JPI OCEANS

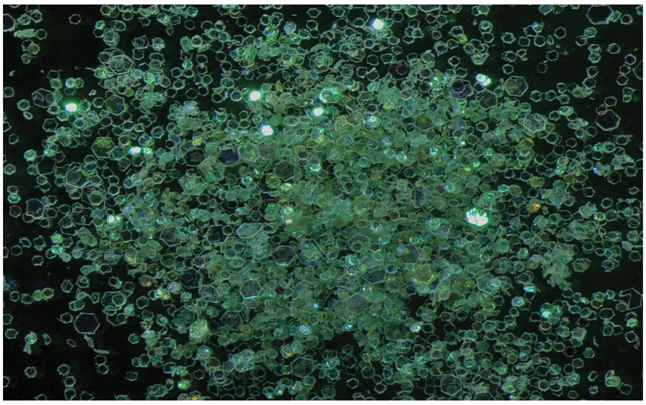
Key Results Microplastics Projects 2016-2019

Introduction

After three years of dedicated microplastics research, four projects (BASEMAN, EPHEMARE, PLASTOX and WEATHER-MIC) funded under the framework of JPI Oceans have presented their results. The projects focused on defining baselines and standards for microplastics analysis, understanding the ecotoxicological effects of microplastics and their associated pollutants, and investigating the weathering of plastics in marine waters.

What are microplastics?

Microplastics are defined as plastic particles that are smaller than 5 mm in size, including particles in the nano-size range[1,2]. The smallest particles studied by the JPI Oceans BASEMAN and WEATHER-MIC projects were a few micrometres in size (equivalent to less than half the thickness of a single human hair). EPHEMARE and PLASTOX tested the effects of particles down to the nano-scale as these are readily ingested by zooplankton and filter feeders. In terms of numbers, 92% of all plastic items found at sea fall into the microplastics category[3]. Although lower in total number of items, macroplastics (>25 mm) account for the largest mass of plastics and can break down into micro- and nanoplastics. Microplastics classify as "primary" when purposefully manufactured to small size, such as microbeads in cosmetics, and "secondary" when resulting from breakdown of any larger plastic object[4].



MICROPLASTIC PARTICLES FOUND IN COSMETIC EYELINER.PHOTO CREDIT: FILIPA BESSA

The mass production of plastics dates back to the end of the 1940s. Plastics are synthetic materials manufactured from a wide range of organic polymers and have countless applications owing to their broad range of physical and chemical properties. For example, polystyrene used to make disposable cups is very different from nylon, used to make fishing nets. The top five plastic polymers contributing most to total plastics, with regard to their current production volumes are polyethylene, polypropylene, polyvinylchloride, polyurethane and polyethylene terephthalate[5].

Furthermore, plastic products contain a wide range of chemical additives including colourants, plasticisers, antioxidants and flame retardants to give them their desired properties. The JPI Oceans microplastics projects studied more than ten types of plastics[6] to understand how they interact with the marine environment and its inhabitants.

Microplastics distribution and abundance

The first report on plastic pollution in the marine environment appeared in the early 1970s[7]. Today we know that microplastics are found in environmental compartments all over the globe, from the tropics to the poles[8] and from the Swiss Alps[9] to the Mariana Trench[10]. The BASEMAN project provides evidence of high microplastics concentrations in various studied areas like the Fram Strait[11,12], Arctic Sea[8], North Sea[13], Rhine river[14], Bergen Fjord[15] and the Mediterranean Sea[16,17,18,19]. Particularly high concentrations were found in closed systems like the Mediterranean Sea and the Bergen Fjord. A remarkable finding was that the microplastics contamination in Arctic Sea ice is among the highest in the world. Additionally, the researchers highlighted that smaller sized microplastics (<100 μm) play a major role in microplastics contamination[8,9,13,14,15,19,20,21,22].

The focus of the collaborative BASEMAN project was the standardisation of methods to describe the abundance and distribution of microplastics in European waters, aiming to facilitate Member State compliance with policy obligations. To achieve this goal, different analytical techniques to identify and quantify microplastics (such as Fourier-transform infrared spectroscopy, Raman spectroscopy and pyrolysis-gas chromatography/mass spectrometry) were compared[20,23], showing the complementary nature of the investigated techniques.

BASEMAN developed new applications, data analysis tools and databases during the project. For example, the researchers generated multi-spectroscopic databases[21,24], to harmonise the different analytical techniques. The development of automated analysis pipelines significantly reduced the working time and personnel demand of the data analysis, also allowing the identification and quantification of microplastics independent from human bias[25].

A dedicated database[24] enabled a standardised analysis of microplastics, adopted by a series of studies in various environmental compartments[8,9,12,13,14,15,20,21,22]. The latest version of this analysis pipeline also facilitates the separation of microplastic particles and fibres within a dataset[21]. To allow the application of these tools for various instruments from all manufacturers, BASEMAN provided the software sIMPle (Systematic Identification of MicroPLastics in the Environment)[26]. It is available free of charge via the website www.simple-plastics.eu and has already been applied to different analytical techniques[27].

