

Microplastics in seawater: sampling strategies, laboratory methodologies, and identification techniques applied to port environment

Environmental Science and Pollution Research

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Online Resource 1 Complete list of the 74 reviewed research articles

[1] Abayomi OA, Range P, Al-Ghouti MA, Obbard JP, Almeer SH, Ben-Hamadou R (2017)

Microplastics in coastal environments of the Arabian Gulf. *Mar Pollut Bull* 124:181–188.

<http://dx.doi.org/10.1016/j.marpolbul.2017.07.011>

[2] Aytan U, Valente A, Senturk Y, Usta R, Sahin FBE, Mazlum RE, Agirbas E (2016) First evaluation of neustonic microplastics in Black Sea waters. *Mar Environ Res* 119:22–30.

<http://dx.doi.org/10.1016/j.marenvres.2016.05.009>

[3] Bagaev A, Khatmullina L, Chubarenko I (2018) Anthropogenic microlitter in the Baltic Sea water column. *Mar Pollut Bull* 129:918–923. <http://dx.doi.org/10.1016/j.marpolbul.2017.10.049>

[4] Baini M, Fossi MC, Galli M, Caliani I, Campani T, Finoia G, Panti C (2018) Abundance and characterization of microplastics in the coastal waters of Tuscany (Italy): the application of the MSFD monitoring protocol in the Mediterranean Sea. *Mar Pollut Bull* 133:543–552.

<https://doi.org/10.1016/j.marpolbul.2018.06.016>

[5] Barrows APW, Neumann CA, Berger ML, Shaw SD (2017) Grab vs. neuston tow net: a microplastic sampling performance comparison and possible advances in the field. *Anal Methods-UK* 9:1446. doi:10.1039/c6ay02387h

[6] Beer S, Garm A, Huwer B, Dierking J, Nielsen TG (2018) No increase in marine microplastic concentration over the last three decades – a case study from the Baltic Sea. *Sci Total Environ* 621:1272–1279. <https://doi.org/10.1016/j.scitotenv.2017.10.101>

[7] Bimali Koongolla J, Andrady AL, Terney Pradeep Kumara PB, Gangabadage CS (2018) Evidence of microplastics pollution in coastal beaches and waters in southern Sri Lanka. *Mar Pollut Bull* 137:277–284. <https://doi.org/10.1016/j.marpolbul.2018.10.031>

[8] Brandon J, Goldstein M, Ohman MD (2016) Long-term aging and degradation of microplastic particles: comparing in situ oceanic and experimental weathering patterns. *Mar Pollut Bull* 110:299–308. <http://dx.doi.org/10.1016/j.marpolbul.2016.06.048>

[9] Cai M, He H, Liu M, Li S, Tang G, Wang W, Huang P, Wei G, Lin Y, Chen B, Hu J, Cen Z (2018) Lost but can't be neglected: huge quantities of small microplastics hide in the South China Sea. *Sci Total Environ* 633:1206–1216. <https://doi.org/10.1016/j.scitotenv.2018.03.197>

[10] Castillo AB, Al-Maslamani I, Obbard JP (2016) Prevalence of microplastics in the marine waters of Qatar. *Mar Pollut Bull* 111:260–267. <http://dx.doi.org/10.1016/j.marpolbul.2016.06.108>

[11] Castro RO, Silva ML, Marques MRC, de Araújo FV (2016) Evaluation of microplastics in Jurujuba Cove, Niterói, RJ, Brazil, an area of mussels farming. *Mar Pollut Bull* 110:555–558. <http://dx.doi.org/10.1016/j.marpolbul.2016.05.037>

[12] Cincinelli A, Scopetani C, Chelazzi D, Lombardini E, Martellini T, Katsoyiannis A, Fossi MC, Corsolini S (2017) Microplastic in the surface waters of Ross Sea (Antarctica): occurrence, distribution and characterization by FTIR. *Chemosphere* 175:391–400. <http://dx.doi.org/10.1016/j.chemosphere.2017.02.024>

[13] Cole M, Webb H, Lindeque PK, Fileman ES, Halsband C, Galloway TS (2014) Isolation of microplastics in biota-rich seawater samples and marine organisms. *Sci Rep-UK* 4:4528. doi:10.1038/srep04528

