UNIVERSITI PUTRA MALAYSIA

ISOLATION AND CHARACTERIZATION OF MICROPLASTICS IN MARINE FOODSTUFF

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FPSK(M) 2017 68

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

October 2017

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in Fulfilment of the Requirement for the Degree of Master of Science

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October 2017

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Due to the persistence and ubiquity of plastic debris in the marine environment, these contaminants have become one of the major threats to the ecosystem. Disposed plastic debris may never degrade but instead breakdown to smaller particles, termed microplastic (MP). Microplastics have been previously detected in a wide array of organisms, however, MP loads in processed seafood products such as canned sardine and saltwater products such as commercial salt originating from various regions of the world has never been investigated. To extract MPs from organisms, an efficient digesting solution is required. In an attempt to select an optimum digesting solution, the efficiency of different oxidative agents (NaClO or H_2O_2), bases (NaOH or KOH), and acids [HCl or HNO_3; concentrated and diluted (5%)] in digesting fish tissues at room temperature (RT, 25 °C), 40, 50, or 60 °C was assessed and those treatments that were efficient in digesting the biological materials (>95%) were evaluated for their compatibility with eight major plastic polymers (assessed through recovery rate, Raman spectroscopy analysis, and morphological changes). Following the selection of appropriate solution, the MP loads in 20 brands of canned sardine originating from 13 countries were assessed. In addition, the presence of MPs in 17 brands of commercial salts originating from 8 countries has been investigated. Among the tested solutions, NaClO, NaOH, and diluted acids did not efficiently digest the biological matrices. The H_2O_2 treatment only at 50 °C resulted in satisfactory digestion efficiency, although it decreased the recovery rate of nylon-6 and nylon-66 and changed the colour of polyethylene terephthalate fragments. Concentrated HCl and HNO_3 treatments at RT fully digested the fish tissues, but also had a destructive impact on most polymers, particularly nylon-6 and nylon-66. Potassium hydroxide solution was able to fully eliminate the biological matrices at all temperatures. However, at 50 and 60 °C, it reduced the recovery rate of polyethylene terephthalate and polyvinyl chloride, and changed the colour of nylon-66. According to our results, treating biological materials with 10% KOH solution and incubating at 40 °C was time and cost-effective, efficient in digesting biological materials, and had no impact on the integrity of the plastic polymers. Study on canned sardine has shown that plastic particles were absent in 16 brands while between 1 and 3 plastic particles per brand were found in the other 4 brands. Out of 21 extracted particles, 28.5% were plastic polymers, 42.8% were additives, 4.7% were non-plastic, and 23.8% were unidentified. The most abundant plastic polymers were polypropylene (33.3%) and polyethylene terephthalate (33.3%). The analysis of commercial salts for MP loads has revealed that MPs were absent in one brand while others contained between 1 and 10 MPs/Kg of salt. Out of the 72 extracted particles, 41.6% were plastic polymers, 23.6% were pigments, 5.50% were amorphous carbon, and 29.1% remained unidentified. The most common plastic polymers were polypropylene (40.0%) and polyethylene (33.3%). Although this study presents a low level of anthropogenic particles intake from the canned sardine (1 to 5 anthropogenic particles per individual per annum) and salts (maximum 37 particles per individual per annum) which warrants negligible health impacts on consumers, however, due to the progressive fragmentation of MPs in the environment, the number of MPs in these products tend to increase. As such, it is highly recommended that the quantification of MPs in foodstuffs to be included as one of the components of food safety management system.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGASINGAN DAN PENCIRIANMIKROPLASTIK DALAM MARIN BAHAN MAKANAN

Oleh

ABOLFAZL GOLIESKARDI

Oktober 2017

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Disebabkan oleh kehadiran saki-baki plastik dalam persekitaran marin, bahan pencemar ini telah menjadi salah satu ancaman utama kepada ekosistem. Saki-baki plastik yang terbuang tidak akan luput, tetapi sebaliknya akan berpecah kepada partikel-partikel kecil dipanggil mikroplastik (MP). Mikroplastik telah dikesan di dalam pelbagai jenis organisma, namun demikian beban MP dalam produk makanan laut yang diproses sardin dalam tin dan produk air masin seperti garam komersil yang berasal dari pelbagai kawasan di dunia belum pernah dikaji lagi. Untuk mengasingkan MP dari organisma, satu larutan yang menghadam diperlukan. Dalam usaha memilih kaedah penghadaman yang optima, keberkesanan agen oksidatif (NaClO or H_2O_2), bes-bes (NaOH or KOH) dan asid-asid [HCl or HNO_3; pekat atau cair (5%)] dalam tisu ikan yang menghadam pada suhu bilik (RT, 25 °C), 40, 50, atau 60 °C dinilai dan rawatan-rawatan yang berkesan dalam menghadam bahan-bahan biologi (>95%) dinilai untuk menguji keberkesanannya dengan lapan polimer plastik utama (dinilai melalui kadar pemulihan, analisis spektroskopi Raman dan perubahan morfologi). Berikutan pilihan larutan yang sesuai, beban MP dalam 20 jenama sardin dalam tin berasal dari 13 buah negara telah dikaji. Tambahan pula, kehadiran MP dalam 17 jenama garam komersial yang berasal dari 8 negara telah dikaji. Dalam kalangan larutan yang diuji, NaClO, NaOH, dan asid cair tidak menghadam matriks penghadaman dengan berkesan. Rawatan H_2O_2 hanya pada 50 °C membawa kepada penghadaman yang baik, walaupun ia mengurangkan kadar pemulihan nilon-6 dan nilon-66 dan mengubah warna serpihan p*olyethylene terephthalate*. Rawatan HCl dan HNO_3 pada suhu bilik menghadam penuh tisu ikan tetapi ia juga memberi kesan buruk kepada kebanyakan polimer, terutamanya nilon-6 dan nilon-66. Larutan potasium hidroksida berjaya membuang terus matriks biologi pada semua suhu. Namun demikian, pada suhu 50 dan 60 °C, ia mengurangkan kadar pemulihan polyethylene terephthalate dan polyvinyl chloride, dan mengubah warna nilon-66. Mengikut keputusannya, merawat bahan biologikal larutan 10% KOH dan inkubasi pada 40 °C menjimatkan masa dan murah, berkesan dalam menghadam bahan biologikal, dan tidak memberi apa-apa impak kepada integriti polimer plastik. Kajian ke atas sardin dalam tin menunjukkan bahawa partikel plastik tidak ada dalam 16 jenama di mana di antara 1 dan 3 partikel plastik dijumpai dalam setiap 4 jenama yang lain. Daripada 21 partikel yang diekstrak, 28.5% adalah polimer plastik, 42.8% adalah bahan penambah, 4.7% bukan plastik, dan 23.8% tidak dikenalpasti. Polimer plastik terbanyak adalah polypropylene (33.3%) dan polyethylene terephthalate (33.3%). Analisis garam komersial untuk beban MP menunjukkan bahawa MP tidak ada dalam satu jenama sementara yang lain mengandungi 1 dan 10 MPs/Kg garam. Daripada 72 partikel yang diekstrak, 41.6% adalah polimer plastik, 23.6% adalah pigmen, 5.50% karbon amorfus, dan 29.1% masih tidak dapat dikenalpasti. Polimer plastik yang paling lazim adalah polypropylene (40.0%) dan polyethylene (33.3%). Walaupun kajian ini membawa kepada aras rendah pengambilan partikel antropogenik dari sardin dalam tin (1 kepada 5 partikel antropogenik setiap individu setahun)dan garam (maksima 37 partikel setiap individu setahun) yang memberi impak yang buruk kepada kesihatan ke atas pengguna, walaubagaimanapun, disebabkan oleh perpecahan progresif MP dalam persekitaran, bilangan MP dalam produk-produk ini semakin meningkat. Oleh itu, saranan terbaik adalah mengkuantifikasi MP dalam barang makanan untuk dimasukkan sekali sebagai salah satu komponen sistem pengurusan keselamatan makanan.

ACKNOWLEDGEMENTS

In the name of God, the most compassionate and the most merciful. To whom I owe the strength and sense of purpose that have enabled me to undertake this thesis, and without His grace and blessing, it would not have been completed.

Firstly, I would like to show my sincere gratitude and appreciation to my supervisor, Dr. Ali Karami Varnamkhasti for his guidance and financial support throughout my Master's degree. Also, I would like to thank my committee members, Dr. Ho Yu Bin and Dr. Babak Salamatinia for their support and insightful comments that contributed vastly to the development of the overall thesis.

Secondly, I would like to thank my family members whom without their love and support through my education; I would not be who I am today.

I certify that an Examination Committee has met on 5 October 2017 to conduct the final examination of Abolfazl Golieskardi on his thesis entitled "Isolation and Characterization of Microplastics in Marine Foodstuff" in accordance with Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science..

