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Supplementary information

An inshore–offshore sorting system revealed from global classification of ocean litter

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Supplementary Materials for

An Inshore-Offshore Sorting System revealed from Global Classification of Ocean Litter

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This PDF file includes:

- **Supplementary methods: Setting uncertainty and bias in the counting**
- **Supplementary Table 1**
- **Supplementary Figs. 1 to 8**
- **Supplementary References**

Other Supplementary Materials for this manuscript include the following separate files:

- **Supplementary Table 2 (*Excel file*).** Correspondence between the joint master category list (JML), the detailed mater list (DML) of litter items and the other category lists of litter used for the present analysis. The table links each item type from a particular list to its equivalent in the other lists.
- **Supplementary Table 3 (*Excel file*).** Weighing factors and uncertainty (*CIs*) applied for the specific item category and counting technique method. CIs Uncertainty is shown through lower and upper limits determining the range in which the true value of a measurement likely lies (see Eq. 2).
- **Supplementary Table 4 (*Excel file*).** Material types and potential origin of the items listed in the DML and JML lists.
- **Conversion Tool (*Excel file*).** The tool allows to transform any litter category list to the Joint Master category List "JML" (130 litter categories, 112 excluding fragments and non-identifiable items).

Supplementary Methods:

Setting uncertainty and bias in the counting

Counting methods used here to inventory litter can be categorised into two broad groups, (*i*) on-site those visual counts and video-image counts; and (*ii*) samplings with sieves and nets. Besides, the risk of overlooking and misidentification is especially high for bottle caps (c.a. 3 cm in diameter) and some short and thin items (*STIs*), namely lolly and cotton bud sticks (c.a. 8 cm in length; c.a. 0.2 cm in diameter), stirrers and straws (> 10 cm in length; ≥ 0.5 cm in diameter) and fishing threads (> 10 cm; c.a. 0.1 cm in diameter). The setting of $\delta^{l,e,t}$ and $\omega^{l,e,t}$ for these difficult-to-detect items was based on previous studies dealing with the ability of the observers to count small objects [1] and with the retention efficiency of meshes [2].

i) On-site visual counts and video-image counts: Small macrolitter items (few centimeters in size) are sometimes difficult to observe, in a similar way as small microplastics (few millimeters and smaller) can be misidentified under a stereomicroscope. With the participation of 12 research teams from around the world, Isobe et al.[1] evaluated the uncertainty in the visual detection of microplastics in natural samples. Relative uncertainty was estimated for microplastic sizes ranging from 0.3 to 5 mm, showing both false recognition and overlooking throughout the entire size interval. On average, plastic items were underestimated by 5% ($\omega^{l,e,t}$ = 1.053) with an uncertainty ($\delta^{l,e,t}$) of ±20%. These statistics were extrapolated to difficult-to-observe items (i.e., bottle caps and *STIs*) in visual surveys, including video monitoring of seafloors as well as counts from elevated positions, in both rivers and ocean surface. In contrast, we used uncorrected counts when provided by divers or by beach surveys due to the better observing conditions and possibility for collecting and verifying controversial items.

Sediment burial or biota-covered surfaces can impede the visual detection of a fraction of the litter deposited on the seafloors. Nevertheless, we assume that litter composition observed in the surveys do represent the recent litter supply, and therefore $\omega^{l,e,t}$ related to biofouling and/or burial was not applied.