- [14] Collignon A, Hecq J, Galgani F, Collard F, Goffart A (2014) Annual variation in neustonic micro- and meso-plastic particles and zooplankton in the Bay of Calvi (Mediterranean-Corsica). *Mar Pollut Bull* 79:293–298. <http://dx.doi.org/10.1016/j.marpolbul.2013.11.023>
- [15] Collignon A, Hecq JH, Galgani F, Voisin P, Collard F, Goffart A (2012) Neustonic microplastic and zooplankton in the North Western Mediterranean Sea. *Mar Pollut Bull* 64(4):861–864. doi:10.1016/j.marpolbul.2012.01.011
- [16] Dai Z, Zhang H, Zhou Q, Tian Y, Chen T, Tu C, Fu C, Luo Y (2018) Occurrence of microplastics in the water column and sediment in an inland sea affected by intensive anthropogenic activities. *Environ Pollut* 242:1557–1565. <https://doi.org/10.1016/j.envpol.2018.07.131>
- [17] de Lucia GA, Caliani I, Marra S, Camedda A, Coppa S, Alcaro L, Campani T, Giannetti M, Coppola D, Cicero AM, Panti C, Bainsi M, Guerranti C, Marsili L, Massaro G, Fossi MC, Matiddi M (2014) Amount and distribution of neustonic micro-plastic off the western Sardinian coast (Central-Western Mediterranean Sea). *Mar Environ Res* 100:10–16. <http://dx.doi.org/10.1016/j.marenvres.2014.03.017>
- [18] Desforges JPW, Galbraith M, Dangerfield N, Ross PS (2014) Widespread distribution of microplastics in subsurface seawater in the NE Pacific Ocean. *Mar Pollut Bull* 79:94–99. <http://dx.doi.org/10.1016/j.marpolbul.2013.12.035>
- [19] Dubaish F, Liebezeit G (2013) Suspended microplastics and black carbon particles in the Jade system, Southern North Sea. *Water Air Soil Poll* 224(2):1–8. doi:10.1007/s11270-012-1352-9
- [20] Edson E, Patterson M (2015) MantaRay: a novel autonomous microplastic sensor for determining particle concentrations in marine ecosystems. Research, Innovation and Scholarship Expo. Category: Engineering and Technology. Abstract ID# 580. Boston (MA; USA)
- [21] Enders K, Lenz R, Stedmon CA, Nielsen TG (2015). Abundance, size and polymer composition of marine microplastics $\geq 10 \mu\text{m}$ in the Atlantic Ocean and their modelled vertical distribution. *Mar Pollut Bull* 100:70–81. <http://dx.doi.org/10.1016/j.marpolbul.2015.09.027>
- [22] Eriksen M, Liboiron M, Kiessling T, Charron L, Alling A, Lebreton L, Richards H, Roth B, Ory NC, Hidalgo-Ruz V, Meerhoff E, Box C, Cummins A, Thiel M (2018) Microplastic sampling with the AVANI trawl compared to two neuston trawls in the Bay of Bengal and South Pacific. *Mar Pollut Bull* 232:430–439. <https://doi.org/10.1016/j.envpol.2017.09.058>

- [23] Erni-Cassola G, Gibson MI, Thompson RC, Christie-Oleza JA (2017) Lost, but found with Nile Red: a novel method for detecting and quantifying small microplastics (1 mm to 20 μ m) in environmental samples. *Environ Sci Technol* 51:13641–13648. doi:10.1021/acs.est.7b04512
- [24] Faur F, Saini C, Potter G, Galgani F, De Alencastro LF, Hagmann P (2015) An evaluation of surface micro- and mesoplastic pollution in pelagic ecosystems of the Western Mediterranean Sea. *Environ Sci Pollut Res* 22(16):12190–12197. <http://dx.doi.org/10.1007/s11356-015-4453-3>
- [25] Figueiredo GM, Vianna TMP (2018) Suspended microplastics in a highly polluted bay: abundance, size, and availability for mesozooplankton. *Mar Pollut Bull* 135:256–265. <https://doi.org/10.1016/j.marpolbul.2018.07.020>
- [26] Frère L, Paul-Pont I, Moreau J, Soudant P, Lambert C, Huvet A, Rinnert E (2016) A semi-automated Raman micro-spectroscopy method for morphological and chemical characterizations of microplastic litter. *Mar Pollut Bull* 113:461–468. <http://dx.doi.org/10.1016/j.marpolbul.2016.10.051>
- [27] Frias JPGL, Otero V, Sobral P (2014) Evidence of microplastics in samples of zooplankton from Portuguese coastal waters. *Mar Environ Res* 95:89–95. <http://dx.doi.org/10.1016/j.marenvres.2014.01.001>
- [28] Gajšt T, Bizjak T, Palatinus A, Liubartseva S, Kržan A (2016) Sea surface microplastics in Slovenian part of the northern Adriatic. *Mar Pollut Bull* 113:392–399. <http://dx.doi.org/10.1016/j.marpolbul.2016.10.031>
- [29] Gallagher A, Rees A, Rowe R, Stevens J, Wright P (2016) Microplastics in the Solent estuarine complex, UK: an initial assessment. *Mar Pollut Bull* 102:243–249. <http://dx.doi.org/10.1016/j.marpolbul.2015.04.002>
- [30] Gorokhova E (2015) Screening for microplastic particles in plankton samples: how to integrate marine litter assessment into existing monitoring programs? *Mar Pollut Bull* 99:271–275. <http://dx.doi.org/10.1016/j.marpolbul.2015.07.056>
- [31] Green DS, Kregting L, Boots B, Blockley DJ, Brickle P, da Costa M, Crowley Q (2018) A comparison of sampling methods for seawater microplastics and a first report of the microplastic litter in coastal waters of Ascension and Falkland Islands. *Mar Pollut Bull* 137:695–701. <https://doi.org/10.1016/j.marpolbul.2018.11.004>

