Plasticus Mare Balticum

A synthesized collection of five independent research reports on plastic pollution in the Baltic Sea

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Executive summary

However diverse they may seem, each of the five report components brought together and presented here are inextricably linked to the others through the focus of location: the Baltic Sea.

The report as a whole seeks to share understanding of the roots of plastic polymer pathways to this sea, then moves to defining the nature and extent of the problem, then passes to the impacts on sea ice habitat and marine species of the region. This is followed by a shift to focus on a sense of what is currently happening in the business world to slow or stop plastic effects, what is possible to anticipate for the future, and which responses from industry and regulation by government policy will be most plausible and effective in mitigating the impacts.

This synthesis of those five reports fits both thematic and geographic lines of inquiry and investigation, but it also combines them in a way that offers decision-makers a sound basis for taking measured action:

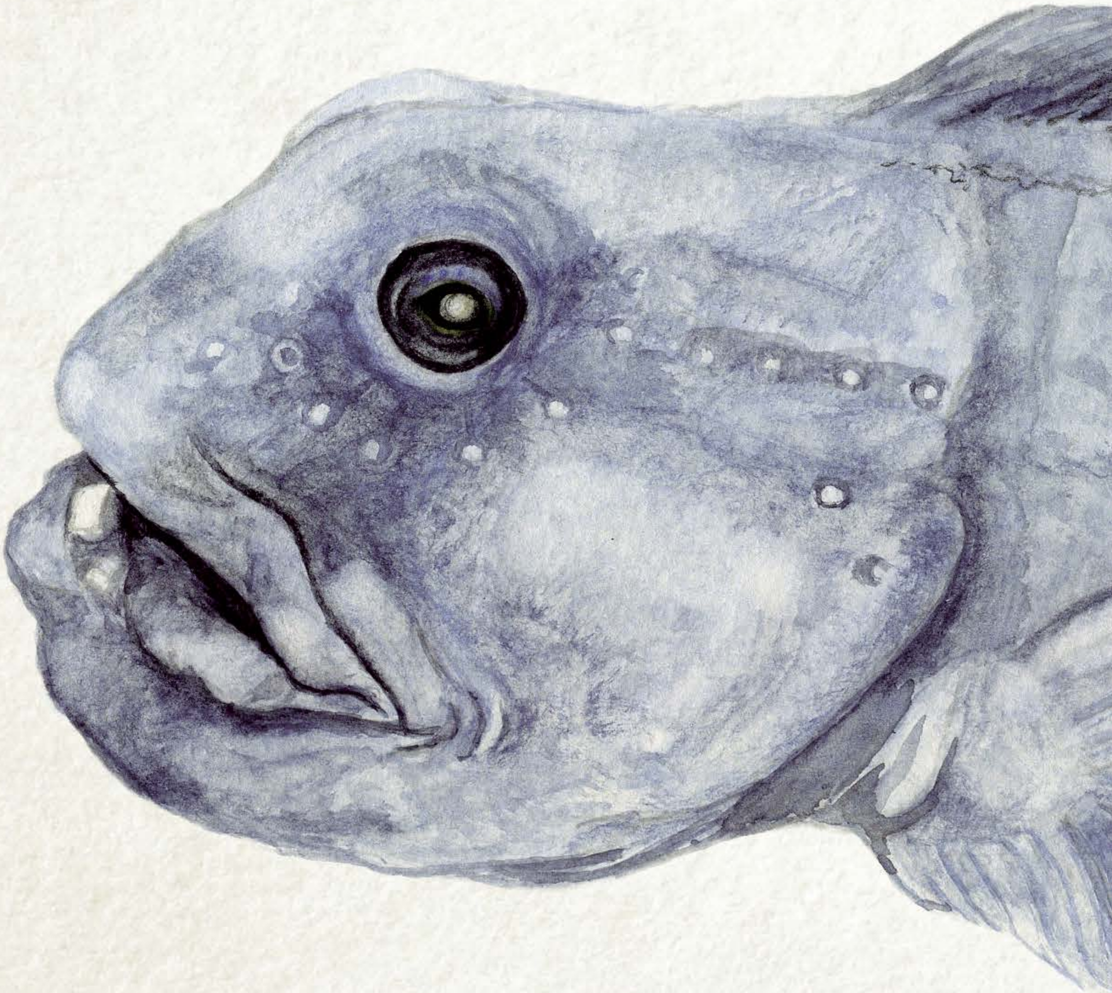
1. The *Marine Plastic Footprint* report develops science-based metrics that measure plastic leakage, in order to increase what they describe as both the materiality (or value) and circularity of plastic. A collaboration by Julien Boucher, Guillaume Billard and Eleonora Simeone, of EA-Shaping Environmental Action; and by Joao Sousa of IUCN.

2. The second report examines what happens when that plastic footprint falls on frozen seas. More specifically, exploring the effect of microplastics on sea ice, using data extracted directly from the Baltic Sea field and also from lab recreations of arctic conditions. The results of these analyses could have implications for the northern and, to a lesser extent, Southern polar ice caps. By Feiyue (Fei) Wang, Nicolas-Xavier Geilfus, Kathleen Munson, Yaroslav Germanov,and Saamia Bhugallo, researchers of the Sea Ice Environmental Research Facility (SERF) at the University of Manitoba, Winnipeg, Canada.

3. Blown above, captured inside, floating below, or sinking to the depths under the frozen surface: the third report examines how microplastics that enter the marine environment might then affect the extent to which they harm a range of important species – ranked and categorized by HELCOM and IUCN's Red List – from invertebrates at the bottom of the food chain, to apex predators at the top, and what that means for marine biodiversity.

4. From laboratory research to industrial production to retail consumption, private sector decision-makers hold the power to slow, stop or reverse the flow of plastic to the sea. Our fourth report undertook a survey of businesses in relevant industries to better understand the levels of awareness, activism, responses, and incentives at work. Marine plastic pollution management sometimes boils down to business management, and one of the most effective ways to modify results is through self-imposed industry measures driven by the need to reduce exposure to brand, finance, or regulatory risk. By Searious Business.

5. As a public sector baseline, what would an effective regulatory framework look like? Our fifth and final report, from the IUCN European Regional Office, examines the body of government policy, with a gap analysis of what may be missing and recommendations on how to improve it.



Atlantic Wolffish
(*Anarhichas lupus*)


Graça Lagrifa
2018

Part I
Polymer precedents: the Baltic Sea offers a geopolitical framework for solving plastic leakage

In this framing chapter, synthesis report writer James Workman compares two forms of marine pollution: oil spills and plastic litter. Both have economic origins, and ecological consequences. For decades visible tanker or oil rig catastrophes have raised alarm of the former's impact on birds and fish, while the latter – nano- and micro-plastic leakage in particular – may be both less visible yet far more insidious and long-lasting in its consequences for marine food web and the ocean ecosystem that supports all life. Subsequent chapters fill knowledge gaps, by illustrating the range and contours of plastic pollution in the microcosm of the Baltic Sea. These negative impacts appear to be worsening with each new study. Yet while a greater understanding of the problem we face is sobering, the parallel offers a pragmatic framework for addressing plastic leakage through similar coordinated policies, incentives, and information sharing tools that helped Baltic countries reduce oil spills from one of the most polluted basins to one that has reduced oil to a negligible level. In that respect, through the growing fog of plastic spreading throughout our seas, the report offers a clear entry point for rational hope and focused action.

As the world confronts the plastic soup spreading across our oceans, people in the Baltic and elsewhere may feel a strong sense of déjà vu, with parallels found in our history of damaging spills. After all, fifty years ago, in two corners of the ocean, humanity woke to a troubling era of another form of careless marine pollution.

First, on January 28, 1969 thousands of barrels gushed into the Pacific Ocean from a drilling rig off the California coastline. Several months later the oil tanker *Palva* ran aground in the Kökar Archipelago in southwest Finland, releasing 150 tonnes of Russian crude. In both cases a sticky black ooze spread out over hundreds of square kilometers, with slicks driven by wind, waves, and currents to coat plants, crustaceans, fish, mammals, and birds, including 33% of Finland's local breeding population of common eider.

They weren't the first. But notably, these back-to-back stories were televised. The regional broadcast of a sudden onslaught on the ocean galvanized millions of shocked viewers to agitate for political reforms. That initial shock would continue to grow over the next half century, as far

larger scale spills would spoil marine ecosystems off Brittany, France; Trinidad and Tobago, the West Indies; Campeche Bay, Mexico; Nova Scotia, Canada; Prince William Sound, Alaska; and most devastatingly the Deepwater Horizon spill in the Gulf of Mexico. Given constant circulation of the ocean conveyer belt, today it is hard to imagine any corner of the sea not impacted by the chemical and biological contamination of oil spills. No coastal country is immune, or innocent. Yet over time, year after year, one relatively small body of water has gained a dubious reputation as being a crude magnet, a "cradle for oil spills," which occurred with astonishing frequency and combined with other sources to rank among the most polluted saltwater ecosystems on earth: the Baltic Sea.

The Baltic Sea defines the brackish heart of Northern Europe. It spreads out over 370,000 km^2, is surrounded by nine countries (Denmark, Germany, Poland, Lithuania, Latvia, Estonia, Russia, Finland and Sweden), and is fed by fourteen international river basins that train a basin covering lands 1,739,000 $km.^2$ The Baltic Sea's defining characteristics – northern latitude, shallow waters, extreme weather, a volatile climate, semi enclosed water body with a vast catchment area, slow water exchanges, sensitive ecology, fragmented, fractal coastline, diverse population and a complex geopolitical context – make it especially vulnerable to marine pollution. The negative ecological and social consequences of oil in the Baltic Sea marine ecosystem has been documented as pervasive, long-lasting, and devastating to the region's natural and human communities. Oil spills cause both immediate and long-term changes in the biotic and abiotic environments.

What caused Baltic Sea oil pollution? Where did it come from? There were, at times, those visibly dramatic incidents of tankers such as the *Palva* in 1969, the *Tsesis* in 1977, the *Antonio Gramsci* in 1979 and yet again in 1987, and the *Eira* in 1984. At the dawn of the 21st century, the tanker *Baltic Carrier* collided with a freight ship and leaked 2,700 tons of crude into the brackish waters south of Falster, Denmark. By then, given the dense concentration of so many vessels shipping to and from so many countries, so often, such collisions and resulting oil leaks began to seem almost "inevitable." The Finnish Environment Institute (SYKE) reported in 2001 a record number of 107 oil spills – roughly one spill every three days. What most of these spills lacked in scale, they made up for in aggregate, cumulative impact. Yet a far more significant source of Baltic marine pollution has been incremental, caused by the subtle daily oil input load from urban areas, industries and illegal deliberate discharges. These rarely attract breathless media coverage, yet according to the Baltic Marine Environment Protection Commission, 80 % of the oil and oil residues in the Baltic Sea come from land-based sources: river discharge and coastal installations.

We emphasize these geographical, ecological and political aspects for a reason. There are profound and striking parallels – in the marine microcosm of the Baltic Sea ecosystem – between oil spills and plastic pollution. The story arc of oil spills lays the foundation for the research beneath and interpretation of this synthesis report on plastic leakages.

Petroleum parallels

For starters, the two sources share similar origins : more than 90% of plastics produced are derived from fossil fuels, and account for an estimated 8% of total oil consumption. According to a McKinsey study, "the greenhouse gas footprint from plastic will become even more significant with the projected surge in consumption. If the current strong growth of plastics usage continues as expected, the emission of greenhouse gases by the global plastics sector will account for 15% of the global annual carbon budget by 2050, up from 1% today."

There are also common distributional effects found in both types of fossil fuel derivatives. Broken up by the elements, spread by wind, carried by waves, distributed by ocean currents, some of the leaked material floats; much of it sinks into sediment. The damages may be immediate or not detected for more than a century. Films cover marine animals of all species, leading to

suffocation and die-offs; portions are ingested by the marine food web, leading to debilitation and death.

In both cases, public officials face growing pressure to act urgently and judiciously. Public awareness has steadily risen in response to graphic images of charismatic animals crippled, mutilated, clogged or suffocated by human waste. Activist campaigns push for product bans, consumer boycotts, coastal cleanups and blunt regulations.

And the risks from both oil and plastic escalated over time. During a 15 year span, from 1995 to 2010, oil transport in the Gulf of Finland increased 10-fold, a trend that continued as Russia opened new oil terminals and increased the capacity of its existing ones. Less visibly, excessive amounts of oil – also like plastic – that have been wasted or spread by accident, risk silent release into the natural environment, flowing off land as runoff into waterways and carried into marine ecosystems. In both cases comes the recognition that the oil and plastic parallel issues pose complex and ingrained challenges, that civilization depends heavily on both the production and consumption of these admittedly toxic substances, and yet that few obvious economically viable alternatives exist.

Useful distinctions

To be sure, there are also important limitations to this Baltic Sea comparison. Foremost, consider the scale or magnitude of the problem. Before it was capped, the worst marine oil spill in human history, the *Deepwater Horizon*, leaked 4.9 million barrels, or 700,000 tonnes of oil. That's horrifying to behold. Yet current reports estimate that humans leak twelve million tonnes of plastic into waterways and, ultimately the sea – each *year*.

Next, consider the difference in synthetic purpose. Form follows function, and refined plastics have been deliberately designed and scientifically engineered to last much longer than crude. While estimates vary, depending on the concentration, the rate of oil biodegradation in the sea is estimated to range from a half-life of a few weeks to a few dozen months. By contrast, a plastic straw will last at least 200 years; a plastic bottle, 450 years; a fishing line 600 years, provided evolution does not speed up the decomposition through microorganisms.

The elements wear down oil and plastic in different ways. Starting with large plastic forms: bags, bottles, caps, containers, synthetic decks, doormats, nets, PVC pipes, straws, toothbrushes, and wraps gradually break up into tiny pieces. As we shall see, other sources – plastic shards, fibers, bits, beads, or dust – were never all that large from the start. Polymer fragments smaller than 5 mm are known as microplastics (MP); even smaller than 100 nm are known as nano plastics (NPs). While not visible to the naked eye, these and larger or macro plastic forms scatter with the wind, tides, waves and ocean currents, forming a 'plastic soup' or marine plastic 'smog' that swirl in ocean gyres. The health impacts of oil and plastic leakages on fish and wildlife are also distinct. Raw organic oil may contaminate marine life for days and weeks; synthetic micro- and nano-plastics, so much more durable by design, may remain in the stomachs of animals for years. The science is still unclear, but some researchers fear the health implications as they explore whether the micro- and nano-particles of waste work their way up the marine food web into the sushi or grilled fillets that sit on our dinner plates.

Another difference is found in the wide diversity of sources. Whether spilled at sea or on land, oil waste is linked to transport, energy and heat generation, while plastics pervade nearly every aspect of our lives: food, drink, shelter, transport, health, hygiene, fashion. The unmanaged waste of single use bags and bottles understandably grab headlines; less easily tracked (as we shall see) are all the diverse yet voluminous primary microplastics and other polymers in paint, cosmetics (nail varnish, toothpaste, facial scrubs etc.), clothing, tyres: a form of pollution made even more troubling because it is hidden in plain sight.

A related distinction is that whereas we can address oil pollution with a narrow focus on a few 'bad actors' acting carelessly in a single sector,

plastics implicate every human, rich or poor. Oil spills are associated with 'dirty and careless crimes.' With plastics, even cleaning up can lead to pollution, as we leak polymers and microfibers when we take showers or run a load of laundry. Worse, by deliberately cracking down on (or consciously refusing to buy) one form of plastic, society may inadvertently be increasing leakage from another source or product.

An unlikely role model

> **THE FOLLOWING PAGES OFFER AN INTEGRATED SYNTHESIS OF A RECENT GROUP OF REPORTS THAT SEEK TO ADVANCE OUR UNDERSTANDING OF RELATED TO THE CAUSES OF, CONSEQUENCES FROM, AND COLLECTIVE ACTION IN RESPONSE TO PLASTIC POLLUTION IN THE BALTIC SEA**

All this makes our current challenge of closing the plastic tap far more politically daunting than it even is with oil. And yet by continuing to compare the two forms of marine pollution leaking into the closed and brackish Baltic Sea, we find, again, that within each mounting crisis lies a profound and hopeful opportunity.