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Declaration by Graduate Student

I hereby confirm that:

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This is to confirm that:

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LIST OF ABBREVIATIONS

BPA	Bisphenol A
DDT	Dichlorodiphenyltrichloroethane
FESEM	Field Emission Scanning Electron Microscope
FTIR	Fourier Transform Infrared Spectroscopy
H_2O_2	Hydrogen peroxide
HCL	Hydrochloric acid
HDPE	High-density polyethylene
HNO_3	Hydrochloric acid
HPLC	High-performance liquid chromatography
KOH	Potassium hydroxide
LDPE	Low-density polyethylene
M-Cell	Microfold cells
Min	Minutes
MP	Microplastic
NaCl	Sodium chloride
NaClO	Sodium hypochlorite
NaOH	Sodium hydroxide
NaI	Sodium iodide
NPCG	North Pacific Centra Gyre
NY6	Nylon-6
NY66	Nylon-66
PAH	Polynuclear Aromatic Hydrocarbon
PCB	Polychlorinated biphenyl
PET	Polyethylene terephthalate
POP	Persistent Organic Pollutants
PP	Polypropylene

PS	Polystyrene
Pyr-GC-MS	Pyrolysis–gas chromatography–mass spectrometry
ROS	Reactive oxygen species
Rpm	Rotate per minute
SEM	Scanning Electron Microscope
USA	United States of America
Nm	Nanometer
µm	Micrometer
mm	Millimeter
MPs/Kg	Microplastics per kilogram
MP/m^3	Microplastic per cubic meter
mL	Milliliter
L	Liter
g/mL	Gram per milliliter
g/cm^3	Gram per cubic centimeter
Kg/L	Kilogram per liter
g	gram
Kg	Kilogram
w/v	Weight over volume
v/v	Volume over volume
h	Hour
^oC	Degrees Celsius

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Aquatic bodies are exposed to various anthropogenic pollutions. Anthropogenic pollution comes in different forms such as solid waste, noise, chemical, and biological. Plastic debris has been a major environmental concern since 1940sand a main subject of scientific studies (Thompson et al., 2009). There is now supporting evidence describing ecological, economical, and social impacts associated with plastic debris in the aquatic bodies worldwide.

Plastics have become an indispensable part of human life due to their low cost, versatility, and corrosion resistance properties (Thompson et al., 2009). Since the mass plastic production in the 1940s (Cole et al., 2011), the annual global demand for plastics has been increasing and is currently standing at 322 million tons (PlasticsEurope, 2016). Many plastics are either directly disposed to the natural environment or by passing through the wastewater treatment process and end up in aquatic bodies (Andrady, 2011). As such, plastics may pose a serious threat from an ecological point of view. It was reported that there are more than 5 trillion plastic items with the net weight of over 250,000 tons are currently floating at the surface of oceans (Eriksen et al., 2014) whereby 5 to 13 million tons of plastic waste are added to this amount on an annual basis (Jambeck et al., 2015).To accelerate the breakdown process of plastic debris in the environment, biodegradable plastic polymers have been developed (O'Brine and Thompson, 2010). Their development was proposed to replace the conventional plastic polymers. However, some of the degradable materials may fragment into microscopic particles and may not degrade any quicker than the conventional plastic polymers (Barnes et al., 2009; O'Brine and Thompson, 2010).

The future input of plastic waste tend to increase due to the high production rate (PlasticsEurope, 2016) and shifting in demographic in favor of immigration to coastal areas (Ribic et al., 2010). The origin of MPs in the environment can be divided into primary and secondary sources. Primary MPs are those manufactured to be of microscopic size (Cole et al., 2011). For example, microbeads employed in cosmetic industries (Fendall and Sewell, 2009) may be directly disposed into the marine environment by passing through the wastewater treatment. Secondary MPs are the result of the breakdown of larger plastic debris into the smaller particles in the size range of 1 to 1000 µm (Karami et al., 2016b).

Microplastics are widely detected in many saltwater and freshwater ecosystems such as Singapore's coastal water (Ng and Obbard, 2006) and Laurentian Great Lakes (Eriksen et al., 2013). The accumulation of MPs in saltwater bodies may be concerning as saltwater is used in the production of abiotic products such as salt. Therefore, MPs may also be collected by the saltpans along with saltwater for the salt manufacturing. Furthermore, due to their abundance and small size, they are readily ingested by the aquatic organisms such as fish which may be caught for human consumption (Figure 1.1).

The vast distribution of MPs coupled with their small size will make them bioavailable to a wide array of aquatic organisms. For example, MPs were detected in seafood products cultured for human consumption such as fish (Rochman et al., 2015) and mussels (Van Cauwenberghe and Janssen, 2014). However, MP loads in the processed seafood products such as canned sardine which are widely consumed globally and the edible part of fish have never been assessed which is of great importance as MPs have shown the ability to translocate to different organs of organisms (e.g., Lu et al., 2016).

Microplastics may elicit their harmful effect through different pathways. Many potentially harmful additives such as bisphenol A (BPA) and phthalates are incorporated during manufacturing of plastics which are known to disrupt endocrine system (Halden, 2010). Furthermore, owing to their lipophilic characteristic, MPs will likely absorb these harmful chemical compounds such as heavy metals and pesticides (Rios et al., 2010) from the marine environment and will subsequently release them when ingested (Bakir et al., 2014). Microplastics may also directly cause micro-injuries in aquatic organisms such as blockage of the digestive system, internal abrasion, and ulceration (Wright et al., 2013b).

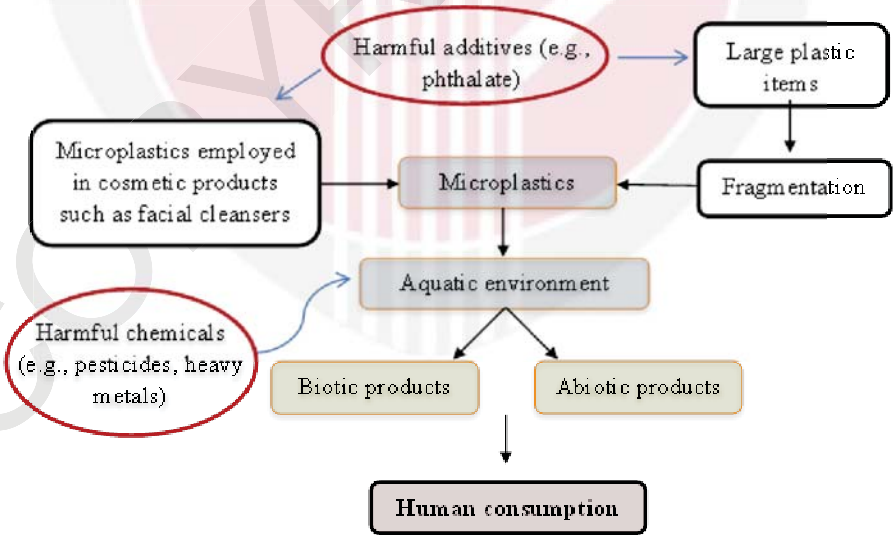

Figure 1.1: Transfer of MPs into human food web

So far, researchers have employed various protocols to extract MPs from biological matrices. Some studies have relied on visual speculation of digestive system under a microscope to estimate the MP loads (Lusher et al., 2013). However, this method cannot be implemented when investigating the presence of MPs in many other aquatic organisms such as mussels. In addition, the number of MPs may be underestimated as the MPs embedded in tissues may not be detected. As such, it was evident that to investigate the presence of MPs in biological tissue, a digestion phase is required to degrade the organic matters without impacting the plastic polymers.

1.2 Problem Statement

To date, a number of digesting agents were employed to remove the biological materials namely, acids (Van Cauwenberghe and Janssen, 2014), bases (Foekema et al., 2013), oxidative agents (Nuelle et al., 2014), and enzyme (Cole et al., 2014). Although the digesting solutions employed by researchers appeared to be somewhat successful in the isolation of MPs from organisms, the information on their performance in degrading organic matters and more importantly, their corrosiveness towards plastic polymers across different temperature are not sufficient.

To date, there are many speculations on the MP contamination of the aquatic environment which led to the investigation of MP loads in the seafood products. However, no study was conducted to assess the MP loads in processed seafood products such as canned sardines that are widely known and directly consumed without prior cleaning process.

Despite the detection of MPs in various seafood products, information on the presence of MPs in abiotic saltwater products which could contain contaminants from the water is scares. Yang et al. (2015) have conducted the only available study on the abiotic products and have reported a high level of MPs (up to 681 MPs/Kg) in Chinese brands of commercial salt samples. However, the chemical composition of every extracted particle was not identified, but the characterization was based on categorizing the particles according to their morphology and identifying the representative particles. Nonetheless, employing the visual identification as standalone in an attempt to identify particles is not a reliable procedure as the number of anthropogenic debris could be significantly overestimated. Furthermore, there is currently no report on the presence of MPs in table salts originating from other parts of the world with a potential 6 billion consumers, not to mention billions of other organisms such as cattle that need to consume salt regularly (Martin and Ward, 1973).

1.3 Significance of the Study

A method has been developed on how to isolate MPs from aquatic organisms based on density separation. This study will provide a benchmark on MP isolation in aquatic organisms.

