Chapter 1

The Microplastic Cycle: An Introduction to a Complex Issue

Michael S. Bank and Sophia V. Hansson

Abstract The microplastic cycle was originally and formally introduced and defined as a novel concept and paradigm for understanding plastic pollution and its fluxes across ecosystem reservoirs. This concept has now been expanded to include macroplastic particles and links all aspects of the fate, transport, and effects of plastic pollution, including source-receptor models in the environment, and expanded on previously established perspectives that viewed the plastic pollution issue in a less integrated manner. The value of this paradigm is that this perspective integrates three basic scientific spheres: environmental chemistry, biology (i.e., trophic transfer), and human health. The goal of this chapter is to introduce readers to the microplastic pollution problem and to outline the microplastic cycle as a concept and holistic paradigm for addressing this ubiquitous environmental and potential public health problem. The specific objectives of this chapter were to (1) introduce this volume and its chapters by outlining the microplastic pollution issue in the context of the entire plastic cycle; (2) evaluate fluxes of microplastics across different ecosystem compartments, including the atmosphere, lithosphere, hydrosphere, and biosphere, including humans; and (3) provide insights on public policy and potential solutions to the microplastic pollution problem.

M. S. Bank (✉)

Institute of Marine Research, Bergen, Norway

University of Massachusetts Amherst, Amherst, MA, USA

e-mail: Michael.Bank@hi.no; mbank@eco.umass.edu

S. V. Hansson

Laboratoire Ecologie Fonctionnelle et Environnement – UMR-5245, CNRS,

Université de Toulouse, Castanet Tolosan, France

e-mail: sophia.hansson@toulouse-inp.fr

© The Author(s) 2022

M. S. Bank (ed.), *Microplastic in the Environment: Pattern and Process*,
Environmental Contamination Remediation and Management,
https://doi.org/10.1007/978-3-030-78627-4_1

1.1 Introduction

Microplastic pollution is a complex problem (Thompson et al. 2004; Windsor et al. 2019) that has considerable consequences for environmental and public health. This pollution issue is a classic transboundary example of how land-based pollution can become extremely widespread, even entering remote regions including pristine mountainous regions, wilderness areas, and the Arctic (Bergmann et al. 2019; Brahney et al. 2020) and the deepest trenches of the ocean (Jamieson et al. 2019). Because plastic pollution is physically visible, this issue has garnered significant interest from a wide array of stakeholders including scientists, policy makers, and especially the media and the public. The overall attention to this issue has been immense and possibly unlike any other pollution issue in the history of science (Sedlak 2017). As a result of this visibility and attention toward the plastic and microplastic pollution issue, new paradigms and holistic perspectives have emerged to evaluate, study, and manage (Borrelle et al. 2020; Lau et al. 2020; Bank et al. 2021) the plastic waste problem. Here we provide an outline for the chapters in this volume and shortly introduce the concept of the microplastic pollution cycle (Bank and Hansson 2019).

The microplastic cycle was originally and formally introduced and defined as a novel concept and paradigm for understanding plastic pollution and its fluxes across ecosystem reservoirs (Bank and Hansson 2019). This concept has now been expanded to include macroplastic particles (Lechthaler et al. 2020) and links all aspects of the fate, transport, and effects of plastic pollution, including source-receptor models (Waldschläger et al. 2020; Hoellein and Rochman 2021), in the environment and expanded on previously established perspectives that tended to view the plastic pollution issue in a less integrated manner. The value of this paradigm is that this perspective integrates three basic scientific spheres: environmental chemistry, biology (i.e., trophic transfer), and human health (Fig. 1.1).

The goal of this chapter is to introduce readers to the microplastic pollution problem and to outline the microplastic cycle as a concept and holistic paradigm for addressing this ubiquitous environmental and potential public health problem. The specific objectives of this chapter were to (1) introduce this volume and its chapters by outlining the microplastic pollution issue in the context of the entire plastic cycle; (2) evaluate fluxes of microplastics across different ecosystem compartments, including the atmosphere, lithosphere, hydrosphere, and biosphere, including humans; and (3) provide insights on public policy and potential solutions to the microplastic pollution problem.

Fig. 1.1 Conceptual figure of the microplastic cycle and the complex movements of plastic particles, and their associated chemicals, through different ecosystem compartments. (Adapted from Bank and Hansson 2019)

1.2 Fluxes of Microplastics Across Ecosystem Compartments

The field of plastic pollution is rapidly moving forward, and over the last few years, research efforts have advanced the understanding of microplastic pollution and the movement of microplastics from urban areas to rivers and lakes, river runoff and transport to the sea, as well as marine dispersion of microplastics across ocean basins and deep ocean layers (Horton et al. 2017; Peng et al. 2018; Hale et al. 2020). Several efforts have been made to summarize, critically review, and provide a larger perspective on the current status of microplastics in the environment (e.g., Sedlak 2017; Horton and Dixon 2018; Akdogan and Guven 2019; Wu et al. 2019; Zhang et al. 2020; Hale et al. 2020). Within this chapter, we therefore only present the issue of plastic pollution across ecosystem compartments in brief and refer to already published literature (e.g., Horton and Dixon 2018; Hale et al. 2020; Bank et al. 2021; Hoellein and Rochman 2021) and relevant chapters within this volume for more comprehensive and detailed descriptions.

1.3 Microplastic and Terrestrial Ecosystems

Despite the fact that the majority of the plastic consumption (the usage of plastic in maritime fishing being the exception) as well as all plastic production occurs on land (Horton and Dixon 2018), the terrestrial environment has received less attention (compared to, e.g., marine ecosystems) when it comes to research on plastic and microplastic pollution. This topic is covered in Chap. 4 (Kallenbach et al. [this volume](#)).

Sources and input of plastic to the terrestrial environment include traffic and vehicle tire abrasion (Kole et al. 2017; Evangeliou et al. 2020), domestic and household activities such as cosmetics and cleaning agents (Murphy et al. 2016), synthetic fibers from clothing and textile washing (Habib et al. 1998; Browne et al. 2011; Napper and Thompson 2016; Boucher and Friot 2017), coatings, paint, and preparatory painting activities such as abrasive blasting (Takahashi et al. 2012; Song et al. 2015; Chae et al. 2015) to name a few. Direct littering and inadequately managed waste, including industrial spillages and release from landfill sites (Sadri and Thompson 2014; Lechner et al. 2014; Mason et al. 2016; Murphy et al. 2016; Kay et al. 2018; Hale et al. 2020 and references therein) also contribute plastic to the terrestrial environment. This is also the case of intentionally or accidentally burning of plastics, i.e., plastics released via poorly controlled disposal through burning or via natural wildfires can release plastic particles to the atmosphere as well as the surrounding environment which will subsequently be transported into nearby waterways (Gullett et al. 2007; Asante et al. 2016; Ni et al. 2016; Hale et al. 2020).