For over the two decades since the peak of oil spills in 2001, the Baltic Sea has undergone a remarkable transformation, with observed oil spills dropping year on year – both offshore and on. Even as tanker traffic and shore refinery activities kept rising, oil leakage into the Baltic kept falling. By the first half of 2014, no slicks had been discovered, and subsequent years marked record all-time lows. More than three quarters of those few spills that still occurred involved quantities of less than 100 litres. The intergovernmental organization HELCOM, established in 1974, has reportedly grown "noticeably more positive in its outlook [and has] set a target of eliminating all oil spills by 2021. In light of recent statistics, this goal seems attainable." On a planet facing bleak news about rising sea level, depleted fisheries, warming seas, bleached corals, ocean acidification, ocean deoxygenation, and deep-sea mining, the quiet decline of oil spills in the Baltic toward a possible vanishing point ranks among the best environmental stories no one has ever heard of.

This steady transformation did not just happen, overnight, on its own. How did it come to pass?

Analysts attribute success to a smart combination of forces. Leaders recognized early on that they could only manage what they measured, and that before coming up with a solution they had first understand the complex dimensions and contours of the oil spill problem. They set out to monitor diverse causes. They documented dark consequences. They calculated what might be known as oil's ecological footprint. In response, they harnessed linked forces that came to include a more focused environmental advocacy, judiciously applied political will, escalated regional surveillance, geospatial data collection and modeling, illuminating ecological impact assessments, increased levels of transparency, policy gap analysis, strategic long-term private sector engagement, meaningful economic incentives, and elevated diplomatic collaboration among Baltic coastal countries.

It is fitting and proper that IUCN should help apply these same lessons and forces to our current marine pollution challenge. To that end, the following pages offer an integrated synthesis of a recent group of reports that seek to advance our understanding of related to the causes of, consequences from, and collective action in response to plastic pollution in the Baltic Sea.

The bad news for the ocean is that plastics, like oil spills, represent a complex wicked problem of our own making. The good news emerging both from these pages and from our previous experience with oil in the Baltic Sea, is that because humans caused it, and humans are recoiling from it, humans have demonstrated that – by better understanding our role – we have it entirely within our power to solve this problem.

Red-necked Grebe
(*Podiceps grisegena*)


2018

Part II
Qualifying causes: subtle sources of Baltic Sea microplastics

All too often popular assumptions about plastic pollution tend to focus energy on the most obvious culprits: bulky, noisy bags, bottles and straws that are blown into a dozen big Asian or African rivers and out to sea where they smother, choke or suffocate marine creatures. To be sure, visible 'macro' plastic presents a large source of ocean pollution, and taxing or targeting them may make sense. Yet recent analysis, distilled in this chapter, shows the extent to which tiny fibers and fragments of micro plastic – some invisible to the naked eye – plays a surprising role in the global problem. To resolve the impacts, developed countries such as those in the Baltic ecosystem need to think about these sources in fresh and innovative ways. This chapter draws lessons from studies including the IUCN evaluation by Julien Boucher and Damien Friot: "Primary microplastics in the ocean."

The phrase "marine plastic pollution" conjures up the conventional image of a human-tossed, wind-blown, gutter-washed, and ocean-bound straw, bottle or bag. Such primary sources of litter debris tend to be big, blatant, and noisy. 'Macro' plastic may slurp up the soda, scrape along the sidewalk or flap in the breeze.

This broad perception makes sense. Extrapolating from trash collected over five years of beach cleanups, Australian scientists project there may be 437 million to 8.3 billion of the .4 gram plastic straws – 4% of plastic volume but far less by weight – clogging world's coastlines. Recent estimates suggest that, worldwide, humans purchase 20,000 plastic bottles per second, and more than a million every minute, putting us on track to buy half a trillion plastic bottles by 2021. And the wrinkled and translucently thin grocery bag exemplifies the 40 % of all plastic items that are used just once, then discarded, with an average working life of 15 minutes or less from checkout stand to kitchen counter.

Years ago, those straws, bags and bottles arrived at our door with scientific pedigrees and convenience. Derived from crude oil or natural gas, they are fabricated from material that starts out as simple links of combined oxygen, hydrogen and carbon monomers like, say, ethylene glycol or dimethyl terephthalate. Under applied heat and pressure, these are forged through chemical reactions into durable, long molecular chains such as polyethylene terephthalate (PET). This 'synthetic miracle' cuts to the heart of our global predicament: the very same functional values that lead to modernity's universal adoption of and deep dependence on plastic materials – cheap, strong, durable, malleable, and lightweight– also makes them seem staggeringly difficult to control, phase out, or replace with some sustainable material.

The loss of synthetic salvation

In fact, synthetic polymers initially helped replace or reduce pressure on countless items made

from other vanishing “natural” resources ranging from tortoise shells and beaver pelts to elephant ivory and tropical forests. Even today, ‘cleaner’ or ‘more sustainable’ alternatives to plastic bags, like the ubiquitous canvas tote handed out at nearly every green conference venue, may deplete fresh water from rivers or generate more carbon emissions in their lifetime. With so many interwoven threads in our economy, there is no direct, simple and free path to sustainability. Boycotts and bans have their appeal, especially in affluent cities. Some may work and achieve their desired and appropriate outcomes. But given such pervasive use, unrivalled properties and low cost, the current global production level of 335 million tonnes of plastic each year, is still expected to double over the next two decades.

Polymer production has “upstream” effects that must be assessed, including impacts from seismic surveys, drilling, extraction, refining, transport, leaching, air emissions and water pollution. More insidious threats arise from usage in a ‘throwaway lifestyle’ as plastic escapes, spills, gets lost, breaks down from abrasion, or bleeds out from human dominion and waste management systems. Plastic waste is far from inevitable. Recycling rates for a few obvious cases, like refundable plastic bottles, have been increasing in recent years in many countries, reaching 31% for Europe, and thrice as high in a few individual Nordic countries. But recycling rates are far lower for most plastic categories. Nevertheless, our polymer-based economy is a long way from being ‘circular.’ Globally, less than half of all plastics are gathered up for recycling, and only 7 % of what gets collected is then transformed into new bottles; much of this is simply down cycled into less valuable forms, rather than re-used or re-cycled. The rest is discarded -- incinerated or dumped in landfills – often inappropriately, and this ‘lost’ amount of secondary plastic flowing into gutters, waterways and ultimately, into the oceans, is known as ‘leakage’ – an amount estimated in the order of magnitude of 12 million tons per year, or 3% of all plastic we produce.

At this point, plastics start breaking down and poisoning marine life, repeatedly, not only from indirect and visible sources like those straws, bags and bottles, but from polymer pathways that we are only beginning to see, acknowledge, and measure.

Many of us have seen or listened to excruciatingly graphic photos and videos of straws extracted from the nostrils of sea turtles, or animal autopsies that reveal entire bags or plastic fragments clogging the stomachs of other turtles (which mistake plastics for jellyfish), baby albatross, sea lion or even whales. Even while squirming, we can’t look away. Yet beyond those deaths of charismatic megafauna lie less obvious yet often more extensive damage from impacts further down the food chain on less visually stirring yet more critical marine habitats that support plants and animals alike. A January 2018 Cornell University global survey of 159 reefs found essential ocean habitats like reefs were degrading under the weight of all the tonnes of plastic bags, bottles and containers annually washed out to sea, broken down into microscopic particles and fibers smaller than 5 millimeters; these persist for many decades or centuries and elevate the disease risk in corals from 4% to 89%. Already an estimated 11 billion plastic items are caught on the region’s reefs; in Myanmar, every single reef in the 700-island Mergui Archipelago is ensnarled, and nearly every plastic-draped coral is diseased.

River vectors as carriers

Fast-developing countries – whose consumers are targeted with small, individually wrapped consumer goods from soaps, cosmetics, food and beverage — understandably seek the lowest cost items, combined with weak institutional waste management capacity to properly dispose of it after use – are especially vulnerable to these large secondary sources of indirect plastic pollution. Rivers have in recent years been recognized as the vectors that deliver the plague of plastic waste into the sea. That riparian focus has implications for the structure and interpretation of this synthesis. After all, the World Bank estimates 200 large streams discharge freshwater into the Baltic Sea, turning it into the world’s largest brackish sea; among these

Baltic-bound currents are the transboundary Oder, Vistula, Venta, Neman, Daugava and Narva Rivers. A global scale research team under Christian Schmidt recently analyzed the waste found in rivers and surrounding landscape, and estimated that a mere ten basins carry 90% of the river-borne plastic that ends up in the ocean. Eight of these river basins -- the Yangtze; Indus; Yellow; Hai He; Ganges; Pearl; Amur; Mekong – are found in Asia, with the remaining two -- the Nile and the Niger, located in Africa. Although there is a great degree of uncertainty with this estimate (ranging from 0.4 to 4 million tonnes per year), it is a good indicator of the importance of rivers as a source of marine litter. It also helps target regions where better waste management practices are needed.

Taken by itself, such research nurtures the tempting conclusion that plastic pollution is really a poor country's problem. More affluent and developed countries, like those found in Northern Europe around the Baltic Sea, have efficient and relatively well-run waste management systems, represent a tiny fraction of global marine pollution. Cities along the Dalälven, Kemijoki, Oder, or Lule älv would thus appear to have little cause for concern, right? What's more, the attention on large or 'macro' plastic misleads some activists into the temptation that the problem can be solved by just building and installing massive plastic-filtering strainers at the mouths of rivers – like, say, the Pasig in the Philippines or the Amazon in South America – to capture, sort and recycle all the littered bottles and bags carried out to ocean gyres by currents. To prevent ocean leakage, plug those river vectors and run currents through a sieve. Presto, global plastic problem solved!

Complex and complicated origins

Unfortunately, leakage down rivers from mis- or un-managed municipal consumer waste, while emphatically important, is just one important source of marine ecosystem contamination, and only the most obvious. 'Plastic' is a simple and narrow word that fails to encompass the vast, varied, and multifaceted reality of polymers and additives, all of which generate very different chemical and physical properties. If a living room fills with smoke, the problem may indeed be the fireplace's sooty chimney, or faulty flue; but that can't distract attention from the dozen people in dark corners quietly chain-smoking cigarettes. Similarly, the causes of plastic marine pollution leakage into the Baltic originate from many places, occur at both macro and micro levels, and are thus far more complex, diffuse and dynamic than may initially appear on the surface.

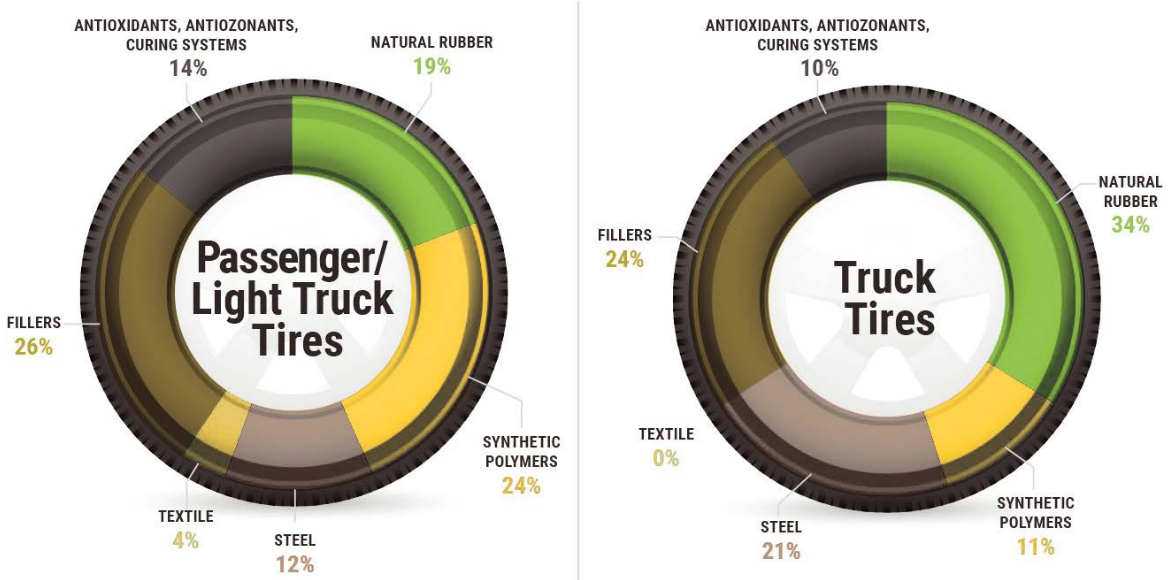
Leakage depends heavily on demographic and geographical contexts. While macroplastics from mismanaged waste remains dominant especially in developing countries along the coast, microplastics are much more pervasive and have more subtle routes to marine environments and can escape detection or filtration as they are carried to rivers and oceans. The contribution of primary microplastics to plastic leakage is 15% globally, and that ratio may, paradoxically, rise higher than macroplastics in industrialized countries of Scandinavia and Northern Europe.

To address this rising proportion requires that decision makers take a closer look at the initiation of polymer pathways: the point where plastics escape human dominion, become part of material 'loss' into the wild, and ultimately 'leak' into the Baltic.

Consider the following vignettes, drawn from real-life scenarios and analyses, that link specific consumer routines and designs with important but often unexpected industries. Each is based on some of the most commonplace yet essential activities taking place day and night, enmeshing cities and suburbs within every neighboring country in the Baltic Sea basin.

Road runoff in the ground transport industry

A middle-aged businessman is driving his BMW 740i luxury sedan, bound northeast on Bundesautobahn 20, colloquially known as the "Baltic Freeway." He departed Hamburg late morning bound for a lunch meeting in Rostok,



Ultimately Driving into the Sea: We may not consciously toss litter out our car windows, but hundreds of millions of drivers each day unconsciously litter our roads with microscopic bits of plastic worn from our vehicle tires, pollution that eventually makes its way into runoff, rivers, and the ocean. Source: US Tyres Manufacturers

passing Audis and Mercedes as he cruises along at 165 kilometers per hour. The car stereo is playing his favorite song, and, alone, he joins in the chorus singing out loud and tapping the steering wheel, so carried away by the melody that he almost misses the exit and must brake hard. On the off-ramp, his screeching wheels leave some black tread on the asphalt.

Braking and turning is the most vocal way car and truck tyres are eroded. Far more particles or 'dust' get lost to nature from the mere act of driving. Over the following months, first blown by gusts of late afternoon wind, followed by pounding sleet and rain, the minute tyre micro-fragments from his skid get dislodged from the nooks and crannies of the pavement and become part of the general runoff. While some portion of the bits become trapped in the grass and soil along the shoulder of the roadway, the rest tumbles and floats into the Kosterbeck, a tributary that joins the Warnow River, which then flows out to the Baltic.

How much tyre polymer is lost in this manner, and of that what amounts subsequently leak into sea? Exact volumes are both critical to assess and difficult to quantify. Studies have identified common, if broad and variable, parameters that influence the size and amount of tyre particles and dust (mg dust/km driven) during driving. These include the average tyre's chemical content and 'softness,' the average vehicle size and weight, average driving speeds, typical pavement surface and condition, temperature or climate, and the nature of contact – smooth forward rolling versus horizontal slippage or skidding.

Many assume the wheels that have for the last century sped billions of us over the earth's surface consist entirely of 'rubber' that is extracted from latex vegetation in natural rainforests. Yet the outer surface of modern tyres are a complex matrix of synthetic polymers, namely Styrene Butadiene Rubber (approximately 24% if a passenger car or 11% if truck/lorry), in a mix with natural rubber and many other chemicals used as reinforcement agents, processing aids, accelerators and retarders, adhesives, and activators. The proportion will vary by need: typically, lorry or truck tires will contain 80% natural rubber, whereas passenger car tires like our businessman's BMW will contain only 15% natural rubber.