This thesis has been focused on MP isolation in canned sardine. Previous studies on MPs in fish were limited to MP isolation from alimentary tract of fish species. However, this could not highlight the transfer of MPs into human food web as the digestive tract is usually not consumed.

An experiment was conducted to investigate the MP contamination in the Chinese salt samples. No study was done to estimate the MP loads in the commercial salts manufactured by other regions of the world with billions of potential consumers.

1.4 Objectives of the Study

The general aim of this research was to investigate the transfer of MPs into human food web at a global scale and furthermore, to estimate a preliminary dietary exposure to MPs. This aim was attained through completion of the following objectives:

1. To develop a protocol to efficiently digest biological materials without affecting the polymer integrity.

2. To isolate and characterize MPs in various brands of canned sardine, originating from different countries.

3. To isolate and characterize MPs in different brands of commercial table salts, manufactured by various countries.

1.5 Research Hypotheses

1. The developed protocol will efficiently digest organic matters without any impact on the polymer integrity.

2. Canned sardines manufactured by different countries are contaminated with MPs.

3. Commercial table salts originating from different countries are contaminated with MPs.

1.6 Novelties

This is the first study to:

1. Investigate MP loads in any processed seafood products.

2. Investigate the MP loads in table salts manufactured by different countries.

1.7 Organization of Thesis

This thesis is organized into seven chapters as follows:

Chapter one: This chapter summarizes the general introduction, problem statement, significance of the study, objectives of the study, research hypotheses, and novelties.

Chapter two: This review chapter explains the plastic debris and their impact on the environment and reviews the previous field studies on plastic accumulation in the environment, MP translocation in organs, biological effects of MPs, and potential hazard associated with MPs.

Chapter three: This chapter explains the methods developed and followed in isolation and characterization of MPs in canned sardines and commercial table salts.

Chapter four: This chapter is the published research article on developing a protocol to isolate MPs in fish.

Chapter five: This chapter is a submitted manuscript on MP isolation in canned sardine.

Chapter six: This chapter is the published research article on MP isolation in commercial salts.

Chapter seven: The last chapter provides summary, conclusion, and recommendation for future studies.

REFERENCES

Acosta-Coley, I., Olivero-Verbel, J., 2015. Microplastic resin pellets on an urban tropical beach in Colombia. *Environ Monit Assess* 187, 435.

Ahmad, N.I., Wan Mahiyuddin, W.R., Tengku Mohamad, T.R., Ling, C.Y., Daud, S.F., Hussein, N.C., Abdullah, N.A., Shaharudin, R., Sulaiman, L.H., 2016. Fish consumption pattern among adults of different ethnics in Peninsular Malaysia. *Food and Nutrition Resource* 60.

Al-Malack, M.H., 2001. Migration of lead from unplasticized polyvinyl chloride pipes. *Journal of Hazardous Materials* 82, 263–274.

Al-Sabagh, A.M., Yehia, F.Z., Eshaq, G., Rabie, A.M., ElMetwally, A.E., 2016. Greener routes for recycling of polyethylene terephthalate. *Egyptian Journal of Petroleum* 25, 53–64.

Andrady, A.L., 2011. Microplastics in the marine environment. M*arine Pollution Bulletin* 62, 1596–1605.

Andrady, A.L., Neal, M.A., 2009. Applications and societal benefits of plastics. Philosophical Transactions of the *Royal Society of London B: Biological Sciences* 364, 1977–1984.

Avio, C.G., Gorbi, S., Milan, M., Benedetti, M., Fattorini, D., d'Errico, G., Pauletto, M., Bargelloni, L., Regoli, F., 2015a. Pollutants bioavailability and toxicological risk from microplastics to marine mussels. *Environmental Pollution* 198, 211–222.

Avio, C.G., Gorbi, S., Regoli, F., 2015b. Experimental development of a new protocol for extraction and characterization of microplastics in fish tissues: First observations in commercial species from Adriatic Sea. *Marine Environmental Research, Particles in the Oceans: Implication for a safe marine environment* 111, 18–26.

Awaad, A., Nakamura, M., Ishimura, K., 2012. Imaging of size-dependent uptake and identification of novel pathways in mouse Peyer's patches using fluorescent organosilica particles. *Nanomedicine: Nanotechnology, Biology and Medicine* 8, 627–636.

Awasthi, K., Kulshrestha, V., Avasthi, D.K., Vijay, Y.K., 2010. Optical, chemical and structural modification of oxygen irradiated PET. *Radiation Measurements* 45, 850–855.

Bachman, M.J., Keller, J.M., West, K.L., Jensen, B.A., 2014. Persistent organic pollutant concentrations in blubber of 16 species of *cetaceans* stranded in the Pacific Islands from 1997 through 2011. *Science of The Total Environment* 488–489, 115–123.

Bakir, A., O'Connor, I.A., Rowland, S.J., Hendriks, A.J., Thompson, R.C., 2016. Relative importance of microplastics as a pathway for the transfer of hydrophobic organic chemicals to marine life. *Environmental Pollution* 219, 56–65.

Bakir, A., Rowland, S.J., Thompson, R.C., 2014. Enhanced desorption of persistent organic pollutants from microplastics under simulated physiological conditions. *Environmental Pollution* 185, 16–23.

Ballent, A., Corcoran, P.L., Madden, O., Helm, P.A., Longstaffe, F.J., 2016. Sources and sinks of microplastics in Canadian Lake Ontario nearshore, tributary and beach sediments. *Marine Pollution Bulletin* 110, 383–395.

Barlaz, M.A., 2006. Forest products decomposition in municipal solid waste landfills. *Waste Management* 26, 321–333.

Barnes, D.K.A., 2002. Biodiversity: Invasions by marine life on plastic debris. *Nature* 416, 808–809.

Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal Society B: Biological Sciences* 364, 1985–1998.

Bellas, J., Martínez-Armental, J., Martínez-Cámara, A., Besada, V., Martínez-Gómez, C., 2016. Ingestion of microplastics by demersal fish from the Spanish Atlantic and Mediterranean coasts. *Marine Pollution Bulletin*. 109, 55–60.

Besseling, E., Foekema, E.M., Van Franeker, J.A., Leopold, M.F., Kühn, S., Rebolledo, E.B., He\s se, E., Mielke, L., IJzer, J., Kamminga, P., others, 2015. Microplastic in a macro filter feeder: Humpback whale *Megaptera novaeangliae*. *Marine pollution bulletin* 95, 248–252.

Besseling, E., Wegner, A., Foekema, E.M., van den Heuvel-Greve, M.J., Koelmans, A.A., 2013. Effects of Microplastic on Fitness and PCB Bioaccumulation by the Lugworm *Arenicola marina* (L.). *Environmental Science and Technology* 47, 593–600.

Boerger, C.M., Lattin, G.L., Moore, S.L., Moore, C.J., 2010. Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. *Marine Pollution Bulletin* 60, 2275–2278.

Bogdal, C., Scheringer, M., Abad, E., Abalos, M., van Bavel, B., Hagberg, J., Fiedler, H., 2013. Worldwide distribution of persistent organic pollutants in air, including results of air monitoring by passive air sampling in five continents. *TrAC Trends in Analytical Chemistry* 46, 150–161.

Borgstrom, G., 2012. Fish As Food V4: Processing: Elsevier.

Brennecke, D., Ferreira, E.C., Costa, T.M.M., Appel, D., da Gama, B.A.P., Lenz, M., 2015. Ingested microplastics (>100 µm) are translocated to organs of the tropical fiddler crab *Uca rapax*. *Marine Pollution Bulletin* 96, 491–495.

Brown, I.J., Tzoulaki, I., Candeias, V., Elliott, P., 2009. Salt intakes around the world: implications for public health. *International journal of epidemiology* 38, 791–813.

Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T., Thompson, R., 2011. Accumulation of Microplastic on Shorelines Woldwide: Sources and Sinks. *Environmental Science and Technology* 45, 9175–9179.

Browne, M.A., Dissanayake, A., Galloway, T.S., Lowe, D.M., Thompson, R.C., 2008. Ingested Microscopic Plastic Translocates to the Circulatory System of the Mussel, Mytilus edulis (L.). *Environmental Science and Technology*. 42, 5026–5031.

Browne, M.A., Galloway, T., Thompson, R., 2007. Microplastic—an emerging contaminant of potential concern? *Integrated Environmental Assessment Management* 3, 559–561.

Browne, M.A., Galloway, T.S., Thompson, R.C., 2010. Spatial patterns of plastic debris along Estuarine shorelines. *Environmental Science and Technology*. 44, 3404–3409.

Browne, M.A., Niven, S.J., Galloway, T.S., Rowland, S.J., Thompson, R.C., 2013. Microplastic Moves Pollutants and Additives to Worms, Reducing Functions Linked to Health and Biodiversity. *Current Biology* 23, 2388–2392.

