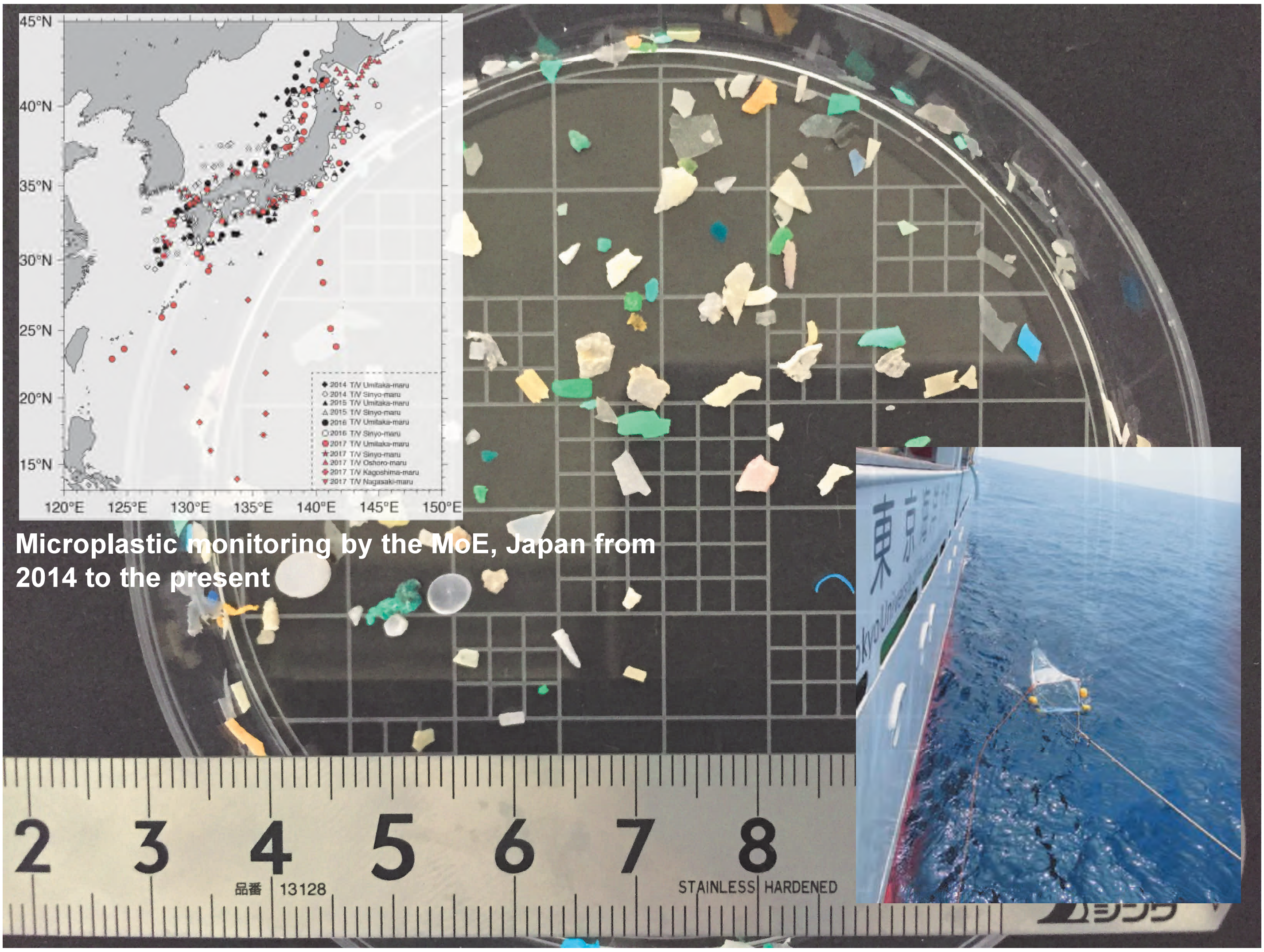
Michida et ak. (2019) downloaded from MoE, Japan website

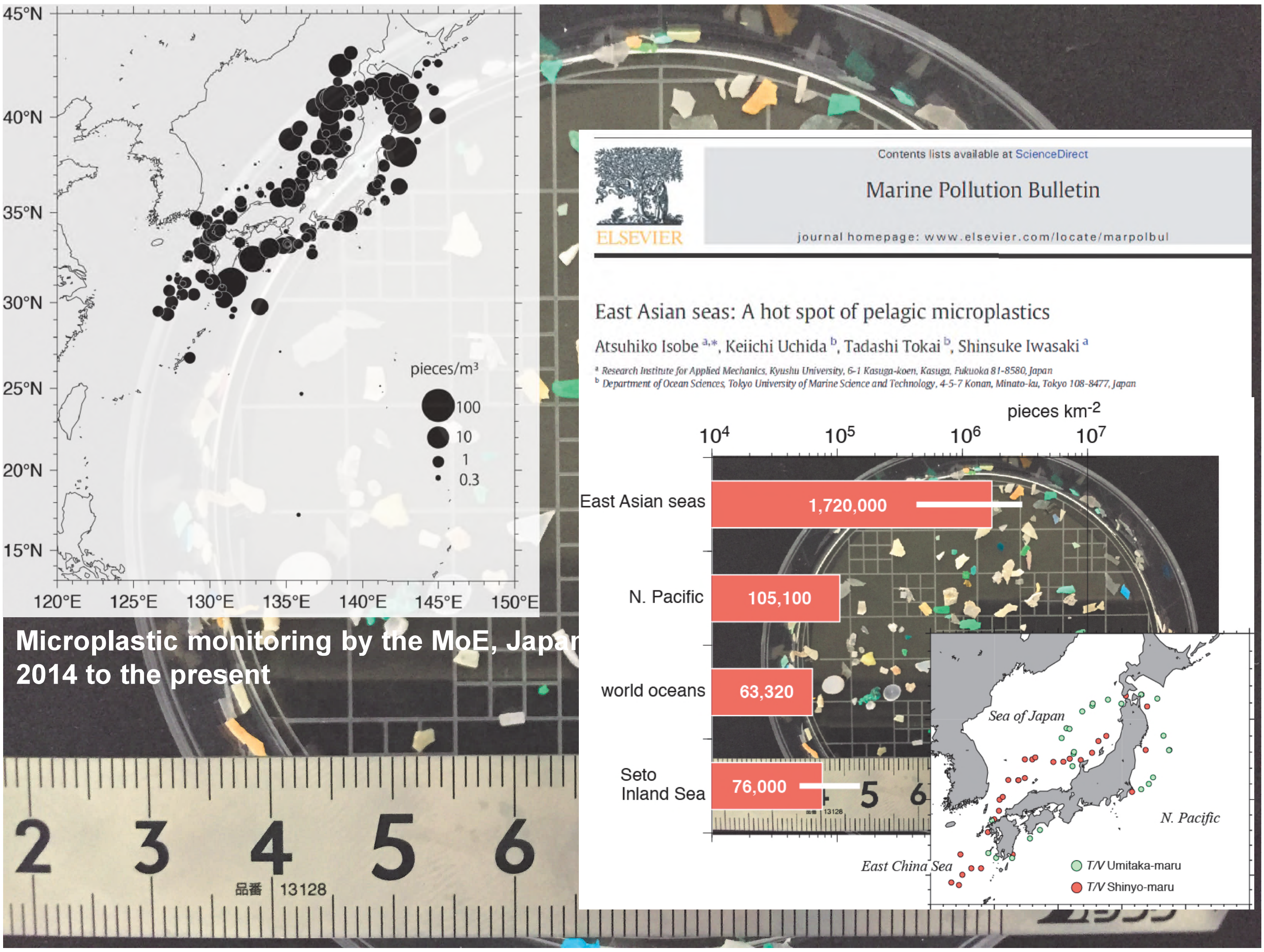
Guidelines for Harmonizing Ocean Surface Microplastic Monitoring Methods