The lens on tyre losses and leakage has policy implications for any coordinated approach to diffuse runoff pollution into marine ecosystems. More vehicles on tyres with more plastic content transporting more plastic weight – or even heavier metal, cloth, wood or glass alternatives

to replace that plastic – all adds up to more polymers entering the sea. The deformation of some thermoset plastics is irreversible, while the deformation of certain rubbers is reversible, which makes them elastic. One way of thinking about this physical difference is that thermoplastics can be re-melted back into a liquid and cooled into a hard form – many times, much like butter in a mold -- whereas thermoset plastics always remain in a permanent solid state. For this reason, tyres (much as any other elastomer) are still counted in the marine litter as a separate category from plastic objects, they should be classified as a potential and significant source of microparticles of polymers probably with the same impacts of microplastic.

With a closer look, only now are we beginning to appreciate just *how* significant. Vehicle tyres rank as the single most important source of particles lost in the environment through mechanical abrasion. The estimated per capita emission from tyre wear ranges from 0.23 to 4.7 kg/year, with a global average of 0.81 kg/year. Translating this general mass of tyre wear particles (TWP) generated brings estimates of 1,327,000 tonnes per year (t/a) for the European Union, of which Germany alone is responsible for 133,000 t/a. The portion of this TWP mass that ultimately enters the aquatic and marine environment depends on the extent of collection and treatment of road runoff, which, admittedly, remains highly variable. Yet researchers estimate roughly that between 9% from Germany highways and 12% from other regions of microparticles from tyre wear ultimately leak into surface waters.

Synthetic clothing in the textile industry

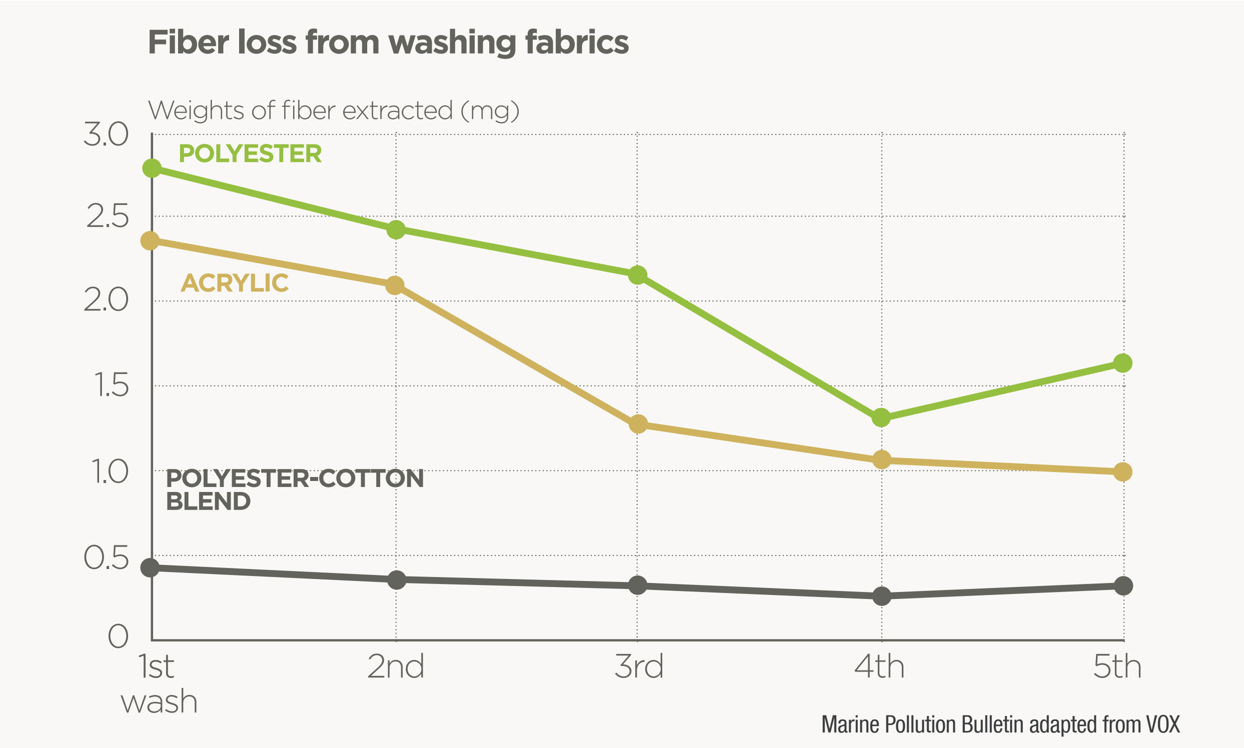
In the suburbs of Riga, a 20-year-old marine biology student at the University of Latvia – one of 14,000 enrolled – returns to her dorm room after a brisk 10-kilometer-long morning jog in the north of the city, right along the coastline. The weather is brisk, following days of rain, and while splashing through the puddles she muddied her new Nike Tech lycra turquoise leggings. Her Columbia Sportswear Titan Ultra short sleeve running shirt helped wick away perspiration, as did her Under Armour socks, while her North Face Polartec fleece allowed her body to breathe while breaking the chilly wind sweeping in off the Baltic.

She couldn't imagine what it was like in the 'olden days' back when her parents and grandparents grew up having to make do with cotton and wool. Still, after several days of activity her clothing had begun to smell a bit... ripe. So when she returned from her morning classes, she bundled all the laundry into a bag, took it to the nearest SpeedQueen, filled one of the larger washing machines, added detergent, closed the door, inserted coins, and pushed the button marked 'Start.'

Her chosen field of study grew out of a lifelong love for the ocean. She didn't realize until a lecture, months later, that the very act of cleaning her 21st century clothes opened yet another source, or polymer pathway, that leaked microplastics into the Baltic.

Synthetic fibers such as polyester, acrylic, and nylon are all forms of plastic. In pure or blended form, they stretch, breathe, warm and endure. They last for years without absorbing moisture from within or allowing it in from outside. These fabrics reduce or avoid the need for grazing sheep for their wool or irrigating cotton on precious arable land that could instead produce food crops. And they improve health and may even save lives by preventing hypothermia. For all these reasons and more, today polymer fabrics constitute almost two thirds of the material that goes into the global manufacturing of clothing.

All of which would be entirely positive, except even these synthetic fabrics don't remain perfectly intact; nor is most clothing designed to last especially long. They break down from literal wear and tear, shedding tiny fibers from the human act of walking around, and that friction grows most intense with more strenuous activity, especially when tossed into washing machines. Most dryers have been built



Unravelling Onshore: Plastic is so utterly interwoven into our daily lives that we may not realize how (above) each time we deploy our washing machine to "clean" our clothing, we also unwittingly "dirty" aquatic ecosystems with microplastics. Appliances and treatment plants lack filtering mechanisms to prevent the tiny fabric fibers (left) from being extracted and reaching the sea.

with mesh to collect lint, the threads dislodged while tumbling together under hot forced air. But most washing machines lack such screens, so pass through into the sewer system of Riga and thousands of other treatment plants which also lack the ability to capture and collect microscopic plastic threads, shards, and bits of synthetic polymer-based clothing, and pass this plastic on through to the Baltic.

As with tyre dust and road skids, the leakage of microplastics from clothing has only been examined in relatively recent years. A groundbreaking 2011 forensic evaluation of sediments offshore found “that the proportions of polyester and acrylic fibers used in clothing resembled those found in habitats that receive sewage-discharges and sewage-effluent itself,” and suggested washing clothes contributed an important source of microplastic. Since then, textiles have been increasingly identified as a source of synthetic microfibres that through wear, tear and laundering make their way to the ocean.

Once again, the extent of this source of pollution will vary by multiple factors. Variables include the type of clothing, the fabric’s age and usage, synthetic/natural blend, the speed and duration of spin cycles, wash temperatures, even size of the load, or detergent (which increases release) or softeners (which reduce loss 35%) used by our Latvian jogger at the SpeedQueen. A 2016 study broke down the impact by make of machine. Beyond water saving benefits, top-load machines released five to seven times the number and mass of microfibers as front-load washers. The chemical mix also matters. Synthetic fabrics with a higher loss rate in microfibres are polyester, acrylic and polypropylene; researchers found the polyester-cotton fabric consistently shed significantly fewer fibers than either 100% polyester or acrylic.

Elsewhere, research suggested that fleece fabrics shed significantly more fibers than other knits; PET fleece sheds an estimated 110,000 fibers per garment and wash. This research paper also found: no significant difference between nylon, acrylic, and PET knits; more

loosely knit textile construction resulted in greater fiber loss; and shedding of fibers can potentially be mitigated with smarter textile construction.

Research is young and evolving, yet some papers indicate that shedding takes place like a curve, initially high, with a loss rate stabilizing after the 5th–10th wash, then worsening as the garment comes apart near the end of its useful life. Overall, the fiber size of clothing polymers ranged between 11.9 and 17.7 micrometers in diameter, and 5 and 8 mm in length. Given the variability of factors, the central, low and high value for the loss rate are based on all values reported in the literature with loss rate of 49/124/245 micrograms per kg of textile wash.

Still, over time, given the volume of fabric, and frequency of washing, those micrograms add up. And impacts are far from innocuous. Later experiments sampling wastewater from domestic washing machines estimated that a single garment – that biology student's lycra leggings, nylon socks, polyester shirt -- can generate 1,900 fibers per wash. By 2017 these estimates appeared to be trending upwards, and one study estimated that the student's Polartec fleece alone might release one million microfibers from that single wash. On average, a single 6 kg wash load of acrylic clothing could release 700,000 plastic microfibers into the sewers, and thence leaching into seas. Given Riga's 600,000 inhabitants, researchers estimate that the city's population could leak roughly six kilograms of micro- and nano-particles of plastic fibres each day, or 400 kilograms per year. These would pass through Jugla's water treatment plant, on the east side of the city, empty into the Berģi and then Ķīšezers water bodies, and from there flow out the Mīlgrāvis directly into the Baltic.

Hygiene in the personal care industry

Many people tend to run their laundry only once a week. Yet these same individuals tend to bathe daily and brush their teeth at least twice. Personal care is a vital element of modern hygiene, and one chilly evening in the larger municipality of Sundsvall, on the coast of central Sweden, a retired couple steps sweaty out of their sauna.

After several decades together, they have by now settled into a routine. Each takes turns, first at the shower, then at the sink. Under a steaming spray blast of hot water, the husband pumps a large bottle of bodywash into their hands to help exfoliate all the dead skin cells and leave his body feeling shiny and smooth. Meanwhile, his wife brushes with a whitening formula to keep her teeth pearly and gleaming. Finally, they each apply deodorant under their arms. Both are responsible consumers and sort their recycling for collection before turning in for the night, unaware of the lasting damages they have sent trickling in a deadly spiral down the drain.

All too often, many facial soaps, body washes, anti-perspirants and toothpastes contain microbeads, tiny balls or spheres of plastic manufactured to amplify the 'scrubbing power' in consumer cleansing products. Ranging from one invisible-to-the-naked-eye micrometer to a pinhead-sized millimeter, the United Nations Environment Program (UNEP) has shown that a single package exfoliating sho wer wash may hold as much polymer in the form of microbeads in the gel as in the plastic bottle that holds it.

Wastewater treatment plants weren't built to manage these recent synthetic polymers. Once in the water system, they can absorb, concentrate, and transport toxic compounds such as polyaromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) and pathogenic microorganisms. Some consider microbeads originating from cosmetics and other personal care products like these among the most problematic microplastics to remove through wastewater treatment plants. As a result, various EU cities and countries have proposed bans on their manufacture in personal care items, but there is still a backlog of products on store shelves and medicine cabinets that have yet to be used.

Fishing gear in the commercial seafood industry

A commercial sprat fisherman eases his vessel out of Pärnu, considered the most important seafood landing port in Estonia, and heads out to deep waters offshore.

The Baltic Sea has long ranked among the world's most intensively fished marine areas, and overexploited species have in some cases begun to decline. Overharvesting has, in turn, caused coastal and offshore ecosystem shifts. The upshot is that each Baltic fisherman must risk more time on the water, working harder, farther out to sea, while facing extreme weather, just to capture a smaller portion from a shrinking supply. Ideally, he wouldn't be out in high waves, half awake, testing his luck in this corner of the Baltic, but given competing pressures, what alternative does he have? The seafloor in these parts are new and unfamiliar to him but he starts to fish. Only later, while winding in a load, does he feel a lurch and a sink in his stomach, suspecting there may be a sunken vessel on which a portion of his aging net gets snagged. Hauling it in, tears half the net loose. Unable to recover it, despite hours of effort, the fragment slips away into the depths, where it starts to drift with the current.

The personal financial loss from equipment (not to mention unharvested fish) he suffers that day is heavy, setting him back a thousand euros when he returns to port with a paltry load. The release of a 'ghost net' into the Baltic brings another form of silent loss, in fish, birds and mammals.

Wild capture fishing methods range from traps to nets and lines. Yet whatever the shape, accelerating in the 1950s, modern fishing gear has been manufactured from material derived from chemical synthesis. Four types of plastic polymer fibres include: polyamide fibers; polyesters; polypropylene; and polyethylene. All share a valuable resistance to weathering, the kind of biological decomposition that ravaged old traditional and natural gear made from rope, twine, woven string and lines. Such properties make them efficient killing devices that may last several centuries on the loose; nets like the one lost may catch 20 % of the usual capacity after three months, subsiding to 6% after two years adrift.

To this direct lethal force, we can add a third indirect form of marine degradation. As the lost line, trap or net breaks down from friction with the elements, exposure and time, it introduces another source of microplastic into the sea, a direct polymer pathway that is in a different category from debris that starts its journey on land, yet in some ways equally hard to quantify.

Still, estimates suggest the global fishing industry emits a substantial amount of microplastics per year in the form of derelict gear. Factors triggering this loss and leakage at sea will vary by storm intensity, wave height, distance from shore, fleet size, gear type, wind and currents. Many still debate how significantly lost fishing gear even contributes to the volume of plastic leakage. Data sources are scarce, and the precise contribution is highly unreliable. And while beach clean-ups and surveys collect enough ropes and fishing nets to show, anecdotally, a ubiquitous form of pollution, there's little quantitative data.

That said, field studies report a prevalence of blue nylon fibres specific to fishing devices. What's more, shipping litter thrown overboard, while supposedly forbidden, contributes to the overall plastic pollution with estimates of 600 kiloton (kt) per year. Typically, we cite the ratio of 80% of marine litter coming from land, based on uncollected waste, while the remaining 20% is directly generated at sea, through marine activities such as fisheries.

With better studies and oversight of an opaque industry, researchers are gradually putting the pieces together, trying to forge a more accurate sense of the scale of the problem. The percentage of lost nets increased proportionately to the distance separating fishing grounds from the coast. Polish shipwrecks may have snagged anywhere from 150 to 450 tonnes of nets. In 2011, one study estimated that five to ten thousand pieces of nets get lost or abandoned each year in the Baltic Sea. The loss of gears took place

regularly only in fisheries targeting demersal fish such as turbot and cod.

Offshore on the waves or even back on the docks, it is hard to monitor what gets caught, let alone what is lost or released at sea. Although the disposal of general waste at sea is prohibited by numerous agreements and conventions (e.g. MARPOL 73/78), illegal dumping is still undertaken, as the possibility of proper waste management on ships will be dependent on suitable port facilities (Mouat et al., 2010). Our prototypical captain did not intend to sacrifice his nylon net, but what can he gain from reporting its loss?

Our best guesstimate on the global input of debris generated at sea is estimated around 0.6 million tonnes per year, with different sources presenting values of 0.6 Mt/a or 1.15 Mt/y for derelict fishing gear. Except from conducting a specific inventory and a worldwide assessment, there is still no possibility of calculating additional and more precise estimate. Thus, data on maritime sources is still scarce, as the vastness of the oceans and the multiple fate scenarios prevent a sound tracing of sources.

Raw pellets and marine paint in the distant ocean shipping industry

In the dark, cold, dead of winter, a large Russian container vessel, flanked by tugboats, eases out of the Big Port of St. Petersburg, headed for warm bright Brazil.

