COMMENTARY

Silent spring in the ocean

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In 1962, Rachel Carson made history when she published her seminal book *Silent Spring* (1), which cataloged the toxic effects of a ubiquitous, but seemingly harmless chemical [dichlorodiphenyltrichloroethane (DDT)]. This work almost single-handedly brought chemical pollution into public consciousness and ignited a global environmental movement. Carson specifically highlighted how DDT was a persistent pollutant that accumulated in the environment and threatened the survival of many bird species by interfering with their breeding cycle. In PNAS, an analogous argument is made for plastic pollution (2), only this time a "silent spring" may be looming in the oceans (Fig. 1).

Plastics are similar to DDT in the sense that they were previously not perceived as a major pollutant, although they persist for centuries, accumulate in the environment, and kill an increasing number of seabirds (2), among hundreds of other species (3, 4). Like for DDT, the magnitude of the problem has escalated rapidly: although in the 1970s and 1980s, less than 10% of surveyed seabirds were affected, on average, today up to 90% of seabirds are found with plastics in their gut (2). If these trends continue, by 2050 this proportion could exceed 99% (2).

Where the analogy breaks down is with respect to cumulative exposure. Total global production of DDT over the last 75 y is estimated at about 1.8 million tons, and production has practically ceased (5). A comparable tonnage of plastics is now produced every 2.2 d (6). Moreover, the rate of production continues to increase exponentially, and the total amount of plastic waste released into ocean waters is projected to increase by an order of magnitude up to the year 2025 (7).

How is this harmful to birds? There are two main pathways: ingestion and entanglement, both of which can be deadly (Fig. 1). Although entanglement can suffocate or restrict the movement of birds, ingestion can block the digestive tract and release significant amounts of toxins that are then taken up by the organism (4). These toxins can accumulate in animal tissues (8) and potentially be transferred up the food chain. However, little is known about the population-level effects of these pollutants (4).

Beyond the visible plastic debris that has been the main topic of inquiry so far, there is an emerging research field surveying the causes and consequences of so-called microplastic pollution (9). This refers to an invisible tide of minuscule plastic beads or fragments that result both from specific production (for example, plastic microbeads are often used in exfoliants, toothpaste, and other cleaning products) or from the physical breakdown of larger items ranging from plastic rope and nets to textile fibers. Due to their small size and extreme ubiquity, microplastics can be ingested (or aspired) by organisms of all sizes, from plankton to humans. Again, we know that these pollutants are found in large quantities in every marine environment (10) and enter the human food chain (11), yet we cannot yet estimate the magnitude of their effects, particularly over the long term.

An interesting synergy between plastic and other pollutants is that many plastic materials bond other pollutants and concentrate them up to 10^6-fold relative to their concentration in seawater (12). Particularly in the warm guts of endotherms, such as birds, or humans, those pollutants are released at rates up to 30 times greater than in the surrounding environment (13). Plastic debris hence acts as a vector for other pollutants, introducing cumulative effects.

Much like other pollutants, plastic debris is very mobile and its effects are not limited to the immediate coastal environment where they are released. Accumulating debris is now found in most deep-sea samples (14), and some of the highest concentrations are found in midocean subtropical gyres, the so-called ocean garbage patches (3). A comprehensive study of plastic waste inputs from land into the ocean (7) concluded that population size, economic status, and the quality of waste management systems to a large extent determine which countries contribute the greatest mass of plastic marine debris. Geographically, Southeast Asia emerged as a major hot spot, with China, Indonesia, and the Philippines collectively releasing more than 40% of an estimated global total 3.8–12.7 million tons of marine plastic debris per year (7).

What are the solutions, then, for preventing another silent spring scenario? A decade after Rachel Carson's book was published, the widespread use of DDT in agriculture was banned in the United States, and soon after globally. Clearly, sweeping bans are a limited

Fig. 1. Plastic pollution has emerged as a global threat to seabirds. Although breeding in a National Marine Sanctuary, albatross chicks on Midway Atoll are threatened by plastic entanglement (*Left*) and ingestion (*Right*). The proportion of similarly affected seabirds may already exceed 90% on a global scale (2). Images courtesy of (*Left*) Ron Hirschi and (*Right*) Claire Fackler/Marine Photobank.

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option for plastics, which are so central to our lives, as I am reminded when typing this on an acrylonitrile butadiene styrene keyboard. Hence, the first choice for reducing plastic pollution is to minimize its release into the environment through integrated waste management systems (7). Such systems include critical infrastructure to collect, transport, safely store, or repurpose discarded plastics. This is particularly urgent in rapidly industrializing countries where waste management systems lag behind accelerating use of disposable plastics. More research into reusable or biodegradable alternatives for single-use plastics could also be an important area of inquiry. In any case, the problem will only be controlled if and when all parties involved (plastic producers, consumers, and regulators) become painfully aware of its magnitude, and its pervasive effects on environmental and human health. This is what Rachel Carson accomplished in 1962, and what Wilcox et al. (2), among others working in this emerging field (7, 9, 15), contribute toward in the ocean.

1 Carson R (1962) *Silent Spring* (Houghton Mifflin Harcourt, Boston).
2 Wilcox C, Van Sebille E, Hardesty BD (2015) Threat of plastic pollution to seabirds is global, pervasive, and increasing. *Proc Natl Acad Sci USA* 112:11899–11904.
3 Kaiser J (2010) The dirt on ocean garbage patches. *Science* 328(5985):1506.
4 Secretariat of the Convention on Biological Diversity (2012) *Impacts of Marine Debris on Biodiversity: Current Status and Potential Solutions*. Technical Series 67 (Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel, Montreal).
5 Anonymous (2002) *Toxilogical Profile for DDT, DDD, and DDE* (US Department of Health and Human Services, Public Health Service Agency for Toxic Substances and Disease Registry, Washington, DC).
6 Plastics Europe (2015) *Plastics—The Facts 2014/2015. An Analysis of European Plastics Production, Demand and Waste Data* (Plastics Europe, Brussels).
7 Jambeck JR, et al. (2015) Marine pollution. Plastic waste inputs from land into the ocean. *Science* 347(6223):768–771.
8 Tanaka K, et al. (2013) Accumulation of plastic-derived chemicals in tissues of seabirds ingesting marine plastics. *Mar Pollut Bull* 69(1-2):219–222.
9 Thompson RC, et al. (2004) Lost at sea: Where is all the plastic? *Science* 304(5672):838.
10 Barnes DKA, Galgani F, Thompson RC, Barlaz M (2009) Accumulation and fragmentation of plastic debris in global environments. *Philos Trans R Soc Lond B Biol Sci* 364(1526):1985–1998.
11 Mathalon A, Hill P (2014) Microplastic fibers in the intertidal ecosystem surrounding Halifax Harbor, Nova Scotia. *Mar Pollut Bull* 81(1):69–79.
12 Mato Y, et al. (2001) Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. *Environ Sci Technol* 35(2):318–324.
13 Bakir A, Rowland SJ, Thompson RC (2014) Enhanced desorption of persistent organic pollutants from microplastics under simulated physiological conditions. *Environ Pollut* 185:16–23.
14 Woodall LC, et al. (2014) The deep sea is a major sink for microplastic debris. *R Soc Open Sci* 1(4):140317.
15 Thompson RC, Swan SH, Moore CJ, vom Saal FS (2009) Our plastic age. *Philos Trans R Soc Lond B Biol Sci* 364(1526):1973–1976.