The Plastisphere—
The Making of a Plasticized World

Marcus Eriksen*

I. INTRODUCTION

The utility of plastic in contemporary society is at a crossroads, where the perceived benefit of single-use, throw-away products and packaging is outweighed by the true cost of persistent waste and fragmented microplastics in terrestrial and marine ecosystems. Plastic pollution is ubiquitous in aquatic environments, from the Mississippi River to the Great Lakes and across all subtropical gyres in the global

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* Marcus Eriksen is currently the Research Director and cofounder of the 5 Gyres Institute. He studies the global distribution and ecological impacts of plastic marine pollution, which has included expeditions sailing 40,000 miles through all five subtropical gyres to discover new garbage patches of plastic pollution around the world.

In 2000, he travelled to Midway Atoll, finding hundreds of Layson Albatross with plastic pouring out of their stomachs. That experience narrowed his focus to plastics. He received his Ph.D. in science education from the University of Southern California in 2003, months before embarking on a 2000-mile, five-month journey down the Mississippi River on a homemade raft of plastic bottles to bring attention to the plastic pollution issue. In 2008, he rafted across the Pacific Ocean from California to Hawaii on JUNK, floating on 15,000 plastic bottles and a Cessna airplane fuselage as a cabin. The journey, 2600 miles in eighty-eight days, brought attention to the work of the 5 Gyres Institute, the organization he cofounded with his wife, Anna Cummins, which is committed to marine conservation through continued research, education, and adventure. Together, they study and lecture about the plague of plastic waste in our watersheds and global ocean.

His first book, *My River Home*, chronicled his Mississippi River experience paralleled with his tour as a Marine in the 1991 Gulf War. The experience of war, sailing across oceans with wonderful crewmates, and long rafting voyages have led to a strong conservation ethic he believes is worth fighting for. "We must understand and define conservation and social justice as our collective self-preservation—a rationale that crosses all boundaries between all people."

ocean. What *Life Magazine* described as "Throw Away Living" in 1955[1] has led to considerable demand for plastic, from less than 2 million tons annually in 1950 to nearly 288 million tons in 2012.[2] Yet managing waste, innovations in environmentally harmless product design, and public awareness of ecological and human health impacts are lacking, leaving even the most remote regions of the planet trashed.

II. HOW MUCH PLASTIC POLLUTION IS OUT THERE?

Once plastic is lost to the environment, it becomes *pollution*, not the politically loaded terms "debris" or "litter." Some have suggested that synthetic polymers in the ocean should be regarded as hazardous waste,[3] a designation that would create new legal tools for mitigation. Plastic pollution is the dominant type of anthropogenic material found in the oceans.[4] Though other types of materials are found in the marine environment (such as glass floats, bottles, light bulbs and tubes, metal cans and derelict traps, and cut wood), 60 to 80% of marine debris is estimated to be plastic.[5] Through degradation by sunlight, biodegradation, chemical and mechanical degradation, plastics fragments disperse globally, accumulating in massive circular currents called subtropical gyres, where wind and waves slow down toward the centers.[6] Microplastics less than 5 mm to macroplastics of all sizes above have been reported since the early 1970s in the subtropical gyres of the North Atlantic,[7] South Atlantic,[8] North Pacific,[9] South Pacific,[10] and outside the

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1. *Throwaway Living*, LIFE, Aug. 1, 1955, at 43.

2. *See* PLASTICSEUROPE, PLASTICS—THE FACTS 2013: AN ANALYSIS OF EUROPEAN PLASTICS PRODUCTION, DEMAND AND WASTE DATA FOR 2011, at 10 fig.2 (2013), *available at* http://www.plasticseurope.org/Document/plastics-the-facts-2013.aspx?FolID=2.