The port holds the two largest terminals in the Baltic Basin, with a combined capacity of 2,250 thousand 'twenty-foot equivalent units,' or TEUs. TEUs are the rectangular, 8-foot-tall metal boxes – easily stacked on deck, or craned onto the backs of trucks and trains – that hold and carry pallets of nearly everything shipped the world, including the raw materials of polymer manufacturing, typically taking the shape of 2-5mm in diameter spheres, and known as virgin plastic pellets, beads or nurdles. Transported in crates from raw production source to final item synthesis, pellets can be lost at any step along the supply chain.

Days later, midway at one of the deepest points of the Baltic, a severe cold snap combined with a heavy winter storm to coat one side of the cargo vessel with thick layers of ice. The weight causes the hull to tilt hard to the port side. Heeling over, the point gravity takes over, and one of the stacks of TEUs, slides hard, slamming against the side of the ship. The top container tips off, strikes the hull, opens and crashes into the sea.

Container losses are not frequent, but they do happen. After a survey of its members, the World Shipping Council estimates that from 2008 to 2013 the sea annually claimed 546 containers lost at sea; including catastrophic events, this average tripled to 1,679 containers lost each year. To put that in perspective, carrier vessels shipped 120 million containers holding $4 trillion worth of goods. Yet the overall number of lost containers is increasing with volume and traffic over time.

To better understand how plastic pellets end up in the environment, a research team from the University of Gothenburg documented, measured and calculated the flows of the pellets via waterways leading out from the production and distribution of a plant in Stenungsund which manufactures approximately five percent of Europe's raw polyethylene. Their analysis quantified continuous leakage at between 3 and 36 million plastic pellets each year. Smaller fractions, known as 'fluff' or 'fragment,' increased raw leakage by more than a hundred times greater than the volume of pellets alone. Researchers also found additional leakage problems during the cleaning, loading, storing and transport phases.

Before departure, the hull of that same container vessel has been coated with a thick, fresh layer of paint. The vessel regains its bearings and stays on course. Yet as it moves through the Baltic, the constant abrasion against sea ice wears off tiny, thin, plastic flakes originating from the aliphatic polyester resin in the paint. (Magnusson and Norén, 2014).

The rate of wear may not be visible, so the leakage may not seem to amount to very much each day at sea. Except there are estimated to be 2,000 large ships sailing in the Baltic marine area at any given moment (half are cargo vessels like this one) with up to 5,500 navigating through every month; countless thousands more leisure and fishing boats ply the waves. All coat their hulls against the elements, and 50 % of that marine paint consists of polymers, or plastic, which wears into the sea over the course of its lifetime. The most optimistic/central/pessimistic annual loss rate estimates for commercial boats are 3/6/9%, respectively (OECD Series on emissions documents, 2009); for smaller but more numerous leisure boats in developed economies it is much higher 10/30/50%.

Consumer waste in the product packaging industry

There are of course, the classic polymer pathways into the Baltic, including mismanaged waste, or 'macro' plastic. In a park outside of Gdańsk, Poland two young parents host a birthday party for their six-year-old twins. It is a festive occasion, marked by acrylic balloons, noisemakers, cone hats, disposable polka-dotted tablecloth, ice packs, sandwich bags, guacamole containers, juice boxes, plastic forks for the cake and spoons for the ice cream. Thirty children have come to celebrate, all bearing gifts of plastic games and toys wrapped in plastic containers tied in acrylic strings and ribbons and bows.

As the sun arcs down, the exhausted parents responsibly bring leftovers and waste to a bin, which is overflowing. They press it down, but the trash system has hit capacity. Within minutes of their departure as their children sleep in the back seat, a strong wind blusters up, tugs at the bin, and blows loose an empty tortilla chips bag. It flies into treetops, briefly snagged, before a gust carries it over to a tributary of the Vistula River, where it partially submerges before being carried by a strong current out into the Baltic.

No one is obviously at fault for this visible source of 'litter,' the leakage of which is inherently difficult to track and quantify. Litter may be identified from municipality cleaning operators' statistics, but not for the fraction that "falls through the cracks" (i.e. the leakage), which is by definition not measured, thus hard to "guesstimate", with a wide range of figures, which are often contested under closer scrutiny. The nature of this quantifiable uncertainty is exactly our point of departure.

Various influencing factors may include level of economic development, legal incentives, social culture, institutional capacity, population density, consumptive habits, packaging, type of litter, and distance to waste receptacles. The Ocean Conservancy argues that improving the current waste-management systems worldwide to increase collection could slash leakage in half. Exposed to time, friction, wind, rain, sun and the elements, large loose debris breaks down in the ocean into microplastics.

Geospatial emphasis

All these polymer pathways contribute to the diffuse and complex face of microplastics today. The scenarios above help us gain a deeper appreciation for the countless and constant linkages between individual consumer and industry, between usage and impact loss and leakage. Once deeply ingrained into the everyday economic matrix of our lives, we can see how the wicked problem of marine plastic pollution doesn't lend itself to easy technocratic solutions or simple, binary frameworks.

That is not to say, fatalistically, that the challenge is beyond our reach. To the contrary, we know this is a crisis, like previous and concurrent ones -- ranging from overfishing, to ozone-depleting hydrofluorocarbons, to carbon emissions – that we can manage. But to do so, we must first measure it to the best of our ability, and the Baltic Sea offers a geographic focus to explore difficult assumptions and vexing questions.

We are told the "Baltic sea is one of the most polluted on earth." If so, what kind of pollution? Others warn, "By eating seafood, humans are

ingesting microplastics on an unprecedented scale." If we are, does the primary source of plastic in seafood originate in our seas, rather than, say, shore-based plastic leaking from Tupperware containers or fileting on acrylic cutting boards? Headlines scream that "microplastics are becoming the biggest threat to ocean health." Compared with overfishing, acidification, warming temperatures and rising tides? Others blame business for greed, or governments for inaction, but unless we can quantify the nature and contours of the problem we're seeking to solve, neither private nor public sector can work in isolation or together to provide consumer wants and protect civic needs. Similarly, calls for a 'ban' may in some cases be reasonable, and in others, irresponsible; only by zooming in on a microcosm and then measuring the various contours of our leaking plastic footprint can we judiciously operate at the tip of a scalpel instead of just swinging a machete in the dark.

The focused synthesis sets out to present a clear-eyed analysis of a relatively focused microcosm. It seeks to lay out the causes, consequences and emerging policy contours of plastics in one marine ecosystem: the Baltic Sea. To that end, the best news about the escalating problem is that with each passing year there is a parallel increase in interest, awareness, and public and private research funds to conduct more scientific analyses that can help answer questions and clarify our targeted efforts.

Research has evolved in diversity, scope and complexity. The level of debate has elevated considerably from the anecdotal reports of bird or turtle entanglement in plastic six-pack beer holders in the 1960s to today's emphasis on how microplastics transfer persistent organic pollutants to marine food webs. Starting with the first dedicated to marine debris, in Honolulu, in November 1984, international conferences have been organized and expanded, helping build consensus around impacts of marine litter. Later, attention shifted to how to address it, monitoring trends, assessing effectiveness of mitigation measures, and more recent concern about microplastics coupled with vast 'garbage patch' gyres. As one metric of growing interest, the nature and causes of plastic pollution drove the most prominent and emotional agenda at the January 2019 World Economic Forum of business leaders, heads of state, and philanthropic interests gathered in Davos.

To be sure, growing global interest cuts both ways. Fear and uncertainty can lead to public policies shaped by emotional panic, establish misguided economic disincentives, waste opportunities and steer energy down blind alleys. Yet peer reviewed research helps cut through the noise to find the signals that matter and guide us.

A subset of research about microplastics has begun to focus on the Baltic, as the world's largest brackish body has come under both severe anthropogenic pressure and rigorous investigations. In November 2018, researchers gathered at the Micro2018 scientific symposium held at Lanzorote, in the Canary Islands, organized around the topic of "Fate and Impact of Microplastics: Knowledge, Actions and Solutions." Among the proceedings a significant share brought experience from the Baltic Sea. One paper tracked how 7 million residents of St. Petersburg produce 112,000 tons of plastic wastes, and how much of it finds its way to the adjacent estuaries. Another analysed the contents of the gastrointestinal tract of 503 coastal and 673 offshore fish individuals in the Baltic to measure the number and kind of ingested microplastics. Still others considered tourism, calculated the effect of wind dynamics, set background contamination baselines, and forged links between marine litter and human pathogens.

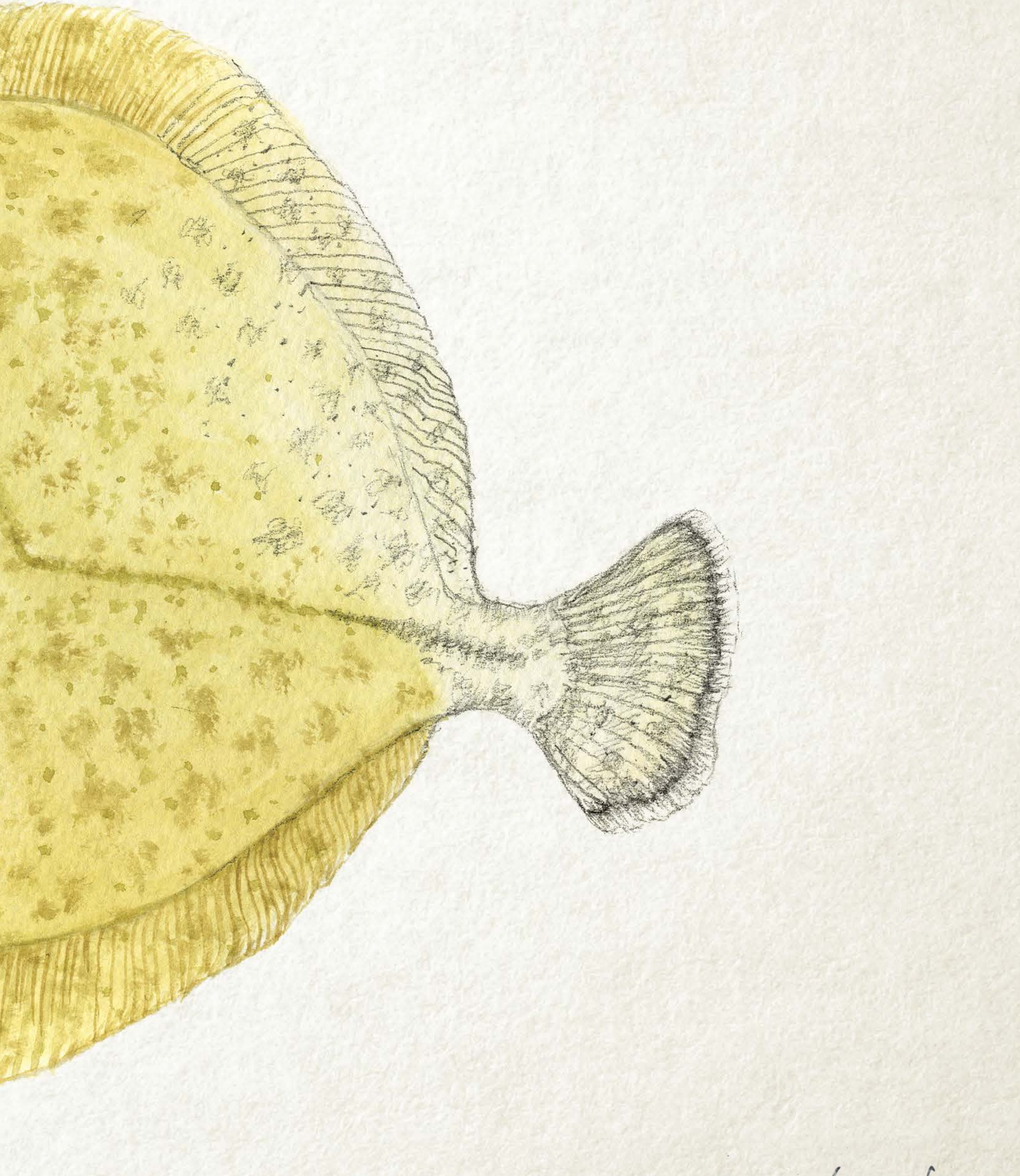
To harness the growing threads of disciplined passion, IUCN has committed to an integrated series of research, modeling, workshops, publications, thematic analyses, and regional assessments of the most effective policies that help "close the plastic tap". Our groundbreaking work "Primary Microplastics in the Oceans" helps map sources and quantities of tiny polymer particles released from household and industrial products, thus encouraging astute new thinking about how to design, produce, consume, re-purpose and dispose of plastics. Other research

and analyses take a regional approach, ranging from the Mediterranean to the Azores to the Small Islands Developing States in the Pacific and Caribbean. IUCN is also developing projects in South Africa, Mozambique, Kenya, Thailand and Vietnam.

IUCN *Close the Plastic Tap* Progamme

Local focus, global insights: This report on microplastics in the Baltic Sea is just one of nearly a dozen assessments and activities under IUCN's programme to "Close the Plastic Tap." Drawing on a diverse geographic and thematic portfolio of case studies allows us to draw more robust conclusions.

Turbot
(*Psetta maxima*)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Part III
Quantifying causal linkages: the marine 'plastic footprint' by item, industry and country

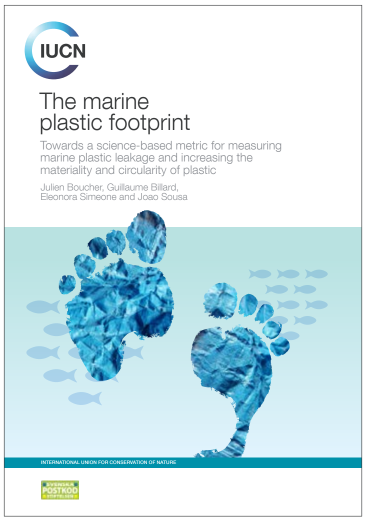
It is vital to have clearly identified, described and qualified the subtle and silent microplastic pathways into the Baltic Sea. The next, and in some ways more difficult step is to measure and quantify the size, dimensions and regional harm to nature by these polymers, an impact colloquially known as the 'plastic footprint.'

Not only our feet leave footprints on sandy beaches – our global reliance on artificial polymers is leading to a visible and pervasive plastic footprint in the marine environment. Globally, we know an estimated 12 million tons of plastic annually leaks into the ocean. Polymers come from various sources and all industries recognize the problem as real. But where does the plastic footprint fall hardest? What are the product, industrial, and geospatial metrics? How heavy, clumsy, diffuse, or granular is the impact? There has been no reliable methodology to answer such questions or assess more precise contours of the marine plastic problem – until now.

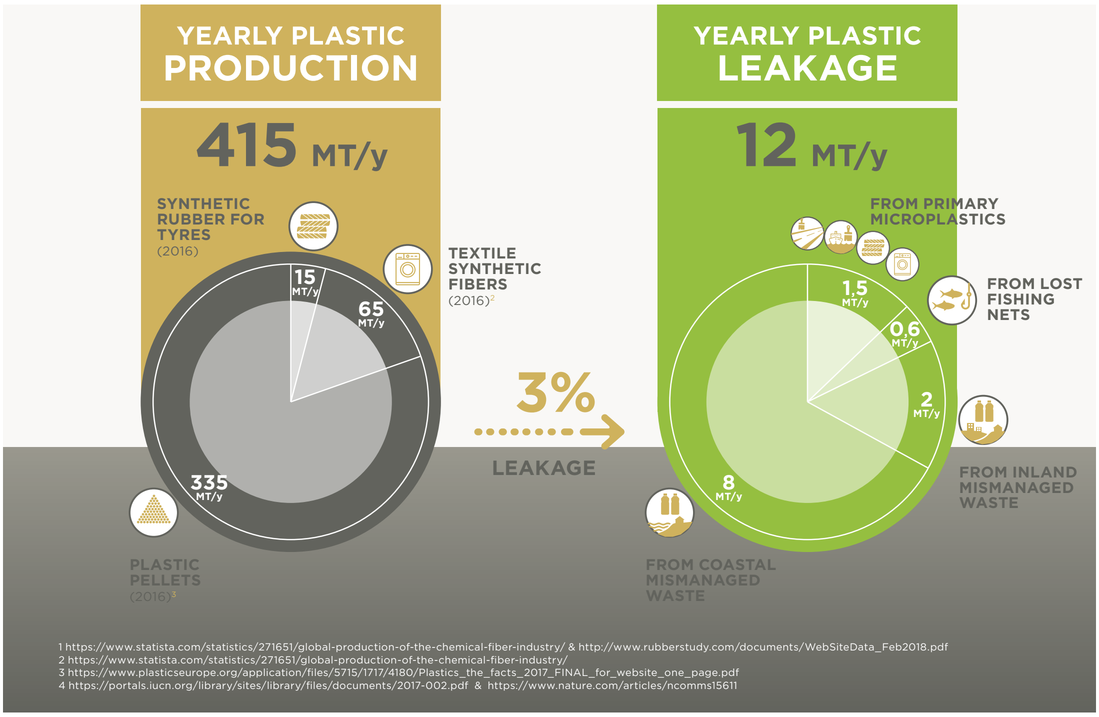
This is the object on the report _The marine plastic footprint_ published early 2020 (on the right).