Version 1.0, May 2019



Ministry of the Environment, JAPAN
May, 2019

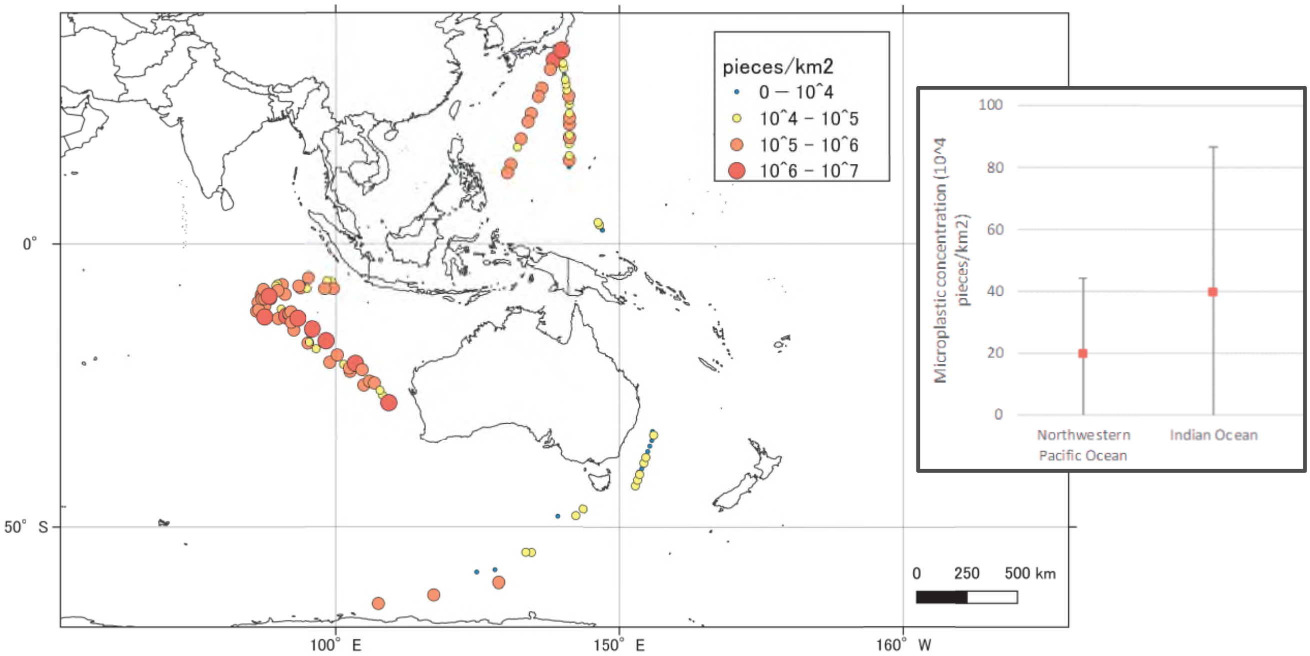

45°N
40°N
35°N
30°N
25°N
20°N
15°N
120°E
125°E
130°E
135°E
140°E
145°E
150°E
2014 T/V Umitaka-maru
2014 T/V Sinyo-maru
2015 T/V Umitaka-maru
2015 T/V Sinyo-maru
2016 T/V Umitaka-maru
2016 T/V Sinyo-maru
2017 T/V Umitaka-maru
2017 T/V Sinyo-maru
2017 T/V Oshoro-maru
2017 T/V Kagoshima-maru
2017 T/V Nagasaki-maru
Microplastic monitoring by the MoE, Japan from
2014 to the present
2 3 4 5 6 7 8
品番 13128
STAINLESS HARDENED


45°N
40°N
35°N
30°N
25°N
20°N
15°N
120°E
125°E
130°E
135°E
140°E
145°E
150°E
pieces/m³
100
10
1
0.3
Microplastic monitoring by the MoE, Japan
2014 to the present
2 3 4 5 6
品番 13128
Contents lists available at ScienceDirect
Marine Pollution Bulletin
ELSEVIER
journal homepage: www.elsevier.com/locate/marpolbul
East Asian seas: A hot spot of pelagic microplastics
Atsuhiko Isobe a,*, Keiichi Uchida b, Tadashi Tokai b, Shinsuke Iwasaki a
a Research Institute for Applied Mechanics, Kyushu University, 6-1 Kasuga-koen, Kasuga, Fukuoka 81-8580, Japan
b Department of Ocean Sciences, Tokyo University of Marine Science and Technology, 4-5-7 Konan, Minato-ku, Tokyo 108-8477, Japan
pieces km-2
10^4
10^5
10^6
10^7
East Asian seas
1,720,000
N. Pacific
105,100
world oceans
63,320
Seto
Inland Sea
76,000
Sea of Japan
N. Pacific
East China Sea
T/V Umitaka-maru
T/V Shinyo-maru

Dr. Defri Yona,

a guest investigator in Kyushu University supported by Matsumae Foundation (June – October, 2019)

Marine Science Department, Brawijaya University

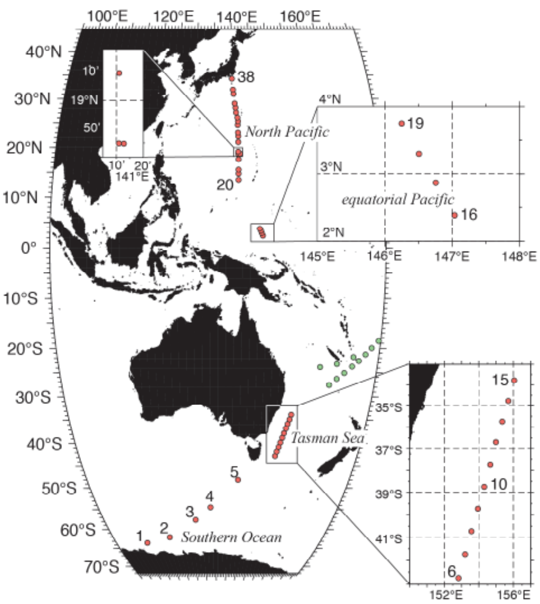


The eastern Indian Ocean may be more contaminated by plastics than the East Asian Sea. (Yona et al., in preparation)