3. Chelsea M. Rochman et al., *Classify Plastic Waste as Hazardous*, 494 NATURE 169, 169 (2013).

4. David K.A. Barnes et al., *Accumulation and Fragmentation of Plastic Debris in Global Environments*, 364 PHIL. TRANSACTIONS ROYAL SOC'Y LONDON SERIES B 1985, 1987 (2009) (noting plastics comprise up to 80% of the waste found on beaches, on the surface of the ocean, and on the seabed).

5. José G.B. Derraik, *The Pollution of the Marine Environment by Plastic Debris: A Review*, 44 MARINE POLLUTION BULL. 842, 843 (2002). *See generally* Mark Anthony Browne et al., *Accumulation of Microplastic on Shorelines Worldwide: Sources and Sinks*, 45 ENVTL. SCI. & TECH. 9175 (2011); Richard C. Thompson et al., *Lost at Sea: Where Is All the Plastic?*, 304 SCIENCE 838 (2004).

6. *See* Kara Lavendar Law et al., *Plastic Accumulation in the North Atlantic Subtropical Gyre*, 329 SCIENCE 1185, 1186 (2010).

7. *Id.* at 1186-87; Edward J. Carpenter & K.L. Smith, Jr., *Plastics on the Sargasso Sea Surface*, 175 SCIENCE 1240, 1240 (1972); John B. Colton, Jr. et al., *Plastic Particles in Surface Waters of the Northwestern Atlantic*, 185 SCIENCE 491, 491 (1974).

8. Peter G. Ryan, *Litter Survey Detects the South Atlantic 'Garbage Patch,'* 79 MARINE POLLUTION BULL. 220, 220 (2014).

gyres in nearshore environments.[11] They have also been found in estuaries,[12] lakes,[13] closed gulfs, bays, and seas.[14] On land, plastics dominate desert landscapes,[15] and wind-driven micro and nanoplastic particles can reach distant terrestrial biomes, evidenced by the inadvertent collection of these particles by pollinating insects.[16]

In half a century of commercial use, plastic pollution has become ubiquitous in all environments. The widely accepted term to describe our geologic time, Anthropocene, or "Age of Man," can be defined stratigraphically by our uniquely manufactured index fossil: the synthetic polymer plastic.

III. WHERE DOES PLASTIC POLLUTION COME FROM?

Plastic waste may enter waterways through storm-water drainage, illegal dumping into nearshore environs, lost fishing gear or other maritime activities, microplastics evading sewage treatment effluent or overflowing during high-volume rain events,[17] or by blowing off beaches[18] or developed structures, like docks and piers.

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9. Robert H. Day et al., *The Quantitative Distribution and Characteristics of Marine Debris in the North Pacific Ocean, 1984-88*, *in* PROCEEDINGS OF THE SECOND INTERNATIONAL CONFERENCE ON MARINE DEBRIS 182, 185 (R.S. Shomura & M.L. Godfrey eds., 1990); C.J. Moore et al., *A Comparison of Plastic and Plankton in the North Pacific Central Gyre*, 42 MARINE POLLUTION BULL. 1297, 1297-98 (2001).

10. Marcus Eriksen et al., *Plastic Pollution in the South Pacific Subtropical Gyre*, 68 MARINE POLLUTION BULL. 71, 72-74 (2013).

11. Fatehi Dubaish & Gerd Liebezeit, *Suspended Microplastics and Black Carbon Particles in the Jade System, Southern North Sea*, 224 WATER, AIR, & SOIL POLLUTION, art. 1352, 2013, at 1, 3; Iván A. Hinojosa & Martin Thiel, *Floating Marine Debris in Fjords, Gulfs and Channels of Southern Chile*, 58 MARINE POLLUTION BULL. 341, 344 (2009); Thompson et al., *supra* note 5.

12. Mark A. Browne et al., *Spatial Patterns of Plastic Debris Along Estuarine Shorelines*, 44 ENVTL. SCI. & TECH. 3404, 3404-06 (2010).

13. Marcus Eriksen et al., *Microplastic Pollution in the Surface Waters of the Laurentian Great Lakes*, 77 MARINE POLLUTION BULL. 177, 178 (2013).