Building from research, our Baltic Sea analysis intends for the first time to offer a robust and comprehensive framework, one that allows multidisciplinary analysts to measure the marine plastic footprint in a uniform way, by adopting a life cycle perspective. Drawing on and calculating from sources identified in the previous section – tyre abrasion, cosmetic microbeads, shedding of synthetic textile fibers or consumer waste – we propose a step-by-step way to measure plastic's leakage, or footprint. This methodology, with forecasting metrics, can be used by public and private decision-makers, at all levels of governance and in any sector, to inform more pragmatic, judicious decisions toward more circularity and materiality of plastic.

To measure the impact of a given product or resource use, companies typically turn to a unique environmental framework known as

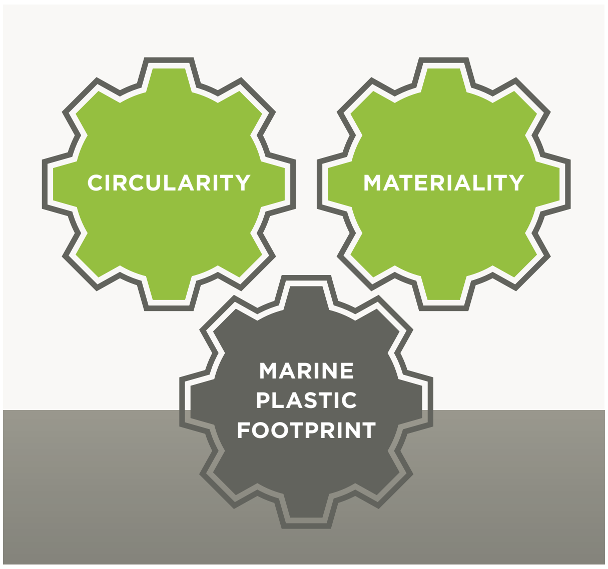


Measuring to Manage: Where does our plastic footprint fall hardest? What are the product, industrial, and geospatial metrics? How heavy, clumsy, diffuse, or granular is the impact? There has been no reliable methodology to answer such questions – until now.

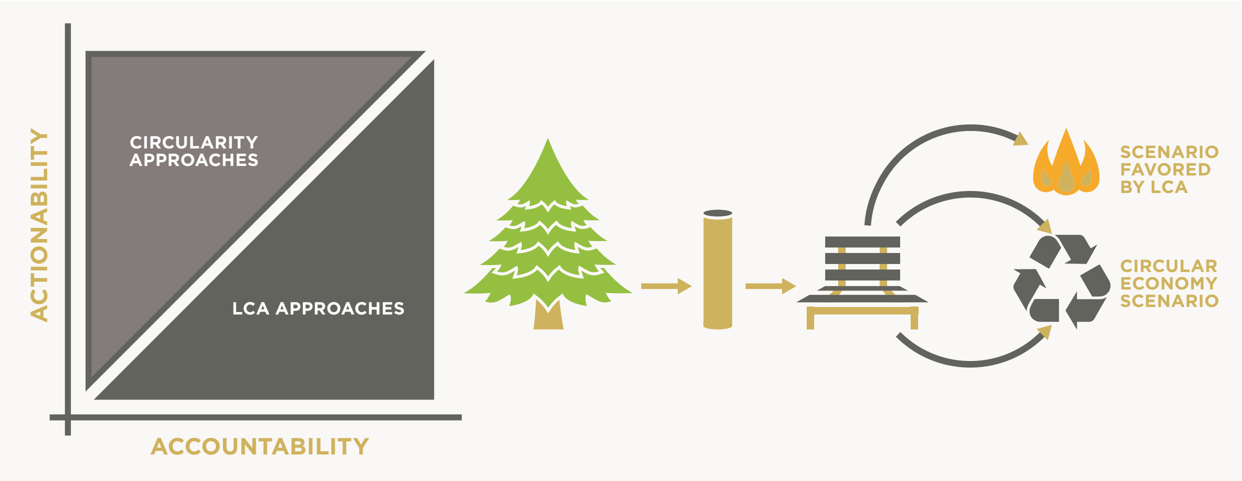


Linear Losses and Leakages: One way of looking at our impact (above) involves simple mathematics. Compare how much plastic is produced, minus what's recovered, and the result is annual leakage. Another pathway (below) emerges through systems thinking, looking at how the plastic footprint relates to governance, durability and economic demands.

life cycle assessment (or analysis) (LCA). Let's say, for example, that a family asks a builder to recommend the greenest option for their kitchen counter: glazed tile, cement, butcher-block, or laminate? That's a hard question to answer. Constructing the counter may be simple, locally isolated, and visible. Reconstructing the counter's planetary harm is complex, globally linked, and often hidden. It requires an inventory of potential flows of pollutants entering different areas of air, water, or soil in different places, and aggregating the associated impacts on each these resources. What's more the builder's advice depends not only on the raw resource extraction and manufactured production, but also on the distance of transport from factory to home, the material's weight and durability, and how it gets disposed or breaks down. LCA enables a standard metric of various impacts in a coherent manner, thus avoiding trade-offs between competing issues.



But for the builder in our example, a glaring problem remains. Existing LCA methodologies quantify the pollution of many globally traded goods (including countertops), from the carbon footprint of lumber, mineral extraction, or seafood harvests to the water footprint of food, energy, or appliances. Others account for the indirect effects of plastic use e.g. depletion of resources, energy consumption or emission of chemical contaminants. Yet LCA methodologies do not account for plastic as a direct pollutant. This lack of appropriate accounting for plastic leakage (coupled with the low price of virgin material) may have by default encouraged companies to massively favour plastic packaging in many



Squaring the Circle: While Life Cycle Analysis is criticized by some for having failed to anticipate the plastic crisis, others see the solution in the concept of a circular economy, or 'circularity ' This diagram compares the different outcomes of 'cycle' vs 'circle, ' allowing more flexibility in how to measure impacts.

situations – perhaps even recommending the family design with a laminate counter as both green and affordable – due to its lightweight nature and low carbon requirements.

In Nairobi, Kenya, in April 2019, the U.N Environment Assembly called for monitoring plastics as an important and lethal source of pollution, seeking a framework to help shift global economic systems towards a more sustainable path for resource efficiency, energy, chemicals and waste management. It also provided an opportunity for participants to discuss the need to adopt life-cycle approaches and invest in innovative business solutions, to reduce plastic leakage into the environment. We must therefore equip the private and public sector with pragmatic LCA tools that provide an inventory of leakage, characterize the factors to assess its impacts, and prioritizes when to use or avoid plastics.

Circle versus cycle?

While LCA is criticized by some for having failed to anticipate the plastic crisis, others see the solution in the concept of a circular economy, or 'circularity.' Boiled down further, this debate pits 'cycle' vs 'circle.'

In contrast to industrial era productivity – a model measured by quantity of "take, make, dispose" -- the circular economic [or, "circularity"] system seeks to minimise waste and maximize multiple usage of resources in a regenerative approach. The term circularity can also be used as a measure or index for the extent to which a company, industry, governing body or institutional system decouples growth from the consumption of finite resources. Circularity prioritizes incentives to recover, reuse and recycle the components, for example, of that kitchen counter: repurposing screws, converting wood into chopping boards, using cement to reinforce roads, transferring tile to bathrooms etc. The challenge of circularity is that it is hard to measure, and few have tried. Some use economics as a circularity metric: the ratio of recirculated value to total product value.

Other metrics simply rely on an analysis of material flows or, in most cases, recycling rates. But is that sufficient accounting? Is circular recycling always the best option? Considering that with recycling come diffuse losses that cause microplastic leakages, would incineration or landfill be preferable at times, to prevent damage to marine ecosystems and to generate energy? These questions highlight the need for tools with adequate accounting of potential leakages and impacts.

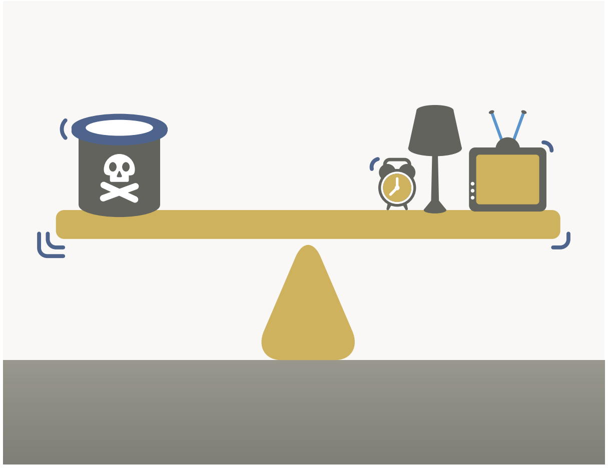
It is tempting to set 'cycles' and 'circles' as opposing metrics, isolated in their own silos. Yet neither concept is static, nor are they permanently etched in stone. Rather, each must evolve to integrate and be complemented by the other. Indeed, a more robust metric of the

plastic footprint may arise through adapting key advantages from both tools, linked together.

In a nutshell: LCA is an accountability (horizontal axis) method that can assess the result and measure the tradeoff between different environmental aspects. It reveals gains from reduced or reused or recycled material, from replacing it with greener alternatives, from increasing its lifespan, and keeping it local: the very principles embraced in the restorative circular economy, which are actionable (vertical axis). Cycles and circles thus interact and feed off each other. Circularity can be used for eco-design projects, for example, which LCA can evaluate and benchmark.

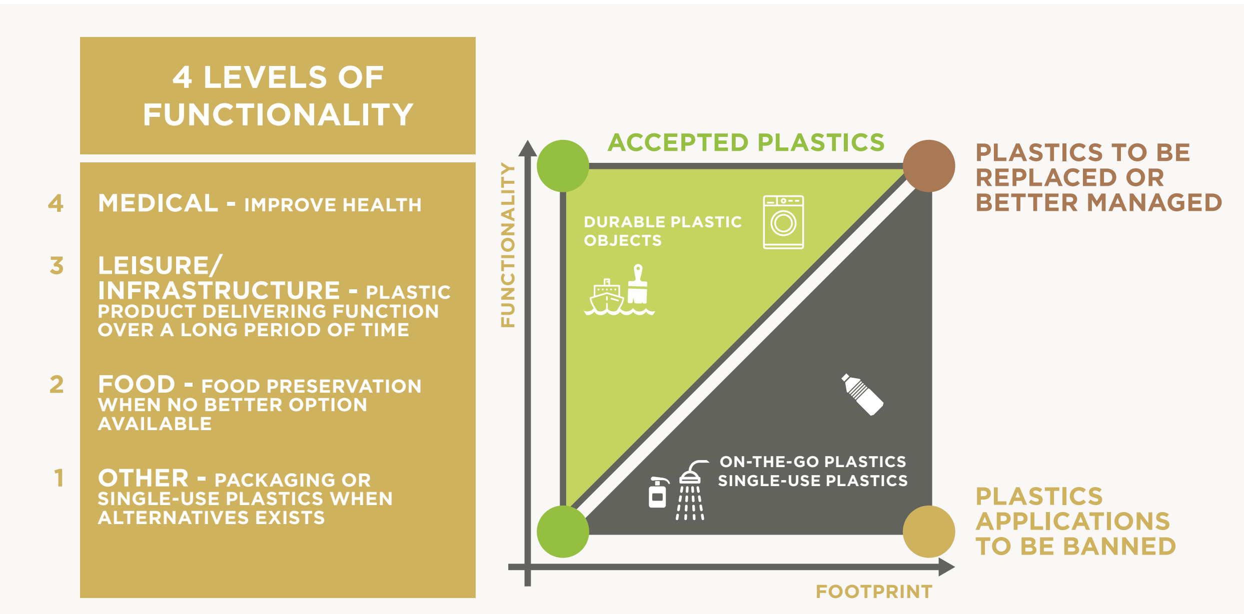
The materiality of plastic

That said, product/packaging eco-design still requires difficult trade-off between service provided and generated impacts. Should a city-wide ban on straws be expanded to include carrier bags? Juice bottles? What about surgical gloves, automobile airbags, or ground beef wrappers? To reach consensus, private companies and public officials alike must understand – at a more than intuitive level – at what point the use of



plastic is critical, and when plastic causes more harm than benefits. This ethical fulcrum, defining good vs bad usage, is known as the materiality of plastics.

The materiality of plastic is a function of the magnitude of the added benefit as well as intensity of use as well as the time of duration gained from this service. In this sense, single-use plastics and over-packaged toy cars may be examples of when plastic should be reduced, as although they may provide some services, the intensity of use and duration of use are almost nul. As avoided material, these represent low-hanging fruits when it comes to impact savings, moving along the spectrum it may be



All Plastics Are Not Created Equal: Some conveniences are slower to break down, more toxic, and less essential to society. These can be banned. Others preserve food and ensure human health; these can be better managed with deposits, or replaced with other materials like glass or organic fibers that break down quickly.

harder to reduce a footprint without altering the functionality of the product. Plastic with a high materiality equates to a high social priority and economic value. Reducing plastic waste and increasing materiality has the double benefit of saving other non-renewable resources.

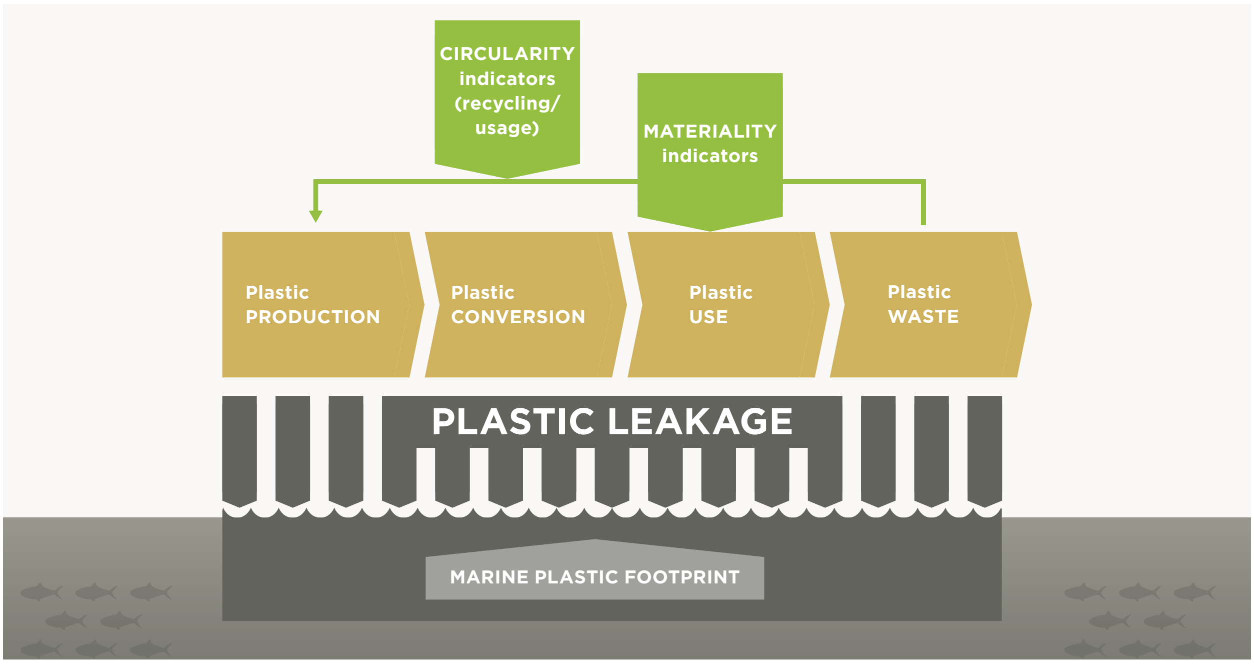
All too often, polymers are considered only for their negative impacts, including the consequences of Baltic Sea microplastic leakage documented in detail over the following two sections. Governments could, in theory, ban it overnight. Yet a world without any plastics would erode living standards for billions. An assessment of materiality – when combined with circularity and LCA – can help fix the plastic leak in a more precise and judicious way. The diagram at left suggests an easy qualitative scoring system, with four levels, that can be easily deployed to help map different plastic applications.