- [32] Güven O, Gökdağ K, Jovanović B, Kıdeyş AE (2017) Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish. *Environ Pollut* 223:286–294. <http://dx.doi.org/10.1016/j.envpol.2017.01.025>
- [33] Hall NM, Berry KLE, Rintoul L, Hoogenboom MO (2015) Microplastic ingestion by scleractinian corals. *Mar Biol* 162(3):725–732. doi:10.1007/s00227-015-2619-7
- [34] Isobe A (2016) Percentage of microbeads in pelagic microplastics within Japanese coastal waters. *Mar Pollut Bull* 110:432–437. <http://dx.doi.org/10.1016/j.marpolbul.2016.06.030>
- [35] Isobe A, Uchida K, Tokai T, Iwasaki S (2015) East Asian seas: a hot spot of pelagic microplastics. *Mar Pollut Bull* 101:618–623. <http://dx.doi.org/10.1016/j.marpolbul.2015.10.042>
- [36] Kang JH, Kwon OY, Lee KW, Song YK, Shim WJ (2015) Marine neustonic microplastics around the southeastern coast of Korea. *Mar Pollut Bull* 96:304–312. <http://dx.doi.org/10.1016/j.marpolbul.2015.04.054>
- [37] Kanhai LDK, Gårdfeldt K, Lyashevskaya O, Hassellöv M, Thompson RC, O'Connor I (2018) Microplastics in sub-surface waters of the Arctic Central Basin. *Mar Pollut Bull* 130:8–18. <https://doi.org/10.1016/j.marpolbul.2018.03.011>
- [38] Khalik WMAWM, Ibrahim YS, Anuar ST, Govindasamy S, Baharuddin NF (2018) Microplastics analysis in Malaysian marine waters: a field study of Kuala Nerus and Kuantan. *Mar Pollut Bull* 135:451–457. <https://doi.org/10.1016/j.marpolbul.2018.07.052>
- [39] Kroon F, Motti C, Talbot S, Sobral P, Puotinen M (2018) A workflow for improving estimates of microplastic contamination in marine waters: a case study from North-Western Australia. *Environ Pollut* 238:26–38. <https://doi.org/10.1016/j.envpol.2018.03.010>
- [40] Lenz R, Enders K, Stedmon CA, Mackenzie DMA, Nielsen TG (2015) A critical assessment of visual identification of marine microplastic using Raman spectroscopy for analysis improvement. *Mar Pollut Bull* 100:82–91. <http://dx.doi.org/10.1016/j.marpolbul.2015.09.026>
- [41] Lima ARA, Costa MF, Barletta M (2014) Distribution patterns of microplastics within the plankton of a tropical estuary. *Environ Res* 132:146–155. <http://dx.doi.org/10.1016/j.envres.2014.03.031>

[42] Lusher AL, Burke A, O'Connor I, Officer R (2014) Microplastic pollution in the Northeast Atlantic Ocean: validated and opportunistic sampling. *Mar Pollut Bull* 88(1):325–333.