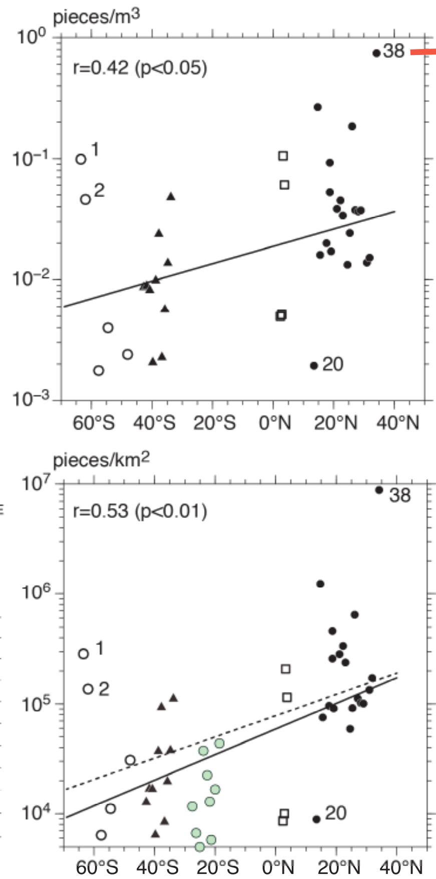
Marine Plastic Pollution proceeds, especially in the Northern Hemisphere

300 µm < Microplastics < 5 mm

Upper: Concentration (pieces/m³)
Lower: Concentration integrated over the water column (pieces/km²)

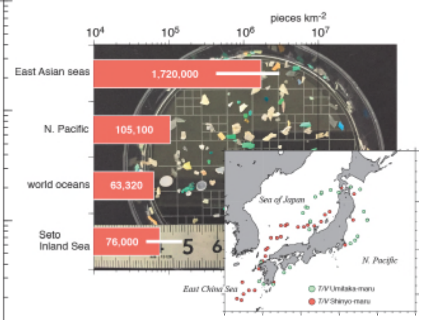


Microplastic surveys in Jan.-Mar. 2016



The nearest station to Japan

In particular, the highest concentration appeared in the East Asian Sea, a hotspot of marine plastic pollution



Isobe et al. (2015)

nature COMMUNICATIONS

ARTICLE

https://doi.org/10.1038/s41467-019-08316-9 OPEN

Abundance of non-conservative microplastics in the upper ocean from 1957 to 2066

Atsuhiko Isobe[1], Shinsuke Iwasaki[2], Keiichi Uchida[3] & Tadashi Tokai[3]

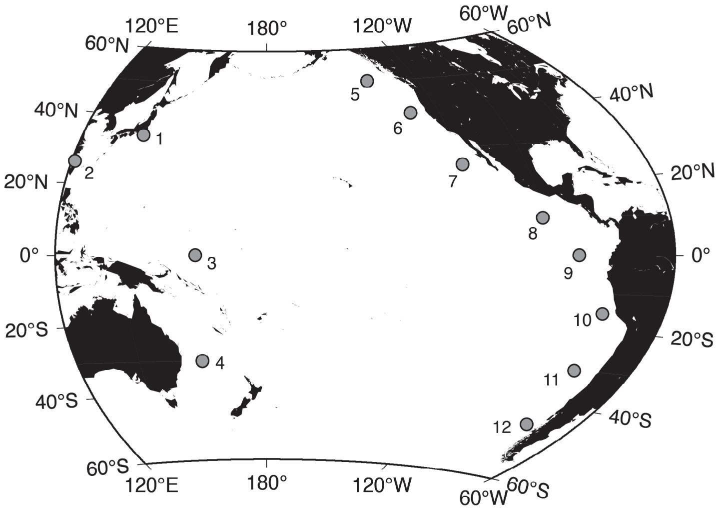
Isobe et al., (2019)

Numerical particle tracking model for predicting microplastic abundance in the Pacific from 1957 to 2066

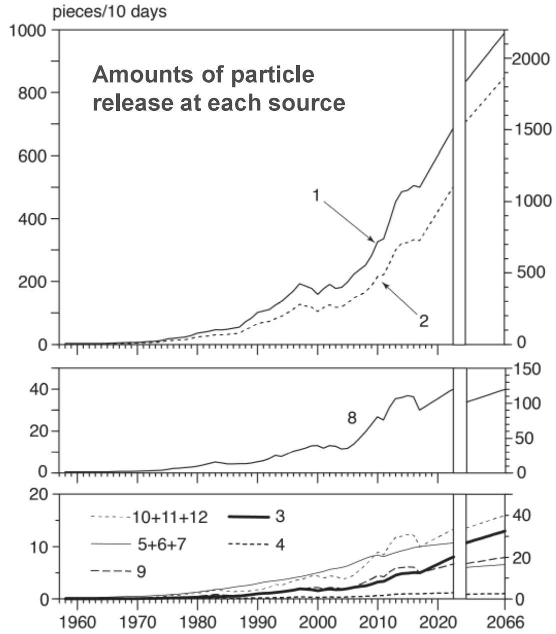
Emission model

1957~present (2016): Present amounts of particle releases at the below 12 sources are proportional to the **mismanaged plastic wastes estimated by Jambeck et al. (2015)**. We assume that the past releases are proportional to the Gross Domestic Product **(GDP) time series** in each region.

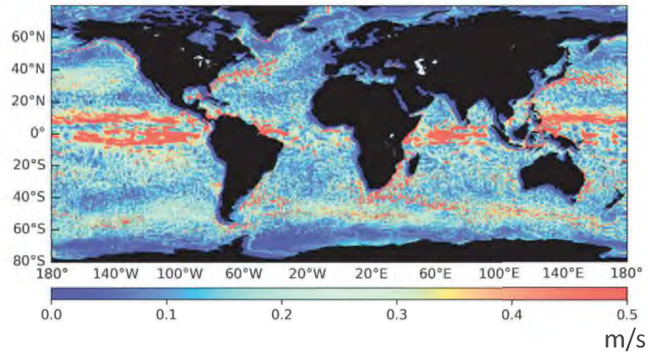
Present~2066: The future amounts of particles release is proportional to the "15-year prediction" in each region provided by Jambeck (2015). The amounts are linearly extrapolated in the years beyond 15 years.