A metric to fix the plastic leak?

Beach clean-ups and offshore waste collection are visible ways to act locally, mitigate impacts, and raise awareness. But addressing the symptoms won't cure the disease. To address marine polymer pathways at their root, we must first close the plastic tap. To reiterate – that doesn't have to mean stop use of plastics, but rather stop it from leaking into the Baltic Sea. For that effort, companies and governments have 3 options:

The first is 'Ecodesign,' where we alter the product (straw, bag, bottle, textile, tyre) either with a better design or less harmful materials. The second approach is 'Stewardship,' in which we better adapt the context where the plastic product is used or disposed and improve waste management and recycling in key markets. The third is a 'Ban,' where governments or companies simply end all procurement and use of a given product and/or replace it with more environmentally friendly alternatives.

All three cases benefit from a regional perspective, acting once stakeholders can identify where and how best to prioritize action. As the maxim goes: you can't manage what you don't measure. In that regard, a narrow focus unlocks a more useful approach to quantifying plastic's footprint. Instead of chasing all plastic everywhere, our approach considers three case studies: a single product's plastic footprint, then examines plastic in a single industry, and finally looks at a regional inventory of plastic flows



No Simple Solutions: To better measure and thus manage plastic waste, governments must first take into account the circularity, usage, production and materiality of the stuff. This allows for more nimble, customized, and effective interventions.

released into the Baltic Sea marine ecosystem. These case studies and efforts don't try to assess releases of other pollutants into terrestrial compartments, nor do they pretend to measure all impacts from plastic leakage on ecosystem or human health. That more comprehensive effort can emerge later, with better knowledge on leakage pathways, plastic fate, exposure and effect.

From loss to leakage

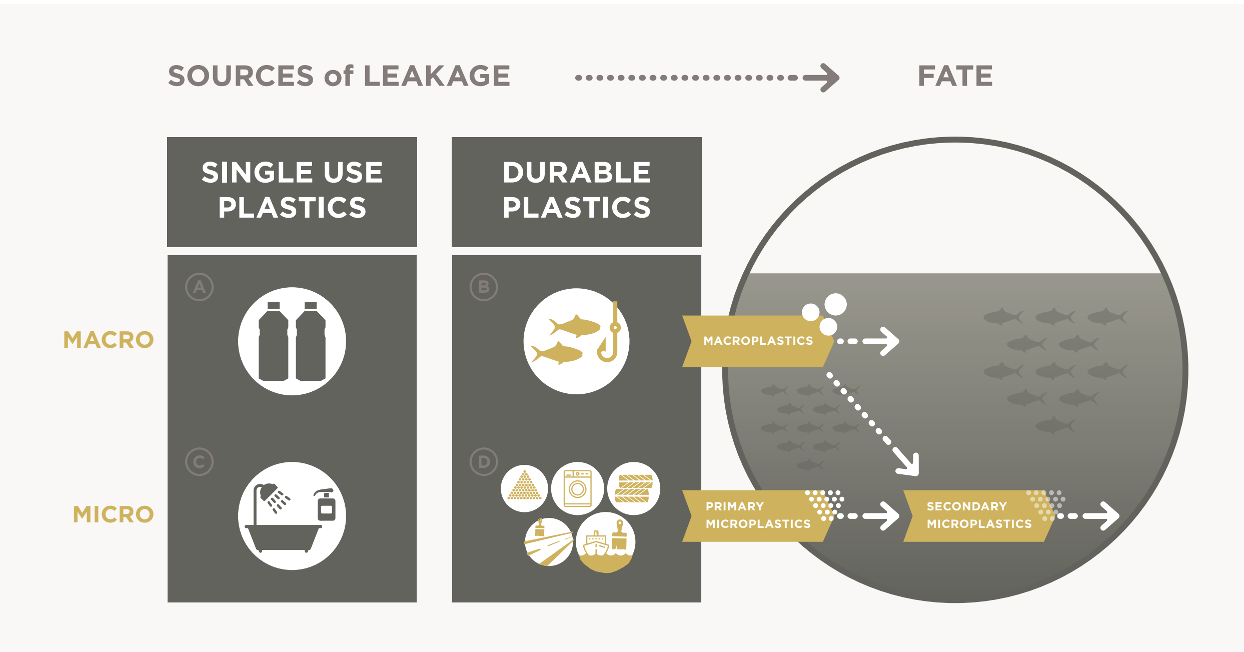
To better understand the degree of loss, and leakage into marine ecosystems, recent syntheses have taken a 'hybrid approach.' Analysts define the different types and stages of leakages, then use key parameters to vary the chosen release rate within each type. Given the high variability in leakage for different products, industries and locations, the goal is to develop a method that allows decision-makers to measure progress, rather than to provide an exacting and quantifiably accurate assessment of the actual leakage.

Yet not all plastic has the same release rate, lifespan, or likelihood of collection. Even plastics with the same size, weight, shape and density may be managed differently, depending on the governance capacity and economy in which it is produced, used and disposed.

The Ocean Conservancy classifies plastic waste by its value and the likeliness to be picked by a waste picker. Beachcombers may repurpose a fishing net; urban children may pick up and return a bottle for deposit. A milkshake straw has no value in reuse or exchange, and so is much more likely to leak into the waste stream. Indeed, only 20 % of the municipal plastic-waste stream (like PET, HDPE) is worth collection, while 80% of plastics dumped or disposed in landfills has low residual value (e.g. thin films), most of which ends up in the environment. These estimates, based on expert knowledge, can be refined once better data become available.

Modeling fate

As we move from calculations of loss, refined through a conceptual understanding of 'leakage,' we get closer to a quantitative framework around a 'plastic footprint.' This last step requires us to introduce the notion of fate.



Projecting the Unpredictable: As we move from calculations of loss, refined through a conceptual understanding of 'leakage,' we get closer to a quantitative framework around a 'plastic footprint.

Indeed, different plastics (polymer types or shape/size of the objects) may have different residence time in the environment. In other words, 1 kg of plastic with a lifespan of 1 year should not be accounted the same way as 1 kg of plastic with a lifespan of 100 years. This is especially important when comparing biodegradable/ bio-based plastics with conventional plastics as they may have different residence time in the environment.

Common Plastic Object	Reference Polymer	Degradation Time (years)
Cigarette filter	Cellulose acetate	1-5 [1]
Plastic bag	Polyethylene	10-20 [1]
Marine buoy	Styrofoam	80 [1]
Plastic bottle	Polyethylene terephthalate	450 [1]
Fishing line	Nylon	600 [2]
Building insulator	Extruded Polystyrene Foam	5000 [2]

Conventional degradation rates of different categories of plastic and plastic applications. Source: [1] MOTE Marine Laboratory Marine Debris Biodegradation time line, 1993. [2] BIOTEC Environmental, 2019.

We thus propose the concept of "plastic equivalents" by analogy with CO_2 equivalents used in the context of climate change to compare and aggregate different greenhouse gases with different warming potentials.

A current limitation of this approach is there is neither any proper definition of degradation rates for plastic in the marine environment, nor any standardized metric to measure this process. The table at left estimates commonly accepted values of polymer degradation in nature, as shown below:

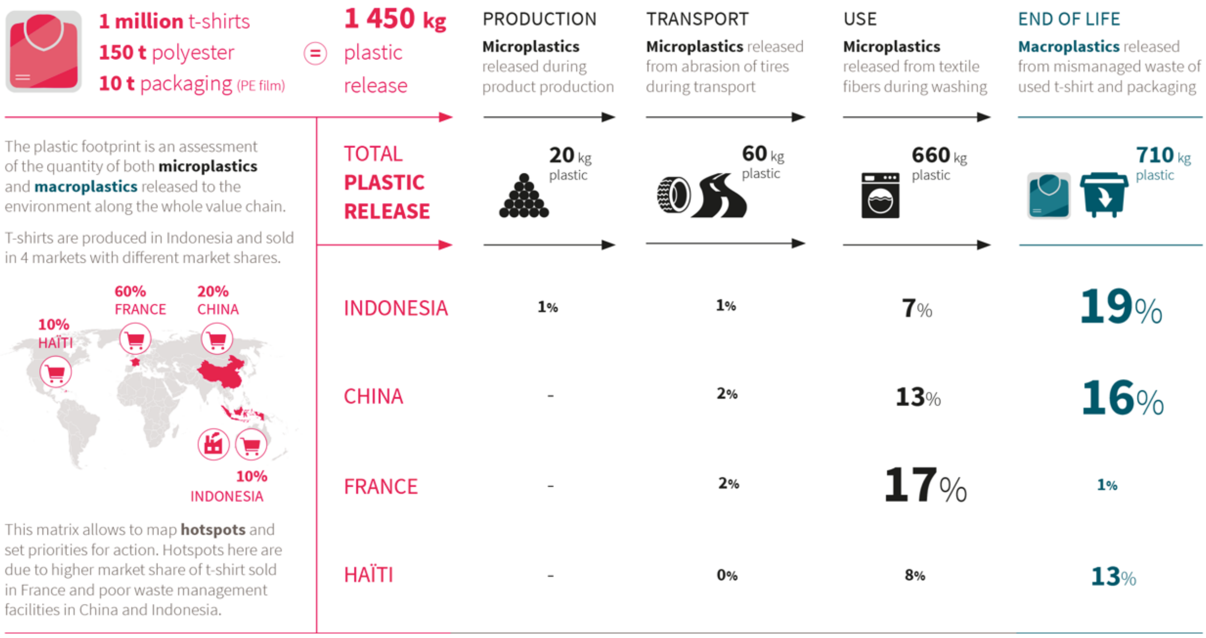
$$PlasticFootprint = \sum_{plasticX} PlasticLeak * \frac{LifeTime_{plasticX}}{LifeTime_{norm}}$$

All polymers degrade over their lifespan, at a fluctuating rate depending the molecular weight distribution of their family. For example, polyethylene, polypropylene and PET are impacted by photo, chemical or thermal degradation at different rates. These are often geographically dependent, on land exposed to heat and ultraviolet rays, or in darkness at the cold ocean bottom. Nature evolves in the direction of dealing with manmade substances. In this formula, the norm is taken as 100 years.

This formula can be extended and adapted to the scope and contours of very different case studies. To demonstrate their application, we consider three progressively complex case studies: a T-shirt manufacturer, the packaging industry, and the countries that share the Baltic Sea.

The textile industry

Not every ingredient can be conveyed by its label, and other footprints may shape our decisions. For years, we have come to understand that it can take 2,700 liters to irrigate the cotton required to manufacture a single t-shirt, which may wear out over a year. To reduce the water footprint, and help shirt last longer, companies and consumers alike may choose to make t-shirts out of a hybrid fabric, which includes polymers. That decision triggers our current problem for all Baltic Sea stakeholders: how then does a company in Estonia measure the plastic footprint of the shirt, and reduce that impact to please customers in Germany, Sweden, and the Russian Federation?



Geography is Destiny? The same plastic item may have a very different fate depending on where it is produced, used, disposed, and collected -- and these dynamics don't always take place in the same country.

The infographic at right attempts to provide an answer. A typical polyester shirt weighs 150 grams; its packaging adds ten grams more. The shirt may now last three years, and there are a million shirts produced each year. The footprint is a function of both the lifecycle of textile manufacture and the plastic release into the marine environment. Applying the outlined methodology to the textile industry in the Baltic, the study found that leakage is geographically dependent and varies greatly from production up to the end of life. The highest losses occur during usage and end of life, with high discrepancies between countries at the final stage of the product's life: for example, we found that the impacts vary significantly from one country to another. Still, this method allows for a sound identification of the plastic leakage for each country for plastic industries exporting in different markets.

The analysis of this footprint shows that context is everything. The origins, destination, weight, content, and leakage rates en route all factor into the unique equation. Different markets reveal different hotpots enabling for the company to set priority for actions.

In some markets the most dominant phase is usage. Elsewhere, in economies with less adapted waste management, the end-of-life phase causes a higher plastic footprint under LCA.

There are also nuances to be researched and teased out. For example, our current set of loss rates do not allow stakeholders to differentiate between distinct fibres, or different washing settings.

The bottling industry: Glass or plastic?

The same methodology can be applied to the packaging industry. Start with the functional unit of a one-litre bottle of Diet Pepsi, bought by a consumer anxious both about her carbon footprint as well as the plastics in the ocean. It is hot. She is thirsty. The cola looks frosty, chilled in the store refrigerator. But she has a choice: should she buy the same beverage in a glass or plastic container?

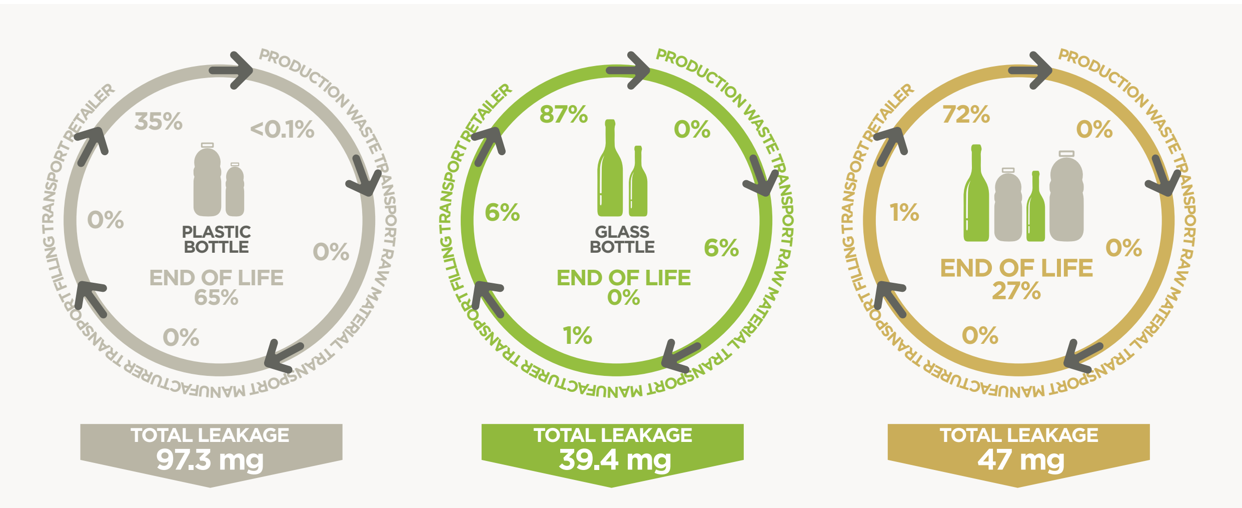
A big part of the answer hinges on the consumer's location. Where does she make the purchase? The plastic footprint is again geographically dependent, and its reduction usually relies in the implementation of waste management strategies and infrastructures. Leakage appears to be inconsistently distributed in different

PLASTIC FOOTPRINT

	PRODUCTION	TRANSPORT	USE PHASE	END-OF-LIFE
GERMANY	0%	2%	32%	1%
RUSSIAN FEDERATION	0%	0%	33%	8%
ESTONIA	0%	0%	17%	1%
SWEDEN	0%	2%	5%	0%

markets, with higher amounts generated in China or Indonesia than in Sweden or Germany. Plastic waste generation appear to be significantly different than the leakage, mainly depending on how that waste is managed. The end-of-life phase of each plastic container dominates the plastic footprint of the two types of bottles.