Agricultural activities can also lead to a discharge of plastics to the terrestrial environment, either through improper disposal of wrapping and bale twine but also via sewage sludge applied to agricultural lands (Mahon et al. 2017; Corradini et al.

2019). For example, Nizzetto et al. (2016) estimated that in Europe alone, 125–850 tons of microplastic per million inhabitants per year are added to agricultural soils via sewage sludge applications. Combined with input from mismanaged waste and littering, the plastic stock stored within terrestrial ecosystems will either lead to a massive accumulation (Horton and Dixon 2018) or act as a source to other ecosystem compartments (Jambeck et al. 2015). It has indeed been shown that urban centers and resuspension of plastic particles in soil are the principal sources for plastics later deposited via wet deposition (Brahney et al. 2020).

1.4 Microplastic and Freshwater Ecosystems

Microplastic pollution in aquatic freshwater ecosystems is highly complex as its environmental compartments include ditches, streams, rivers, estuaries, temporary and permanent wetlands, ponds, dams, and lakes, all of which have different characteristics in terms of hydrology, chemistry, flora, and fauna as well as their surrounding watershed and land-use patterns. Furthermore, freshwater ecosystems can act as both a receiver, sink, and transporter of plastic pollution (Eerkes-Medrano et al. 2015; Horton and Dixon 2018; Li et al. 2018; van Emmerik and Schwarz 2020). For example, direct littering, as well as mismanaged waste or inadequate waste disposal, acts as sources of plastic to the aquatic environment through wind transport, atmospheric deposition, and/or surface runoff from adjacent lands (Horton et al. 2017; Xia et al. 2020). Hitchcock (2020) recently showed that storm events act as key drivers of microplastic contamination in aquatic systems. For example, microplastic abundance was >40-fold higher during, and directly after, a storm event compared to before. Similar results were also found by Xia et al. (2020) who showed that rainfall is a significant driver of environmental microplastic pollution to inland surface waters. It should be noted though that both studies concluded that it is not the rain directly that causes this increase in plastic input but rather the surface runoff caused by the rain events during which plastics (macro- and microscale) were transported from land to the associated aquatic ecosystems. This is further supported by the results of Boucher and Friot (2017), as well as Horton et al. (2017), who showed that storm drainage and urban runoff is often untreated and unfiltered, allowing macroplastic from littering as well as microplastics from, e.g., degraded wear of tires, vehicles, and road paint, to be washed directly into nearby aquatic systems.

Once deposited, the plastic may degrade from primary to secondary particles and be efficiently dispersed (Williams and Simmons 1996; Weinstein et al. 2016) or be retained in the sediment (Castañeda et al. 2014; Klein et al. 2015; Nizzetto et al. 2016). Furthermore, it has also been shown that rivers may act as major pathways in the transport of plastic from land to the ocean (Jambeck et al. 2015; Schmidt et al. 2017; Lebreton et al. 2017), even being referred to as “highways for microplastics” (Barbuzano 2019). For example, it has been estimated that rivers and estuaries

release 0.47–2.75 million tons of plastic to the ocean on an annual basis (Schmidt et al. 2017; Lebreton et al. 2017).

Although much research has been focused on river ecosystems, it has also been shown that plastic pollution also occurs within ponds and lakes across the globe (Eriksen et al. 2013; Free et al. 2014; Baldwin et al. 2016; Vaughan et al. 2017; Alfonso et al. 2020). For example, in a recent study, Alfonso et al. (2020) concluded that microplastic pollution occurs even in lakes located in remote and relatively pristine areas such as the Patagonian Andes which is considered to be one of the most sparsely populated and remote regions of the world. However, in contrast to rivers, lakes and ponds are more likely to retain plastic that has been settled in the sediment, without further transport to the ocean, and would therefore likely accumulate plastic over time (Vaughan et al. 2017; Horton and Dixon 2018). Here the fate, distribution, and impacts of plastic pollution across a range of different particle size classes are discussed in Chaps. 4 and 7 (Kallenbach et al. [this volume](#); Gomes et al. [this volume](#)).

1.5 Microplastic and Marine Ecosystems

Microplastic pollution in marine ecosystems is largely a result of terrestrial runoff and plastic industrial wastes, although abandoned fishing gear is also recognized as an important source (Xue et al. 2020). This topic is widely studied and is covered in more detail by seminal papers including Cole et al. (2011), Hidalgo-Ruz et al. (2012), Wright et al. (2013), Sharma and Chatterjee (2017), Choy et al. (2019), Isobe et al. (2019), Onink et al. (2019), Allen et al. (2020), Hale et al. (2020), Kane et al. (2020), van Sebille et al. (2020), as well as Chap. 5 (Lundebye et al. [this volume](#)). Human activities in the coastal zone including fishing, aquaculture (Lusher et al. 2017), tourism, and marine industry are also important sources of microplastic pollution in saltwater environments. Here the sources, fate, and transport dynamics and effects of plastic and microplastic pollution across a range of different size classes are discussed in Chaps. 4, 5, 7, 8, and 9 (Kallenbach et al. [this volume](#); Lundebye et al. [this volume](#); Gomes et al. [this volume](#); Garrido Gamarro and Costanzo [this volume](#); Marathe and Bank [this volume](#)).