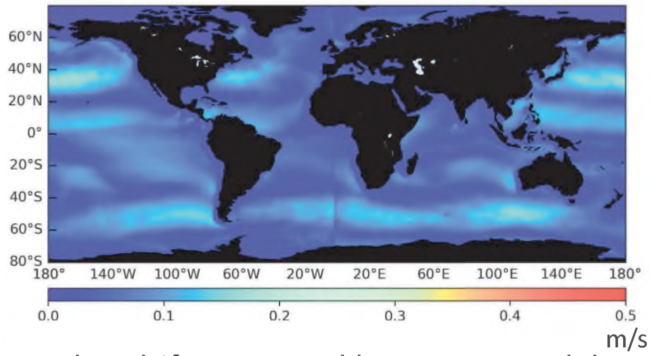
1: East Asia (Japan, China, Korea, ...), 2: Southeast Asia 3: Western equatorial Pacific, 4:Oceania, 5+6+7:North America, 8: Central America 9: Eastern equatorial Pacific 10+11+12: South America



Numerical particle tracking model
for predicting microplastic abundance in the Pacific
from 1957 to 2066

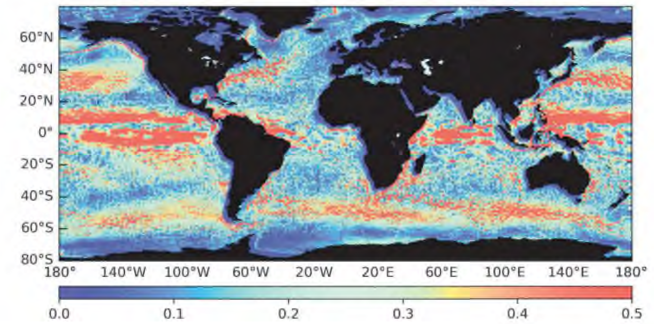


HYCOM Ocean re-analysis current in 2015



Stokes drift computed by a wave model driven by satellite winds in 2015

HYCOM + Stokes drift in 2015



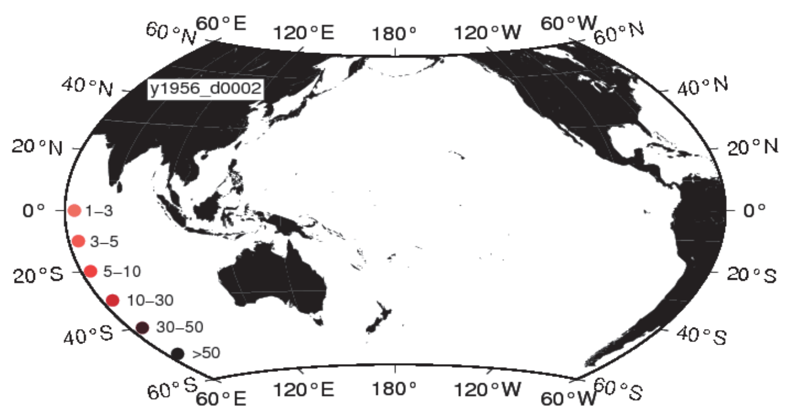
The combined ocean currents (HYCOM + Stokes drift) in 2015 were repeatedly given to the model background. The daily updated currents were linearly interpolated at each time steps.

Numerical particle tracking model
for predicting microplastic abundance in the Pacific
from 1957 to 2066

Generation, transport, and removal of pelagic microplastics in the upper ocean were reproduced in a numerical model to reproduce the present status, and future abundance.

$$\mathbf{X}(t+\Delta t) = \mathbf{X}(t) + \mathbf{U}\Delta t + \frac{1}{2}\left(\mathbf{U}\cdot\nabla_H\mathbf{U} + \frac{\partial \mathbf{U}}{\partial t}\right)\Delta t^2 + R\sqrt{2K_h\Delta t}(\mathbf{i},\mathbf{j}) - \gamma$$

sink term



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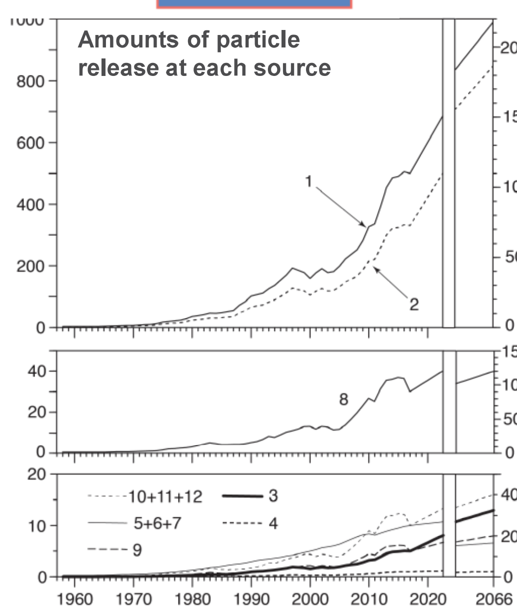
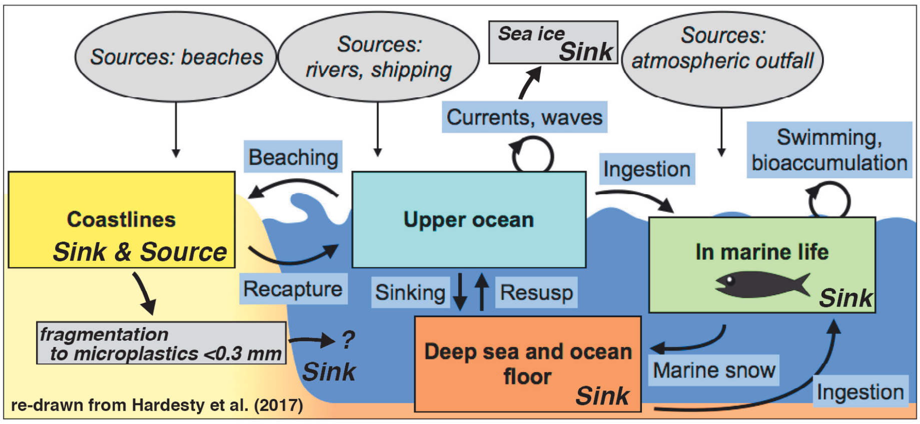


Numerical particle tracking model for predicting microplastic abundance in the Pacific from 1957 to 2066

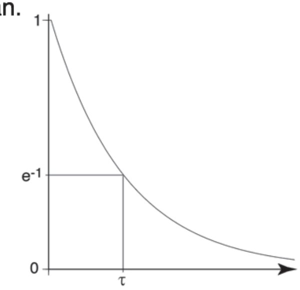
Pelagic microplastics are unlikely to remain in the upper oceans eternally, although the plastics are little decomposed in the nature. This is because microplastics have "sink processes" such as sinking to deep ocean via marine organisms, absorbing into sandy beaches or sea ice, fragmentation into tiny microplastics that we have not yet observed, and moving into unknown marine sectors.

$$\mathbf{X}(t+\Delta t) = \mathbf{X}(t) + \mathbf{U}\Delta t + \frac{1}{2}\left(\mathbf{U}\cdot\nabla_H\mathbf{U} + \frac{\partial\mathbf{U}}{\partial t}\right)\Delta t^2 + R\sqrt{2K_h\Delta t}(\mathbf{i},\mathbf{j}) - \gamma$$