14. Amandine Collignon et al., *Neustonic Microplastic and Zooplankton in the North Western Mediterranean Sea*, 64 MARINE POLLUTION BULL. 861, 861-62 (2012); Peter G. Ryan, *A Simple Technique for Counting Marine Debris at Sea Reveals Steep Litter Gradients Between the Straits of Malacca and the Bay of Bengal*, 69 MARINE POLLUTION BULL. 128, 130 (2013).

15. *See generally* E.R. Zylstra, *Accumulation of Wind-Dispersed Trash in Desert Environments*, 89 J. ARID ENV'TS 13, 13-14 (2013).

16. *See* Gerd Liebezeit & Elisabeth Liebezeit, *Non-Pollen Particulates in Honey and Sugar*, 30 FOOD ADDITIVES & CONTAMINANTS: PART A 2136, 2137 (2013).

17. *See* EPA, EPA-833-R-07-007, REPORT TO CONGRESS: COMBINED SEWER OVERFLOWS TO THE LAKE MICHIGAN BASIN, at ES-4 (2007); Browne et al., *supra* note 5, at 9175-76.

18. Peter G. Ryan et al., *Monitoring the Abundance of Plastic Debris in the Marine Environment*, 364 PHIL. TRANSACTIONS ROYAL SOC'Y B 1999, 2000 (2009).

Looking to the beaches of remote islands in the gyres, there is a preponderance of fishing-industry-related debris,[19] including nets, buoys, and line surrounded by durable consumer goods like shoes, buckets and crates, bottles and caps, and other random hard plastic objects from toys to umbrella handles. These island surveys represent what survives at sea over time, favoring thick plastic buoys over thin plastic bags or foamed polystyrene. The preponderance of fishing-industry-related debris in remote island surveys varies widely from mainland coastal surveys, where the derelict fishing gear drops to roughly 20%, leaving the majority of debris representing single-use throw away plastic items.[20] In 2012, the Ocean Conservancy's International Coastal Cleanup harnessed the efforts of over 561,000 volunteers in 97 countries to pick up over 10 million pounds of pollution along 17,700 miles of shoreline.[21] Their report documents the top 10 pollutants found as cigarettes and cigarette filters, food wrappers and containers, plastic bottles, plastic bags, lids and caps, plastic tableware, straws and stirrers, glass bottles, beverage cans, and paper bags.[22] These products, though globally represented, are most prevalent in developing nations that typically have little to no infrastructure for waste management. Burning waste or discarding it into rivers or at the edge of town is the norm for many countries with limited alternatives.

In developed nations, where relatively less plastic is lost to the environment, a new threat of microplastics has recently been uncovered. A recent expedition across the Great Lakes in North America described a large abundance of 0.5 mm spherical polyethylene particles,[23] rivaling the counts of microplastics in most ocean samples. A comparison revealed similarities in size, color, shape, and composition to microbeads commonly used in consumer facial cleansers as an exfoliant.[24] Plastic microbeads in this application are intended to be washed into the sink and presumably captured by municipal wastewater treatment facilities.[25] Yet many sewage treatment plants likely do not capture floating,

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19. *See* Oliver J. Dameron et al., *Marine Debris Accumulation in the Northwestern Hawaiian Islands: An Examination of Rates and Processes*, 54 MARINE POLLUTION BULL. 423, 423 (2007).

20. *See* S.B. Sheavly & K.M. Register, *Marine Debris & Plastics: Environmental Concerns, Sources, Impacts and Solutions*, 15 J. POLYMERS & ENV'T 301, 301-02 (2007).

21. OCEAN CONSERVANCY, WORKING FOR CLEAN BEACHES AND CLEAN WATER: 2013 REPORT 6, 14 (2013).

22. *Id.* at 14.

23. Eriksen et al., *supra* note 13, at 178-79.

24. *Id.* at 180.