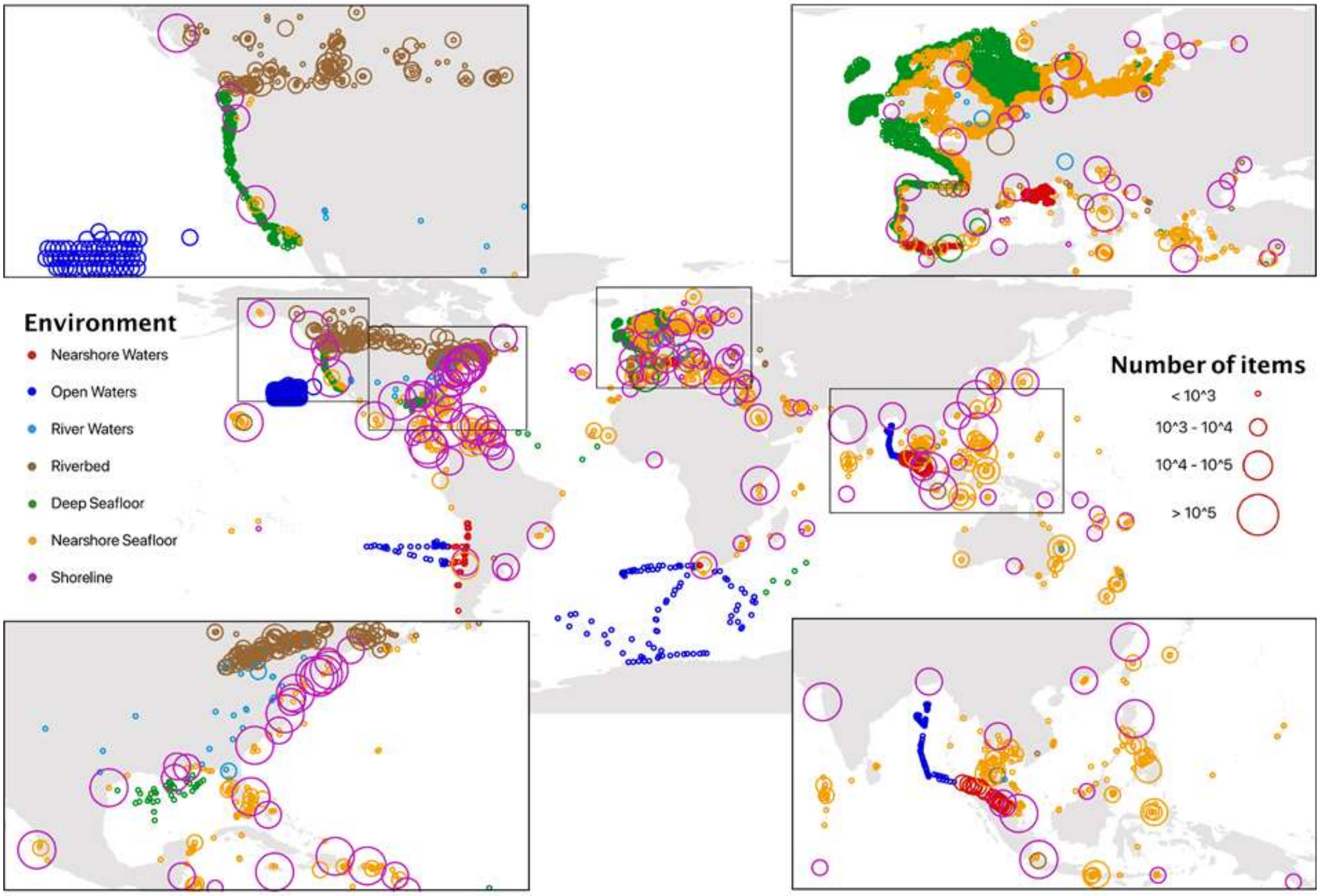
ii) Samplings with sieves and nets: Mesh apertures set the size threshold for items collected by sieves and nets. They are generally square-shaped. While the aperture size typically refers to the length of the side of the square and minimum size to be sampled, the diagonal of the square represents the operative lower size limit for the objects that will be efficiently retained by the net. Therefore, small bottle caps (c.a. 3 cm in diameter) must be efficiently sampled with mesh apertures ≤ 2 cm. In meshes with apertures of 2.5 cm, bottle caps could pass through the net since their size ranges from the square side length to the diagonal of the aperture (3.5 cm). Similarly, *STIs* such as straws, lolly and bud sticks or threads may be missed when their diameter is shorter than the mesh aperture.

Lares et al.[2] quantified the losses from meshes for a range of particle sizes and shapes (i.e., rounded and elongated). On the basis of this study, we applied a $\omega^{l,e,t}$ = 1.20 with $\delta^{l,e,t}$= ±8% to bottle caps sampled with mesh apertures of 2.5 cm, mainly used in nearshore and open waters. Bottle caps are mainly lost from the net tows with mesh apertures wider than 3 cm. These net tows just comprising 9% of the total tows in the deep seafloor and 12% of the nearshore ones, were discarded for computing the share of this particular item. Lares et al. also estimated the losses of *STIs* with diameter:length ratio from 1:30 to 1:300. On the basis that mesh apertures in the litter surveys were one order of magnitude wider than the diameter of the *STIs*, we applied a $\omega^{l,e,t}$ = 1.10 with $\delta^{l,e,t}$= ±10% for rigid *STIs* (i.e., straws, lolly and bud sticks), and a $\omega^{l,e,t}$ = 1.26 with $\delta^{l,e,t}$= ±25% for flexible *STIs* (i.e., strings and fishing threads).