sink term

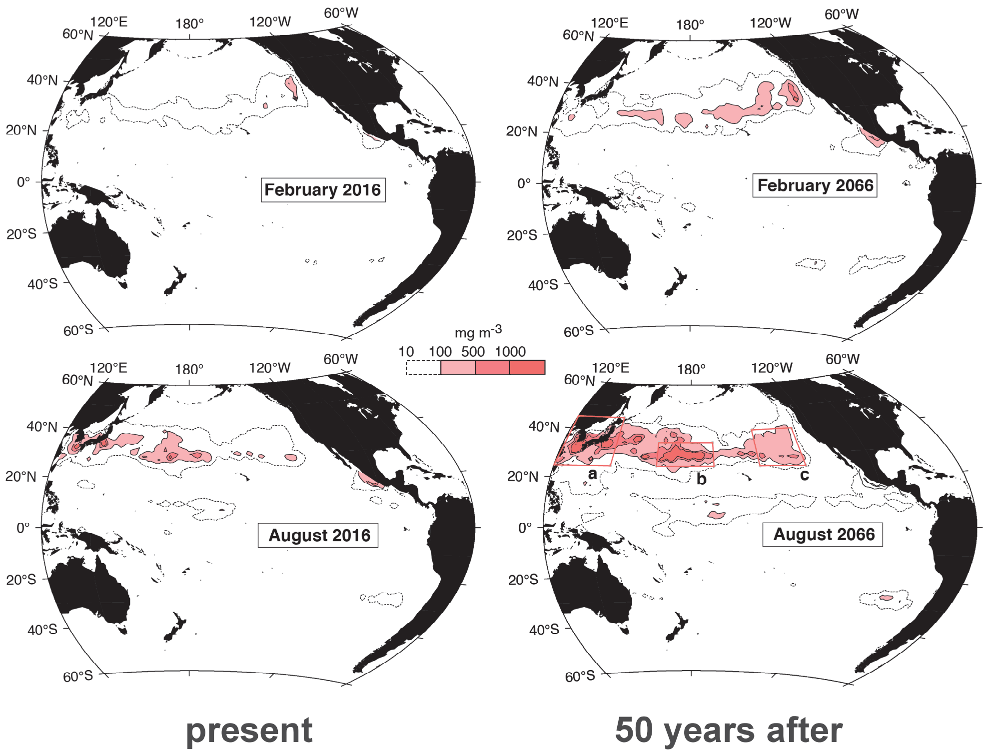


Modeled particles are randomly removed from the model domain so as that the amount of particles released at a specific time reduced to e^{-1} after the "removal time", τ . The removal time τ can be regarded as the "average transit time" of particles in the upper ocean.



T: removal timescale of microplastics in the upper oceans

Numerical particle tracking model for predicting microplastic abundance in the Pacific from 1957 to 2066

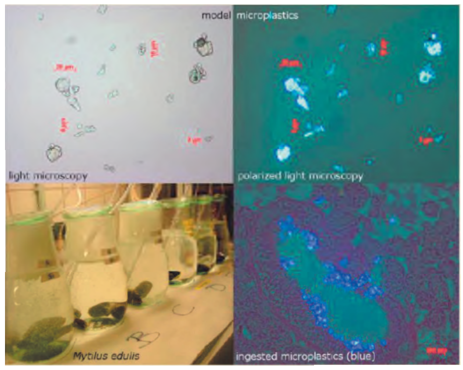


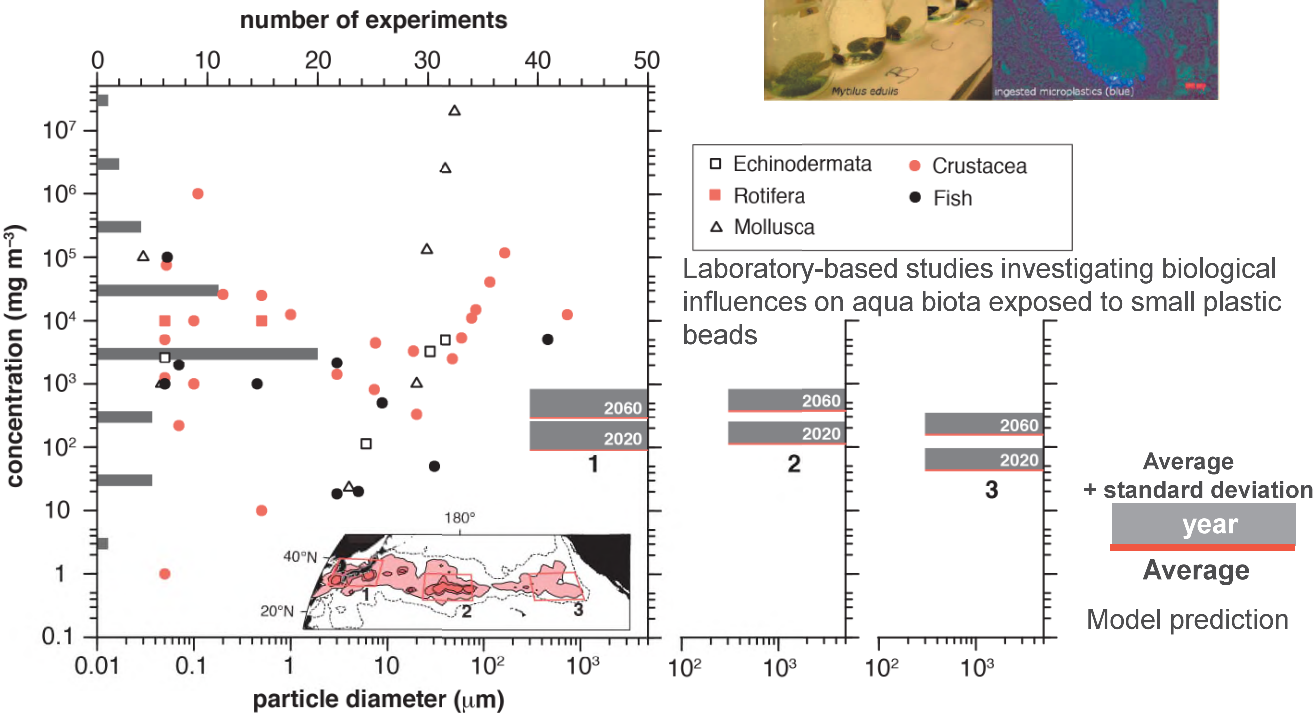
Three areas (**a**, **b**, and **c**) with the high concentration are revealed in the model.

The high concentrations in the upper ocean are remarkable in **boreal summer in the Northern Hemisphere**, owing to the relatively calm oceanic conditions, and owing to the concentration denser than the Southern Hemisphere.

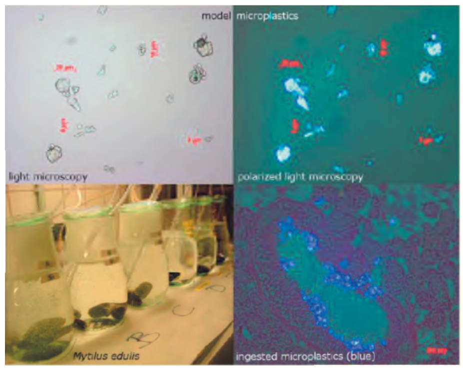
The concentration at areas **a** and **b** after 50 years (2066) becomes 100~1000 mg/m^3, **one order of magnitude larger** than the present oceans.