<http://dx.doi.org/10.1016/j.marpolbul.2014.08.023>

[43] Lusher AL, Tirelli V, O'Connor I, Officer R (2015) Microplastics in Arctic polar waters: the first reported values of particles in surface and sub-surface samples. *Sci Rep-UK* 5:14947. doi:10.1038/srep14947

[44] Maes T, Van der Meulen MD, Devriese LI, Leslie HA, Huvet A, Frère L, Robbens J, Vethaak AD (2017) Microplastic baseline surveys at the water surface and sediments of the North-East Atlantic. *Front Mar Sci* 4:135. doi:10.3389/fmars.2017.00135

[45] Morgana S, Ghigliotti L, Estévez-Calvar N, Stifanese R, Wieckzorek A, Doyle T, Christiansen JS, Faimali M, Garaventa F (2018) Microplastics in the Arctic: a case study with sub-surface water and fish samples off Northeast Greenland. *Environ Pollut* 242:1078–1086.

<https://doi.org/10.1016/j.envpol.2018.08.001>

[46] Ng KL, Obbard JP (2006) Prevalence of microplastics in Singapore's coastal marine environment. *Mar Pollut Bull* 52:761–767. doi:10.1016/j.marpolbul.2005.11.017

[47] Norén F (2007) Small plastic particles in Coastal Swedish waters. KIMO Report, pp. 11.

[48] Palatinus A, Viršek MK, Kaberi E (2015) DeFishGear protocols for sea surface and beach sediment sampling and sample analysis. pp. 27. <http://mio-ecsde.org/wp-content/uploads/2014/12/Protocols-sea-surfacebeach-sediments-Feb15.pdf>

[49] Pan Z, Guo H, Chen H, Wang S, Sun X, Zou Q, Zhang Y, Lin H, Cai S, Huang J (2019) Microplastics in the Northwestern Pacific: abundance, distribution, and characteristics. *Sci Total Environ* 650:1913–1922. <https://doi.org/10.1016/j.scitotenv.2018.09.244>

[50] Qu X, Su L, Li H, Liang M, Shi H (2018) Assessing the relationship between the abundance and properties of microplastics in water and in mussels. *Sci Total Environ* 621:679–686.

<https://doi.org/10.1016/j.scitotenv.2017.11.284>

[51] Reisser J, Shaw J, Wilcox C, Hardesty BD, Proietti M, Thums M, Pattiaratchi C (2013) Marine plastic pollution in waters around Australia: characteristics, concentrations, and pathways. *PloS One* 8(11). doi: e80466

- [52] Sagawa N, Kawaai K, Hinata H (2018) Abundance and size of microplastics in a coastal sea: comparison among bottom sediment, beach sediment, and surface water. *Mar Pollut Bull* 133:532–542. <https://doi.org/10.1016/j.marpolbul.2018.05.036>
- [53] Saliu F, Montano S, Garavaglia MG, Lasagni M, Seveso D, Galli P (2018) Microplastic and charred microplastic in the Faafu Atoll, Maldives. *Mar Pollut Bull* 136:464–471. <https://doi.org/10.1016/j.marpolbul.2018.09.023>
- [54] Setälä O, Magnusson K, Lehtiniemi M, Norén F (2016) Distribution and abundance of surface water microlitter in the Baltic Sea: a comparison of two sampling methods. *Mar Pollut Bull* 110(1):177–183. <http://dx.doi.org/10.1016/j.marpolbul.2016.06.065>
- [55] Shim WJ, Song YK, Hong SH, Jang M (2016) Identification and quantification of microplastics using Nile Red staining. *Mar Pollut Bull* 113:469–476. <http://dx.doi.org/10.1016/j.marpolbul.2016.10.049>
- [56] Song YK, Hong SH, Jang M, Kang JH, Kwon OY, Han GM, Shim WJ (2014) Large accumulation of micro-sized synthetic polymer particles in the sea surface microlayer. *Environ Sci Technol* 48:9014–9021. <http://dx.doi.org/10.1021/es501757s>
- [57] Song YK, Hong SH, Jang M, Han GM, Rani M, Lee J, Shim WJ (2015) A comparison of microscopic and spectroscopic identification methods for analysis of microplastics in environmental samples. *Mar Pollut Bull* 93:202–209. doi:10.1016/j.marpolbul.2015.01.015
- [58] Stöhr R (2016) Microplastic in the Sea. A research approach by One Earth – One Ocean. pp. 13. <https://oneearth-oneocean.com/wp-content/uploads/Microplastic-in-the-sea-report-I.pdf>
- [59] Suaria G, Avio CG, Mineo A, Lattin GL, Magaldi MG, Belmonte G (2016) The Mediterranean plastic soup: synthetic polymers in Mediterranean surface waters. *Sci Rep-UK* 6:37551. doi:10.1038/srep37551
- [60] Sun X, Liang J, Zhu M, Zhao Y, Zhang B (2018) Microplastics in seawater and zooplankton from the Yellow Sea. *Environ Pollut* 242:585–595. doi:10.1016/j.envpol.2018.07.014
- [61] Sutton R, Mason SA, Stanek SK, Willis-Norton E, Wren IF, Box C (2016) Microplastic contamination in the San Francisco Bay, California, USA. *Mar Pollut Bull* 109:230–235. <http://dx.doi.org/10.1016/j.marpolbul.2016.05.077>