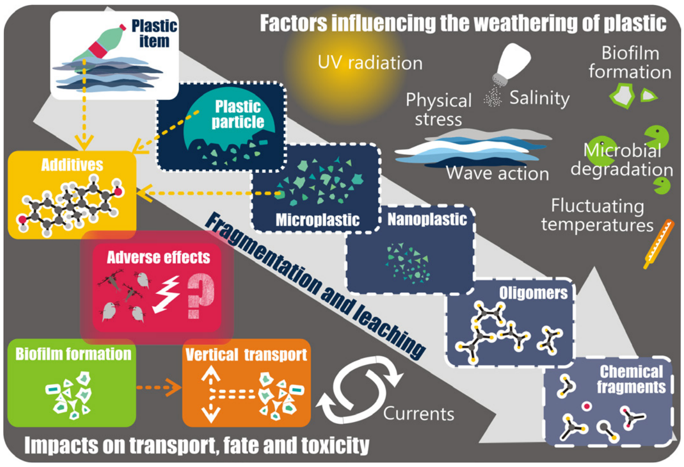
Inter-lab comparisons among participating BASEMAN partners, using their new microplastics reference kit, showed that additional method development (including strict quality assurance/quality control criteria) is needed to quantify the particle fraction smaller than 100 µm with meaningful reproducibility. To optimise the density separation of microplastics from sediments, scientists investigated different systems. In addition, different purification methods (such as the use of alkaline digestion, enzymatic digestion[28] and wet oxidation – including Fenton's reagent[11,14]) were developed and evaluated. One major outcome was the development of a purification reactor[13], which reduced contamination risks and improved the ease of use.

Researchers from the BASEMAN partnership embarked on joint scientific cruises in Galway Bay (Ireland) and Ria de Vigo (NW Spain) to facilitate the comparison, evaluation and standardisation of sampling methodologies for microplastics in sediment and water[29]. Additionally, they proposed various marine species to include in biomonitoring of microplastics in European waters. Finally, BASEMAN developed three white papers on standardisation/harmonisation protocols for monitoring microplastics in seawater, sediments and biota (in collaboration with the JPI Oceans project EPHEMARE)[30,31,32].

The researchers highlighted possible issues with biodegradable plastics, which are promoted as less harmful to the environment. During a research campaign, scientists found polycaprolactone (which is considered biodegradable) in nearly 10% of their net tows[19]. Under laboratory conditions, it breaks down in around 6-12 days[19]. However, the BASEMAN findings suggest that this type of plastic does not readily degrade in natural sea conditions and may therefore not be a viable solution to reduce marine litter[19]. The project further suggests that future research should focus on the sinks and sources, fates and residence times of various polymers, especially concerning the smaller-sized microplastics [8,9,13,14,15,19,20,21,22].

Weathering

When plastic is introduced into the ocean, its properties change and it breaks down yielding smaller particles due to exposure to oxygen, sunlight, waves, biofilms, etc[33,34]. These different factors influencing plastic weathering must be considered when assessing the environmental fate and impacts of microplastics. The WEATHER-MIC project focused on the effect of weathering on the physicochemical properties, surface characteristics, environmental fate and potential toxic effects of microplastics.



SUMMARY OF THE FACTORS INFLUENCING THE WEATHERING OF PLASTIC IN THE MARINE ENVIRONMENT WITH RESULTING IMPACTS ON TRANSPORT AND FATE PROCESSES AND POSSIBLE ADVERSE EFFECTS. FIGURE CREDIT: JAHNKE ET AL.[33]

The research led to a novel mass spectrometry "fingerprinting" method to identify plastic polymers following artificial weathering experiments[35]. The development of advanced models, combined with monitoring data, enabled further investigation of the transport of microplastics in the water column and coastal environment. The researchers also adapted OECD guidelines for the ecotoxicological testing of chemical substances to microplastic particles. This allowed them to screen the effects of virgin and weathered microplastics and their leachates in a standardised way. Their newly developed standard testing procedure enables researchers to evaluate the fitness-related consequences of microplastics on consumers[36].

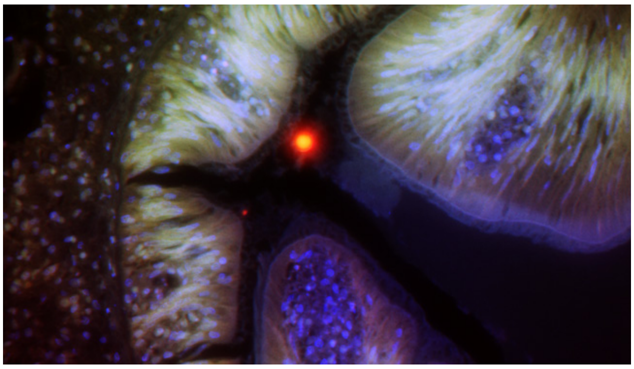
WEATHER-MIC also studied the effects of microbial community attachment (biofilms) on microplastics[15]. These biofilms can have an effect on the swimming behaviour of grazers exposed to microplastics[37].

Pre-production polymers with low additive contents were shown to elicit only limited effects[38], indicating that additives may account for a major share of observed effects. Hence, consumer products containing additives demand greater attention. WEATHER-MIC thus highlights the importance of including weathering effects in risk assessments of microplastics pollution in real world environments.