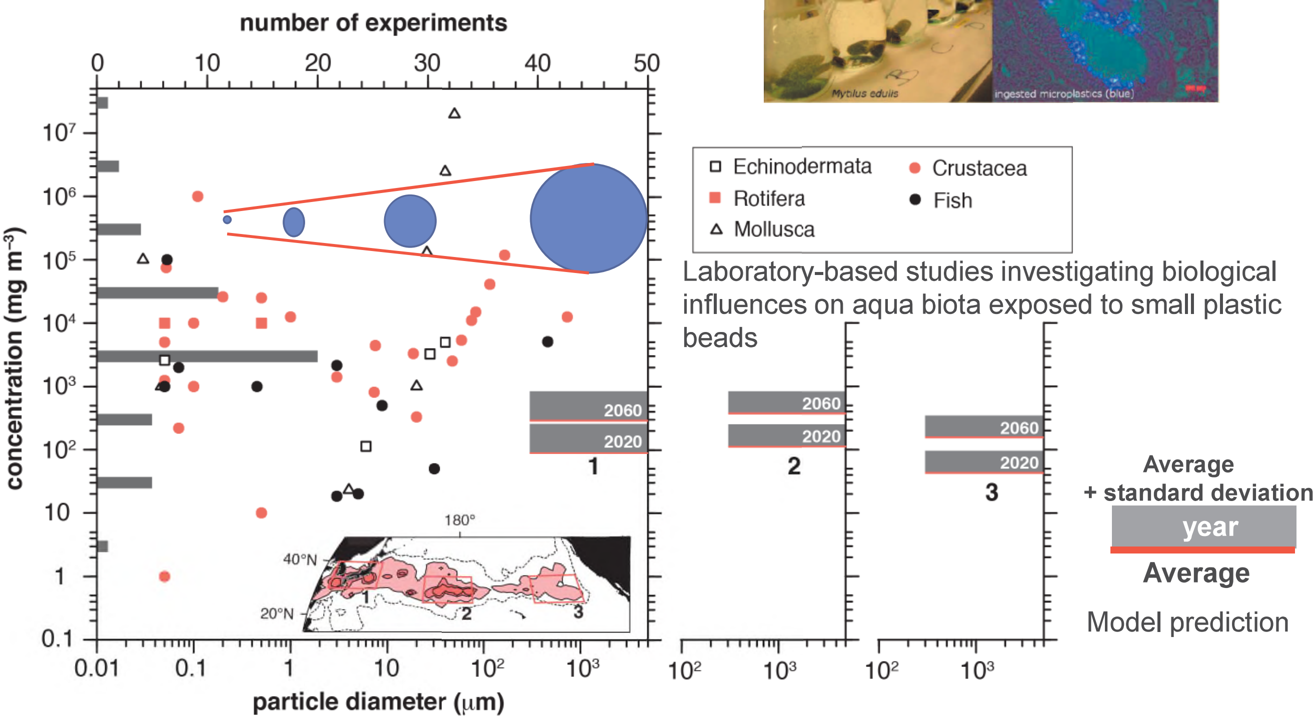
Unless the amount of mismanaged plastic waste is reduced substantially, marine plastic pollution is likely to proceed to a point of no return, beyond which marine organisms will be harmed, as has been shown in laboratory experiments.





There remains a large gap between microplastic observations (hence, modeling) and laboratory-based studies with respect to sizes of microplastics to which aquatic biota are exposed.





To do

Toward the sustainable reduction of plastics in the world, based on the sciences

To uncover the generation, transport, and fate of microplastics in the world's ocean
- How do microplastics generate?
- How are microplastics transported?
- Where do microplastics go?

Marine plastic circulation

To monitor the current status of microplastic abundance in the world's ocean
- We have to develop the monitoring methods of microplastics < 300 µm.
- We have to standardize and harmonize of microplastic abundance.

Observations

To uncover impact of plastic pollution on marine ecosystems
- What is the threshold concentration of microplastic abundance?
- How are plastics harmful to marine biota?

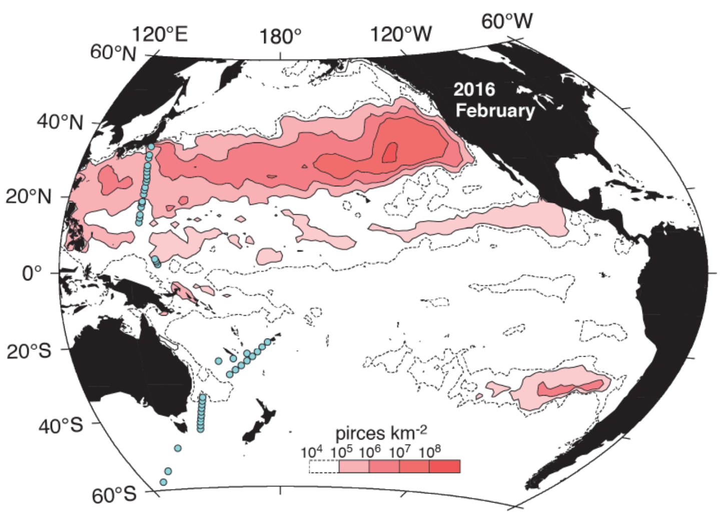
Risk assessment

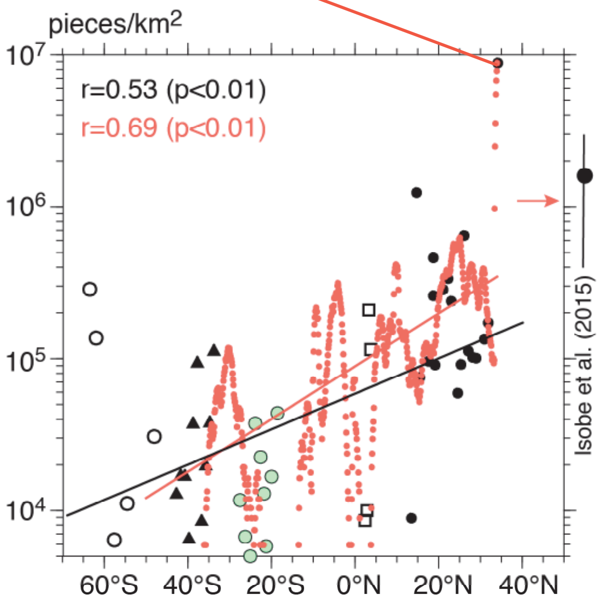
To develop environmentally-friendly plastics and/or new materials

Environmentally-friendly materials

Modeled concentration integrated over the water column without sink term (pieces/km^2; red dots)

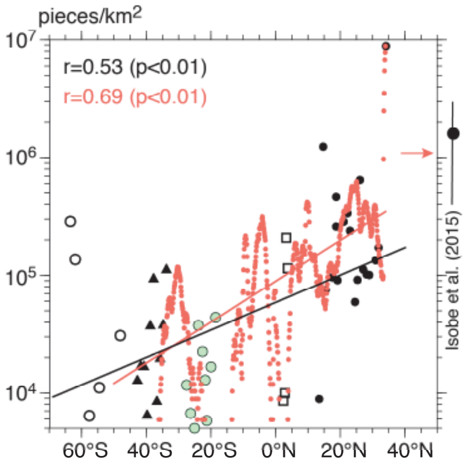
The modeled concentration at 34N (northernmost station) was adjusted to that observed at the same location, and thus, modeled concentrations in other locations were automatically determined.