On the front end, the manufacturing origin, or source of the bottle is surprisingly significant. The weight of glass puts more pressure on tyres, energy and other factors during conveyance over long distances. The resulting paradox is that a glass bottle can have a greater plastic footprint than a plastic bottle due to the higher impacts from transportation.



Tracing to the Source: The matrix of stages (above) and quantified proportions (below) hint and the wide range of place-based differences and unique challenges when confronting plastic pollution, which is why a single policy response rarely has the same outcome for different national or local governments.

What may tip the scales, in both cases, is whether the store offers incentives for her to deposit the bottle once she has emptied it, five minutes later. Ensuring recycling or re-use of plastic bottles is a potent way to reduce plastic footprint.

Yet another variable, only starting to emerge, is whether the bottle was manufactured from virgin, recycled, or even degradable plastic. The latter two lower the impact of the footprint. Still, current degradation rates are guesstimates used to demonstrate the capacity of the methodology to capture this parameter.

The Baltic Basin

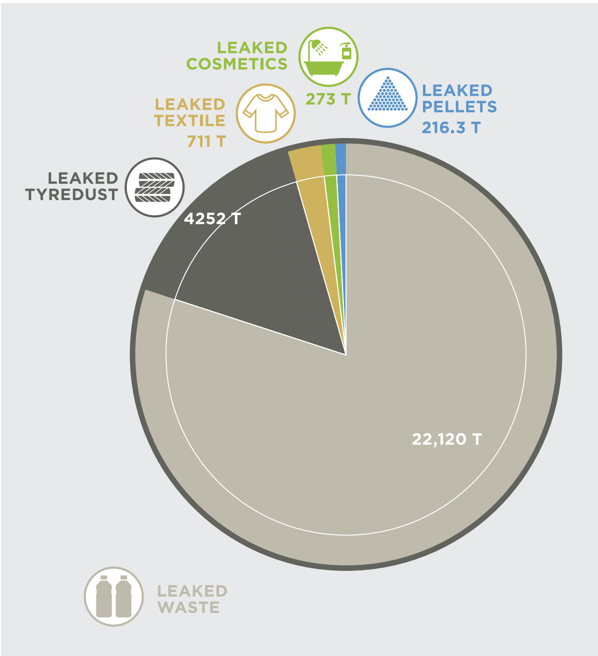
As we have seen in the preceding sections, few corners of the ocean are as complex as the Baltic Sea. The effects of offshore activities ranging from fishing to recreation to merchant navigation are inextricably linked to and mixed up with important human densities, consumer decisions and commercial processes along its many coasts. Ingredients of municipal, agricultural and industrial waste combine into a potentially toxic stew of urban runoff, inorganic plant nutrients and plastic debris of all sizes. Plastic pollution in this region has been reported for surface, seafloor and shoreline compartments, and seem to be present in higher densities close to shore and urbanised areas. How can we make sense of all the polymer pathways described earlier, not just defining their character but quantifying the extent and flow of their impacts?

Our regional case study attempts to do just that. The aim of this first attempt has been to identify hotspots of plastic leakage and map the plastic footprint of the countries connected to the Baltic Sea, through waterways and watersheds. It includes not only the nine coastal states but also the upstream countries – Czech Republic, Slovakia and Belarus – whose rivers flow into the Baltic or are part of a wider watershed connecting with the Baltic. While other useful studies have estimated plastic leakage down transboundary rivers, these did not always take into account certain important factors – distance, governance, type or size of plastic – that varied wildly from border to border.

To map the leakage, our approach set out to calculate mismanaged plastic waste generation for each village, town and city of a country. We then applied a 'release rate' that depended on their geographical location. Through Geographical Information Systems (GIS), the precise distance to shore was calculated for every population point, and waste management data was inserted inside a matrix.

This matrix, in turn, aimed to combine updated waste data with socio-environmental parameters such as population densities, watershed configuration and surface water run-off. Given the broad size spectrum of debris, we also investigated the leakage of microplastics: the virgin pellets, cosmetic beads, tyre dust and synthetic fibres illustrated earlier. Finally, we used GIS to visually represent the different aspects of the plastic footprint of the Baltic, per population points (cities) and watersheds.

The results not only highlight an intense plastic leakage into the Baltic Sea, they also help pinpoint how, where, and what the sources are and do. The leakage has been dominated by macroplastics and linked to high population densities and/or inefficient waste management infrastructures.



Contribution of different plastic sources to the overall plastic leakage in the Baltic Basin.

$Leak_{waste}$: 22,120 tonnes year^{-1}
$Leak_{Tyres}$: 4252 tonnes/year^{-1}
$Leak_{Textile}$: 711 tonnes/year^{-1}
$Leak_{Cosmetics}$: 273 tonnes/year^{-1}
$Leak_{Pellets}$: 0.9 tonnes/year^{-1}

} $Leak_{micro}$

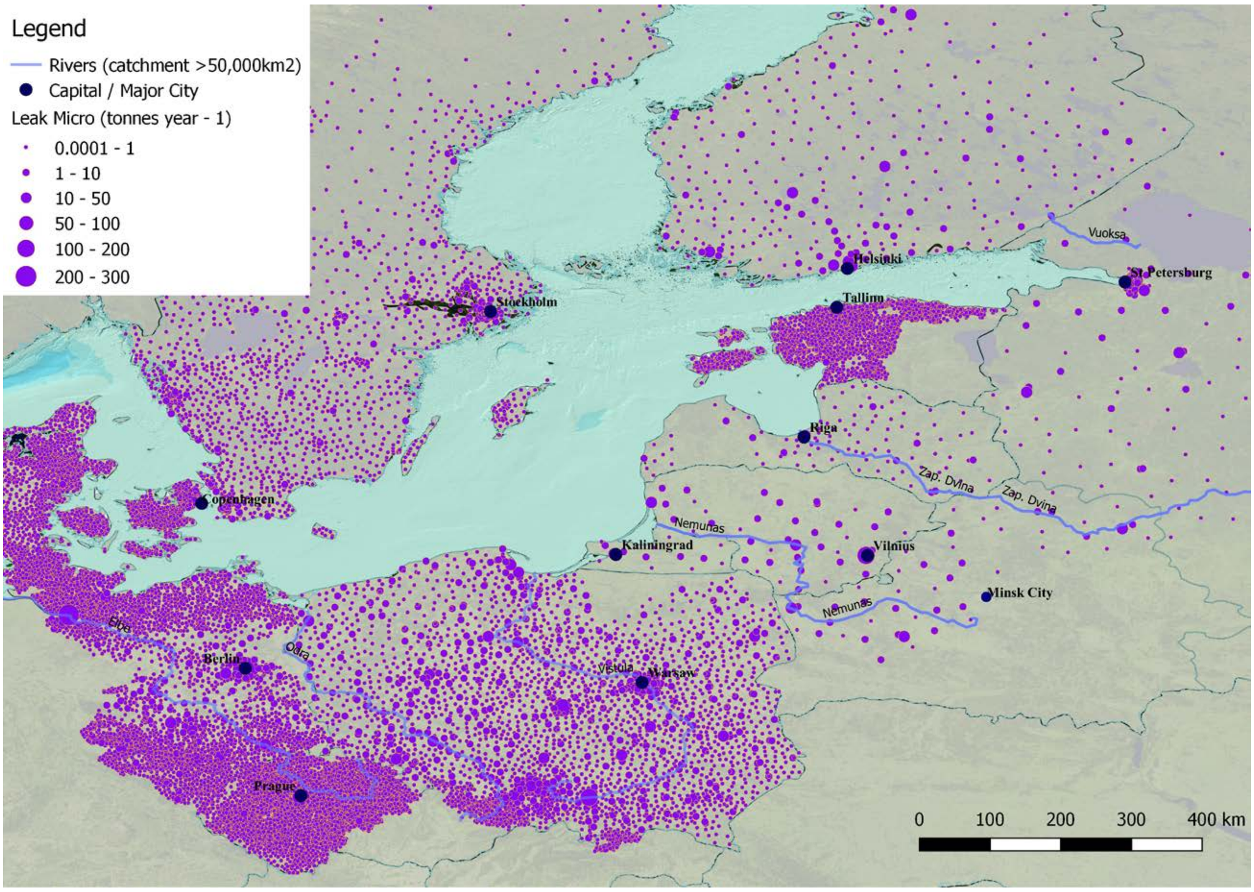
On the one hand, total $\boldsymbol{Leak_{waste}}$ is estimated at 22,120 tonnes year^{-1} for the Baltic Basin. On the other hand, $\boldsymbol{Leak_{micro}}$ is estimated at 5237 tonnes. The $\boldsymbol{Leak_{micro}}$ present very contrasted concentration patterns. Tyre dust is the highest contributor to the overall microplastic leakage (see table below), with clear geographical differences.

The four sources of microplastics appear to be less pervasive than the macroplastic leakage in the Baltic Sea. A chart or table is one way to convey this information.

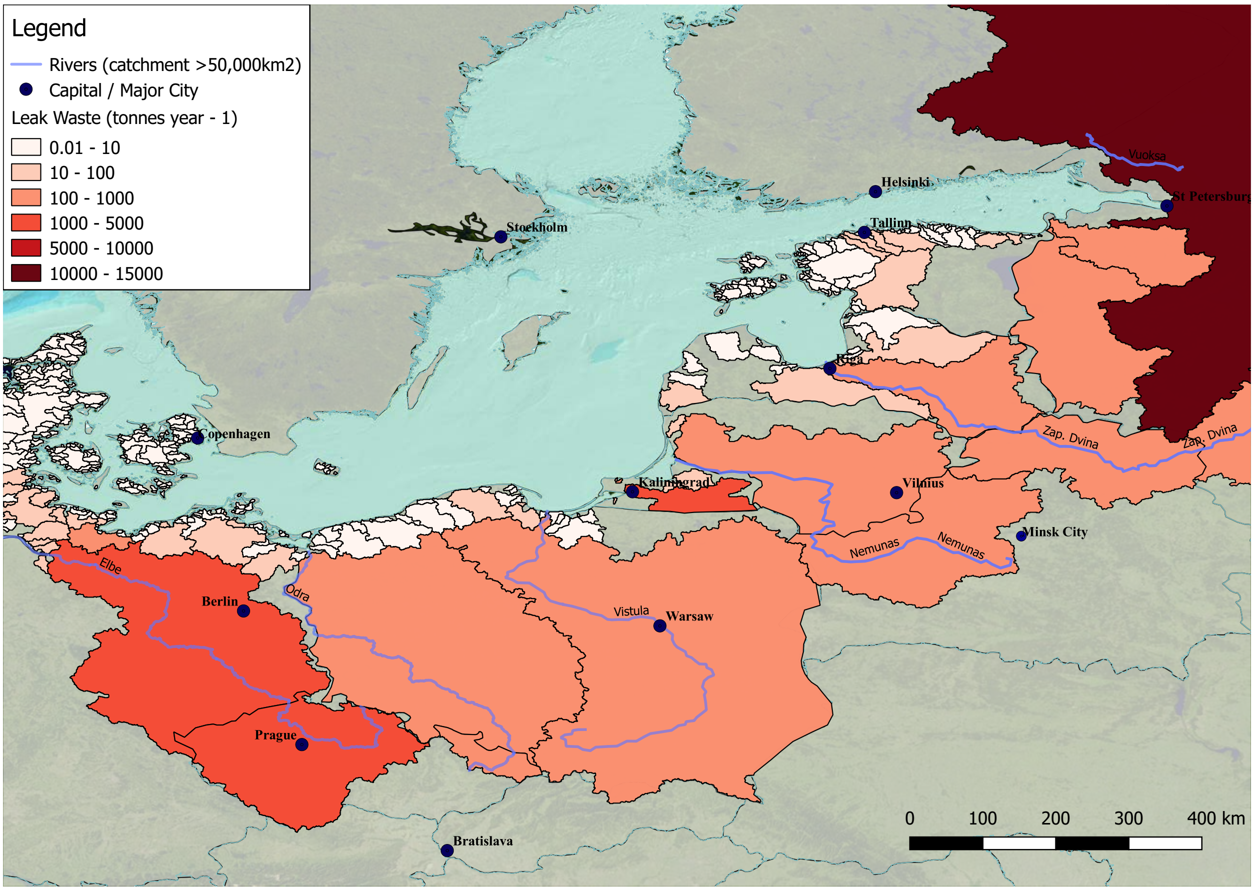
Yet a far more powerful and graphic reflection of the Baltic Basin's plastic footprint is a geographical heat map. The position of each village/town/city is represented by dots, with population points having a corresponding value of $\boldsymbol{Leak_{micro}}$.

In addition to population points, watershed leakage was investigated to represent which basin is likely to be more affected by plastic pollution. Waste generation, population densities and water surface run-off were some of the many parameters investigated for watershed pollution. Each leakage point in a watershed was added together to obtain a total value for each individual watershed. Only watersheds directly communicating with the Baltic Sea were kept.

In absolute and per capita leakage rates, there is a clear imbalance between the northern and southern states of the Baltic Basin. Each citizen of Denmark generates 12,7 kg of plastic; each Swede generates 29,3 kg. The Russian Federation



Connecting the Dots: This map shows where leakages are either concentrated or diffuse. Such analyses early on help governments better deploy funds and programmes to make the most of limited resources.



Given imperfect and often scattered data, the maps are attempts to locate plastic hotspots, and are not a pure reflection of the ground reality. Therefore, the case study and resulting maps was not designed to be a regulatory tool for enforcement, nor as a benchmark for competitive intra-baltic rivalry. Concentrations may evolve or dissipate over time due to policies, clean-up campaigns, wind or rain events, and general environmental dynamics.

shows the highest mismanaged waste index (96 %) with a high per capita plastic waste generation of 59 kg. This is coupled with un-sufficient waste collection schemes and a large share (14%) of plastic in the waste stream. The map above, using a hydrological model, depicts watersheds that are either connected to the Baltic Sea or host a river flowing into the sea. However, the model does not cover watersheds above 60 degrees north latitude, except for the Neva watershed overlapping the Russian Federation and Finland.

Parameters vary over time and by location. Great dissimilarities exist in waste collection schemes around the Baltic Sea, with some countries generating high levels of mismanaged plastic waste (MPW) and non-collected fractions of waste. Given imperfect and often scattered data, the maps are attempts to locate plastic hotspots, and are not a pure reflection of the ground reality. Therefore, the case study and resulting maps was not designed to be a regulatory tool for enforcement, nor as a benchmark for competitive intra-Baltic rivalry. Concentrations may evolve or dissipate over time due to policies, clean-up campaigns, wind or rain events, and general environmental dynamics.

At the same time, the broad strokes are hard to ignore. It appears clear that the Baltic Sea could better concentrate its finite resources not only on municipal, macro-sized waste, but on the larger yet subtler threat from microplastics.

Outlook

This section on quantitative causes has introduced several novel contributions. It offers new routes for calculating the plastic footprint from items, companies, and countries. It shows how to reconcile the life cycle analysis

perspective with the principles of a circular economy, linking the probability of leakage with the residual economic value of wastes. It outlines a dataset of loss and release rates to calculate the footprint, then focuses on three case studies, first on a textile company, then the larger packaging industry, and ultimately builds to the regional footprint of the regional Baltic Sea basin, estimated at approximatively 27,300 tonnes, with a macroplastic leakage nearly four times larger (at 22,120 tonnes) than that from microplastic debris (5237 tonnes).