Ingestion and accumulation

Microplastics can be taken up by a wide range of marine organisms and, for example, clog their filter apparatus or gastrointestinal tracts. The EPHEMARE and PLASTOX projects both conducted field and laboratory studies investigating microplastics ingestion and potential for accumulation. Their research output included the development of methods for extracting microplastic from biological samples[39,40]. For example, the researchers found microplastics in mussels and in the guts of crabs and wild-caught fish, highlighting ingestion is widespread in the marine environment across species with different feeding strategies and from different trophic levels and habitats[41,42,43,44,45]. Microplastics abundance varied significantly among different species and organisms of the same species.

Filter feeders (e.g. mussels)[46,47], deposit feeders (e.g. beach hoppers)[48] and predators (e.g. fish)[49] being fed in laboratory conditions actively ingest, but also egest microplastics within the size range of their common food. In most organisms, larger microplastic particles (>20 μm) do not accumulate and transit quickly through the digestive tract before being expelled. Subsequently, these faeces or pseudo-faeces accumulate in bio-deposit aggregates.



SECTION ACROSS THE DIGESTIVE TRACT OF A MUSSEL AFTER EXPOSURE TO SEAWATER CONTAINING MICROPLASTICS. THE MICROPLASTIC PARTICLE IS VISIBLE IN BRIGHT RED. PHOTO CREDIT: CATIA GONÇALVES

In mussels, particles smaller than 2 μm translocated from the digestive gland into the gills and were eventually excreted. Current models show no accumulation of microplastics inside mussels exposed to environmental concentrations. Field samples confirmed this prediction.

Laboratory studies demonstrated the transfer of microplastics from prey to predator in experimental food chains[50]. However, bioaccumulation generally does not occur as the particles are excreted at a similar rate to which they are taken up. It is necessary, however, to consider that current experimental studies and field campaigns rarely detect nanoplastics due to technical limitations and costly or time-consuming analytical methods.

Effects of microplastics on marine organisms

The EPHEMARE and PLASTOX projects also studied the toxicological effects of microplastics at different trophic levels in the marine ecosystem. The leaching of toxic additives and the sorption and transport of persistent organic and metal pollutants were additional impacts investigated in the studies. EPHEMARE and PLASTOX set up collaborative experiments among partner laboratories to study the cellular, molecular, physiological and biological effects of microplastics in the marine environment.

The experiments used virgin microplastic reference materials, environmentally relevant reference materials[51] and microplastic particles with added organic and metal pollutants to investigate the impacts on a wide array of species, from bacteria to fish. Toxicity to organisms was assessed using ecologically relevant endpoints, including behaviour (affecting the ability to find food and partners), reproduction, embryogenesis and mortality. To stimulate the industry to produce more environmentally friendly materials, and regulatory agencies to set environmental standards for plastics, EPHEMARE developed toxicity tests specifically suitable for microplastics[52].

The projects tested microplastics at environmentally relevant concentrations and did not detect lethality or acute toxicity in marine organisms. Microplastics generally did not seem to induce mortality, nor significantly affect growth, nor cause mutagenic effects. Results showed only subtle effects on the organisms' health status, such as cellular and oxidative stress and a range of species-specific nonlethal effects[53,54,55,56,57,58].

However, in bivalves (a class of molluscs) microplastics led to a decrease of energy reserves[59]. Larger (125-500 μm) particles negatively affected the efficiency of digestion due to stress, toxicity and lower nutrient uptake[59]. Lugworms exposed to microplastics showed decreased feeding activity over time. Predatory fish showed a significant decrease in female growth and reproductive outcomes (i.e. a decreased larval hatching rate) when exposed to microplastics, with and without sorbed pollutants[60]. In phytoplankton, a reduced growth rate and reduced chlorophyll production may occur, although standard endpoints are not very sensitive[61].

Recent scientific publications have thus revealed low toxicity of virgin microplastics on marine biota[33,35,36,37,38,39,40,60,62,63,64]. However, these studies did not focus on the additive chemicals that are present in microplastics in the marine environment. A wide range of organic and metal additives are used in the production of plastic materials and some types of plastic can contain up to 20-30% in weight of chemical additives. Studies conducted in PLASTOX and EPHEMARE have shown that chemical additives can leach out into marine[65,66,67,68] and fresh[50,69] waters, where they can exert toxic effects[70,71]. PLASTOX also developed a novel method for the extraction and analysis of a wide range of polar and nonpolar organic chemicals in seawater[72].

To fill knowledge gaps, the researchers highlighted the need to assess hotspots of microplastics pollution, the long-term environmental effects of microplastics and to consider the full scope and cumulative impact of multiple pressures on the ocean.

Effects of sorbed organic pollutants

While microplastics release additive chemicals, they can also sorb and transport hydrophobic chemicals and metals from their surrounding media, prior to ingestion by biota. As a result, microplastics may represent an alternative exposure route for such pollutants. In addition to assessing the direct effects of microplastics, the PLASTOX and EPHEMARE projects also studied sorption of different persistent organic pollutants (POPs) to a range of polymer types and investigated the ecotoxicological impact of POPs and metals associated with microplastics on key European marine species.