The marine environment has a unique set of physicochemical conditions, ocean circulation patterns, pressure, and water column dynamics (Choy et al. 2019; Onink et al. 2019; Kane et al. 2020; van Sebille et al. 2020) that govern the sources, fate, and transport dynamics of microplastics in addition to other important aspects such as biofouling and biofilm production (Zettler et al. 2013), as well as release or adsorption of secondary contaminants (Sharma and Chatterjee 2017). Additionally, microplastics are made with a variety of polymers, have different molecular structures, and are extremely diverse regarding their size, shape, color, and density and are viewed as a complex suite of contaminants (Rochman et al. 2019). These different properties of microplastics influence their distribution, buoyancy and sinking properties, their fate, and transport dynamics within marine ecosystems and govern

their bioavailability and trophic transfer to marine biota (Sharma and Chatterjee 2017). The concept of marine snow (e.g., the continuous settling of mostly organic particles from upper regions of the water column) is an important mechanism that can transport microplastics from the ocean's surface layer to deep pelagic and meso-pelagic zones and may also enhance their bioavailability to biota inhabiting benthic habitats (Porter et al. 2018). Based on modeling simulations, Koelmans et al. (2017) estimated that 99.8% of aquatic plastic pollution since 1950 has settled beneath the ocean surface layer by 2016 with an additional ~9.4 million tons settling per year. Furthermore, while it is known that microplastics are transported to the seafloor by vertical settling from the surface, the spatial distribution, fate, and transport dynamics of microplastics are now understood to also be largely governed by sea bottom, thermohaline currents (Kane et al. 2020).

Microplastic in the ocean is a primary concern for ultimately two important and interrelated reasons. First, microplastics in the ocean can absorb and release toxic substances (Gouin et al. 2011) and are ingested by marine biota (Laist 1997; Cole et al. 2011; Wright et al. 2013), including seafood species (Smith et al. 2018). Microplastics are often found in high abundances in both the water column (Choy et al. 2019) and in deep-sea sediments (Kane et al. 2020) where they can then be taken up by biota. Second, the potential human health risks from the direct and indirect effects of microplastic pollution are also a primary concern (Bank et al. 2020; Barboza et al. 2018, 2020). However, while microplastic exposures have been reported to have negative effects on biota, ultimately many critical uncertainties regarding their complex toxicological profiles still remain, and overall much remains poorly understood (Hidalgo-Ruz et al. 2012; Wright et al. 2013; Kögel et al. 2020). Furthermore, the relationship between seafood safety is also not well understood although some recent investigations have identified important linkages between wild marine fish, microplastics, and toxic compounds such as bisphenol A (Barboza et al. 2020). These findings illustrate the importance and need for more comprehensive surveillance regarding the connection between seafood safety, human exposure, toxics, and overall food security (Barboza et al. 2018; Lundebye et al. [this volume](#)).

1.6 Microplastic and the Atmosphere

The fate and quantification of microplastics in the atmosphere are less explored compared to other ecosystem compartments, yet recent advancements have been made (Zhang et al. 2020). For example, recent studies have focused on microplastic occurrence in the atmosphere and have demonstrated significant microplastic atmospheric deposition in urban environments in, e.g., France (Dris et al. 2015, 2016; Gasperi et al. 2018), Germany (Klein and Fischer 2019), the UK (Stanton et al. 2019; Wright et al. 2020), Iran (Dehghani et al. 2017; Abbasi et al. 2019), and China (Cai et al. 2017; Liu et al. 2019).

However, like other environmental contaminants such as PAHs and metals, microplastic suspended in the atmosphere can also be subject to long-range transport and atmospheric deposition (Zhang et al. 2020 and reference therein). Studies based on microplastic in the atmosphere, in wet deposition and in soils, strongly indicate that the atmosphere may act as an important pathway in the dispersal of microplastic on a global scale by transporting microplastic from urban areas to remote locations (Dris et al. 2016; Peeken et al. 2018; Allen et al. 2019; Roblin et al. 2020). It has, for example, been recently shown that microplastic from atmospheric deposition can be found in remote areas such as the French Pyrenees (Allen et al. 2019) and the Alps (Ambrosini et al. 2019; Bergmann et al. 2019) but also in the Arctic (Bergmann et al. 2019; Zhang et al. 2019) and in ocean surface air (Liu et al. 2019; Wang et al. 2020). Further, Allen et al. (2019) showed that not only did atmospheric deposition of microplastic occur at their remote sampling site in the French Pyrenees (i.e., no urban populations or development within ≥ 95 km) but also that this deposition was comparable to the atmospheric deposition found in megacities such as Dongguan or Paris (Dris et al. 2016; Cai et al. 2017). Roblin et al. (2020) also showed that in four remote sites in Ireland, the majority (i.e., 70%) of the investigated anthropogenic and plastic microfibers were deposited via wet atmospheric deposition, whereas Brahney et al. (2020) showed that dry deposition of plastic also plays an important role in the global plastic cycle, especially when it comes to long-range and/or global transport.

Although microplastic particles exist in a diverse array of shapes, sizes, molecules, and molecular structures, their general low material density, small size, and high surface area enable them to easily enter and become suspended in the air (Dris et al. 2016; Abbasi et al. 2019; Wang et al. 2020). Anthropogenic activities in the terrestrial environment, such as direct littering, inadequately managed waste, industrial spillages, and release from landfill sites, are therefore all considered potential sources of microplastic to the atmosphere. However, although the ocean is generally perceived as a receiver and sink of macro- to nanoscale plastic (Eriksen et al. 2013, 2014; Isobe et al. 2019), deposited either directly (via, e.g., mismanagement of maritime fishing) or indirectly via river runoff or atmospheric deposition, it has recently been shown that the ocean may also act as a source of plastic back to the atmosphere via wind-driven sea spray formation and bubble burst ejection (Allen et al. 2020). As such, marine microplastic hotspots may therefore act not just as a sink but also as a source of microplastics to the atmospheric compartment contributing to long-range and terrestrial microplastic transport. This would mean a continuum of the transfer of plastic between ecosystem compartments and environmental reservoirs and that just as carbon, nitrogen, mercury, or lead, plastic too follows the pathway of full environmental and biogeochemical cycles (Bank and Hansson 2019).

1.7 Microplastic in Biota

Biological organisms, including humans, are important receptors of microplastics and are exposed via air, water, and ingestion of microplastics and through consuming the food items containing them (Cole et al. 2011; Wright et al. 2013; Gall and Thompson 2015; Anbumani and Kakkar 2018; Prinz and Korez 2020). The size class of plastic particles (Wright et al. 2013; Kögel et al. 2020) and association with other toxic compounds are recognized as an important concept regarding its overall toxicity, and microplastic particles are now viewed as a complex suite of contaminants (Rochman et al. 2019). Ecotoxicology and effects of microplastics on biota are synthesized in this volume in Chap. 7 (Gomes et al. [this volume](#)), and aspects of human health are covered in Chaps. 5 (Lundebye et al. [this volume](#)), 8 (Garrido Gamarro and Costanzo [this volume](#)), and 9 (Marathe and Bank [this volume](#)).