Bürkle GmbH, 2015. Chemische Beständigkeit von Kunststoffen (Germany, Bad Bellingen) [WWW Document]. URL https://www.buerkle.de/de/chemische-bestaendigkeit (accessed 5.8.17).

Carpenter, E.J., Anderson, S.J., Harvey, G.R., Miklas, H.P., Peck, B.B., 1972. Polystyrene Spherules in Coastal Waters. *Science* 178, 749–750.

Carpenter, E.J., Smith, K.L., 1972. Plastics on the Sargasso Sea Surface. *Science* 175, 1240–1241.

Chae, D.-H., Kim, I.-S., Kim, S.-K., Song, Y.K., Shim, W.J., 2015. Abundance and Distribution Characteristics of Microplastics in Surface Seawaters of the Incheon/Kyeonggi Coastal Region. *Archives of Environmental Contamination Toxicology* 69, 269–278.

Champion, J.A., Mitragotri, S., 2006. Role of target geometry in phagocytosis. *Proceedings of National Academy of Sceiences* 103, 4930–4934.

Charvat, R.A., 2005. Coloring of plastics: Fundamentals. John Wiley & Sons.

Chittenden, R.H., Smith, E.E., 1890. On the Primary Cleavage Products formed in the Digestion of Gluten-casein of Wheat by Pepsin-hydrochloric Acid. *The Journal of physiology* 11, 410.

Choy, C.A., Drazen, J.C., 2013. Plastic for dinner? Observations of frequent debris ingestion by pelagic predatory fishes from the central North Pacific. *Marine Ecology Progress Series* 485, 155–163.

Christie, R.M., 1994. Pigments, dyes and fluorescent brightening agents for plastics: An overview. *Polymer international* 34, 351–361.

Claessens, M., Meester, S.D., Landuyt, L.V., Clerck, K.D., Janssen, C.R., 2011. Occurrence and distribution of microplastics in marine sediments along the Belgian coast. *Marine Pollution Bulletin* 62, 2199–2204.

Claessens, M., Van Cauwenberghe, L., Vandegehuchte, M.B., Janssen, C.R., 2013. New techniques for the detection of microplastics in sediments and field collected organisms. Marine Pollution Bulletin 70, 227–233.

Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J., Galloway, T.S., 2013. Microplastic Ingestion by Zooplankton. *Environmental Science and Technology.* 47, 6646–6655.

Cole, M., Lindeque, P., Halsband, C., Galloway, T.S., 2011. Microplastics as contaminants in the marine environment: A review. *Marine Pollution Bulletin* 62, 2588–2597.

Cole, M., Webb, H., Lindeque, P.K., Fileman, E.S., Halsband, C., Galloway, T.S., 2014. Isolation of microplastics in biota-rich seawater samples and marine organisms. *Scientific Reports* 4.

Collard, F., Gilbert, B., Eppe, G., Parmentier, E., Das, K., 2015. Detection of anthropogenic particles in fish stomachs: an isolation method adapted to identification by Raman spectroscopy. *Archives of environmental contamination and toxicology* 69, 331–339.

Collard, F., Gilbert, B., Eppe, G., Roos, L., Compère, P., Das, K., Parmentier, E., 2017. Morphology of the filtration apparatus of three planktivorous fishes and relation with ingested anthropogenic particles. *Marine Pollution Bulletin* 116, 182–191.

Collignon, A., Hecq, J.-H., Glagani, F., Voisin, P., Collard, F., Goffart, A., 2012. Neustonic microplastic and zooplankton in the North Western Mediterranean Sea. *Marine Pollution Bulletin* 64, 861–864.

Colomban, P., Gouadec, G., 2009. Raman and IR micro-analysis of high performance polymer fibres tested in traction and compression. *Composites Science and Technology* 69, 10–16.

Cózar, A., Echevarría, F., González-Gordillo, J.I., Irigoien, X., Úbeda, B., Hernández-León, S., Palma, Á.T., Navarro, S., García-de-Lomas, J., Ruiz, A., Fernández-de-Puelles, M.L., Duarte, C.M., 2014. Plastic debris in the open ocean. *Proceedings of National Academy of Sciences* 111, 10239–10244.

Cózar, A., Sanz-Martín, M., Martí, E., González-Gordillo, J.I., Ubeda, B., Gálvez, J.Á., Irigoien, X., Duarte, C.M., 2015. Plastic accumulation in the Mediterranean Sea. *PloS one* 10, e0121762.

Crompton, T.R., 2015. Plastics Reinforcement and Industrial Applications. CRC Press.

Dantas, D.V., Barletta, M., Costa, M.F. da, 2012. The seasonal and spatial patterns of ingestion of polyfilament nylon fragments by estuarine drums (*Sciaenidae*). *Environmental Science and Pollution Research* 19, 600–606.

Darnerud, P.O., 2003. Toxic effects of brominated flame retardants in man and in wildlife. Environment International, *The State-of-Science and Trends of BFRs in the Environment* 29, 841–853.

Dau, B.K., Gilardi, K.V.K., Gulland, F.M., Higgins, A., Holcomb, J.B., Leger, J.S., Ziccardi, M.H., 2009. Fishing gear–related injury in california marine wildlife. *Journal of Wildlife Diseases* 45, 355–362.

Davidson, K., Dudas, S.E., 2016. Microplastic Ingestion by Wild and Cultured Manila Clams (*Venerupis philippinarum*) from Baynes Sound, British Columbia. *Archives of Environmental Contaminationand Toxicology* 71, 147–156.

Davies, J.M., 1984. Long term mortality study of chromate pigment workers who suffered lead poisoning. *British journal of industrial medicine* 41, 170–178.

Davison, P., Asch, R.G., 2011. Plastic ingestion by mesopelagic fishes in the North Pacific Subtropical Gyre. *Marine Ecology Progress Series* 432, 173–180.

De Witte, B., Devriese, L., Bekaert, K., Hoffman, S., Vandermeersch, G., Cooreman, K., Robbens, J., 2014. Quality assessment of the blue mussel (Mytilus edulis): Comparison between commercial and wild types. *Marine pollution bulletin* 85, 146–155.

Deepak, K.L.N., Rao, S.V., Rao, D.N., 2011. Effects of thermal treatment on femtosecond laser fabricated diffraction gratings in polystyrene. *Applied Surface Science* 257, 9299–9305.

Dehaut, A., Cassone, A.-L., Frère, L., Hermabessiere, L., Himber, C., Rinnert, E., Rivière, G., Lambert, C., Soudant, P., Huvet, A., Duflos, G., Paul-Pont, I., 2016. Microplastics in seafood: Benchmark protocol for their extraction and characterization. *Environmental Pollution* 215, 223–233.

Dekiff, J.H., Remy, D., Klasmeier, J., Fries, E., 2014. Occurrence and spatial distribution of microplastics in sediments from Norderney. *Environmental Pollution* 186, 248–256.

Deng, Y., Zhang, Y., Lemos, B., Ren, H., 2017. Tissue accumulation of microplastics in mice and biomarker responses suggest widespread health risks of exposure. *Scientific Reports* 7.

Derraik, J.G.B., 2002. The pollution of the marine environment by plastic debris: a review. *Marine Pollution Bulletin* 44, 842–852.

Desforges, J.-P.W., Galbraith, M., Ross, P.S., 2015. Ingestion of Microplastics by Zooplankton in the Northeast Pacific Ocean. Archives of Environmental Contamination and Toxicology 69, 320–330.

Devriese, L.I., van der Meulen, M.D., Maes, T., Bekaert, K., Paul-Pont, I., Frère, L., Robbens, J., Vethaak, A.D., 2015. Microplastic contamination in brown shrimp (*Crangon crangon*, Linnaeus 1758) from coastal waters of the Southern North Sea and Channel area. *Marine Pollution Bulletin* 98, 179–187.

Dirkse, T.P., Timmer, R., 1969. The corrosion of zinc in KOH solutions. *Journal of The Electrochemical Society* 116, 162–165.

do Sul, J.A.I., Costa, M.F., Barletta, M., Cysneiros, F.J.A., 2013. Pelagic microplastics around an archipelago of the Equatorial Atlantic. *Marine pollution bulletin* 75, 305–309.

Doyle, M.J., Watson, W., Bowlin, N.M., Sheavly, S.B., 2011. Plastic particles in coastal pelagic ecosystems of the Northeast Pacific ocean. *Marine Environmental Research* 71, 41–52.

Earney, F.C.F., 2012. Marine Mineral Resources. Routledge.

Eberhardt, K., Stiebing, C., Matthäus, C., Schmitt, M., Popp, J., 2015. Advantages and limitations of Raman spectroscopy for molecular diagnostics: an update. *Expert Review of Molecular Diagnostics* 15, 773–787.

Ellahi, S., Hester, R.E., Williams, K.P.J., 1995. Waveguide resonance Raman spectroscopy of degraded PVC. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy* 51, 549–553.

Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., Galgani, F., Ryan, P.G., 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, e111913.