In recent years, a number of studies have attempted to investigate the bioavailability of microplastics-sorbed contaminants, mostly focusing on ingestion of contaminated microplastics by aquatic species, and reporting transfer and accumulation in tissues and toxicological effects[73]. A previous study has highlighted that under environmentally relevant exposure scenarios, the microplastics exposure route for organic contaminants is negligible with respect to the combined intake from food and water[74].

The studies conducted within the framework of the PLASTOX and EPHEMARE projects highlighted the complexity of this issue. The degree of pollutant bioavailability was partially related to the specific combination of plastic and pollutant and partially related to the experimental design and exposure conditions. The bioavailability of sorbed POPs and metals differed between species and was strongly dependent on factors such as lipid content, gut residence time of microplastics, as well as the presence of dissolved pollutants in the surrounding environment. As a result, a range of different outcomes were observed, including increased bioavailability[37], no significant change in bioavailability[75,7677] and even a clear reduction in bioavailability[76]. Furthermore, detailed sorption studies conducted within PLASTOX showed that POPs accumulate more in polyethylene than in polypropylene, polystyrene and polyethylene terephthalate, suggesting that both sorbent (e.g. polymer type) and sorbate properties (e.g. molecular size and polarity), as well as extrinsic environmental conditions influence the sorption process.

PLASTOX, among other recent studies, indicated that the current knowledge on smaller microplastic particles (<10 μm) and nanoplastics (<1μm) is still limited. The smaller the plastic particles, the more environmental and human health risks they may pose. Additional research on their current environmental concentrations is thus of utmost importance. Since knowledge gaps remain and new research questions have arisen, JPI Oceans launched a second joint call for transnational research projects which led to the selection of six cutting-edge research projects on microplastics in the ocean.

The six selected projects (ANDROMEDA, HOTMIC, FACTS, microplastiX, i-plastic, RESPONSE) will perform research on sources of microplastics, methods for identifying smaller micro- and (nano-) plastics, monitoring their circulation in marine systems and their effects on marine organisms.

The previous JPI Oceans microplastics projects also put special emphasis on public outreach via social media, workshops, stakeholder meetings, popularized publications and awareness raising campaigns. One example is the EPHEMARE photo competition - IMPACT 2017. A complete overview is available in their project reports, which you can access through the following links:

http://www.jpi-oceans.eu/baseman

https://www.jpi-oceans.eu/ephemare

https://www.jpi-oceans.eu/plastox

http://jpi-oceans.eu/weather-mic

Background and policy context

'ZOO PLASTICS' - PHOTO CREDIT: FILIPA BESSA

Plastics in the marine environment have become a major concern because of their persistence in the environment including the oceans, and adverse consequences to marine life. According to estimates from Eunomia (2016) between 27—67 million tons of plastic can be found in the world's ocean as of 2016.

In recent years many governmental initiatives have been launched to reduce the input of plastics into the (marine) environment. A ban on microbeads in cosmetics has come into force in many countries. In January 2018, the EU published its plastics strategy that aims to transform the way products are designed, produced, used and recycled in the EU so that the current 30% recycling rate can be increased dramatically.

However, plastic pollution of the ocean is not only a European problem, but a global problem. The necessity to tackle the plastics issue was recognised by both the G7 and G20 countries. In particular, the groups of states acknowledge that marine litter, in particular plastic litter, poses a global challenge, directly affecting marine and coastal life and ecosystems and potentially also human health. Accordingly, increased effectiveness and intensity of work is required to reduce the input of plastic litter into the environment. Under the Agenda 2030 for Sustainable Development of the United Nations countries worldwide also pledge to tackle the marine litter issue.

The EU Marine Strategy Framework Directive (MSFD – 2008/56/EC) requires the maintenance or achievement of Good Environmental Status of the Seas and Oceans in order to protect marine species and habitats from human activity. The 2017 Commission Decision 2017/848/EU on the Common Understanding of the Directive replacing Decision 2010/477/EU sets out requirements to develop new criteria and specifications and standardised methods for monitoring and assessment. The Decision requires the development of new mandatory criteria under Descriptor 10 for litter and micro litter in the environment and the impact of the litter on marine species through ingestion and entanglement.

Endnotes

1 GESAMP, 2015. Sources, fate and effects of microplastics in the marine environment (part 1). Available: http://www.gesamp.org/publications/reports-and-studies-no-90.

2 GESAMP, 2016. Sources, fate and effects of microplastics in the marine environment (part 2). Available: http://www.gesamp.org/publications/microplastics-in-the-marine-environment-part-2

3 Eriksen, M., Lebreton, L. C., Carson, H. S., Thiel, M., Moore, C. J., Borerro, J. C., ... & Reisser, J. (2014). Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PloS one, 9(12), e111913.

4 Cole, M., Lindeque, P., Halsband, C., & Galloway, T. S. (2011). Microplastics as contaminants in the marine environment: a review. Marine pollution bulletin, 62(12), 2588-2597.