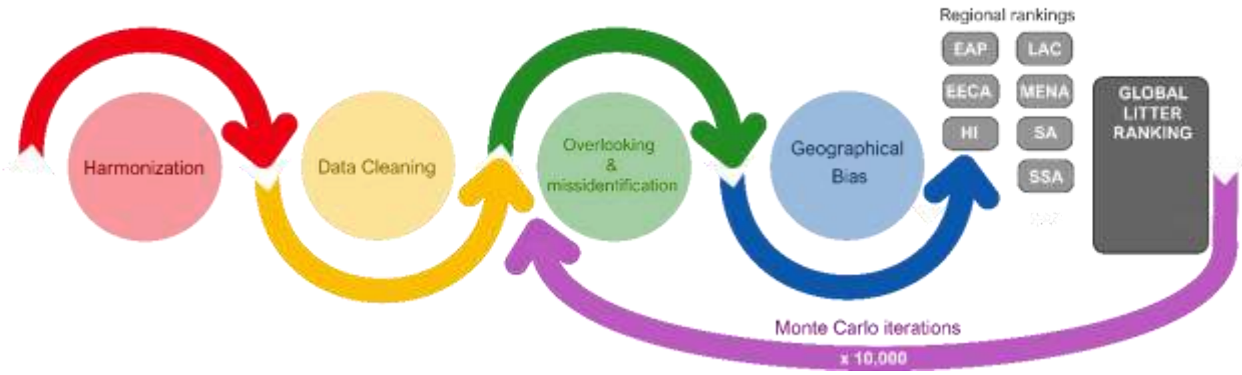
To loosely deal with the possible uncertainties due to the detectability of the items, we applied an additional increase of 20% to the relative uncertainty of all 112 litter categories in the JML List. In the case of the difficult-to-detect items (bottle caps and *STIs*), the above-mentioned uncertainties were further expanded by adding 20%. The end result was that $\delta^{l,e,t}$ ranged from a minimum of ±20% up to ±45% (Table S3).

Supplementary Table 1. Environments and data sources assembled for the present study. Samplings in onshore and nearshore environments are associated to seven socio-economic regions comprising High Income region (HI), East Europe and Central Asia (EECA), South Asia (SA), East Asia and Pacific (EAP), Latin America and Caribbean (LAC), Middle East and North Africa (MENA), and Sub-Saharan Africa (SSA)[3] while offshore samplings are associated to Atlantic (AO), Pacific (PO), Indian (IO), Mediterranean (MS), Southern Ocean (SO), Black Sea (BS) and the Caribbean (C). The number in brackets in the "Total items" column refers to the identifiable objects out of the total count.