Eriksen, M., Mason, S., Wilson, S., Box, C., Zellers, A., Edwards, W., Farley, H., Amato, S., 2013. Microplastic pollution in the surface waters of the Laurentian Great Lakes. *Marine Pollution Bulletin* 77, 177–182.

Eriksson, P., Jakobsson, E., Fredriksson, A., 2001. Brominated flame retardants: a novel class of developmental neurotoxicants in our environment? *Environ Health Perspect* 109, 903–908.

Fanning, D., 1988. A mortality study of lead workers, 1926–1985. A*rchives of Environmental Health: An International Journal* 43, 247–251.

Farber, J.M., Todd, E.C., 2000. Safe Handling of Foods. CRC Press.

Farrell, P., Nelson, K., 2013. Trophic level transfer of microplastic: *Mytilus edulis* (L.) to *Carcinus maenas* (L.). *Environmental Pollution* 177, 1–3.

Fendall, L.S., Sewell, M.A., 2009. Contributing to marine pollution by washing your face: Microplastics in facial cleansers. *Marine Pollution Bulletin* 58, 1225–1228.

Florence, A.T., Sakthivel, T., Toth, I., 2000. Oral uptake and translocation of a polylysine dendrimer with a lipid surface. *Journal of Controlled Release* 65, 253–259.

Foekema, E.M., De Gruijter, C., Mergia, M.T., van Franeker, J.A., Murk, A.J., Koelmans, A.A., 2013. Plastic in North Sea Fish. *Environmental Science and Technology* 47, 8818–8824.

Foulon, V., Le Roux, F., Lambert, C., Huvet, A., Soudant, P., Paul-Pont, I., 2016. Colonization of polystyrene microparticles by Vibrio crassostreae: light and electron microscopic investigation. *Environmental Science & Technology* 50, 10988–10996.

Free, C.M., Jensen, O.P., Mason, S.A., Eriksen, M., Williamson, N.J., Boldgiv, B., 2014. High-levels of microplastic pollution in a large, remote, mountain lake. *Marine Pollution Bulletin* 85, 156–163.

Frias, J., Sobral, P., Ferreira, A.M., 2010. Organic pollutants in microplastics from two beaches of the Portuguese coast. *Marine Pollution Bulletin* 60, 1988–1992.

Frias, J.P.G.L., Otero, V., Sobral, P., 2014. Evidence of microplastics in samples of zooplankton from Portuguese coastal waters. *Marine Environmental Research* 95, 89–95.

Fries, E., H. Dekiff, J., Willmeyer, J., Nuelle, M.-T., Ebert, M., Remy, D., 2013. Identification of polymer types and additives in marine microplastic particles using pyrolysis-GC/MS and scanning electron microscopy. *Environmental Science: Processes & Impacts* 15, 1949–1956.

Galgani, F., Leaute, J.P., Moguedet, P., Souplet, A., Verin, Y., Carpentier, A., Goraguer, H., Latrouite, D., Andral, B., Cadiou, Y., others, 2000. Litter on the sea floor along European coasts. *Marine pollution bulletin* 40, 516–527.

Gall, S.C., Thompson, R.C., 2015. The impact of debris on marine life. *Marine Pollution Bulletin* 92, 170–179.

Ghorpade, N., Mehta, V., Khare, M., Sinkar, P., Krishnan, S., Rao, C.V., 2002. Toxicity Study of Diethyl Phthalate on Freshwater Fish Cirrhina mrigala. *Ecotoxicology and Environmental Safety* 53, 255–258.

Gray, L.E., Ostby, J., Furr, J., Price, M., Veeramachaneni, D.N.R., Parks, L., 2000. Perinatal Exposure to the Phthalates DEHP, BBP, and DINP, but Not DEP, DMP, or DOTP, Alters Sexual Differentiation of the Male Rat. Toxicological Sciences 58, 350–365.

Gregory, M.R., 2009. Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Philosophical Transactions of the Royal Society B: Biological Sciences* 364, 2013–2025.

Gregory, M.R., 1996. Plastic “scrubbers” in hand cleansers: a further (and minor) source for marine pollution identified. *Marine Pollution Bulletin* 32, 867–871.

Habib, D., Locke, D.C., Cannone, L.J., 1998. Synthetic fibers as indicators of municipal sewage sludge, sludge products, and sewage treatment plant effluents. *Water, Air, and Soil Pollution* 103, 1–8.

Halden, R.U., 2010. Plastics and Health Risks. *Annual Review of Public Health* 31, 179–194.

Heskett, M., Takada, H., Yamashita, R., Yuyama, M., Ito, M., Geok, Y.B., Ogata, Y., Kwan, C., Heckhausen, A., Taylor, H., Powell, T., Morishige, C., Young, D., Patterson, H., Robertson, B., Bailey, E., Mermoz, J., 2012. Measurement of persistent organic pollutants (POPs) in plastic resin pellets from remote islands: Toward establishment of background concentrations for International Pellet Watch. *Marine Pollution Bulletin* 64, 445–448.

Hidalgo-Ruz, V., Gutow, L., Thompson, R.C., Thiel, M., 2012. Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification. *Environmental Science and Technology* 46, 3060–3075.

Holmes, L.A., Turner, A., Thompson, R.C., 2012. Adsorption of trace metals to plastic resin pellets in the marine environment. *Environmental Pollution* 160, 42–48.

Horton, A.A., Svendsen, C., Williams, R.J., Spurgeon, D.J., Lahive, E., 2016. Large microplastic particles in sediments of tributaries of the River Thames, UK – Abundance, sources and methods for effective quantification. *Marine Pollution Bulletin*.

IARC, 2010. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Carbon Black, Titanium Dioxide, and Talc. World Health Organization, Lyon, France.

Imhof, H.K., Ivleva, N.P., Schmid, J., Niessner, R., Laforsch, C., 2013. Contamination of beach sediments of a subalpine lake with microplastic particles. *Current Biology* 23, R867–R868.

Imhof, H.K., Laforsch, C., Wiesheu, A.C., Schmid, J., Anger, P.M., Niessner, R., Ivleva, N.P., 2016. Pigments and plastic in limnetic ecosystems: A qualitative and quantitative study on microparticles of different size classes. *Water research* 98, 64–74.

Imhof, H.K., Schmid, J., Niessner, R., Ivleva, N.P., Laforsch, C., 2012. A novel, highly efficient method for the separation and quantification of plastic particles in sediments of aquatic environments. *Limnology and Oceanography: Methods* 10, 524–537.

Imhof, H.K., Sigl, R., Brauer, E., Feyl, S., Giesemann, P., Klink, S., Leupolz, K., Löder, M.G.J., Löschel, L.A., Missun, J., Muszynski, S., Ramsperger, A.F.R.M., Schrank, I., Speck, S., Steibl, S., Trotter, B., Winter, I., Laforsch, C., 2017. Spatial and temporal variation of macro-, meso- and microplastic abundance on a remote coral island of the Maldives, Indian Ocean. *Marine Pollution Bulletin* 116, 340–347.

Ito, M., Nagai, K., 2007. Analysis of degradation mechanism of plasticized PVC under artificial aging conditions. *Polymer Degradation and Stability* 92, 260–270.

Jabeen, K., Su, L., Li, J., Yang, D., Tong, C., Mu, J., Shi, H., 2017. Microplastics and mesoplastics in fish from coastal and fresh waters of China. *Environmental Pollution* 221, 141–149.

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. *Science* 347, 768–771.

Jani, P.U., Florence, A.T., McCarthy, D.E., 1992. Further histological evidence of the gastrointestinal absorption of polystyrene nanospheres in the rat. *International Journal of Pharmaceutics* 84, 245–252.

Jenkins, M., Mills, N., 2005. Plastics: Microstructure and Engineering Applications. Butterworth-Heinemann.

Jeong, C.-B., Kang, H.-M., Lee, M.-C., Kim, D.-H., Han, J., Hwang, D.-S., Souissi, S., Lee, S.-J., Shin, K.-H., Park, H.G., Lee, J.-S., 2017. Adverse effects of microplastics and oxidative stress-induced MAPK/Nrf2 pathway-mediated defense mechanisms in the marine copepod Paracyclopina nana. *Scientific Reports* 7.

Johnson, A., Salvador, G., Kenney, J., Robbins, J., Kraus, S., Landry, S., Clapham, P., 2005. Fishing Gear Involved in Entanglements of Right and Humpback Whales. *Marine Mammal Science* 21, 635–645.

Karami, A., Christianus, A., Ishak, Z., Syed, M.A., Courtenay, S., 2011. The effects of intramuscular and intraperitoneal injections of Benzo[a]pyrene on selected biomarkers in Clarias gariepinus. *Ecotoxicology and Environmental Safety* 74, 1558–66.

Karami, A., Golieskardi, A., Choo, C.K., Romano, N., Bin, H., Salamatinia, B., 2017. A high-performance protocol for extraction of microplastics in fish. *Science of The Total Environment* 578, 485–494.