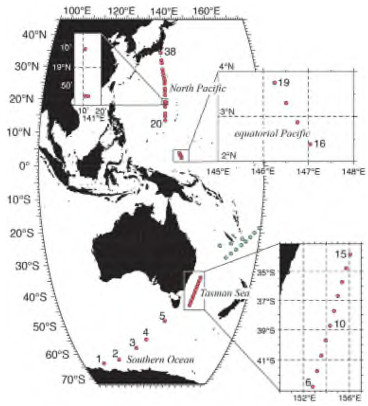


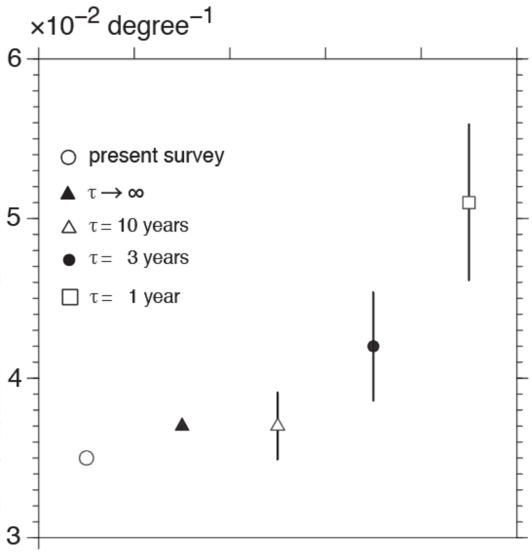


It seems likely that the modeled concentrations are overestimated especially in the Northern Hemisphere by approx. 30~50%.

Computation of north-south gradient (α) by different τ , the removal timescale of microplastics in the upper ocean







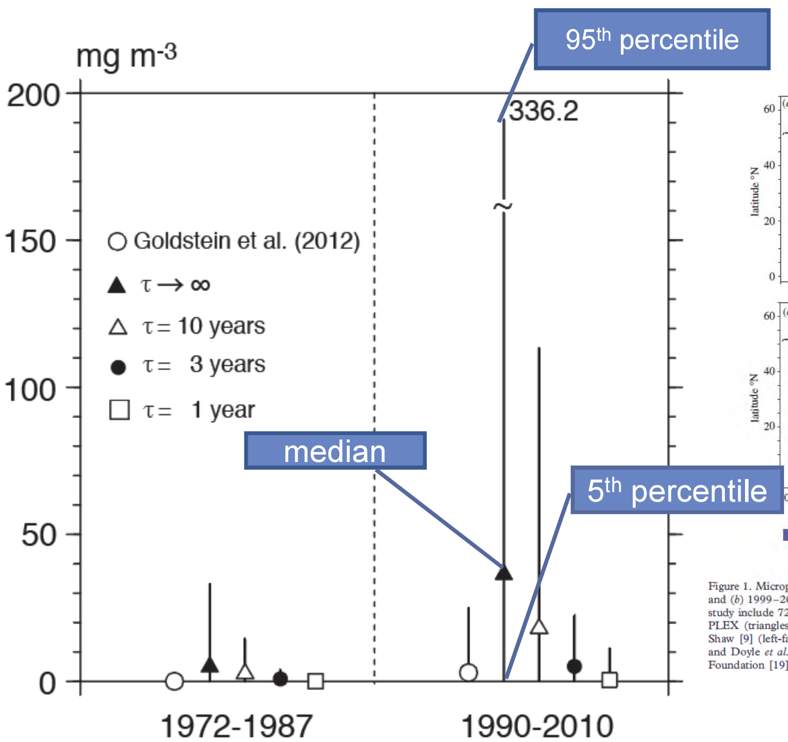
$$C_0 10^{\alpha\phi}$$

$$C_0 = 0.02 \text{ pieces m}^{-3}$$

$$\alpha = 0.0072 \text{ degree}^{-1}$$

α computed using τ<1 year overestimates the north-south gradient of microplastic abundance.

Comparison with Goldstein et al. (2012)'s historical data for microplastic concentration (mg/m³) in the upper ocean



Goldstein et al., (2012)

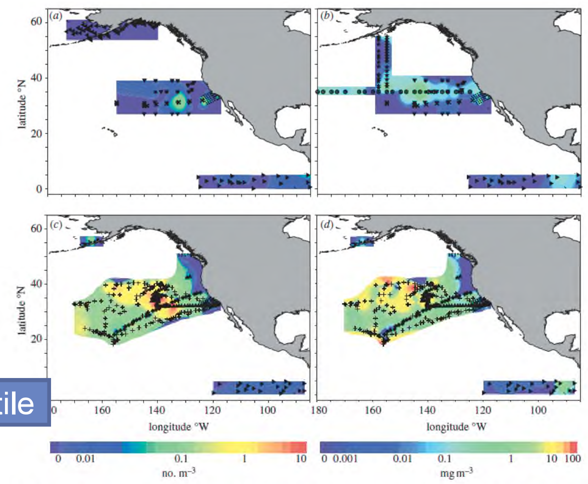
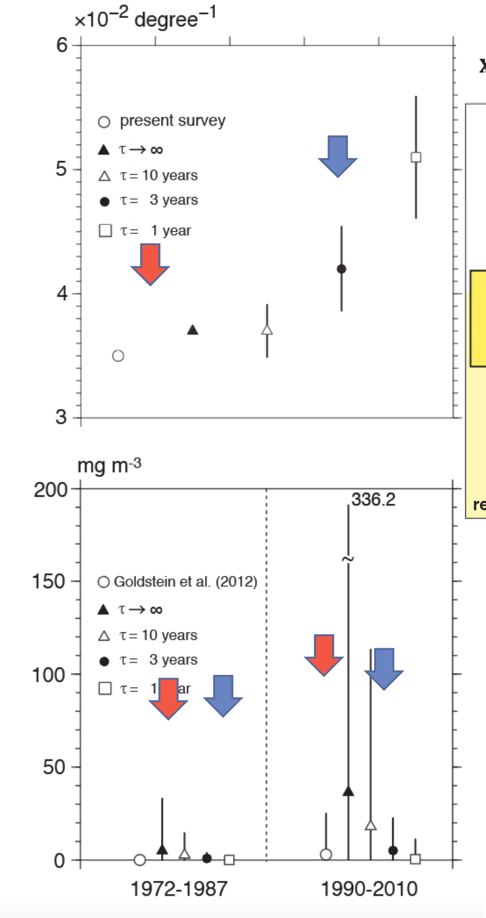


Figure 1. Microplastic concentrations in 1972–1987 and 1999–2010. Numerical concentration (no. m−3) for (a) 1972–1987 and (b) 1999–2010; microplastic mass concentration (mg m−3) for (c) 1972–1987 and (d) 1999–2010. New data from this study include 7205 (asterisks), 7210 (inverted triangles), Southtow 13 (cross symbols), STAR (right-facing triangles), SEAPLEX (triangles) and EX1006 (diamonds). Published data are Wong et al. [7] (crossed circles), Shaw [8] (stars), Day & Shaw [9] (left-facing triangles), Gilfillan et al. [10] (filled circles) and Doyle et al. [11] (filled circles). Gilfillan et al. [10] and Doyle et al. [11] have overlapping stations. Non-peer-reviewed publicly available data from Algalita Marine Research Foundation [19] (plus symbols).