5 Plastics Europe, 2019. Plastics – the Facts 2019. Available: https://www.plasticseurope.org/application/files/9715/7129/9584/FINAL_web_version_Plastics_the_facts2019_14102019.pdf

6 The different types of plastics studied/encountered include:
Polyethylene (PE) – including Low-Density Polyethylene (LDPE) and High-Density Polyethylene (HDPE), Polypropylene (PP), Polystyrene (PS), Polyethylene terephthalate (PET), Polycaprolactone (PCL), Polyvinylchloride (PVC), Polyamide (PA), Polyester, Polyurethane (PU), Ethylenevinyl acetate (EVA), Polyacrylic, Polyisoprene, Epoxydic resin, Polybuthylene terephtha late, Polyterpenic rubber, Polyvinyl acetate (PVA), silicone and copolymers.

7 Carpenter, E. J., & Smith, K. L. (1972). Plastics on the Sargasso Sea surface. Science, 175(4027), 1240-1241.

8 Peeken, I., Primpke, S., Beyer, B., Gütermann, J., Katlein, C., Krumpen, T., Bergmann, M., Hehemann, L., & Gerdts, G. (2018). Arctic sea ice is an important temporal sink and means of transport for microplastic. Nature communications, 9(1), 1-12.

9 Bergmann, M., Mützel, S., Primpke, S., Tekman, M. B., Trachsel, J., & Gerdts, G. (2019). White and wonderful? Microplastics prevail in snow from the Alps to the Arctic. Science advances, 5(8), eaax1157.

10 Jamieson, A. J., Brooks, L. S. R., Reid, W. D. K., Piertney, S. B., Narayanaswamy, B. E., & Linley, T. D. (2019). Microplastics and synthetic particles ingested by deep-sea amphipods in six of the deepest marine ecosystems on Earth. Royal Society open science, 6(2), 180667.

11 Bergmann, M., Wirzberger, V., Krumpen, T., Lorenz, C., Primpke, S., Tekman, M. B., & Gerdts, G. (2017). High quantities of microplastic in Arctic deep-sea sediments from the HAUSGARTEN observatory. Environmental Science & Technology, 51(19), 11000-11010.

12 Tekman, M.B., Wekerle, C., Lorenz, C., Primpke, S., Hasemann, C., Gerdts, G., Bergmann, M. (2020). Tying up loose ends of microplastic pollution in the Arctic: Distribution from the sea surface, through the water column to deep-sea sediments at the HAUSGARTEN observatory. Environmental Science & Technology.

13 Lorenz, C., Roscher, L., Meyer, M. S., Hildebrandt, L., Prume, J., Löder, M. G., Primpke, S., & Gerdts, G. (2019). Spatial distri bution of microplastics in sediments and surface waters of the southern North Sea. Environmental Pollution, 252, 1719-1729.

14 Mani, T., Primpke, S., Lorenz, C., Gerdts, G., & Burkhardt-Holm, P. (2019). Microplastic pollution in benthic midstream sediments of the Rhine River. Environmental science & technology, 53(10), 6053-6062.

15 Haave, M., Lorenz, C., Primpke, S., & Gerdts, G. (2019). Different stories told by small and large microplastics in sediment-first report of microplastic concentrations in an urban recipient in Norway. Marine pollution bulletin, 141, 501-513.

16 Filgueiras, A. V., Gago, J., Campillo, J. A., & León, V. M. (2019). Microplastic distribution in surface sediments along the Spanish Mediterranean continental shelf. Environmental Science and Pollution Research, 26(21), 21264-21273.

17 Palatinus, A., Kovač Viršek, M., Robič, U., Grego, M., Bajt, O., Šiljić, J., Suaria, G., Liubartseva, S., Coppini, G., Peterlin, M.(2019). Marine litter in the Croatian part of the middle Adriatic Sea: Simultaneous assessment of floating and seabed macro and micro litter abundance and composition. Marine Pollution Bulletin, 139, 427-439.

18 Romanelli G., Zampetti G., Cicero A.M., Carpentieri S., Di Vito S. and Matiddi M. (2018) Sea Water Contamination in the Vicinity of the Italian Minor Islands Caused by Microplastic Pollution. Water, 10, 1108.

19 Suaria, G., Avio, C.G., Mineo, A., Lattin, G., Magaldi, M.G., Belmonte, G., Moore, C.M., Regoli, F., Aliani, S. (2016). The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters. Scientific Reports 6, 37551.

20 Cabernard, L., Roscher, L., Lorenz, C., Gerdts, G., & Primpke, S. (2018). Comparison of Raman and Fourier transform infrared spectroscopy for the quantification of microplastics in the aquatic environment. Environmental science & technology, 52(22), 13279-13288.

21 Primpke, S., Dias, P. A., & Gerdts, G. (2019). Automated identification and quantification of microfibres and microplastics. Analytical methods, 11(16), 2138-2147.

22 Primpke, S., Imhof, H., Piehl, S., Lorenz, C., Löder, M., Laforsch, C., & Gerdts, G. (2017). Mikroplastik in der Umwelt: Umwelt chemie. Chemie in unserer Zeit, 51(6), 402-412.