One of the primary issues confronting the assessment of microplastics in biota is the lack of standardized approaches, and in general this limits the progress regarding the potential abatement of microplastic pollution as well as the study of toxicological profiles which are inherently complex (Rochman et al. 2019; Koelmans et al. 2020). However, recently progress has been made regarding the development of probability-based models of species sensitivity distribution that correct for issues driven by the incompatibility of data and results from experiments caused by differences in the microplastic types used in effect studies compared to those that are truly environmentally relevant in natural settings (Koelmans et al. 2020). Moreover, of equal importance regarding the improvement of environmentally relevant exposure conditions (e.g., size and shape) for microplastic ecotoxicology studies is the need for verification of background contamination and addressing associated risks from inhibition of food or reduced nutrition, as well as internal and external physical damage from microplastics (de Ruijter et al. 2020).

The rise of microplastics as a ubiquitous pollutant has made human exposure, largely through ingestion and inhalation, inevitable, and little is known about the effects of microplastics on human health (Prata et al. 2020). Human exposure to microplastics is difficult to study especially considering that the critically needed, low-level exposure, clinical trials are complicated by the fact that no true controls groups exist due to everyone being exposed to plastic constituents over the course of their lifetime (Vandenberg et al. 2007; North and Halden 2013). Therefore, epigenetic and other comparable approaches will likely be required to further understand the potential health effects in humans. Increasingly there is a growing concern that the indirect effects of microplastic pollution may present considerable risks to human health. An important example of this is the role of microplastic pollution in antibiotic resistance (Parthasarathy et al. 2019; Laganà et al. 2019; Bank et al. 2020) which is synthesized in Chap. 9 (Marathe and Bank [this volume](#)). Lastly, there is also a great need for cellular and systemic toxicological investigations in humans as has been recently proposed by Yong et al. (2020).

1.8 Microplastics and Public Policy

Recently microplastic pollution has garnered significant interest from governments and policy makers, and policy aspects are covered in this volume in Chaps. 10 and 11 (Wagner [this volume](#); Wingfield and Lim [this volume](#)). This issue is viewed as a planetary boundary threat (Galloway et al. [2017](#); Lam et al. [2018](#); Villarrubia-Gómez et al. [2018](#); Carney Almroth and Eggert [2019](#)) and from a policy standpoint will ideally involve governance strategies (Vince and Hardesty [2017](#)) that occur at local, regional, and global scales and that consider all ecosystem compartments (Bank et al. [2021](#)). Additionally, a description and outline of the newly established Basel Convention Global Plastic Waste Partnership are presented in Chap. 10 (Wingfield and Lim [this volume](#)). The policy of microplastics has been reviewed by Sheavly and Register ([2007](#)), Pahl and Wyles ([2017](#)), Dauvergne ([2018](#)), Lam et al. ([2018](#)), Raubenheimer and McIlgorm ([2018](#)), Vince and Hardesty ([2018](#)), Black et al. ([2019](#)), as well as Carney Almroth and Eggert ([2019](#)) with recent IPCC style assessments also being undertaken by Borrelle et al. ([2020](#)) and Lau et al. ([2020](#)).

1.9 Conclusions

Microplastic and plastic pollution in general is an inherently complex issue. Moving ahead it is clear that small-scale and local efforts can have important global implications and can provide guidance regarding research and policy priorities. Of critical importance will be the estimation of fluxes and pools or the movement of microplastics and plastic particles across ecosystem compartments (Bank and Hansson [2019](#); Hoellein and Rochman [2021](#)). These fluxes, and the microplastic concept in general, will serve as a critical foundation for global mass balance estimates and models (Bank et al. [2021](#)). Such estimates and models can then be used to employ a structured approach, in the context of global environmental change processes, to support the identification of microplastic indicators, important pathways, mechanisms, and the general advancement of science and effective policymaking to holistically address this important environmental problem.

References

- Abbasi S, Keshavarzi B, Moore F, Turner A, Kelly FJ, Dominguez AO, Jaafarzadeh N (2019) Distribution and potential health impacts of microplastics and microrubbers in air and street dusts from Asaluyeh County, Iran. *Environ Pollut* 244:153–164
- Akdogan Z, Guven B (2019) Microplastics in the environment: a critical review of current understanding and identification of future research needs. *Environ Pollut* 254:113011
- Alfonso MB, Scordo F, Seitz C, Mavo Manstretta GM, Ronda AC, Arias AH, Tomba JP, Silva LI, Perillo GME, Piccolo MC (2020) First evidence of microplastics in nine lakes across