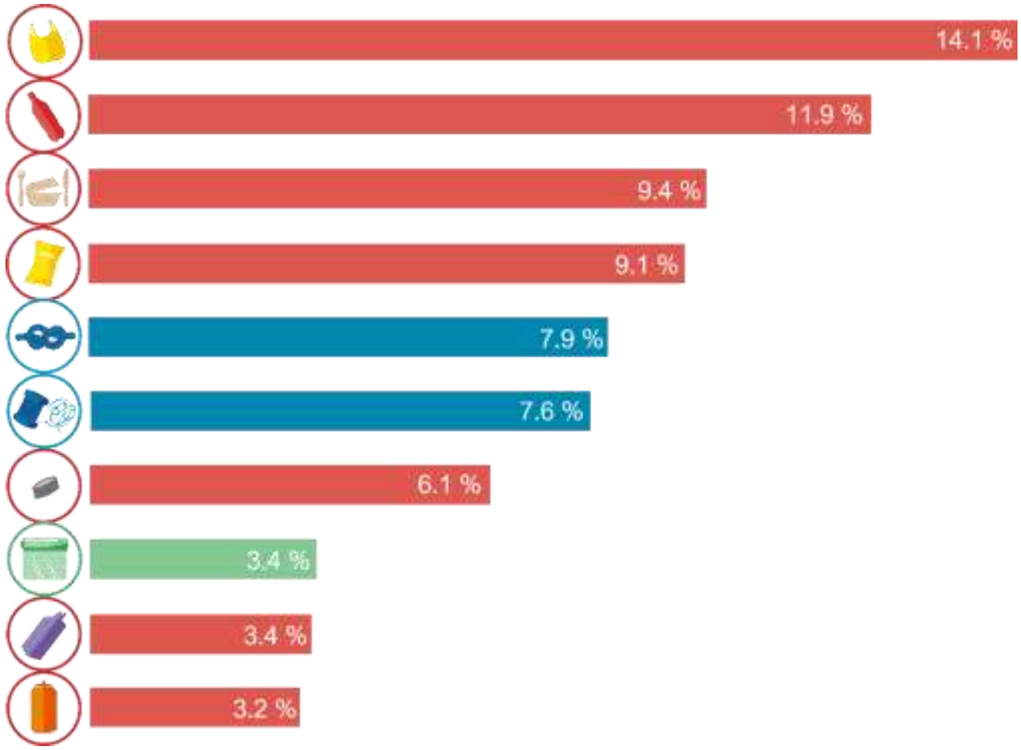
Environment	Methods	World Regions	Total items	Sources
River waters	Floating barriers, retention booms, stationary-point visual census on surface waters, and census of stranded litter in river banks	HI, EECA, EAP	1,950,571	Gasperi et al. (2014)[4] Carson et al. (2013)[5] IHA (2017)[6]: González-Fernández et al (2018)[7] Marine and Coastal Resources Research and Development Institute Department of Marine and Coastal Resources, Bangkok, THAILAND[8] Blettler et al. (2017)[9] Van Emmerik et al.(2018)[10] (2019)[11] This study [12]
Riverbed	Visual census by diving, and nets anchored to river bed	EAP, EECA, HI, MENA,	25,386	Morrit et al. (2014)[13] Project AWARE®, Dive Against Debris (2018)[14]
Shoreline	Beach cleanups carried out by Ocean Conservancy in 2010 and Marine Litter Watch between 2013 and 2018.	EAP, EECA, HI, LAC, MENA, SA, SSA	9,864,628	Ocean Conservancy (2011)[15] Marine Litter Watch [16]
Nearshore waters (< 100 km from shoreline)	Surface trawling macro -nets and strip-transect visual census from vessels.	HI, LAC, SA, SSA	13,153	Thiel et al. (2003)[17] Ryan (2013)[18] Ryan et al. (2014)[19] Thiel et al. (2018)[20] This study[21–26]
Open waters (> 100 km from shoreline)	Surface trawling macro -nets, and strip-transect visual census from vessels.	PO, IO, AO, SO	4,788	Ryan (2014)[27] Ryan (2013)[18] Lebreton et al. (2018)[28] Thiel et al. (2018)[20]
Nearshore seafloor (< 100 m depth, < 100 km from shoreline)	Scuba divers and bottom trawling nets.	EAP, EECA, HI, LAC, MENA, SA, SSA	694,947	Project AWARE®, Dive Against Debris (2018)[14] Sánchez et al. (2013)[29] Ioakeimidis et al. (2014)[30] Kuriyama et al. (2003)[31] OSPAR[32] ICES[33]
Deep seafloor (> 100 m depth, < 100 km from shoreline)	Video camera and bottom trawling nets	AO, PO, MS, BS, C.	75,728	García-Rivera et al. (2017)[34] Debrot et al. (2014)[35] Wei et al. (2012)[36] Ioakeimidis et al. (2014)[30] Keller et al. (2010)[37] OSPAR[32] ICES[33] This study[38] Woodall et al. (2015)[39]



Supplementary Fig. 1. Global distribution of the data sources compiled in the present study. The circles show the locations of sampling sites. The color of the circles relates to the types of environments sampled, while their size represents the number of items retrieved from each sampling site (see legend). The four regions with the highest sample density are framed and zoomed in.