25. Lisa S. Fendall & Mary A. Sewell, *Contributing to Marine Pollution by Washing Your Face: Microplastics in Facial Cleansers*, 58 MARINE POLLUTION BULL. 1225, 1225 (2009).

nonbiodegradable, particles of this size.[26] Further, when cities employ combined sewage overflow, which merges stormwater with raw sewage on heavy rain days, the microbeads bypass sewage treatment plants altogether and flow directly into the aquatic environment.[27] Sewage effluent also contains microfibers from the washing of synthetic textiles from both laundry facilities and household wastewater.[28]

Increases in coastal population density, climate change, and the rapid growth of plastic production have led to catastrophic events like hurricanes, floods, and tsunamis leaving a legacy of plastic waste. Though these events are isolated cases, the contribution of plastic pollution is significant. For example, the U.S. government estimated 118 million cubic yards of debris were created by Hurricane Katrina.[29] What remains at sea is unknown.

In a recent survey of marine impacts from the 2011 Japanese tsunami, researchers sailed from Tokyo to Hawaii while observing the subsurface debris field. During the twenty-six-day voyage, the crew detected 820 objects during forty-one nonconsecutive hours of sea surface observations, of which 98% were plastic, representing bottles, shoes, combs, crates and buckets, toys, fishing gear, foam insulation attached to building materials, a truck tire, and half of a fiberglass fishing boat.[30] This expedition across the Pacific Ocean after a natural disaster, much like the debris survey following Hurricane Katrina, demonstrates the persistence of plastic.

IV. WHAT IS THE IMPACT OF PLASTIC POLLUTION ON WILDLIFE?

The Convention on Biological Diversity summarized, based on reports, that marine debris has impacted 663 species of marine life.[31] A wide range of marine life is impacted by plastic pollution through entanglement or ingestion, including marine mammals, birds, and

26. *Id.*
27. *See* EPA, *supra* note 17, at 1-2.
28. Browne et al., *supra* note 5, at 9177.
29. U.S. EXEC. OFFICE OF THE PRESIDENT, THE FEDERAL RESPONSE TO HURRICANE KATRINA: LESSONS LEARNED 62 (2006).
30. *See 2012 Expedition To Study Plastic Marine Pollution in the Japanese Tsunami Debris Field*, 5 GYRES INSTITUTE, 5gyres.org/media/Tokyo_Hawaii_Report_5_gyres.pdf (last visited Feb. 16, 2014).
31. SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY & THE SCIENTIFIC AND TECHNICAL ADVISORY PANEL—GEF, IMPACTS OF MARINE DEBRIS ON BIODIVERSITY: CURRENT STATUS AND POTENTIAL SOLUTIONS 9 (2012), *available at* http://www.cbd.int/doc/publications/cbd-ts-67-en.pdf.

reptiles.[32] One snapping turtle appeared on the doorstep of the New Orleans Audubon Zoo in the 1990s with a plastic ring from the neck of a milk jug bound around its waist. The turtle, weighing over 3 pounds, was the size of a football. The constriction from the plastic ring prevented the shell and vertebrae from fusing, resulting in an hourglass shape of the carapace, earning her the moniker "Mae West."[33] This deformity also demonstrated the durability of plastic. Turning to the ocean, all sea turtle species are represented in hundreds of necropsy reports and observations of entanglement. Ecological impacts of plastic pollution include the transportation of invasive species. Plastics ranging from the size of resin pellets to large derelict nets and vessels may transport microbial communities, invertebrates, and larger organisms to nonnative regions.[34]

Plastic pollution is not benign in the environment or when ingested, and has the potential to cause harm through desorption of chemicals from the plastic. Several persistent organic pollutants (POPs) bind to plastic as it is transported throughout a watershed, buried in sediment, or floating in the ocean.[35] A single pellet may attract up to one million times the concentration of some pollutants as the ambient seawater,[36] making those chemicals readily available to marine life. Food mimicry, based on color, shape or presence of biofilms, is one mechanism driving wildlife to ingest plastics, in addition to filter feeding and respiration. Once in the stomach POPs may desorb due to changes in pH, temperature, or the presence of surfactants.[37]

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32. Jan A. van Franeker et al., *Monitoring Plastic Ingestion by the Northern Fulmar* Fulmarus glacialis *in the North Sea*, 159 ENVTL. POLLUTION 2609, 2609 (2011); David W. Laist, *Overview of the Biological Effects of Lost and Discarded Plastic Debris in the Marine Environment*, 18 MARINE POLLUTION BULL. 319, 319-20 (1987).