- Patagonia (South America). *Sci Total Environ* 733:139385. <https://doi.org/10.1016/j.scitotenv.2020.139385>.
- Allen S, Allen D, Phoenix VR, Le Roux G, Durántez Jiménez P, Simonneau A, Binet S, Galop D (2019) Atmospheric transport and deposition of microplastics in a remote mountain catchment. *Nat Geosci* 12:339–344
- Allen S, Allen D, Moss K, Le Roux G, Phoenix VR, Sonke JE (2020) Examination of the ocean as a source for atmospheric microplastics. *PLoS One* 15:e0232746
- Ambrosini R, Azzoni RS, Pittino F, Diolaiuti G, Franzetti A, Parolini M (2019) First evidence of microplastic contamination in the supraglacial debris of an alpine glacier. *Environ Pollut* 253:297–301
- Anbumani S, Kakkar P (2018) Ecotoxicological effects of microplastics on biota: a review. *Environ Sci Pollut Res* 25:14373–14396
- Asante KA, Pwamang JA, Amoyaw-Osei Y, Ampofo JA (2016) E-waste interventions in Ghana. *Rev Environ Health* 31(1):145–148
- Baldwin AK, Corsi SR, Mason SA (2016) Plastic debris in 29 Great Lakes tributaries: relations to watershed attributes and hydrology. *Environ Sci Technol* 50(19):10377–10385
- Bank MS, Hansson SV (2019) The plastic cycle: a novel and holistic paradigm for the Anthropocene. *Environ Sci Technol* 53(13):7177–7179
- Bank MS, Ok YS, Swarzenski PW (2020) Microplastic's role in antimicrobial resistance. *Science* 369(6509):1315
- Bank MS, Swarzenski PW, Duarte CM, Rillig M, Koelmans B, Metian M, Kershaw P, Wright S, Provencher J, Sanden M, Jordaan A, Wagner M, Thiel M, Ok YS (2021) A global microplastic pollution observation system to aid policy. *Environ Sci Technol* 55(12):7770–7775
- Barboza LGA, Vethaak AD, Lavorante BRBO, Lundebey A-K, Guilhermino L (2018) Marine microplastic debris: an emerging issue for food security, food safety and human health. *Mar Pollut Bull* 133:336–348
- Barboza LGA, Cunha SC, Monteiro C, Fernandes JO, Guilhermino L (2020) Bisphenol A and its analogs in muscle and liver of fish from the North East Atlantic Ocean in relation to microplastic contamination. Exposure and risk to human consumers. *J Hazard Mater* 393:122419
- Barbuzano J (2019) Rivers are a highway for microplastics into the ocean. *Eos* 100. <https://doi.org/10.1029/2019EO130375>. Published on 09 August 2019
- Bergmann M, Mützel S, Primpke S, Tekman MB, Trachsel J, Gerdtz G (2019) White and wonderful? Microplastics prevail in snow from the Alps to the Arctic. *Sci Adv* 5:eaax1157
- Black JE, Kopke K, O'Mahony C (2019) A trip upstream to mitigate marine plastic pollution – a perspective focused on the MSFD and WFD. *Front Mar Sci* 6:689
- Borrelle SB, Ringma J, Lavender Law K, Monnahan CC, Lebreton L, McGivern A, Murphy E, Jambeck J, Leonard GH, Hilleary MA, Eriksen M, Possingham HP, De Frond H, Gerber LR, Polidoro B, Tahir A, Bernard M, Mallos N, Barnes M, Rochman CM (2020) Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. *Science* 369(6510):1515–1518
- Boucher J, Friot D (2017) Primary microplastics in the oceans: a global evaluation of sources. IUCN, Gland
- Brahney J, Hallerud M, Heim E, Hahnenberger M, Sukumaran S (2020) Plastic rain in protected areas of the United States. *Science* 368:1257–1260
- Browne MA, Crump P, Niven SJ, Teuten E, Tonkin A, Galloway T, Thompson R (2011) Accumulation of microplastic on shorelines worldwide: sources and sinks. *Environ Sci Technol* 45(21):9175–9179
- Cai L, Wang J, Peng J, Tan Z, Zhan Z, Tan X, Chen Q (2017) Characteristic of microplastics in the atmospheric fallout from Dongguan city, China: preliminary research and first evidence. *Environ Sci Pollut Res* 24:24928–24935
- Carney Almroth B, Eggert H (2019) Marine plastic pollution: sources, impacts, and policy issues. *Rev Environ Econ Policy* 13:317–326
- Castañeda RA, Avlijas S, Simard MA, Ricciardi A, Smith R (2014) Microplastic pollution in St. Lawrence River sediments. *Can J Fish Aquat Sci* 71(12):1767–1771

- Chae DH, Kim IS, Kim SK, Song YK, Shim WJ (2015) Abundance and distribution characteristics of microplastics in surface seawaters of the Incheon/Kyeonggi Coastal region. *Arch Environ Contam Toxicol* 69(3):269–278
- Choy CA, Robison BH, Gagne TO, Erwin B, Firl E, Halden RU, Hamilton JA, Katija K, Lisin SE, Rolsky C, Van Houtan S. K. (2019) The vertical distribution and biological transport of marine microplastics across the epipelagic and mesopelagic water column. *Sci Rep* 9:7843
- Cole M, Lindeque P, Halsband C, Galloway SC (2011) Microplastics as contaminants in the marine environment: a review. *Mar Pollut Bull* 62:2588–2597
- Corradini F, Meza P, Eguiluz R, Casado F, Huerta-Lwanga E, Geissen V (2019) Evidence of microplastic accumulation in agricultural soils from sewage sludge disposal. *Sci Total Environ* 671:411–420
- Dauvergne P (2018) Why is the global governance of plastic failing the oceans? *Glob Environ Chang* 51:22–31
- de Ruijter VN, Redondo-Hasselerharm PE, Gouin T, Koelmans AA (2020) Quality criteria for microplastic effect studies in the context of risk assessment: a critical review. *Environ Sci Technol* 54:11692–11705
- Dehghani S, Moore F, Akhbarizadeh R (2017) Microplastic pollution in deposited urban dust, Tehran metropolis, Iran. *Environ Sci Pollut Res* 24:20360–20371
- Dris R, Gasperi J, Rocher V, Saad M, Renault N, Tassin B (2015) Microplastic contamination in an urban area: a case study in Greater Paris. *Environ Chem* 12:592–599
- Dris R, Gasperi J, Saad M, Mirande C, Tassin B (2016) Synthetic fibers in atmospheric fallout: a source of microplastics in the environment? *Mar Pollut Bull* 104:290–293
- Eerkes-Medrano D, Thompson RC, Aldridge DC (2015) Microplastics in freshwater systems: a review of the emerging threats, identification of knowledge gaps and prioritisation of research needs. *Water Res* 75:63–82
- 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. *Mar Pollut Bull* 77:177–182
- Eriksen M, Lebreton LCM, Carson HS, Thiel M, Moore CJ, Borerro JC, Galgani F, Ryan PG, 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
- Evangelidou N, Grythe H, Klimont Z, Heyes C, Eckhardt S, Lopez-Aparicio S, Stohl A (2020) Atmospheric transport is a major pathway of microplastics to remote regions. *Nat Commun* 11:3381
- Free CM, Jensen OP, Mason SA, Eriksen M, Williamson NJ, Boldgiv B (2014) High-levels of microplastic pollution in a large, remote, mountain lake. *Risk Anal* 34:156–163
- Gall SC, Thompson RC (2015) The impact of debris on marine life. *Mar Pollut Bull* 92:170–179
- Galloway TS, Cole M, Lewis C (2017) Interactions of microplastic debris throughout the marine ecosystem. *Nat Ecol Evol* 1:1–8
- Garrido Gamarro E, Costanzo V (this volume) Dietary exposure to plastic particles, plastic additives and contaminants through seafood consumption. In: Bank MS (ed) *Microplastic in the environment: pattern and process*. Springer, Cham
- Gasperi J, Wright SL, Dris R, Collard F, Mandin C, Guerrouache M, Langlois V, Kelly FJ, Tassin B (2018) Microplastics in air: are we breathing it in? *Curr Opin Environ Sci Health* 1:1–5
- Gomes T, Bour A, Coutris C, Almeida AC, Brâte IL, Wolf R, Bank MS, Lusher AL (this volume) Ecotoxicological impacts of micro- and nanoplastics in terrestrial and aquatic environments. In: Bank MS (ed) *Microplastic in the environment: pattern and process*. Springer, Cham
- Gouin T, Roche N, Lohmann R, Hodges G (2011) A thermodynamic approach for assessing the environmental exposure of chemicals absorbed to microplastic. *Environ Sci Technol* 45:1466–1472
- Gullett BK, Linak WP, Touati A, Wasson SJ, Gatica S, King CJ (2007) Characterization of air emissions and residual ash from open burning of electronic wastes during simulated rudimentary recycling operations. *J Mater Cycles Waste Manag* 9(1):69–79