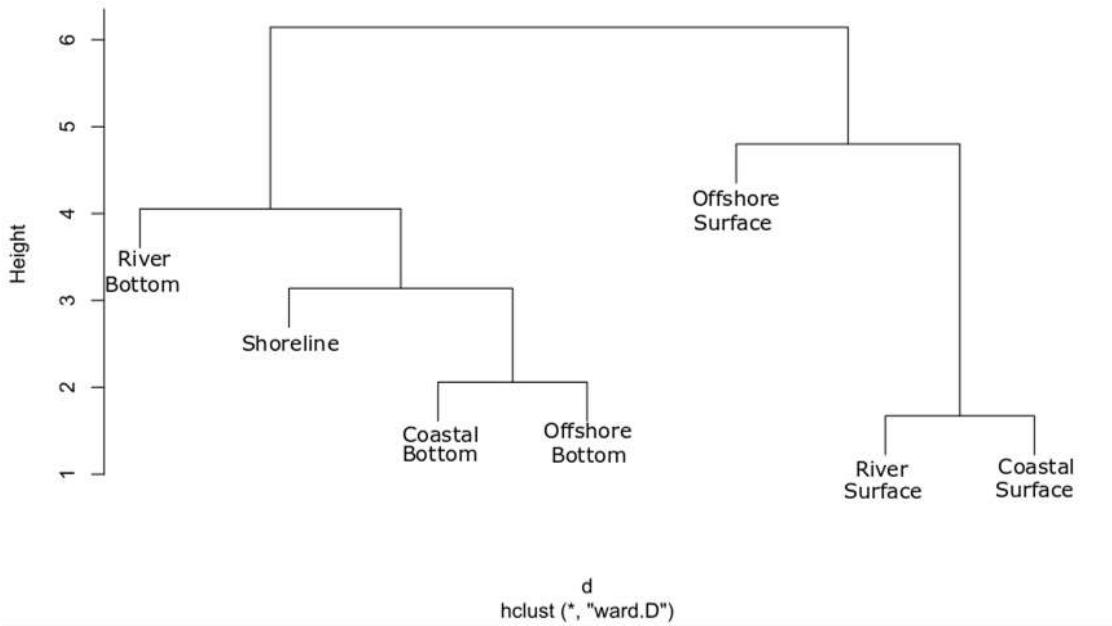


Supplementary Fig. 2. Workflow diagram through the steps of the standardization process of data sources. (Red) Harmonization of the different category lists of litter items into a joint master litter category list (JML, Table S2). (Yellow) Data cleaning by removal of small and non-identifiable items. (Green) Accounting for the overlooking and misidentification of items by applying weighting factors ($\omega^{l,e,t}$) and relative uncertainties ($\delta^{l,e,t}$) (Table S3). (Blue) Accounting for the geographical bias in the samplings through the pooling of litter counts into seven world socioeconomic regions to derive a global litter ranking. (Purple) Monte Carlo iterations (10,000 runs per environment cf. Methods).

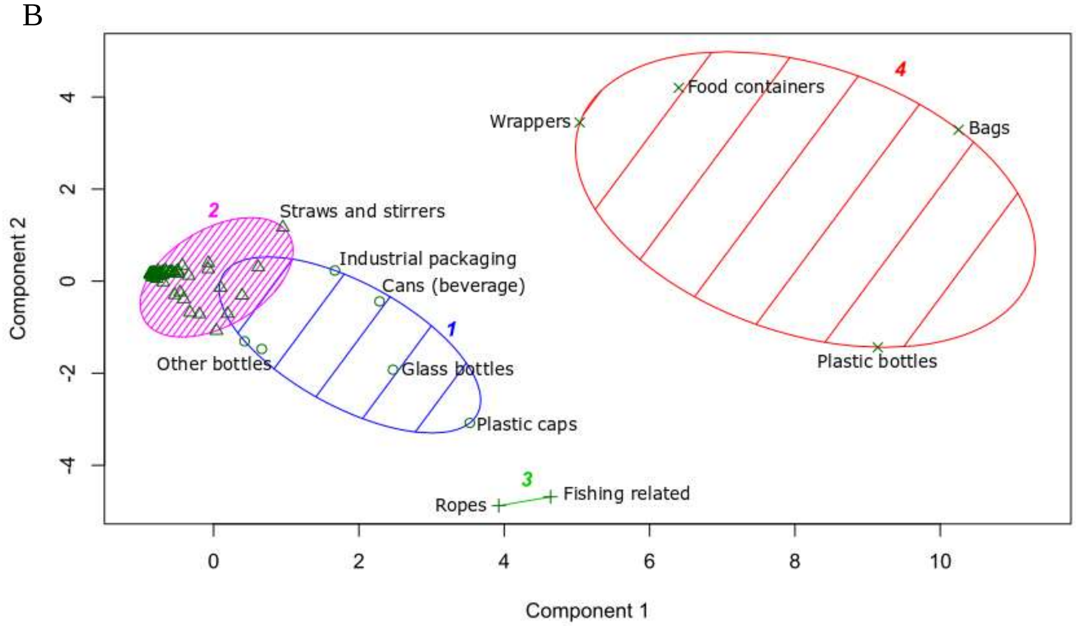


Supplementary Fig. 3. Top 10 litter items across seven aquatic ecosystems globally. In decreasing order: Bags, plastic bottles, food containers and cutlery, wrappers, synthetic rope, fishing related, plastic caps and lids, strapping bands and industrial packaging, glass bottles and cans (beverage). The colours of the bars correspond to take-out/consumer (red), ocean & waterway (blue) and industrial & household (green) origins.