23 Käppler, A., Fischer, M., Scholz-Böttcher, B. M., Oberbeckmann, S., Labrenz, M., Fscher, D., Eichhorn, K. & Voit, B. (2018). Comparison of m-ATR-FTIR spectroscopy and py-GCMS as identification tools for microplastic particles and fibers isolated from river sediments. Analytical and bioanalytical chemistry, 410(21), 5313-5327

24 Primpke, S., Wirth, M., Lorenz, C., & Gerdts, G. (2018). Reference database design for the automated analysis of microplastic samples based on Fourier transform infrared (FTIR) spectroscopy. Analytical and bioanalytical chemistry, 410(21), 5131-5141.

25 Primpke, S., Lorenz, C., Rascher-Friesenhausen, R., & Gerdts, G. (2017). An automated approach for microplastics analysis using focal plane array (FPA) FTIR microscopy and image analysis. Analytical Methods, 9(9), 1499-1511.

26 Primpke, S., Cross, R.K., Mintenig, S., Vianello, A., Gerdts, G., Vollertsen, J., 2019. Systematic Identification of Microplastics in the Environment: A siMPle independent software tool for spectroscopic analysis. Appl. Spectrosc. Under minor Revisions.

27 Meyns, M., Primpke, S., & Gerdts, G. (2019). Library based identification and characterisation of polymers with nano-FTIR and IR-sSNOM imaging. Analytical Methods, 11(40), 5195-5202.

28 Löder, M. G., Imhof, H. K., Ladehoff, M., Löschel, L. A., Lorenz, C., Mintenig, S., ... & Gerdts, G. (2017). Enzymatic purification of microplastics in environmental samples. Environmental science & technology, 51(24), 14283-14292.

29 Olga Carretero, João P. G. L Frias, Diego Pereiro, Clara Lopes, Joana Antunes, José M. Andrade, Andrea Camedda, Alenka Goruppi, Giuseppe Andrea de Lucia, Maria Luiza Pedrotti, Paula Sobral, Miguel Caetano, Valentina Tirelli, Róisín Nash, Jesus Gago (2017). Microplastic sampling comparison (BASEMAN Cruise Report). Available: https://www.researchgate.net/publication/317279446_Microplastic_sampling_comparison

30 Frias, J., Pagter, E., Nash, R., O'Connor, I., Carretero, O., Filgueiras, A., ... & Sobral, P. (2018). Standardised protocol for monitoring microplastics in sediments. Deliverable 4.2.

31 Bessa, F., Frias, J. P. G. L., Kögel, T., Lusher, A., Andrade, J., Antunes, J., ... & Pedrotti, M. L. (2019). Harmonized protocol for monitoring microplastics in biota (Doctoral dissertation, D4. 3 BASEMAN report).

32 Gago, J., Filgueiras, A., Pedrotti, M. L., Caetano, M., & Frias, J. (2018). Standardised protocol for monitoring microplastics in seawater. Deliverable 4.1.

33 Jahnke, A., Arp, H. P. H., Escher, B. I., Gewert, B., Gorokhova, E., Kühnel, D., ... & Toorman, E. (2017). Reducing uncertainty and confronting ignorance about the possible impacts of weathering plastic in the marine environment. Environmental Science & Technology Letters, 4(3), 85-90.

34 Rummel, C. D., Jahnke, A., Gorokhova, E., Kühnel, D., & Schmitt-Jansen, M. (2017). Impacts of biofilm formation on the fate and potential effects of microplastic in the aquatic environment. Environmental Science & Technology Letters, 4(7), 258-267.

35 Gewert, B., Plassmann, M., Sandblom, O., & MacLeod, M. (2018). Identification of chain scission products released to water by plastic exposed to ultraviolet light. Environmental Science & Technology Letters, 5(5), 272-276.

36 Gerdes, Z., Hermann, M., Ogonowski, M., & Gorokhova, E. (2019). A novel method for assessing microplastic effect in suspension through mixing test and reference materials. Scientific reports, 9(1), 1-9.

37 Gorokhova, E., Konnecke, O., Ogonowski, M., Gerdes, Z., & Wiklund, A. K. E. (2018). Alterations in swimming behavior of Daphnia exposed to polymer and mineral particles: towards understanding effects of microplastics on planktonic filtrators. bioRxiv, 406587.

38 Rummel, C. D., Escher, B. I., Sandblom, O., Plassmann, M. M., Arp, H. P. H., MacLeod, M., & Jahnke, A. (2019). Effects of Leachates from UV-Weathered Microplastic in Cell-Based Bioassays. Environmental science & technology, 53(15), 9214-9223.

39 Kühn, S., Van Werven, B., Van Oyen, A., Meijboom, A., Rebolledo, E. L. B., & Van Franeker, J. A. (2017). The use of potassium hydroxide (KOH) solution as a suitable approach to isolate plastics ingested by marine organisms. Marine Pollution Bulletin, 115(1-2), 86-90.

40 Gonçalves, C., Martins, M., Costa, M. H., & Costa, P. M. (2018). Development of a method for the detection of polystyrene microplastics in paraffin-embedded histological sections. Histochemistry and cell biology, 149(2), 187-191.