33. 5 Gyres Institute, *Mae West Turtle & Plastic*, YOUTUBE (Aug. 16, 2010), http://www.youtube.com/watch?v=X6Z6HiSqtO4.

34. David K.A. Barnes, *Invasions by Marine Life on Plastic Debris*, 416 NATURE 808, 808 (2002); Murray R. Gregory, *Environmental Implications of Plastic Debris in Marine Settings—Entanglement, Ingestion, Smothering, Hangers-On, Hitch-Hiking and Alien Invasions*, 364 PHIL. TRANSACTIONS ROYAL SOC'Y B 2013, 2018 (2009).

35. *See* Lorena M. Rios et al., *Quantitation of Persistent Organic Pollutants Adsorbed on Plastic Debris from the Northern Pacific Gyre's "Eastern Garbage Patch,"* 12 J. ENVTL. MONITORING 2226, 2226–27 (2010); Emma L. Teuten et al., *Potential for Plastics to Transport Hydrophobic Contaminants*, 41 ENVTL. SCI. & TECH. 7759, 7759 (2007); Emma L. Teuten et al., *Transport and Release of Chemicals from Plastics to the Environment and to Wildlife*, 364 PHIL. TRANSACTIONS ROYAL SOC'Y B 2027, 2032 (2009).

36. Yukie Mato et al., *Plastic Resin Pellets as a Transport Medium for Toxic Chemicals in the Marine Environment*, 35 ENVTL. SCI. & TECH. 318, 323 (2001).

37. Adil Bakir et al., *Enhanced Desorption of Persistent Organic Pollutants from Microplastics Under Simulated Physiological Conditions*, 185 ENVTL. POLLUTION 16, 17 (2014).

Lab studies of ingested plastic nanoparticles have shown an uptake of particle sizes under 10μm into the circulatory system of mussels[38] that can bridge trophic levels into crustaceans[39] and other secondary consumers.[40] Some persistent pollutants, like polybrominated diphenyls (PBDEs), flame-retardant chemicals used in plastic product manufacturing, may transfer to birds after ingestion.[41] In laboratory experiments with lugworms ingesting plastic particles laden with PBDEs, the lugworms desorbed the chemical, which resulted in a marked reduction in feeding response.[42] Polychlorinated biphenyls (PCBs), an environmentally persistent industrial chemical used as a thermal insulator, has been shown to transfer to lugworms through ingestion of microplastics,[43] as well as in seabirds that ingest larger plastic items.[44]

V. WHAT IS THE IMPACT OF PLASTIC AND PLASTICIZERS ON HUMAN HEALTH?

How plastic marine pollution affects human health includes a long chain of cause and effect. This chain follows the path of plastic waste through the watershed as it accumulates toxins, flows to the ocean, and degrades over time into fragments the size of fish food that desorb toxins into the marine organisms humans harvest for food. Yet, before people even sit down to dinner, many plastic products we touch, wear, sit on, drink, or eat can leach synthetic compounds into our bodies. Many of the chemical building blocks of plastic, or the additives that give it varied properties, have adverse effects on humans and other mammals. Polymerization leaves some monomers unbounded and free to migrate from food containers, bottles, and utensils. Many plasticizers included as

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38. Mark A. Browne et al., *Ingested Microscopic Plastic Translocates to the Circulatory System of the Mussel* Mytilus edulis *(L.)*, 42 ENVTL. SCI. & TECH. 5026, 5028 (2008).