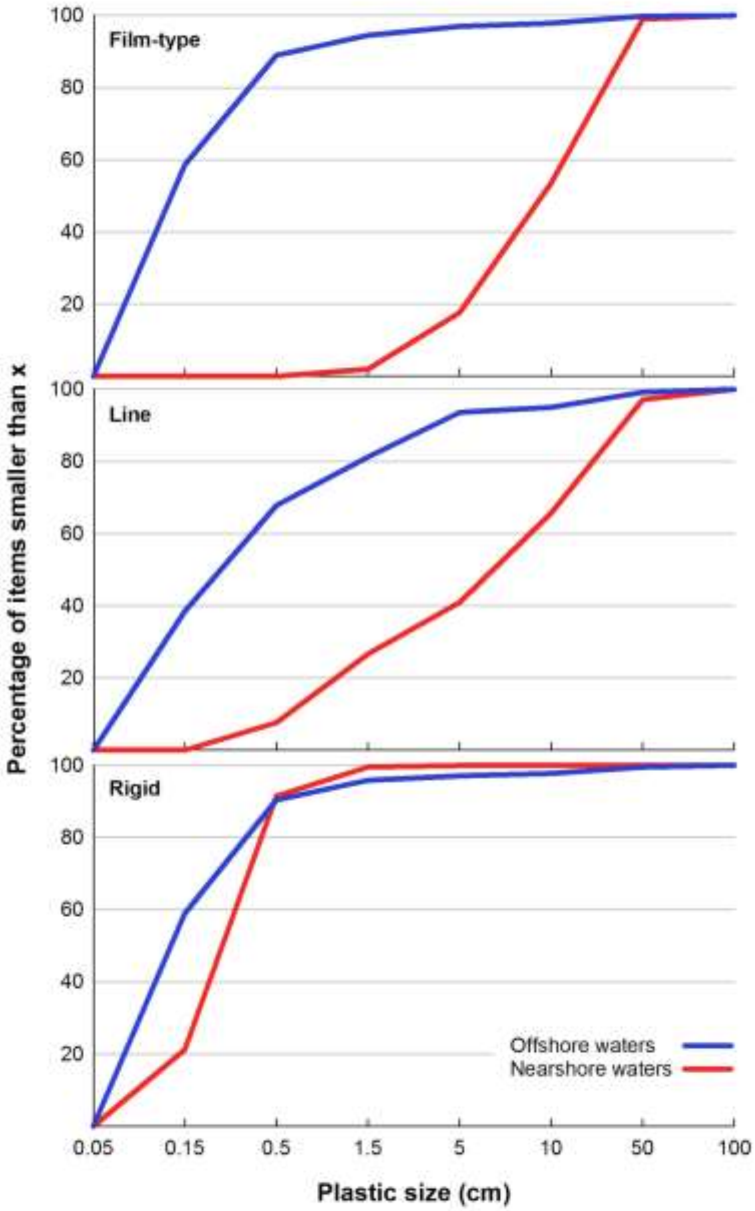
A



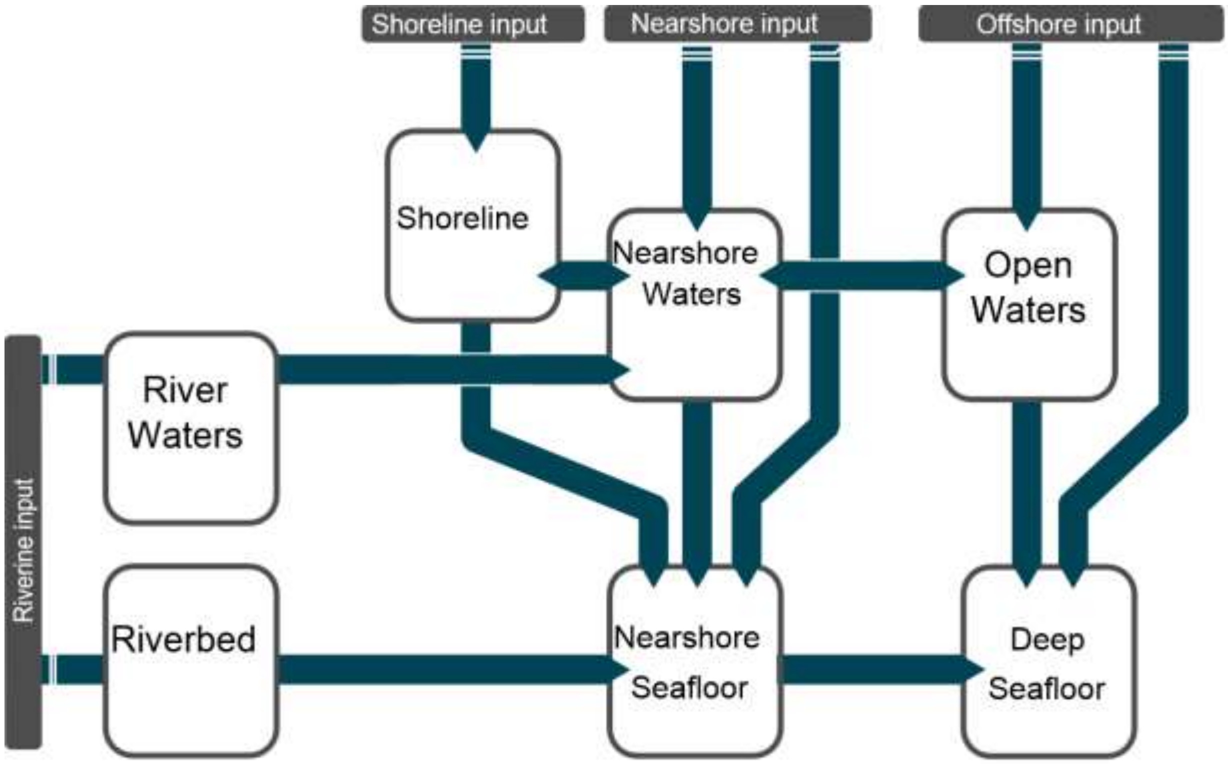
B



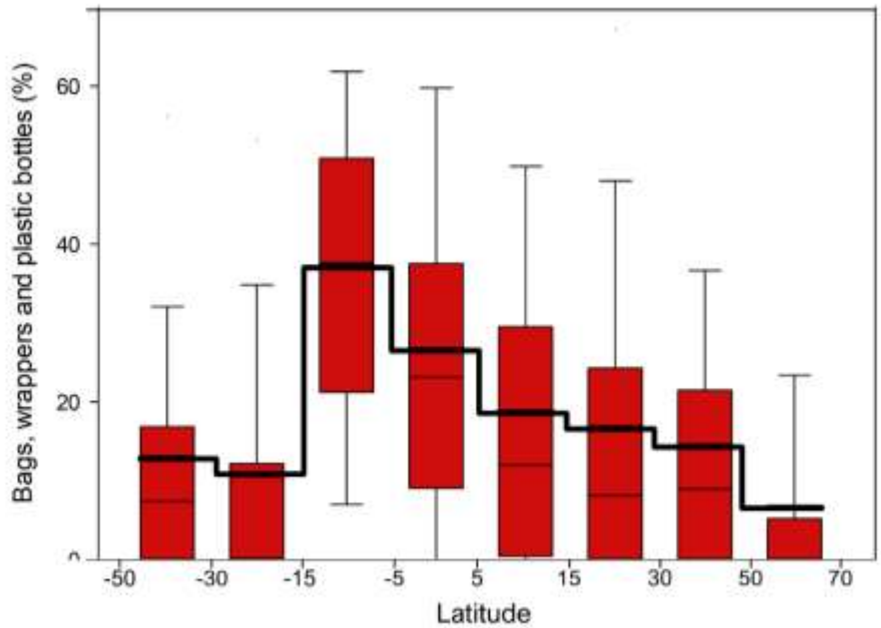
Supplementary Fig. 4. Cluster analysis of litter composition per environment. (A) Cluster analysis overviewing the level of similarity between the seven global environments based on the litter composition of each environment. (B) Clustplot grouping litter from the seven environments into four clusters, defined by two components explain 74.3% of the variability. Clusters are numbered 1 to 4.