41 Wieczorek, A. M., Morrison, L., Croot, P. L., Allcock, A. L., MacLoughlin, E., Savard, O., Brownlow, H., & Doyle, T. K. (2018). Frequency of microplastics in mesopelagic fishes from the Northwest Atlantic. Frontiers in Marine Science, 5, 39.

42 Kühn, S., Schaafsma, F. L., van Werven, B., Flores, H., Bergmann, M., Egelkraut-Holtus, M., ... & van Franeker, J. A. (2018). Plastic ingestion by juvenile polar cod (Boreogadus saida) in the Arctic Ocean. Polar biology, 41(6), 1269-1278.

43 Piarulli, S., Scapinello, S., Comandini, P., Magnusson, K., Granberg, M., Wong, J. X., ... & Airoldi, L. (2019). Microplastic in wild populations of the omnivorous crab Carcinus aestuarii: A review and a regional-scale test of extraction methods, including microfibres. Environmental pollution, 251, 117-127.

44 Kühn, S., van Franeker, J. A., O'donoghue, A. M., Swiers, A., Starkenburg, M., van Werven, B., ... & Lindeboom, H. (2020). Details of plastic ingestion and fibre contamination in North Sea fishes. Environmental Pollution, 257, 113569.

45 Piarulli, S., Vanhove, B., Comandini, P., Scapinello, S., Moens, T., Vrielinck, H., ... & Van Colen, C. (2020). Do different habits affect microplastics contents in organisms? A trait-based analysis on salt marsh species. Marine Pollution Bulletin, 153, 110983.

46 Fernández, B., & Albentosa, M. (2019). Insights into the uptake, elimination and accumulation of microplastics in mussel. Environmental pollution, 249, 321-329.

47 Gonçalves, C., Martins, M., Sobral, P., Costa, P. M., & Costa, M. H. (2019). An assessment of the ability to ingest and excrete microplastics by filter-feeders: a case study with the Mediterranean mussel. Environmental pollution, 245, 600-606.

48 Tosetto, L., Brown, C., & Williamson, J. E. (2016). Microplastics on beaches: ingestion and behavioural consequences for beachhoppers. Marine biology, 163(10), 199.

49 Espinosa, C., Cuesta, A., & Esteban, M. Á. (2017). Effects of dietary polyvinylchloride microparticles on general health, immune status and expression of several genes related to stress in gilthead seabream (Sparus aurata L.). Fish & shellfish immunology, 68, 251-259.

50 Van Colen, C., Vanhove, B., Diem, A., & Moens, T. (2020). Does microplastic ingestion by zooplankton affect predator-prey interactions? An experimental study on larviphagy. Environmental Pollution, 256, 113479.

51 Kühn, S., Van Oyen, A., Booth, A. M., Meijboom, A., & Van Franeker, J. A. (2018). Marine microplastic: Preparation of relevant test materials for laboratory assessment of ecosystem impacts. Chemosphere, 213, 103-113.

52 Beiras, R., Tato, T., & López-Ibáñez, S. (2019). A 2-Tier standard method to test the toxicity of microplastics in marine water using Paracentrotus lividus and Acartia clausi larvae. Environmental toxicology and chemistry, 38(3), 630-637.

53 Capolupo, M., Franzellitti, S., Valbonesi, P., Lanzas, C. S., & Fabbri, E. (2018). Uptake and transcriptional effects of polystyrene microplastics in larval stages of the Mediterranean mussel Mytilus galloprovincialis. Environmental Pollution, 241, 1038-1047.

54 Wathsala, R. H. G. R., Franzellitti, S., Scaglione, M., & Fabbri, E. (2018). Styrene impairs normal embryo development in the Mediterranean mussel (Mytilus galloprovincialis). Aquatic Toxicology, 201, 58-65.

55 González-Soto, N., Hatfield, J., Katsumiti, A., Duroudier, N., Lacave, J. M., Bilbao, E., ... & Cajaraville, M. P. (2019). Impacts of dietary exposure to different sized polystyrene microplastics alone and with sorbed benzo [a] pyrene on biomarkers and whole organism responses in mussels Mytilus galloprovincialis. Science of the Total Environment, 684, 548-566.

56 Wieczorek, A. M., Croot, P. L., Lombard, F., Sheahan, J. N., & Doyle, T. K. (2019). Microplastic ingestion by gelatinous zooplankton may lower efficiency of the biological pump. Environmental science & technology, 53(9), 5387-5395.

57 Cole, M., Coppock, R., Lindeque, P. K., Altin, D., Reed, S., Pond, D. W., ... & Booth, A. M. (2019). Effects of nylon microplastic on feeding, lipid accumulation, and moulting in a coldwater copepod. Environmental science & technology, 53(12), 7075-7082.

58 Franzellitti, S., Capolupo, M., Wathsala, R. H., Valbonesi, P., & Fabbri, E. (2019). The Multixenobiotic resistance system as a possible protective response triggered by microplastic ingestion in Mediterranean mussels (Mytilus galloprovincialis): Larvae and adult stages. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology, 219, 50-58.

59 Bour, A., Haarr, A., Keiter, S., & Hylland, K. (2018). Environmentally relevant microplastic exposure affects sediment-dwelling bivalves. Environmental pollution, 236, 652-660.