- [62] Syakti AD, Bouhroum R, Hidayati NV, Koenawan CJ, Boulkamh A, Sulistyo I, Lebarillier S, Akhlus S, Doumenq P, Wong-Wah-Chung P (2017) Beach macro-litter monitoring and floating microplastic in a coastal area of Indonesia. *Mar Pollut Bull* 122:217–225. <http://dx.doi.org/10.1016/j.marpolbul.2017.06.046>
- [63] Syakti AD, Hidayati NV, Jaya YV, Siregar SH, Yude R, Suhendy Asia L, Wong-Wah-Chung P, Doumenq P (2018) Simultaneous grading of microplastic size sampling in the Small Island of Bintan water, Indonesia. *Mar Pollut Bull* 137:593–600. <https://doi.org/10.1016/j.marpolbul.2018.11.005>
- [64] Tamminga M, Hengstmann E, Fischer EK (2018) Microplastic analysis in the South Funen Archipelago, Baltic Sea, implementing manta trawling and bulk sampling. *Mar Pollut Bull* 128:601–608. <http://doi.org/10.1016/j.marpolbul.2018.01.066>
- [65] Tang G, Liu M, Zhou Q, He H, Chen K, Zhang H, Hu J, Huang Q, Luo Y, Ke H, Chen B, Xu X, Cai M (2018) Microplastics and polycyclic aromatic hydrocarbons (PAHs) in Xiamen coastal areas: implications for anthropogenic impacts. *Sci Total Environ* 634:811–820. <https://doi.org/10.1016/j.scitotenv.2018.03.336>
- [66] Thompson RC, Olsen Y, Mitchell RP, Davis A, Rowland SJ, John AWG, McGonigle D, Russell AE (2004) Lost at sea: where is all the plastic? *Science* 304:838 p. doi:10.1126/science.1094559
- [67] Tsang YY, Mak CW, Liebich C, Lam SW, Sze ETP, Chan KM (2017) Microplastic pollution in the marine waters and sediments of Hong Kong. *Mar Pollut Bull* 115:20–28. <http://dx.doi.org/10.1016/j.marpolbul.2016.11.003>
- [68] Tunçer S, Artüz OB, Demirkol M, Artüz ML (2018) First report of occurrence, distribution, and composition of microplastics in surface waters of the Sea of Marmara, Turkey. *Mar Pollut Bull* 135:283–289. <https://doi.org/10.1016/j.marpolbul.2018.06.054>
- [69] van der Hal N, Ariel A, Angel DL (2017) Exceptionally high abundances of microplastics in the oligotrophic Israeli Mediterranean coastal waters. *Mar Pollut Bull* 116:151–155. <http://dx.doi.org/10.1016/j.marpolbul.2016.12.052>
- [70] Viršek MK, Palatinus A, Koren S, Peterlin M, Horvat P, Kržan A (2016) Protocol for microplastics sampling on the sea surface and sample analysis. *JOVEJ Vis Exp* 118:55161. doi:10.3791/55161
- [71] Zhao S, Zhu L, Li D (2015) Microplastic in three urban estuaries, China. *Environ Pollut* 206:597–604. <http://dx.doi.org/10.1016/j.envpol.2015.08.027>

[72] Zhao S, Zhu L, Wang T, Li D (2014) Suspended microplastics in the surface water of the Yangtze Estuary System, China: first observations on occurrence, distribution. *Mar Pollut Bull* 86:562–568.
<http://dx.doi.org/10.1016/j.marpolbul.2014.06.032>

[73] Zhu J, Zhang Q, Li Y, Tan S, Kang Z, Yu X, Lan W, Cai L, Wang J, Shi H (2019) Microplastic pollution in the Maowei Sea, a typical mariculture bay of China. *Sci Total Environ* 658:62–68.
<https://doi.org/10.1016/j.scitotenv.2018.12.192>

[74] Zobkov MB, Esiukova EE, Zyubin AY, Samusev IG (2019) Microplastic content variation in water column: the observations employing a novel sampling tool in stratified Baltic Sea. *Mar Pollut Bull* 138:193–205