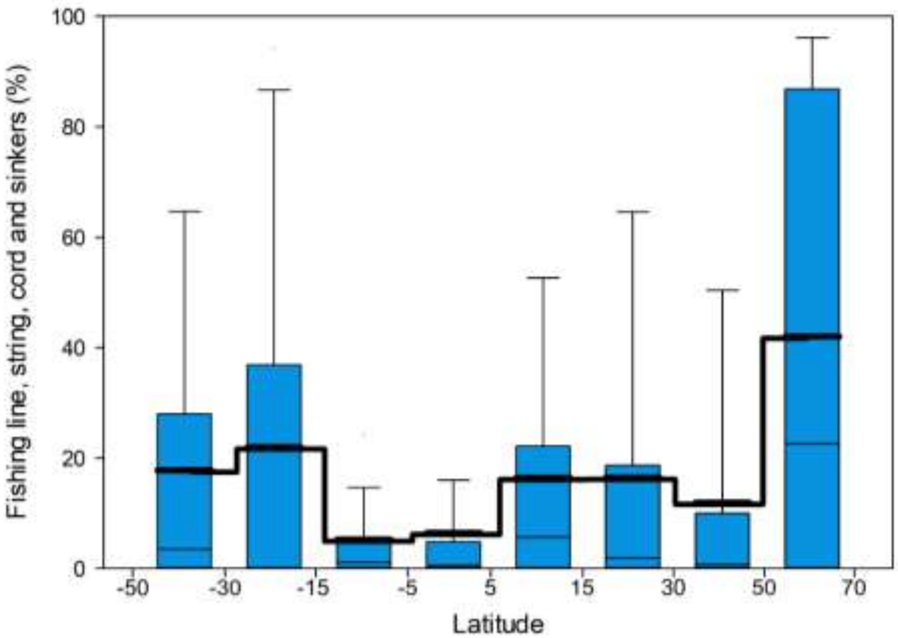


Supplementary Fig. 5. Cumulative frequency distributions describing the size distribution of floating plastics in nearshore and offshore waters. The three types of plastics considered, film-type, line and rigid items, showed statistical different distributions in nearshore and offshore waters (df = 6; p < 2.2e-16 for all plastic types; χ^2 = 18470, 662 and 29060 for film-type, line and rigid plastic, respectively). Cumulative frequency distributions followed logistic cumulative density function in coastal waters and Pareto-shaped distribution in open ocean. Samples of plastics in nearshore and offshore waters are shown in Fig. 3.

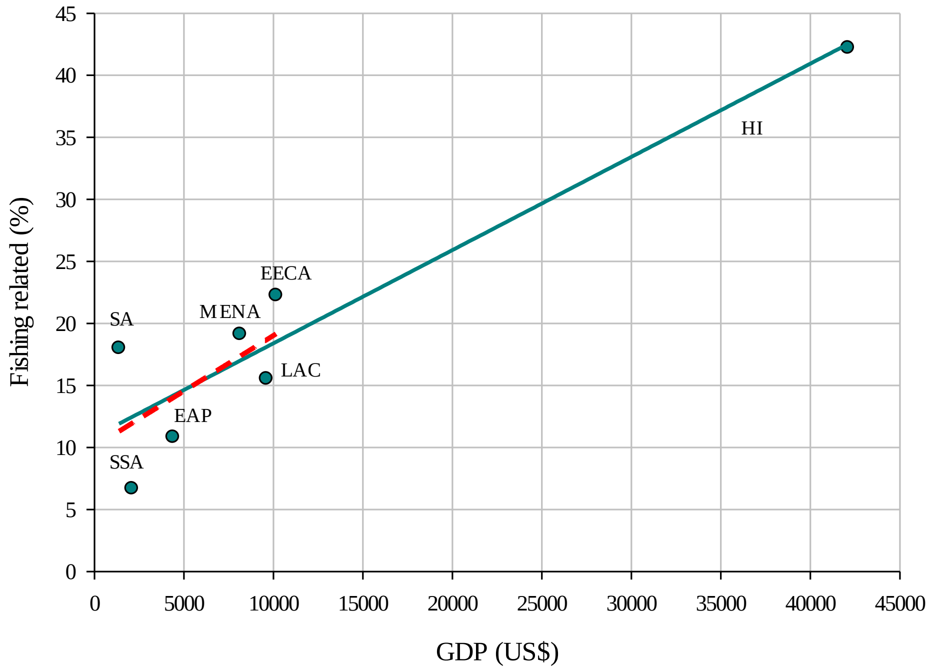


Supplementary Fig. 6. Generic diagram of potential flow paths of litter between environments. All potential flows were assumed to be unidirectional with the exception of those connecting shoreline, nearshore waters, and open waters.





Supplementary Fig. 7. Proportion of main take-out and fishing-related items per latitude. Take-out single-used items comprise bags, wrappers and plastic bottles, while fishing related items mainly include synthetic ropes, strings, cords, threads and nets. Whisker-box plots show the variability found in the nearshore-seafloor samples grouped by ranges of latitude at global scale. Black step line in each graph indicates the averaged percentage.



Supplementary Fig. 8. Proportion of fishing related items in the nearshore seafloors of the seven major socioeconomic regions versus the regional Gross Domestic Product (GDP constant 2010 US$). Blue line corresponds to the linear least-square fitting (*Fishing-related items* (%) = 10.8793 + 0.0008 * GDP (US$), n = 7, R^2 = 0.86, p = 0.0025). Red dashed line is the result or removing HI region from the fitting (*Fishing-related items* (%) = 10.0708 + 0.0009 *GDP (US$), n = 7, R^2 = 0.36, p = 0.2076). GDP per region was computed by using national GDP constant 2010 US$ averaged for the years 2010-2016 weighted by national coastal population**.**

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