60 Pannetier, P., Morin, B., Le Bihanic, F., Dubreil, L., Clérandeau, C., Chouvellon, F., ... & Cachot, J. (2020). Environmental samples of microplastics induce significant toxic effects in fish larvae. Environment international, 134, 105047.

61 Gambardella, C., Piazza, V., Albentosa, M., Bebianno, M. J., Cardoso, C., Faimali, M., ... & Sendra, M. (2019). Microplastics do not affect standard ecotoxicological endpoints in marine unicellular organisms. Marine pollution bulletin, 143, 140-143.

62 Beiras, R., Bellas, J., Cachot, J., Cormier, B., Cousin, X., Engwall, M., Gambardella, C., Garaventa, F., Keiter, S., Le Bihanic, F., López-Ibáñez, S., Piazza, V., Rial, D., Tato, T., Vidal-Liñán, L. 2018a. Ingestion and contact with polyethylene microparticles does not cause toxicity on marine zooplankton. Journal of Hazardous Materials, 30: 452-460.

63 Espinosa C, García Beltrán JM, Esteban MA, Cuesta A. (2018). In vitro effects of virgin microplastics on fish head-kidney leucocyte activities. Environmental Pollution, 235: 30-38.

64 Jovanovic B., Gökdag K., Güven O., et al. (2018). Virgin microplastics are not causing imminent harm to fish after dietary exposure. Mar Pollut Bull 130: 123-131.

65 Paluselli, A., Fauvelle, V., Schmidt, N., Galgani, F., Net, S., & Sempéré, R. (2018). Distribution of phthalates in marseille bay (NW Mediterranean Sea). Science of the total environment, 621, 578-587.

66 Paluselli, A., Fauvelle, V., Galgani, F., & Sempéré, R. (2018). Phthalate release from plastic fragments and degradation in seawater. Environmental science & technology, 53(1), 166-175.

67 Schmidt, N., Fauvelle, V., Ody, A., Castro-Jimenez, J., Jouanno, J., Changeux, T., ... & Sempere, R. (2019). The amazon river: a major source of organic plastic additives to the tropical north atlantic?. Environmental science & technology, 53(13), 7513-7521.

68 Schmidt, N., Fauvelle, V., Castro-Jiménez, J., Lajaunie-Salla, K., Pinazo, C., Yohia, C., & Sempere, R. (2019). Occurrence of perfluoroalkyl substances in the Bay of Marseille (NW Mediterranean Sea) and the Rhône River. Marine pollution bulletin, 149, 110491.

69 Schmidt, N., Castro-Jiménez, J., Fauvelle, V., Ourgaud, M., & Sempere, R. (2020). Occurrence of organic plastic additives in surface waters of the Rhône River (France). Environmental Pollution, 257, 113637

70 Oliviero, M., Tato, T., Schiavo, S., Fernández, V., Manzo, S., & Beiras, R. (2019). Leachates of micronized plastic toys provoke embryotoxic effects upon sea urchin Paracentrotus lividus. Environmental pollution, 247, 706-715.

71 Capolupo, M., Sørensen, L., Jayasena, K. D. R., Booth, A. M., & Fabbri, E. (2020). Chemical composition and ecotoxicity of plastic and car tire rubber leachates to aquatic organisms. Water research, 169, 115270.

72 Fauvelle, V., Castro-Jimenez, J., Schmidt, N., Carlez, B., Panagiotopoulos, C., & Sempere, R. (2018). One-single extraction procedure for the simultaneous determination of a wide range of polar and nonpolar organic contaminants in seawater. Frontiers in Marine Science, 5, 295.

73 Ziccardi, L. M., Edgington, A., Hentz, K., Kulacki, K. J., & Driscoll, S. K. (2016). Microplastics as vectors for bioaccumulation of hydrophobic organic chemicals in the marine environment: A state-of-the-science review. Environmental toxicology and chemistry, 35(7), 1667-1676.

74 Koelmans, A. A., Bakir, A., Burton, G. A., & Janssen, C. R. (2016). Microplastic as a vector for chemicals in the aquatic environment: critical review and model-supported reinterpretation of empirical studies. Environmental science & technology, 50(7), 3315-3326.

75 Beiras, R., Muniategui-Lorenzo, S., Rodil, R., Tato, T., Montes, R., López-Ibáñez, S., ... & Quintana, J. B. (2019). Polyethylene microplastics do not increase bioaccumulation or toxicity of nonylphenol and 4-MBC to marine zooplankton. Science of the Total Environment, 692, 1-9.

76 Garrido, S., Linares, M., Campillo, J. A., & Albentosa, M. (2019). Effect of microplastics on the toxicity of chlorpyrifos to the microalgae Isochrysis galbana, clone t-ISO. Ecotoxicology and environmental safety, 173, 103-109.

77 Sørensen, L., Rogers, E., Altin, D., Salaberria, I., & Booth, A. M. (2020). Sorption of PAHs to microplastic and their bioavailability and toxicity to marine copepods under co-exposure conditions. Environmental Pollution, 258, 113844.

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