39. Paul Farrell & Kathryn Nelson, *Trophic Level Transfer of Microplastic:* Mytilus edulis *(L.) to* Carcinus maenas *(L.)*, 177 ENVTL. POLLUTION 1, 3 (2013).

40. Outi Setälä et al., *Ingestion and Transfer of Microplastics in the Planktonic Food Web*, 185 ENVTL. POLLUTION 77, 81 (2014).

41. Kosuke Tanaka et al., *Accumulation of Plastic-Derived Chemicals in Tissues of Seabirds Ingesting Marine Plastics*, 69 MARINE POLLUTION BULL. 219, 220 (2013).

42. Mark Anthony Browne et al., *Microplastic Moves Pollutants and Additives to Worms, Reducing Functions Linked to Health and Biodiversity*, 23 CURRENT BIOLOGY 2388, 2389, 2391 (2013).

43. Ellen Besseling et al., *Effects of Microplastic on Fitness and PCB Bioaccumulation by the Lugworm* Arenicola marina *(L.)*, 47 ENVTL. SCI. & TECH. 593, 598 (2013).

44. Rei Yamashita et al., *Physical and Chemical Effects of Ingested Plastic Debris on Short-Tailed Shearwaters,* Puffinus tenuirostris*, in the North Pacific Ocean*, 62 MARINE POLLUTION BULL. 2845, 2848 (2011).

additives are not bonded to the polymer. Some of these compounds bioaccumulate in our bodies.

Bisphenol A (BPA)—the building block of polycarbonates—and phthalates—the plastic additive that turns hardened PVC into pliable vinyl—are both known endocrine disruptors.[45] This is not surprising in the case of BPA, which was invented as a synthetic estrogen,[46] yet proved to be more appealing as a plastic additive. Today, BPA is ubiquitous in synthetic chemical burdens placed on the human body. Possible exposure sources range from the lining of metal cans for food storage,[47] to CDs, DVDs, polycarbonate dishware, and receipt paper from cash registers. BPA has been linked to many developmental disruptions, including early puberty, increased prostate size, obesity, insulin inhibition, hyperactivity, and learning disabilities.[48]

Phthalates, like BPA, are also problematic as endocrine disruptors,[49] with effects including obesity, feminization in males, and insulin resistance.[50] Different phthalates are found in paints, toys, cosmetics, and food packaging, added for the purpose of increasing durability, elasticity, and pliability. In medical applications, such as intravenous bags and tubes, phthalates are prone to leaching after long storage, exposure to elevated temperatures, and as a result of the high concentration of phthalates present—up to 40% by weight.[51] Although phthalates metabolize quickly, in a week or less, we are continuously exposed to them through contact with plastics, like vinyl and soft plastic products.

A large number of other additives and contaminants commonly found in consumer plastic products raise human health and ecological

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45. *See* Eva C. Bonefeld-Jørgensen et al., *Endocrine-Disrupting Potential of Bisphenol A, Bisphenol A Dimethacrylate, 4-n-Nonylphenol, and 4-n-Octylphenol* in Vitro*: New Data and a Brief Review*, 115 ENVTL. HEALTH PERSP. (SUPPLEMENT 1) 69, 69, 74 (2007); EPA, BISPHENOL A ACTION PLAN 1, 2 (2010).

46. E.C. Dodds & Wilfrid Lawson, *Synthetic Estrogenic Agents Without the Phenanthrene Nucleus*, 137 NATURE 996, 996 (1936).

47. *See* José Antonio Brotons et al., *Xenoestrogens Released from Lacquer Coatings in Food Cans*, 103 ENVTL. HEALTH PERSP. 608, 608 (1995).

48. *See* Frederick S. vom Saal & Claude Hughes, *An Extensive New Literature Concerning Low-Dose Effects of Bisphenol A Shows the Need for a New Risk Assessment*, 113 ENVTL. HEALTH PERSP. 926, 928, 930 (2005).