- Habib D, Locke DC, Cannone LJ (1998) Synthetic fibers as indicators of municipal sewage sludge, sludge products, and sewage treatment plant effluents. *Water Air Soil Pollut* 103:1–8
- Hale RC, Seeley ME, La Guardia MJ, Mai L, Zeng EY (2020) A global perspective on microplastics. *J Geophys Res Oceans* 125:e2018JC014719
- Hidalgo-Ruz V, Gutow L, Thompson RC, Thiel M (2012) Microplastics in the marine environment: a review of the methods used for identification and quantification. *Environ Sci Technol* 46:3060–3075
- Hitchcock JN (2020) Storm events as key moments of microplastic contamination in aquatic ecosystems. *Sci Total Environ* 734:139436
- Hoellein TJ, Rochman CM (2021) The “plastic cycle”: a watershed-scale model of plastic pools and fluxes. *Front Ecol Environ* 2021. <https://doi.org/10.1002/fee.2294>
- Horton AA, Dixon SJ (2018) Microplastics: an introduction to environmental transport processes. *WIREs Water* 5:e1268
- Horton AA, Walton A, Spurgeon DJ, Lahive E, Svendsen C (2017) Microplastics in freshwater and terrestrial environments: evaluating the current understanding to identify the knowledge gaps and future research priorities. *Sci Total Environ* 586:127–141
- Isobe A, Iwasaki S, Uchida K, Tokai T (2019) Abundance of non-conservative microplastics in the upper ocean from 1957 to 2066. *Nat Commun* 10:417
- Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, Narayan R, Law KL (2015) Plastic waste inputs from land into the ocean. *Science* 347(6223):768–771. <https://doi.org/10.1126/science.1260352>
- Jamieson AJ, Brooks LSR, Reid WDK, Piernsey SB, Narayanaswamy BE, Linley TD (2019) Microplastics and synthetic particles ingested by deep-sea amphipods in six of the deepest marine ecosystems on Earth. *R Soc Open Sci* 6:180667
- Kallenbach EMF, Rødland ES, Buenaventura NT, Hurley R (this volume) Microplastics in terrestrial and freshwater environments. In: Bank MS (ed) *Microplastic in the environment: pattern and process*. Springer, Cham
- Kane IA, Clare MA, Miramontes E, Wogelius R, Rothwell JJ, Garreau P, Pohl F (2020) Seafloor microplastic hotspots controlled by deep-sea circulation. *Science* 368:1140–1145
- Kay P, Hiscoe R, Moberley I, Bajic L, McKenna N (2018) Wastewater treatment plants as a source of microplastics in river catchments. *Environ Sci Pollut Res* 25(20):20,264–20,267. <https://doi.org/10.1007/s11356-018-2070-7>
- Klein M, Fischer EK (2019) Microplastic abundance in atmospheric deposition within the Metropolitan area of Hamburg, Germany *Sci Total Environ* 685:96–103
- Klein S, Worch E, Knepper TP (2015) Occurrence and spatial distribution of microplastics in river shore sediments of the rhine-main area in Germany. *Environ Sci Technol* 49(10):6070–6. <https://doi.org/10.1021/acs.est.5b00492>
- Koelmans AA, Kooi M, Law KL, Van Sebille E (2017) All is not lost: deriving a top-down mass budget of plastic at sea. *Environ Res Lett* 12:114028
- Koelmans AA, Redondo-Hasselerharm PE, Mohamed Nor NH, Kooi M (2020) Solving the non-alignment of methods and approaches used in microplastic research to consistently characterize risk. *Environ Sci Technol* 54:12307–12315
- Kögel T, Bjørøy Ø, Toto B, Bienfait AM, Sanden M (2020) Micro- and nanoplastic toxicity on aquatic life: determining factors. *Sci Total Environ* 709:136050
- Kole PJ, Löhr AJ, Van Bellegheem FG AJ, Ragas AMJ (2017) Wear and tear of tyres: a stealthy source of microplastics in the environment. *Int J Environ Res Public Health* 14:1265
- Laganà P, Caruso G, Corsi I, Bergami E, Venuti V, Majolino D, La Ferla R, Azzaro M, Cappello S (2019) Do plastics serve as a possible vector for the spread of antibiotic resistance? First insights from bacteria associated to a polystyrene piece from King George Island (Antarctica). *Int J Hyg Environ Health* 222:89–100
- Laist D (1997) Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In: Coe J, Rogers D (eds) *Marine debris: sources, impacts, and solutions*. Springer, New York, pp 99–140