Karami, A., Karbalaei, S., Bagher, F.Z., Ismail, A., Simpson, S.L., Courtenay, S.C., 2016a. Alterations in juvenile diploid and triploid African catfish skin gelatin yield and amino acid composition: Effects of chlorpyrifos and butachlor exposures. *Environmental Pollution* 215, 170–177.

Karami, A., Romano, N., Galloway, T., Hamzah, H., 2016b. Virgin microplastics cause toxicity and modulate the impacts of phenanthrene on biomarker responses in African catfish (*Clarias gariepinus*). *Environmental Research* 151, 58–70.

Karl, H., Ostermeyer, U., Bauer, H., Miller, A., Mohn, K., Müller-Hohe, E., Neuhaus, H., Pölzelbauer, C., Stumme, B., Walter, M., Wernusch, J., Werth, B.-M., Wittmann, C., 2014. Collaborative study for quantification of Anisakis larvae in spiked salmon fillets (*Salmo salar*) by a modified Codex digestion method. *Journal of Consumer Protection and Food Safety*. Verbr. Lebensm. 9, 359–365.

Kelts, K., Hsü, K.J., 1978. Freshwater carbonate sedimentation, in: Lakes. Springer, pp. 295–323.

Klemchuk, P.P., 1990. Degradable plastics: A critical review. *Polymer Degradation and Stability* 27, 183–202.

Koch, H.M., Calafat, A.M., 2009. Human body burdens of chemicals used in plastic manufacture. *Philosophical Transactions of the Royal Society B: Biological Sciences* 364, 2063–2078.

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, 3315–3326.

Kukulka, T., Proskurowski, G., Morét-Ferguson, S., Meyer, D.W., Law, K.L., 2012. The effect of wind mixing on the vertical distribution of buoyant plastic debris. *Geophysical Research Letters* 39, L07601.

Lacasse, K., Baumann, W., 2004. Textile Chemicals: Environmental data and facts. *Springer Science & Business Media*.

Langård, S., Norseth, T., 1975. A cohort study of bronchial carcinomas in workers producing chromate pigments. *British journal of industrial medicine* 32, 62–65.

Lanier, B.V., 1981. The World Supply and Demand Picture for Canned Small Pelagic Fish. Food And Agriculture Organization Of The United Nations, Rome, Italy.

Lattin, G.L., Moore, C.J., Zellers, A.F., Moore, S.L., Weisberg, S.B., 2004. A comparison of neustonic plastic and zooplankton at different depths near the southern California shore. *Marine Pollution Bulletin* 49, 291–294.

Law, K.L., Morét-Ferguson, S., Maximenko, N.A., Proskurowski, G., Peacock, E.E., Hafner, J., Reddy, C.M., 2010. Plastic accumulation in the North Atlantic subtropical gyre. *Science* 329, 1185–1188.

Lenz, R., Enders, K., Stedmon, C.A., Mackenzie, D.M.A., Nielsen, T.G., 2015. A critical assessment of visual identification of marine microplastic using Raman spectroscopy for analysis improvement. *Marine Pollution Bulletin* 100, 82–91.

Li, J., Qu, X., Su, L., Zhang, W., Yang, D., Kolandhasamy, P., Li, D., Shi, H., 2016. Microplastics in mussels along the coastal waters of China. *Environmental Pollution* 214, 177–184.

Li, J., Yang, D., Li, L., Jabeen, K., Shi, H., 2015. Microplastics in commercial bivalves from China. *Environmental Pollution* 207, 190–195.

Liebezeit, G., Liebezeit, E., 2015. Origin of Synthetic Particles in Honeys. Polish *Journal of Food and Nutrition Sciences* 65, 143–147.

Liebezeit, G., Liebezeit, E., 2014. Synthetic particles as contaminants in German beers. *Food Additives & Contaminants: Part A* 31, 1574–1578.

Liebezeit, G., Liebezeit, E., 2013. Non-pollen particulates in honey and sugar. *Food Additives & Contaminants: Part A* 30, 2136–2140.

Lima, A.R.A., Costa, M.F., Barletta, M., 2014. Distribution patterns of microplastics within the plankton of a tropical estuary. *Environmental Research* 132, 146–155.

Lingen, C.D.V.D., 2002. Diet of sardine *Sardinops sagax* in the southern Benguela upwelling ecosystem. *South African Journal of Marine Science* 24, 301–316.

Lithner, D., Larsson, Å., Dave, G., 2011. Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. *Science of The Total Environment* 409, 3309–3324.

Lu, Y., Zhang, Y., Deng, Y., Jiang, W., Zhao, Y., Geng, J., Ding, L., Ren, H., 2016. Uptake and Accumulation of Polystyrene Microplastics in Zebrafish (*Danio rerio*) and Toxic Effects in Liver. Environ. Sci. Technol. 50, 4054–4060.

Luís, L.G., Ferreira, P., Fonte, E., Oliveira, M., Guilhermino, L., 2015. Does the presence of microplastics influence the acute toxicity of chromium(VI) to early juveniles of the common goby (*Pomatoschistus microps*)? A study with juveniles from two wild estuarine populations. *Aquatic Toxicology* 164, 163–174.

Lusher, A.L., McHugh, M., Thompson, R.C., 2013. Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. *Marine Pollution Bulletin* 67, 94–99.

Lusher, A.L., Welden, N.A., Sobral, P., Cole, M., 2017. Sampling, isolating and identifying microplastics ingested by fish and invertebrates. *Analytical Methods* 9, 1346–1360.

Maddams, W.F., Royaud, I.A.M., 1991. The application of Fourier transform Raman spectroscopy to the identification and characterisation of polyamides—II. Double-number nylons. *Spectrochimica Acta Part A: Molecular Spectroscopy* 47, 1327–1333.

Mani, T., Hauk, A., Walter, U., Burkhardt-Holm, P., 2015. Microplastics profile along the Rhine River. *Scientific Reports* 5, 17988.

Martin, R.E., Carter, E.P., Jr, G.J.F., Davis, L.M., 2000. Marine and Freshwater Products Handbook. CRC Press, Lancaster, PA.

Martin, S.C., Ward, D.E., 1973. Salt and meal-salt help distribute cattle use on semidesert range. *Journal of Range Management* 94–97.

Mažeikienė, R., Statino, A., Kuodis, Z., Niaura, G., Malinauskas, A., 2006. In situ Raman spectroelectrochemical study of self-doped polyaniline degradation kinetics. *Electrochemistry communications* 8, 1082–1086.

McCormick, A., Hoellein, T.J., Mason, S.A., Schluep, J., Kelly, J.J., 2014. Microplastic is an Abundant and Distinct Microbial Habitat in an Urban River. *Environmental Science and Technology* 48, 11863–11871.

Mizraji, R., Ahrendt, C., Perez-Venegas, D., Vargas, J., Pulgar, J., Aldana, M., Ojeda, F.P., Duarte, C., Galbán-Malagón, C., 2017. Is the feeding type related with the content of microplastics in intertidal fish gut? *Marine Pollution Bulletin*.

Mohanraj, V.J., Chen, Y., 2006. Nanoparticles - A review. *Tropical Journal of Pharmaceutical Research* 5, 561–573.

Moore, C.., Lattin, G.L., Zellers, A.F., 2005. Working our way upstream: a snapshot of landbased contributions of plastic and other trash to coastal waters and beaches of Southern California, in: Proceedings of the Plastic Debris Rivers to Sea Conference. Algalita Marine Research Foundation, Long Beach, CA.

Moore, C.J., 2008. Synthetic polymers in the marine environment: A rapidly increasing, long-term threat. *Environmental Research, The Plastic World* 108, 131–139.

Moore, C.J., Lattin, G.L., Zellers, A.F., 2011. Quantity and type of plastic debris flowing from two urban rivers to coastal waters and beaches of Southern California. J. Integr. *Coastal Zone Management* 11, 65–73.

Morét-Ferguson, S., Law, K.L., Proskurowski, G., Murphy, E.K., Peacock, E.E., Reddy, C.M., 2010. The size, mass, and composition of plastic debris in the western North Atlantic Ocean. *Marine Pollution Bulletin* 60, 1873–1878.

Morgan, R.L., Hill, M.J., Barham, P.J., Van der Pol, A., Kip, B.J., Ottjes, R., Van Ruiten, J., 2001. A study of the phase behaviour of polyethylene blends using micro-Raman imaging. *Polymer* 42, 2121–2135.

Murphy, J., 2001. Additives for Plastics Handbook. Elsevier.

Murray, F., Cowie, P.R., 2011. Plastic contamination in the decapod crustacean Nephrops norvegicus (Linnaeus, 1758). *Marine Pollution Bulletin* 62, 1207–1217.

Nagae, S., Nakamae, K., 2002. Characterization of glass fiber/nylon-6 interface by laser Raman spectroscopy. *International journal of adhesion and adhesives* 22, 139–142.

Naji, A., Esmaili, Z., Khan, F.R., 2017. Plastic debris and microplastics along the beaches of the Strait of Hormuz, Persian Gulf. *Marine Pollution Bulletin* 114, 1057–1062.

National Marine Fisheries Service, 2016. Fisheries of the United States.