49. *See* John D. Meeker et al., *Phthalates and Other Additives in Plastics: Human Exposure and Associated Health Outcomes*, 364 PHIL. TRANSACTIONS ROYAL SOC'Y B 2097, 2098-2106, 2108 (2009).

50. Richard W. Stahlhut et al., *Concentrations of Urinary Phthalate Metabolites Are Associated with Increased Waist Circumference and Insulin Resistance in Adult U.S. Males*, 115 ENVTL. HEALTH PERSP. 876, 880 (2007).

51. Christoph Buchta et al., *Transfusion-Related Exposure to the Plasticizer Di(2-ethylhexyl)phthalate in Patients Receiving Plateletpheresis Concentrates*, 45 TRANSFUSION 798, 800-01 (2005).

concerns. Most notable are PCBs,[52] polyfluorinated compounds (PFCs),[53] the pesticide/sanitizer triclosan [54] used in over-the-counter drugs, antimicrobial hand soaps and some toothpaste brands, flame retardants, particularly PBDEs,[55] and nonylphenols.

VI. WHAT IS THE FATE OF PLASTIC POLLUTION IN THE OCEAN?

There are multiple known and suspected pathways whereby the estimated 1.8 million tons of plastic pollution in the subtropical gyres will leave the ocean. Sea Education Association (SEA), based in the Woods Hole Oceanographic Institution, reassessed archived plankton net tows spanning twenty-two years and found no significant increase in microplastics on the sea surface, regardless of well-documented increases in coastal inputs over the same time.[56] Islands in the gyres function as natural nets, with thousands of miles of coastline receiving plastic pollution that washes ashore and requires substantial clean-up efforts. On Hawaii's Kamillo Beach, an estimated 165 tons of plastic pollution were removed by volunteers since 2003.[57] We know that plastics degrade into microplastics and ever-smaller particles by photo and mechanical degradation,[58] that microbial degradation of polyethylene happens slowly,[59] and that some microplastics sink to the deep sea floor.[60]

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52. *See generally* Julie B. Herbstman et al., *Determinants of Prenatal Exposure to Polychlorinated Biphenyls (PCBs) and Polybrominated Diphenyl Ethers (PBDEs) in an Urban Population*, 115 ENVTL. HEALTH PERSP. 1794 (2007).

53. *See generally* Hermann Fromme et al., *Perfluorinated Compounds—Exposure Assessment for the General Population in Western Countries*, 212 INT'L J. HYGIENE & ENVTL. HEALTH 239 (2009); John P. Giesy et al., *Global Biomonitoring of Perfluorinated Organics*, 1 SCI. WORLD 627 (2001).

54. *See generally* Ki Chang Ahn et al., In Vitro *Biologic Activities of the Antimicrobials Triclocarban, Its Analogs, and Triclosan in Bioassay Screens: Receptor-Based Bioassay Screens*, 116 ENVTL. HEALTH PERSP. 1203 (2008); Talia E.A. Chalew & Rolf U. Halden, *Environmental Exposure of Aquatic and Terrestrial Biota to Triclosan and Triclocarban*, 45 J. AM. WATER RESOURCES ASSOC. 4 (2009).

55. *See generally* Lucio G. Costa et al., *Polybrominated Diphenyl Ether (PBDE) Flame Retardants: Environmental Contamination, Human Body Burden and Potential Adverse Health Effects*, 79 ACTA BIOMED 172 (2008); G.T. Yogui & J.L. Sericano, *Polybrominated Diphenyl Ether Flame Retardants in the U.S. Marine Environment: A Review*, 35 ENV'T INT. 655 (2009).

56. *See* Law et al., *supra* note 6, at 1186.