- Lam C, Ramanathan S, Carbery M, Gray K, Vanka KS, Maurin C, Bush R, Palanisami T (2018) A comprehensive analysis of plastics and microplastic legislation worldwide. *Water Air Soil Pollut* 229:345
- Lau WWY, Shiran Y, Bailey RM, Cook E, Stuchtey MR, Koskella J, Velis CA, Godfrey L, Boucher J, Murphy MB, Thompson RC, Jankowska E, Castillo A, Pilditch TD, Dixon B, Koerselman L, Kosior E, Favoino E, Gutberlet J, Baulch S, Atreya ME, Fischer D, He KK, Petit MM, Sumaila UR, Neil E, Bernhofen MV, Lawrence K, Palardy JE (2020) Evaluating scenarios toward zero plastic pollution. *Science* 369:1455–1461
- Lebreton LCM, van der Zwet J, Damsteeg JW, Slat B, Andrady A, Reisser J (2017) River plastic emissions to the world's oceans. *Nat Commun* 8:15611
- Lechner A, Keckeis H, Lumesberger-Loisl F, Zens B, Krusch R, Tritthart M, Glas M, Schludermann E (2014) The Danube so colourful: a potpourri of plastic litter outnumbers fish larvae in Europe's second largest river. *Environ Pollut* 188:177–181
- Lechthaler S, Waldschläger K, Stauch G, Holger Schüttrumpf H (2020) The way of microplastic through the environment. *Environment* 7:73
- Li J, Liu H, Chen JP (2018) Microplastics in freshwater systems: a review on occurrence, environmental effects, and methods for microplastics detection. *Water Res* 137:362–374
- Liu K, Wu T, Wang X, Song Z, Zong C, Wei N, Li D (2019) Consistent transport of terrestrial microplastics to the ocean through atmosphere. *Environ Sci Technol* 53:10612–10619
- Lundebye A-K, Lusher AL, Bank MS (this volume) Marine microplastics and seafood: implications for food security. In: Bank MS (ed) *Microplastic in the environment: pattern and process*. Springer, Cham
- Lusher AL, Hollman PCH, Mendoza-Hill JJ (2017) Microplastics in fisheries and aquaculture: status of knowledge on their occurrence and implications for aquatic organisms and food safety. *FAO Fisheries and Aquaculture Technical Paper*. No. 615. Rome, Italy.
- Mahon AM, O'Connell B, Healy MG, O'Connor I, Officer R, Nash R, Morrison L (2017) Microplastics in sewage sludge: effects of treatment. *Environ Sci Technol* 51:810–818
- Marathe NP, Bank MS (this volume) The antibiotic resistance-microplastic connection. In: Bank MS (ed) *Microplastic in the environment: pattern and process*. Springer, Cham
- Mason SA, Gameau D, Sutton R, Chu Y, Ehmann K, Barnes J, Fink P, Papazissimos D, Rogers DL (2016) Microplastic pollution is widely detected in US municipal wastewater treatment plant effluent. *Environ Pollut* 218:1045–1054
- Murphy F, Ewins C, Carbonnier F, Quinn B (2016) Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment. *Environ Sci Technol* 50(11):5800–5808
- Napper IE, Thompson RC (2016) Release of synthetic microplastic plastic fibres from domestic washing machines: effects of fabric type and washing conditions. *Mar Pollut Bull* 112(1):39–45
- Ni HG, Lu SY, Mo T, Zeng H (2016) Brominated flame retardant emissions from the open burning of five plastic wastes and implications for environmental exposure in China. *Environ Pollut* 214:70–76
- Nizzetto L, Langaas S, Futter M (2016) Correspondence—Pollution: do microplastics spill on to farm soils? *Nature* 537:488
- North EJ, Halden RU (2013) Plastics and environmental health: the road ahead. *Rev Environ Health* 28:1–8
- Onink V, Wichmann D, Delandmeter P, van Sebille E (2019) The role of Ekman currents, geostrophy, and Stokes drift in the accumulation of floating microplastic. *J Geophys Res Oceans* 124:1474–1490
- Pahl S, Wyles KJ (2017) The human dimension: how social and behavioural research methods can help address microplastics in the environment. *Anal Methods* 9:1404–1411
- Parthasarathy A, Tyler AC, Hoffman MJ, Savka MA, Hudson AO (2019) Is plastic pollution in aquatic and terrestrial environments a driver for the transmission of pathogens and the evolution of antibiotic resistance? *Environ Sci Technol* 53:1744–1745
- Peeken I, Primpke S, Beyer B, Gütermann J, Katlein C, Krumpfen T, Bergmann M, Hehemann L, Gerdts G (2018) Arctic sea ice is an important temporal sink and means of transport for microplastic. *Nat Commun* 9:1505