Navas-Acien, A., Guallar, E., Silbergeld, E.K., Rothenberg, S.J., 2007. Lead Exposure and Cardiovascular Disease: A Systematic Review. *Environmental Health Perspectives* 115, 472–482.

Neves, D., Sobral, P., Ferreira, J.L., Pereira, T., 2015. Ingestion of microplastics by commercial fish off the Portuguese coast. *Marine Pollution Bulletin* 101, 119–126.

Ng, K.L., Obbard, J.P., 2006. Prevalence of microplastics in Singapore's coastal marine environment. *Marine Pollution Bulletin* 52, 761–767.

Nielsen, A.S., Batchelder, D.N., Pyrz, R., 2002. Estimation of crystallinity of isotactic polypropylene using Raman spectroscopy. *Polymer* 43, 2671–2676.

Norén, F., Naustvoll, L.J., 2010. Survey of microscopic anthropogenic particles in Skagerrak. Report commissioned by Klima-og Forurensningsdirektoratet.

Nuelle, M.-T., Dekiff, J.H., Remy, D., Fries, E., 2014. A new analytical approach for monitoring microplastics in marine sediments. *Environmental Pollution* 184, 161–169.

Obbard, R.W., Sadri, S., Wong, Y.Q., Khitun, A.A., Baker, I., Thompson, R.C., 2014. Global warming releases microplastic legacy frozen in Arctic Sea ice. *Earth's Future* 2, 315–320.

O'Brine, T., Thompson, R.C., 2010. Degradation of plastic carrier bags in the marine environment. *Marine Pollution Bulletin* 60, 2279–2283.

Oehlmann, J., Schulte-Oehlmann, U., Kloas, W., Jagnytsch, O., Lutz, I., Kusk, K.O., Wollenberger, L., Santos, E.M., Paull, G.C., Look, K.J.W.V., Tyler, C.R., 2009. A critical analysis of the biological impacts of plasticizers on wildlife. *Philosophical Transactions of the Royal Society B: Biological Sciences* 364, 2047–2062.

Ogata, Y., Takada, H., Mizukawa, K., Hirai, H., Iwasa, S., Endo, S., Mato, Y., Saha, M., Okuda, K., Nakashima, A., Murakami, M., Zurcher, N., Booyatumanondo, R., Zakaria, M.P., Dung, L.Q., Gordon, M., Miguez, C., Suzuki, S., Moore, C., Karapanagioti, H.K., Weerts, S., McClurg, T., Burres, E., Smith, W., Velkenburg, M.V., Lang, J.S., Lang, R.C., Laursen, D., Danner, B., Stewardson, N., Thompson, R.C., 2009. International Pellet Watch: Global monitoring of persistent organic pollutants (POPs) in coastal waters. 1. Initial phase data on PCBs, DDTs, and HCHs. *Marine Pollution Bulletin* 58, 1437–1446.

Oguzie, E.E., 2006. Studies on the inhibitive effect of Occimum viridis extract on the acid corrosion of mild steel. *Materials Chemistry and Physics* 99, 441–446.

Ory, N.C., Sobral, P., Ferreira, J.L., Thiel, M., 2017. Amberstripe scad Decapterus muroadsi (Carangidae) fish ingest blue microplastics resembling their copepod prey along the coast of Rapa Nui (Easter Island) in the South Pacific subtropical gyre. *Science of The Total Environment* 586, 430–437.

Pająk, A., Rybiński, P., Janowska, G., Kucharska-Jastrząbek, A., 2014. The thermal properties and the flammability of pigmented elastomeric materials. *Journal of Thermal Analysis and Calorimetry* 117, 789–798.

Patil, D.B., Sharma, A.R., 2011. Study on the Corrosion Kinetics of Iron in Acid and Base Medium. *Journal of Chemistry* 8, S358–S362.

Pirc, U., Vidmar, M., Mozer, A., Kržan, A., 2016. Emissions of microplastic fibers from microfiber fleece during domestic washing. *Environmental Science and Pollution Research* 23, 22206–22211.

PlasticsEurope, 2016. An analysis of European plastics production, demand and waste data.

PlasticsEurope, 2014. An Analysis of European Latest Plastics Production, Demand and Waste Data.

PlasticsEurope, 2012. An Analysis of European Plastics Production, Demand and Waste Data.

Pope, J.C., Sue, H.-J., Bremner, T., Blümel, J., 2014. High-temperature steam-treatment of PBI, PEEK, and PEKK polymers with H2O and D2O: A solid-state NMR study. *Polymer* 55, 4577–4585.

Possatto, F.E., Barletta, M., Costa, M.F., Ivar do Sul, J.A., Dantas, D.V., 2011. Plastic debris ingestion by marine catfish: An unexpected fisheries impact. *Marine Pollution Bulletin* 62, 1098–1102.

Powell, J.J., Faria, N., Thomas-McKay, E., Pele, L.C., 2010. Origin and fate of dietary nanoparticles and microparticles in the gastrointestinal tract. *Journal of Autoimmunity, The Environment, Geoepidemiology and Autoimmune Disease* 34, J226–J233.

Powles, J., Fahimi, S., Micha, R., Khatibzadeh, S., Shi, P., Ezzati, M., Engell, R.E., Lim, S.S., Danaei, G., Mozaffarian, D., others, 2013. Global, regional and national sodium intakes in 1990 and 2010: a systematic analysis of 24 h urinary sodium excretion and dietary surveys worldwide. *BMJ open* 3, e003733.

Pruter, A.T., 1987. Sources, quantities and distribution of persistent plastics in the marine environment. *Marine Pollution Bulletin* 18, 305–310.

Qiu, Q., Peng, J., Yu, X., Chen, F., Wang, J., Dong, F., 2015. Occurrence of microplastics in the coastal marine environment: First observation on sediment of China. *Marine Pollution Bulletin* 98, 274–280.

Rands, M.R.W., Adams, W.M., Bennun, L., Butchart, S.H.M., Clements, A., Coomes, D., Entwistle, A., Hodge, I., Kapos, V., Scharlemann, J.P.W., Sutherland, W.J., Vira, B., 2010. Biodiversity Conservation: Challenges Beyond 2010. *Science* 329, 1298–1303.

Reddy, M.S., Basha, S., Adimurthy, S., Ramachandraiah, G., 2006. Description of the small plastics fragments in marine sediments along the Alang-Sosiya ship-breaking yard, India. *Estuarine, Coastal and Shelf Science* 68, 656–660.

Ribic, C.A., Sheavly, S.B., Rugg, D.J., Erdmann, E.S., 2010. Trends and drivers of marine debris on the Atlantic coast of the United States 1997–2007. *Marine Pollution Bulletin* 60, 1231–1242.

Rios, L.M., Jones, P.R., Moore, C., Narayan, U.V., 2010. Quantitation of persistent organic pollutants adsorbed on plastic debris from the Northern Pacific Gyre's "eastern garbage patch." *Jornal of Environmental Monitoring* 12, 2226–2236.

Rios, L.M., Moore, C., Jones, P.R., 2007. Persistent organic pollutants carried by synthetic polymers in the ocean environment. *Marine Pollution Bulletin* 54, 1230–1237.

Rochman, C.M., Hoh, E., Hentschel, B.T., Kaye, S., 2013a. Long-Term Field Measurement of Sorption of Organic Contaminants to Five Types of Plastic Pellets: Implications for Plastic Marine Debris. *Environmental Science and Technology* 47, 1646–1654.

Rochman, C.M., Hoh, E., Kurobe, T., Teh, S.J., 2013b. Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. *Scientific Reports* 3, 3263.

Rochman, C.M., Tahir, A., Williams, S.L., Baxa, D.V., Lam, R., Miller, J.T., Teh, F.-C., Werorilangi, S., Teh, S.J., 2015. Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. *Scientific Reports* 5.

Rossi, G., Barnoud, J., Monticelli, L., 2014. Polystyrene Nanoparticles Perturb Lipid Membranes. *Journal of Physical Chemistry Letters* 5, 241–246.

Sadri, S.S., Thompson, R.C., 2014. On the quantity and composition of floating plastic debris entering and leaving the Tamar Estuary, Southwest England. *Marine Pollution Bulletin* 81, 55–60.

Seifert, J., Sass, W., 1990. Intestinal Absorption of Macromolecules and Small Particles. *Digestive Disease Intervention* 8, 169–178.

Serrano, R., Nácher-Mestre, J., Portolés, T., Amat, F., Hernández, F., 2011. Non-target screening of organic contaminants in marine salts by gas chromatography coupled to high-resolution time-of-flight mass spectrometry. *Talanta* 85, 877–884.

Shah, A.A., Hasan, F., Hameed, A., Ahmed, S., 2008. Biological degradation of plastics: A comprehensive review. *Biotechnology Advances* 26, 246–265.

Shaw, D.G., Day, R.H., 1994. Colour-and form-dependent loss of plastic micro-debris from the North Pacific Ocean. *Marine Pollution Bulletin* 28, 39–43.