57. Personal Communication with Executive Director, Hawaii Wildlife Fund **[author: pls provide source and date]**

58. Anthony L. Andrady, *Microplastics in the Marine Environment*, 62 MARINE POLLUTION BULL. 1596, 1598 (2011).

59. *See* Kumar Harshvardhan & Bhavanath Jha, *Biodegradation of Low-Density Polyethylene by Marine Bacteria from Pelagic Waters, Arabian Sea, India*, 77 MARINE POLLUTION BULL. 100, 105-06 (2013). *See generally* Erik R. Zettler et al., *Life in the "Plastisphere": Microbial Communities on Plastic Marine Debris*, 47 ENVTL. SCI. & TECH. 7137 (2013).

Microplastics have been found throughout the vertical water column, suspended beneath the sea surface, where most ocean sampling takes place. It may be that the ingestion of microplastic fragments by fish and zooplankton may package these particles in fecal pellets that are excreted and slowly sink. The ultimate fate of microplastics in the marine environment is poorly known.

VII. PRODUCER RESPONSIBILITY FOR PLASTIC POLLUTION IN THE TWENTY-FIRST CENTURY

In the early 1970s, Iron Eyes Cody was portrayed on television across the United States as the "Crying Indian" in public service advertisements designed to curtail litter along the new interstate highway system. The organization Keep America Beautiful, with significant funding from Philip Morris, Anheuser-Busch, PepsiCo, and Coca-Cola, ran the ad with the tag line: "People Start Pollution. People Can Stop It." The focus was on consumer behavior as the principle source of litter, rather than a fair assessment of product design.

A focus on consumer behavior rather than product design has prevailed over decades of increasing plastic use and nonbiodegradable waste, and in developing countries where waste management is nonexistent, single-use plastic packaging is a pervasive pollutant. The appropriate ethic, demonstrated by the failure of "litter-focused campaigns" over the last four decades is that producer responsibility must demonstrate successful recovery or environmental harmlessness. Responsibility for product end-life is now shifting to this ethic, albeit with resistance from many manufacturers of plastic and its products, based on the concept of extended producer responsibility (EPR). Under the EPR approach, a manufacturer that creates plastic products or plastic packaging must demonstrate a successful system of material recovery after consumer use; otherwise, an environmentally harmless alternative must be used. Simply put, all products and packaging must demonstrate a successful recovery plan, either voluntary or incentive-based recovery schemes, or they must be environmentally harmless. "Benign by design" is the new motto, evoking a plethora of green chemistry and product design solutions for efficient recovery, ease of repair, or biodegradable parts. The transition to EPR will require phase-outs of polluting products and packaging, which may occur voluntarily, by bans, or by assessed fees. Traditionally, tax-payer funded municipal waste management collects,

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60. Lisbeth Van Cauwenberghe et al., *Microplastic Pollution in Deep-Sea Sediments*, 182 ENVTL. POLLUTION 495, 498 (2013).

transports, sorts, recycles, burns, or buries plastic waste. EPR promises to reduce waste volume, while also reducing persistent waste in the environment.

EPR does not absolve the public of responsibility for litter. Nor does it account for the millions of tons of plastic pollution in the gyres and leaving coastal watersheds daily. Though EPR is essential to curbing the creation of plastic pollution, many developing nations lack the waste management system necessary to collect the current waste. Without opportunities for recovery, the norm for much of the world is to burn or bury plastic. Two additional solutions apply here: build infrastructure for waste management in developing nations and promote general public awareness about the ecological, economical, and human health concerns associated with plastic pollution.

The future of research on this issue will focus on the ultimate fate of plastic pollution in all environments and further define the impacts of persistent chemicals from plastics on humans and other life forms. How do we mitigate the inputs while we monitor the outputs? What will change how we view plastics is an honest, science-based analysis of the true cost to society and the sea. But the ocean is not where solutions will begin. Despite the unfathomable mass of plastic pollution globally, it is challenging to mitigate the problem based on data from the gyres, where garbage patches are in international waters and the plastic is too degraded to assess blame or remedy. Effective solutions must begin upstream, to the behavior of the consumer and the design of the product. It is where we can assign responsibility, either through the good will of the producer, customer demand, or the legislative arm of governments. To save our synthetic seas, we must take responsibility at the source of the problem.