- Peng X, Chen M, Chen S, Dasgupta S, Xu H, Ta K, Du M, Li J, Guo Z, Bai S (2018) Microplastics contaminate the deepest part of the world's ocean. *Geochem Perspect Lett* 9:1–5
- Porter A, Lyons BP, Galloway TS, Lewis C (2018) Role of marine snows in microplastic fate and bioavailability. *Environ Sci Technol* 52:7111–7119
- Prata JC, da Costa JP, Lopes I, Duarte AC, Rocha-Santos T (2020) Environmental exposure to microplastics: an overview on possible human health effects. *Sci Total Environ* 702:134455
- Prinz N, Korez Š (2020) Understanding how microplastics affect marine Biota on the cellular level is important for assessing ecosystem function: a review. In: Jungblut S, Liebich V, Bode-Dalby M (eds) *YOUARES 9 – the oceans: our research, our future*. Springer, Cham, pp 101–120. ISBN: 978-3-030-20389-4
- Raubenheimer K, McIlgorm A (2018) Can the basel and stockholm conventions provide a global framework to reduce the impact of marine plastic litter? *Mar Policy* 96:285–290
- Roblin B, Ryan M, Vreugdenhil A, Aherne J (2020) Ambient atmospheric deposition of anthropogenic microfibers and microplastics on the Western Periphery of Europe (Ireland). *Environ Sci Technol* 54:11100–11108
- Rochman CM, Brookson C, Bikker J, Djuric N, Earn A, Bucci K, Athey S, Huntington A, McIlwraith H, Munno K, De Frond H, Kolomijeca A, Erdle L, Grbic J, Bayoumi M, Borrelle SB, Wu T, Santoro S, Werbowski LM, Zhu X, Giles RK, Hamilton BM, Thaysen C, Kaura A, Klasios N, Ead L, Kim J, Sherlock C, Ho A, Hung C (2019) Rethinking microplastics as a diverse contaminant suite. *Environ Toxicol Chem* 38:703–711
- Sadri SS, Thompson RC (2014) On the quantity and composition of floating plastic debris entering and leaving the Tamar Estuary, Southwest England. *Mar Pollut Bull* 81:55–60
- Schmidt C, Krauth T, Wagner S (2017) Export of plastic debris by rivers into the Sea. *Environ Sci Technol* 51:12246–12253
- Sedlak D (2017) Three lessons for the microplastics voyage. *Environ Sci Technol* 51:7747–7748
- Sharma S, Chatterjee S (2017) Microplastic pollution, a threat to marine ecosystem and human health: a short review. *Environ Sci Pollut Res Int* 27:21530–21547
- Sheavly SB, Register KM (2007) Marine debris & plastics: environmental concerns, sources, impacts and solutions. *J Polym Environ* 15:301–305
- Smith M, Love DC, Rochman CM, Neff RA (2018) Microplastics in seafood and the implications for human health. *Curr Environ Health Rpt* 5:375–386
- Song YK, Hong SH, Jang M, Han GM, Shim WJ (2015) Occurrence and distribution of microplastics in the sea surface microlayer in Jinhae Bay, South Korea. *Arch Environ Contam Toxicol* 69(3):279–287
- Stanton T, Johnson M, Nathanail P, MacNaughtan W, Gomes RL (2019) Freshwater and airborne textile fibre populations are dominated by 'natural', not microplastic, fibres. *Sci Total Environ* 666:377–389
- Takahashi CK, Turner A, Millward GE, Glegg GA (2012) Persistence and metallic composition of paint particles in sediments from a tidal inlet. *Mar Pollut Bull* 64:133–137
- Thompson RC, Olsen Y, Mitchell RP, Davis A, Rowland SJ, John AW, McGonigle D, Russell AE (2004) Lost at sea: where is all the plastic? *Science* 304:838
- van Emmerik T, Schwarz A (2020) Plastic debris in rivers. *WIREs Water* 7:e1398
- van Sebille E, Aliani S, Law KL, Maximenko N, Alsina JM, Bagaev A, Bergmann M, Chapron B, Chubarenko I, Cózar A, Delandmeter P, Egger M, Fox-Kemper B, Garaba SP, Goddijn-Murphy L, Hardesty BD, Hoffman MJ, Isobe A, Jongedijk CE et al (2020) The physical oceanography of the transport of floating marine debris. *Environ Res Lett* 15:023003
- Vandenberg LN, Hauser R, Marcus M, Olea N, Welshons WV (2007) Human exposure to bisphenol A (BPA). *Reprod Toxicol* 24:139–177
- Vaughan R, Turner SD, Rose NL (2017) Microplastics in the sediments of a UK urban lake. *Environ Pollut* 229:10–18
- Villarrubia-Gómez P, Cornell SE, Fabres J (2018) Marine plastic pollution as a planetary boundary threat—the drifting piece in the sustainability puzzle. *Mar Policy* 96:213–220
- Vince J, Hardesty BD (2017) Plastic pollution challenges in marine and coastal environments: from local to global governance. *Restor Ecol* 25:123–128. <https://doi.org/10.1111/rec.12388>

- Vince J, Hardesty BD (2018) Governance solutions to the tragedy of the commons that marine plastics have become. *Front Mar Sci* 5:214
- Wagner M (this volume) Solutions to plastic pollution: a conceptual framework. In: Bank MS (ed) *Microplastic in the environment: pattern and process*. Springer, Cham
- Waldschläger K, Lechthaler S, Stauch G, Schüttrumpf H (2020) The way of microplastic through the environment – application of the source-pathway-receptor model (review). *Sci Total Environ* 713:136584
- Wang X, Li C, Liu K, Zhu L, Song Z, Li D (2020) Atmospheric microplastic over the South China Sea and East Indian Ocean: abundance, distribution and source. *J Hazard Mater* 389:121846
- Weinstein JE, Crocker BK, Gray AD (2016) From macroplastic to microplastic: degradation of high-density polyethylene, polypropylene, and polystyrene in a salt marsh habitat. *Environ Toxicol Chem* 35:1632–1640
- Williams AT, Simmons SL (1996) The degradation of plastic litter in rivers: implications for beaches. *J Coast Conserv* 2:63–72
- Windsor FM, Durance I, Horton AA, Thompson RC, Tyler CR, Ormerod SJ (2019) A catchment-scale perspective of plastic pollution. *Glob Chang Biol* 25:1207–1221
- Wingfield S, Lim M (this volume) The United Nations Basel convention’s global plastic waste partnership: history, evolution and progress. In: Bank MS (ed) *Microplastic in the environment: pattern and process*. Springer, Cham
- Wright SL, Thompson RC, Galloway TS (2013) The physical impacts of microplastics on marine organisms: a review. *Environ Pollut* 178:483–492
- Wright SL, Ulke J, Font A, Chan KLA, Kelly FJ (2020) Atmospheric microplastic deposition in an urban environment and an evaluation of transport. *Environ Int* 136:105411
- Wu P, Huang J, Zheng Y, Yang Y, Zhang Y, He F, Chen H, Quan G, Yan J, Li T, Gao B (2019) Environmental occurrences, fate, and impacts of microplastics. *Ecotoxicol Environ Saf* 184:109612
- Xia W, Rao Q, Deng X, Chen J, Xie P (2020) Rainfall is a significant environmental factor of microplastic pollution in inland waters. *Sci Total Environ* 732:139065
- Xue B, Zhang L, Li R, Wang Y, Guo J, Yu K, Wang S (2020) Underestimated microplastic pollution derived from fishery activities and “Hidden” in deep sediment. *Environ Sci Technol* 54:2210–2217
- Yong CQY, Valiyaveetil S, Tang BL (2020) Toxicity of microplastics and nanoplastics in mammalian systems. *Int J Environ Res Public Health* 17:1509
- Zettler ER, Mincer TJ, Amaral-Zettler LA (2013) Life in the “plastisphere”: microbial communities on plastic marine debris. *Environ Sci Technol* 47:7137–7146
- Zhang Y, Gao T, Kang S, Sillanpää M (2019) Importance of atmospheric transport for microplastics deposited in remote areas. *Environ Pollut* 254:112953
- Zhang Y, Kang S, Allen S, Allen D, Gao T, Sillanpää M (2020) Atmospheric microplastics: a review on current status and perspectives. *Earth Sci Rev* 203:103118

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter’s Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter’s Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.