Shinzawa, H., Ozaki, Y., Chung, H., 2012. Study of the pre-melting behavior of polyethylene using Raman spectroscopy combined with two-dimensional (2D) correlation spectroscopy. *Vibrational Spectroscopy* 60, 154–157.

Sivan, A., 2011. New perspectives in plastic biodegradation. Current Opinion in Biotechnology, Energy biotechnology – *Environmental biotechnology* 22, 422–426.

Sokka, L., Antikainen, R., Kauppi, P.E., 2007. Municipal solid waste production and composition in Finland—Changes in the period 1960–2002 and prospects until 2020. *Resources, Conservation and Recycling* 50, 475–488.

Song, Y.K., Hong, S.H., Jang, M., Han, G.M., Rani, M., Lee, J., Shim, W.J., 2015. A comparison of microscopic and spectroscopic identification methods for analysis of microplastics in environmental samples. *Marine Pollution Bulleti*n 93, 202–209.

Stojicic, S., Zivkovic, S., Qian, W., Zhang, H., Haapasalo, M., 2010. Tissue dissolution by sodium hypochlorite: effect of concentration, temperature, agitation, and surfactant. *Journal of endodontics* 36, 1558–1562.

Suhrhoff, T.J., Scholz-Böttcher, B.M., 2016. Qualitative impact of salinity, UV radiation and turbulence on leaching of organic plastic additives from four common plastics — A lab experiment. *Marine Pollution Bulletin* 102, 84–94.

Sussarellu, R., Suquet, M., Thomas, Y., Lambert, C., Fabioux, C., Pernet, M.E.J., Goïc, N.L., Quillien, V., Mingant, C., Epelboin, Y., Corporeau, C., Guyomarch, J., Robbens, J., Paul-Pont, I., Soudant, P., Huvet, A., 2016. Oyster reproduction is affected by exposure to polystyrene microplastics. *Proceedings of the National Academy of Sciences* 113, 2430–2435.

Tanaka, K., Takada, H., 2016. Microplastic fragments and microbeads in digestive tracts of planktivorous fish from urban coastal waters. *Scientific Reports* 6.

Teuten, E.L., Saquing, J.M., Knappe, D.R.U., Barlaz, M.A., Jonsson, S., Björn, A., Rowland, S.J., Thompson, R.C., Galloway, T.S., Yamashita, R., Ochi, D., Watanuki, Y., Moore, C., Viet, P.H., Tana, T.S., Prudente, M., Boonyatumanond, R., Zakaria, M.P., Akkhavong, K., Ogata, Y., Hirai, H., Iwasa, S., Mizukawa, K., Hagino, Y., Imamura, A., Saha, M., Takada, H., 2009.

Transport and Release of Chemicals from Plastics to the Environment and to Wildlife. *Philosophical Transactions: Biological Sciences* 364, 2027–2045.

Thermo fisher Scientific, 2016. Chemical Compatibility Guide. Available at: https://tools.thermofisher.com/content/sfs/manuals/chem-comp-sample-storage-guide-PFLSPSTORAGECHEM-EN.pdf.

Thompson, R., Moore, C., Andrady, A., Gregory, M., Takada, H., Weisberg, S., 2005. New Directions in Plastic Debris. *Science* 310, 1117–1117.

Thompson, R.C., Olsen, Y., Mitchell, R.P., Davis, A., Rowland, S.J., John, A.W.G., McGonigle, D., Russell, A.E., 2004. Lost at Sea: Where Is All the Plastic? *Science* 304, 838–838.

Thompson, R.C., Swan, S.H., Moore, C.J., Saal, F.S. vom, 2009. Our plastic age. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 364, 1973–1976.

Tomba, J.P., Mana, C.D., Perez, C.J., Desimone, P.M., Galland, G.B., 2016. Microstructural characterization of semicrystalline copolymers by Raman spectroscopy. *Polymer Testing* 52, 71–78.

Turner, A., 2010. Marine pollution from antifouling paint particles. *Marine Pollution Bulletin* 60, 159–171.

Van Cauwenberghe, L., Claessens, M., Vandegehuchte, M.B., Janssen, C.R., 2015. Microplastics are taken up by mussels (*Mytilus edulis*) and lugworms (*Arenicola marina*) living in natural habitats. *Environmental Pollution* 199, 10–17.

Van Cauwenberghe, L., Janssen, C.R., 2014. Microplastics in bivalves cultured for human consumption. *Environmental Pollution* 193, 65–70.

Van Cauwenberghe, L., Vanreusel, A., Mees, J., Janssen, C.R., 2013. Microplastic pollution in deep-sea sediments. *Environmental Pollution* 182, 495–499.

Veres, M., Tóth, A., Mohai, M., Bertóti, I., Szépvölgyi, J., Tóth, S., Himics, L., Koós, M., 2012. Two-wavelength Raman study of poly (ethylene terephthalate) surfaces modified by helium plasma-based ion implantation. *Applied Surface Science* 263, 423–429.

Vilímová, P., Tokarskỳ, J., Peikertová, P., Kutláková, K.M., Plaček, T., 2016. Influence of thermal and UV treatment on the polypropylene/graphite composite. *Polymer Testing* 52, 46–53.

Volkheimer, G., 1993. Persorption of microparticles. *Pathologe* 14, 247–252.

Volkheimer, G., 1974. Passage of particles through the wall of the gastrointestinal tract. *Environ Health Perspect* 9, 215–225.

von Moos, N., Burkhardt-Holm, P., Köhler, A., 2012. Uptake and Effects of Microplastics on Cells and Tissue of the Blue Mussel Mytilus edulis L. after an Experimental Exposure. *Environmental Science and Technology* 46, 11327–11335.

Wan, B.-Z., Kao, C.-Y., Cheng, W.-H., 2001. Kinetics of Depolymerization of Poly(ethylene terephthalate) in a Potassium Hydroxide Solution. *Industrial and Engineering Chemistry Research* 40, 509–514.

Warne, D., 1988. Manual on Fish Canning, FAO fisheries technical paper. Food and Agriculture Organization of the United Nations, Rome.

Watts, A.J.R., Urbina, M.A., Corr, S., Lewis, C., Galloway, T.S., 2015. Ingestion of Plastic Microfibers by the Crab Carcinus maenas and Its Effect on Food Consumption and Energy Balance. *Environmental Scienceand Technology* 49, 14597–14604.

Wesley, I.J., Hendra, P.J., 1994. The low temperature Fourier Transform Raman spectrum of polystyrenes. *Spectrochimica Acta Part A: Molecular Spectroscopy* 50, 1959–1966.

Whitehead, P.J.., 1985. FAO species catalogue. 1985 Vo1.7. *Clupeoid* fishes of the world. An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, anchovies and wolfherrings. Part 1 - *Chirocentridae*, *Clupeidae* and *Pristigasteridae*. FAO Fisheries Synopsis, Rome.

Winston, J.E., 1982. Drift plastic—An expanding niche for a marine invertebrate? *Marine Pollution Bulletin* 13, 348–351.

Wittcoff, H.A., Reuben, B.G., Plotkin, J.S., 2012. Industrial organic chemicals. John Wiley & Sons.

Woodall, L.C., Sanchez-Vidal, A., Canals, M., Paterson, G.L.J., Coppock, R., Sleight, V., Calafat, A., Rogers, A.D., Narayanaswamy, B.E., Thompson, R.C., 2014. The deep sea is a major sink for microplastic debris. *Open Science* 1, 140317.

Wright, S.L., Rowe, D., Thompson, R.C., Galloway, T.S., 2013a. Microplastic ingestion decreases energy reserves in marine worms. *Current Biology* 23, R1031–R1033.

Wright, S.L., Thompson, R.C., Galloway, T.S., 2013b. The physical impacts of microplastics on marine organisms: A review. *Environmental Pollution* 178, 483–492.

Wypych, G., 2017. Handbook of Plasticizers, 3rd ed. ChemTec Publishing, Toronto.

Yang, D., Shi, H., Li, L., Li, J., Jabeen, K., Kolandhasamy, P., 2015. Microplastic Pollution in Table Salts from China. *Environmental Science and Technology* 49, 13622–13627.

Yonkos, L.T., Friedel, E.A., Perez-Reyes, A.C., Ghosal, S., Arthur, C.D., 2014. Microplastics in Four Estuarine Rivers in the Chesapeake Bay, U.S.A. *Environmental Science and Technology* 48, 14195–14202.

Yoshioka, T., Okayama, N., Okuwaki, A., 1998. Kinetics of hydrolysis of PET powder in nitric acid by a modified shrinking-core model. *Industrial & engineering chemistry research* 37, 336–340.

Yoshioka, T., Sato, T., Okuwaki, A., 1994. Hydrolysis of waste PET by sulfuric acid at 150 C for a chemical recycling. *Journal of applied polymer science* 52, 1353–1355.

Zhao, S., Zhu, L., Li, D., 2015. Microplastic in three urban estuaries, China. *Environmental Pollution* 206, 597–604.