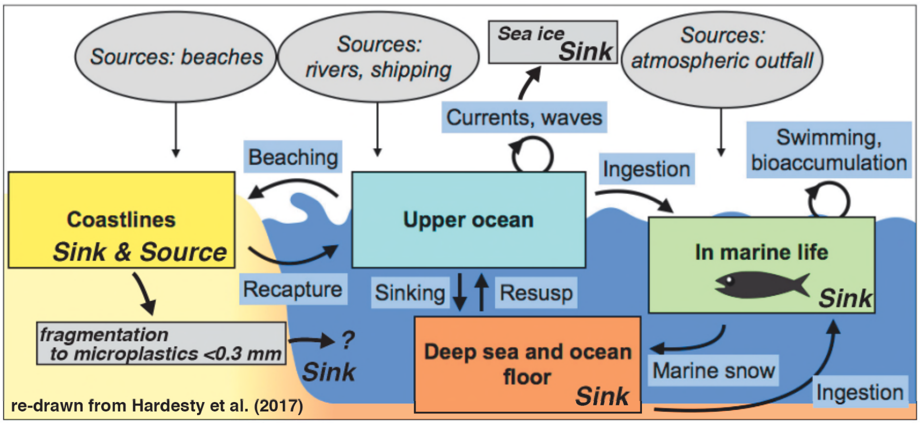
τ >10 years overestimates the increasing rate of microplastic abundance observed by Goldstein et al. (2012)

We assumed that pelagic microplastics (0.3 mm < δ < 5 mm) in the upper layer removed on the timescale of 3 years



$$\mathbf{X}(t+\Delta t) = \mathbf{X}(t) + \mathbf{U}\Delta t + \frac{1}{2}\left(\mathbf{U}\cdot\nabla_H\mathbf{U} + \frac{\partial \mathbf{U}}{\partial t}\right)\Delta t^2 + R\sqrt{2K_h\Delta t}(\mathbf{i},\mathbf{j}) - \gamma$$

sink term



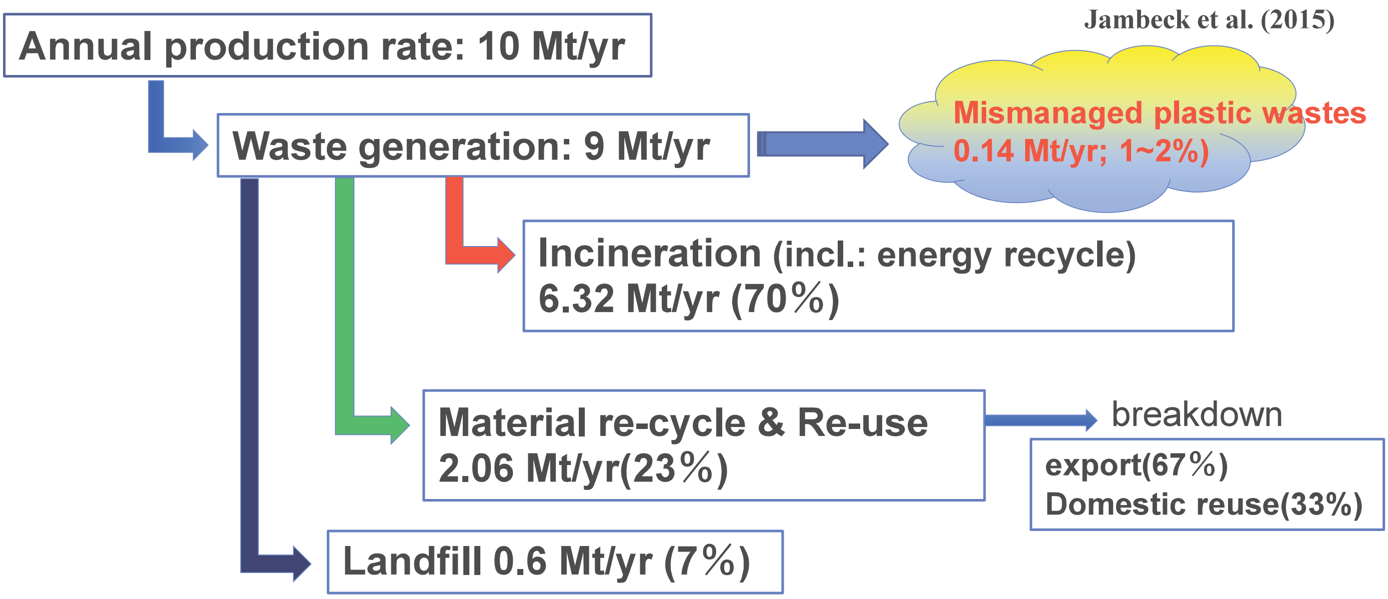
The computation was conducted from 1957 to 2066 with the removal timescale of 3 years.

The removal processes with the timescale of 3 years are unknown, probably including fragmentation into undetectable tiny microplastics, settling onto seafloor, absorbing into marine biota, absorbing into sandy beaches, etc.

Sources of microplastics

Plastic waste flow in Japan

(Plastic waste management Institute, 2017)



- Recycle and/or reuse of plastic wastes in Japan face the upper limit.
- Nonetheless, Japan still generates 0.14 Mt/yr of mismanaged plastic wastes
- In general, remining 1~2 % is very difficult to remove.
- Prioritized should not be recycle & reuse of plastics, but reduce of the plastics in the society.
- However, we have to note that plastics is not luxury materials only for rich people in wealthy class, but for relatively poor people.
- Rapid reduction of plastics may lead to other risks in the society.
- “Sustainable reduction” in line with scientific evidence is required.

Lesson from Japan case

SATREPS PROGRAM SPONCERED BY JST/JICA
FY2019(build-up), 2020~2014

Formation of a center of excellence for marine plastic pollution studies in the Southeast Asian seas

PI: Prof. Atsuhiko Isobe, Research Institute for Applied Mechanics

PI in Thailand： Prof. Voranop Viyakarn, Chulalomgkorn Univ.

Research activities	Build -up	Year 1	Year 2	Year 3	Year 4	Year 5
1st Step (Sattahip project)	Planning of field works	Analyses for generation & route of plastic wastes, monitoring on beaches, coral reefs, estuaries, marine organisms & POPs			**Prototype of Action plan and improvement**	—
2nd Step (Development over Thailand)	Planning of field works	Monitoring in Gulf of Thailand, numerical modeling	Analyses for generation & route of plastic wastes, monitoring on beaches, coral reefs, estuaries, marine organisms & POPs			**●Action plan to combat marine plastic litter in Thailand ●Establishment the Center of Excellence**
3rd Step (Development over ASEAN countries)	—	—	Exchange the knowledge among ASEAN researchers, support of monitoring design in ASEAN countries, training of monitoring			Symposium "Marine plastic pollution in ASEAN regions" on T/V UMITAKA-maru
capacity development	—	Training and PhD students in Japan, public awareness in Thailand	Training and PhD students in Japan, public awareness in Thailand	Training and PhD students in Japan, public awareness in Thailand	Training and PhD students in Japan, public awareness in Thailand	Training and PhD students in Japan, public awareness in Thailand

Samae-San Island (2018/10)