Yet it is only a first step. Having now measured the quality and quantity of plastic in the Baltic Sea, regional stakeholders are better equipped to manage it. Through setting governance rules, increased transparency, economic incentives, and broader awareness campaigns. The findings of the footprint exercise can help build consensus with the textile and tyre/automotive industries to improve the rules, loss rates and generic data used for calculations. More granular sets of data will ensure the methodology is more actionable. We can refine the leakage pathways by considering different waste characteristics as well as local parameters such as wind, slope, or urban infrastructure.

The flip side of a footprint that shows past underestimation of microplastics is that it suggests that even the 2% littering rate, or macroplastics, may in some cases be over-estimated. Emerging plastic footprinting methodologies should also consider bio-based, and the degradation time of different plastics.

Calculating and mapping the plastic footprint may also unlock potential for exciting new tools. By quantifying what might be the 'plastic leakage budget,' companies and countries linked to the Baltic Sea basin may investigate the possibility of achieving plastic neutrality (through removal, recovery or beach clean-ups) or plastic offsetting (where, as with carbon trading, one country or industry mitigates its ongoing plastic by paying another for using less than its share of an overall reduced target).

Abstract maps and models, no matter how compelling, can only persuade so far on their own. They may lack credibility unless balanced by 'ground truthing.' Field data can help reconcile top-down plastic footprinting estimates, with the validation provided by bottom-up approaches, allowing us to compare the modelled predictions with reality. Riverine systems, those well-known vectors of plastic pollution, would be ideal sampling environments to calibrate modelled predictions.

There is now enough evidence to say that plastic pollution is ubiquitous in the marine environment. Allocating resources to shift towards a more circular economy would be greatly beneficial, as well as adopting measures to reduce the usage of single use plastics. But action requires more than information about the quality and quantity of plastics flowing into the ocean. It demands motivation, pressure from public and private stakeholders who understand the impacts on the places they live and work. Only by understanding both the causes of and the consequences from plastic, – on marine habitat, and on its biodiversity – can the region develop the political will to act.

Terek Sanpiper
(*Xenus cinereus*)


Graça Laguifa
2018

Part IV
Habitat consequences: microplastics embedded in Baltic Sea ice

In previous chapters, a growing and already abundant body of research allowed us to extract key lessons from extensive knowledge compiled, conducted and analysed by other teams. Yet gaps remain. Two of the largest, most complex, yet least understood impacts on oceans stem from climate change and from microplastics. The two dynamics do not take place in a vacuum from each other. The interplay between microplastics and the formation and thawing cycle of sea ice could thus have either negligible or profound consequences for life on earth. Lacking a solid baseline of scientific evidence or data points as a reference, we set out with university scientists to generate primary information, moving from controlled conditions of 'microcosms' in a University of Manitoba laboratory condition to a living 'macrocosm' on the wild, frigid edge of the Baltic Sea. The full research will be published soon: Distribution and impacts of microplastic incorporation within sea ice. By Geilfus N.-X.1, Munson K. M.1, Sousa J.2, Germanov Y.1, Bhugallo S.1, Babb D.1, and Wang F.1*

There is a reason research into marine plastic pollution has often gravitated toward urban coastlines: that's where most people interact with the sea. While not quite a formula, the warmer the waters, the more attractive the beach, and the closer marine plastic washes up near a large port or city by the higher the number of private observations. Those data points translate into public concern, mobilized funds, grant proposals, global conferences, extensive studies, and private or political decisions.

Only very recently have researchers turned their lenses outward, to examine remote and inhospitable regions, studying the subtle and complex effects of marine plastic leakage. While several studies have reported plastics in the Arctic, only two have looked at microplastic concentrations in sea ice. These studies have found plastic in Arctic surface seawater and sea ice, suggesting that even the otherworldly polar north is far from immune to contamination by polymer particles. It may in fact be a microplastic magnet.

Until now, no study had examined the implications: how tiny plastics possibly affect the melting and freezing cycles of sea ice. The lack of such literature is curious, especially when one considers how much attention is focused on the extent and consequences of the impacts on polar ice caps on global warming alone.

Polar plastic's potential power

Sea ice is not only by itself an important ecosystem, where its growth and shrinkage

provide a barometer of human induced global climate change. Polar ice (though not the isolate Baltic) also affects the deep-water, itself controlling the overall oceanic circulation, which controls our planet's current climate system. How much plastic might be embedded in sea ice, and can that amount influence sea-ice formation and melting and its role in climate processes?

Once in the ocean, currents can transport microplastics over long distances, reaching the Arctic Ocean and bringing potential risks to the Arctic marine ecosystem. The various causes, consequences and pathways of the polymers in the Arctic remain poorly understood, even though sea ice may be an important means of transport for these contaminants. Microplastics in sea ice are reported to be several orders of magnitude higher than those in Arctic seawater.

Yet the processes and rates of microplastic incorporation within Arctic sea ice, as well as their impacts on sea ice properties, remain largely unknown. An Arctic Ocean study would be optimal, but challenging, due to extreme conditions, remote distances, travel and operational expense and the related risks that such an ambitious polar expedition would entail. However, working in a microcosm experimental set up, with universities and set up a coastal sampling plan along the Baltic Sea will considerably reduce the cost. So microcosm experiments were set up to approximate this, in the laboratory as well as Scandinavian coastal sites along the Baltic Sea.

Given the high northern latitude, seasonal temperatures, and rich biodiversity, there are obvious parallels between Baltic sea ice cover and that in the Arctic Ocean or other polar seas. Still, key differences in the Baltic Sea need to be noted. These include: the nearly enclosed physical geography that limits circulation of microplastics; the brackish waters in which ice forms, resulting in low bulk salinities and porosities; the slightly milder climate means high variability in the maximum ice extent, with rain and freeze-melt cycles during the winter. Roughly a third of the sea ice mass, and up to half of its thickness, may come from metamorphic snow, instead of frozen seawater. Related, higher concentration of organic material in the Baltic may affect the chemical and thus optical properties of the sea ice, which in turn may alter the albedo effect or absorption of solar radiation. Saline ice (more common in the south) is more porous than freshwater ice (associate in the north). Above all, ice cover lasts half the year in the northernmost regions yet in recent years appears only rarely in the southern Baltic Sea, during severely cold winters.

Researchers can take these nuanced considerations into account. Yet that last point underscores the urgency of understanding the marine ecosystem consequences of these polymer pathways. The planet's sea ice is already under threat, besieged by global warming, with temperatures rising fastest the closer we go to extreme polar regions.

Compound consequences

Sea ice albedo (ratio between light reflected and light incident) is a key property for sea ice. Due to its high albedo (i.e. radiated most of the solar energy back into the sky), sea ice remains cool and cool the surrounding air, water down. However, that may change when colorful plastic particles – those red bottle cap shards, blue lycra microfibers, black tyre bits, brown pellets, green fragments of nylon fishing nets, tiny orange marine paint strips – floating in seawater end up incorporated within the ice cover. The incorporation of plastic particles may affect the sea ice albedo by decreasing it, and potentially starting to warm and melt the ice around it.

Sea ice has its own seasons, each with related potential impacts from microplastics. In the autumn or Fall, if sea ice formation is delayed, snow ends up directly in the ocean. One possible impact is sea surface freshening, a thinner layer of snow on sea ice, increased challenges for, say, polar bears, which needs snow for their dens. In the Spring, if microplastics melt sea ice earlier, snowfall may again directly end up in the ocean, freshening the seawater, altering the chemical, biological and physical properties at the surface.

The lack of sea ice bloom may have a strong impact on all arctic sea ice ecosystems. In sum, as sea ice forms, it may 'scavenge' microplastics; in the spring it may then be associated with the phytoplankton bloom be eaten alongside algae, taken into the marine food web. With more ice melt, microplastics are released into the ocean, where zooplankton come at this concentration as well.

Due to their low density, can microplastics floating at or near the surface of seawater be readily incorporated within the ice matrix? Will this enrich the sea ice – atmosphere interface? Could this process impact the absorption of incident solar radiation, with a feedback on the sea ice albedo and thus sea ice melt? Finally, as sea ice thickens, might more particles be incorporated within the ice structure, affecting the light penetration depth in sea ice as well as photochemical and photo-biological processes that occur in sea ice?

To investigate these questions, the Baltic Sea study set out to determine: 1) the incorporation and partitioning of microplastics between seawater and sea ice, as sea ice grows, 2) the impact of microplastics on the sea ice albedo, and 3) the effects of microplastics on the growth and melting rates of sea ice.

Manitoba microcosms

The team began testing samples in a working outdoor laboratory at University of Manitoba's Sea Ice Environmental Research Facility (SERF). Heaters in an outdoor saline swimming pool melted roughly 430 cubic meters of sea ice, with experiments conducted in the open, where researchers could expose the lab to ambient temperatures, wind and solar radiation.

Two sets of twelve microcosms – each measuring one cubic meter – were constructed within the SERF pool, using galvanized aluminum pipes as frames and cotton bed sheets as walls. Seawater could pass though the sheets while microplastics remain. Sump pumps to ensured water circulation throughout the experiment. Microplastics were added to the microcosms under low (~120 particles L^{-1}), medium (~ 384 particles L^{-1}) and high (~ 1200 particles L^{-1}) concentrations.

Three replicates and three controls were placed randomly within the pool. One set was dedicated to disruptive and destructive sea ice sampling, with a focus on the ice cores, or columns which were collected for analysis five times in January and February. The other twelve microcosms were dedicated to light reflectance.

Rather than investigate a single polymer synthesis, researchers considered the effects from a representative mix of plastic used. Within the saline water, the ingredients added to 'season' this plastic 'soup' recipe thus consisted of 21% polypropylene (PP) + 32% polyethylene terephthalate (PET) + 47% polyvinyl chloride (PVC). These ingredients came in irregular shapes, sizes (µm to mm) and colors (blue, yellow, purple and translucent).

The results offered a quite literally more granular understanding of the kinds of dynamics that might be occurring in the natural world. It helped indicate how much floating polymer bits were 'scavenged' by the ice crystals within the ice structure.

The SERF experiment has three mains finding:

1. Microplastics don't seem to affect the sea ice growth.

2. Microplastics seem to affect sea ice salinity, with consequence on the brine volume of the ice, which will impact the sea ice permeability. This can be linked to the GHG exchanges between the ice and the atmosphere.

3. Sea ice albedo: while we were expecting to see a decrease of the sea ice albedo (reflectance) we saw the opposite with an increase of the sea ice reflectance as the microplastics concentration increase in the ice. What will that be if we had chosen black particles? What will happen if our light measurement were done during springtime when solar energy could be more intense? The thermal

conductivity of the microplastics is different than the one from the ice. Microplastics will "heat up" faster and melt its surrounding ice.

Researchers also found microplastics in the control microcosms, where none were intended nor deliberately added. Why? Perhaps groundwater and salts used to make the artificial seawater had not been tested for potential contamination. Or microplastics could have permeated through the bed sheets, despite a fine mesh size. Since most microplastics were loose at the top sea ice interface with the atmosphere, the most likely explanation is that particles were highly mobile, blown there by strong winds to cause cross-contamination during the experiment.

Validation in the wild

Micro analysis of albedo effects and ice core sample formation under lab conditions can be, quite literally, illuminating. Yet a heated outdoor swimming pool is a far cry from the 'real world' conditions under which sea ice forms, builds, breaks up and melts. So, the second part of the research set out to validate the initial University of Manitoba SERF outcomes by heading into the field.

From 15 to 26 February of 2018, a three-person field team made a ten-day expedition out onto the ice in the Baltic Sea, Gulf of Bothnia. In freezing white conditions that were described as both brutal and at the same time beautiful, exposure to the cold impacted the health of researchers without hats. Yet the validation effort met its goals. They collected sea ice cores (up to 35 cm thick) at nine sea ice stations, accessed from shore around the Gulf of Bothnia, in Sweden and Finland.

The selected stations were adjacent to potential riverine sources of microplastics. Samples were shipped frozen back to the University of Manitoba, where the presence and distribution of various types of microplastics were determined from melted sea ice core sections and compared with the mesocosm study.

Suspected microplastics were observed at all stations, albeit at concentrations lower than those observed at SERF. Particle distributions were homogenous throughout the entire ice thickness. In contrast to the outdoor lab experiments, we did not observe high microplastics density at the surface of the ice. The lack of enhanced incorporation appears to be due to more homogeneous microplastic distribution in the water column. This longer equilibration time could also impact the size distribution of microplastic particles, with degradation processes decreasing particle size relative to the manual grinding used at SERF.

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2018

Part V
Biodiversity consequences: polymer impacts on Baltic species

Nordic marine habitats set the stage for the complex drama of species that seek food and shelter from it. So, just as researchers have only begun to unlock the ways and extent to which polymer pathways alter the dynamics of sea ice structure – illuminating those fluorescent microplastic squiggles ice core dyed with Nile red stain – this synthesis distills the consequences when those microscopic bits, beads, threads, and fragments are frozen or melt out to play a lead role in the Baltic Sea's biodiversity. To better understand the role of microplastic ingestion (and by suffocating and scraping, macroplastic) marine pollution as a possible threat multiplier for biodiversity in the Baltic, researchers from [...] carried out a desktop study for IUCN, using the available literature on species in the region to identify which rare or endangered species are most impacted by plastic leakage pollution in the Baltic Sea, and how this has been investigated as a possible threat multiplier to some of the most valuable and at-risk populations.

t one level, plastic's impact on marine life is its best known and yet least understood dynamic. On screens, tablets, phones and news magazine shoots, popular media have drawn public attention to the often-excruciating ways leakage harms charismatic animals. But while nearly possible to look away from (or forget) images of afflicted individuals – the turtle entangled in fluorescent plastic fishing nets; the stork body-wrapped in a clear thin garbage bag; the hermit crab lugging around a white plastic mouthwash cap as his home; the seahorse with tail clinging to a pink cotton ear swab – these stories say little about the broader and long term fates of their population as a whole. They don't easily convey the more profound and widespread risks of microplastic ingestion or smothering. They can't illustrate how species interact within a food chain, in a specific geographic context, and how polymer leakage weakens populations, or speeds local extinction. This chapter anchors emotional drama to nuanced scientific rigor, within the Baltic Sea region.

Worldwide, scientists have documented microplastics in at least 114 aquatic species, some of which are found, fished and eaten by humans. These species and the marine habitats on which they depend on have long suffered human pressures. In our Anthropocene, marine life has long been besieged by overfishing, emissions, acidification, marine traffic, excess nutrient runoff, warming, oil spills, and loss of estuarine and coastal nurseries. None of these forces act in isolation; they compound stress as each layer squeezes life from within and without. As such, the Baltic Sea again offers an instructive microcosm as it now absorbs yet another shock to the system, threatened by a menacing, occupying army of microplastics. The consequences of polymer pathways show plastics pushing certain plant and animals

– including already threatened and commercially valuable food species – past a tipping point.

In this literal sea of troubles, the challenge of mapping the consequences of a plastic footprint lies in where to start, and how to focus attention. Measured against oceanic eras, the brackish shallow Baltic Sea's marine life support system is still in its infancy. Plants and animals with a high tolerance for saline conditions only immigrated into the basin over the last 10,000-15,000 years. More recently still, humans deliberately or accidentally introduced hundreds of non-indigenous and some invasive species. There is only one known endemic species. Dating back a few centuries, natural histories identify the range and health of commercial fish populations (herring, cod, sprat, Atlantic salmon and sea bass), but scientific data collection and analyses of the more extensive integrated ecosystem began only six decades ago.

Drawing on limited, imperfect and scattered sources of literature on the Baltic, one collaborative effort of historians, archaeologists, paleo-ecologists, and fisheries and marine mammal researchers in 2010 estimated there to be at least 6,065 species. Moving up the food pyramid, this spectrum of biodiversity includes 1,700 phytoplankton, 442 phytobenthos, at least 1,199 zooplankton, at least 569 meiozoobenthos, 1,476 macrozoobenthos, at least 380 vertebrate parasites, about 200 fishes, 83 birds, and a few dozen mammal species.

To better understand the role of micro- and macroplastic on the marine food web, researchers narrowed the scope of which species to include in the desktop study. Given the interwoven matrix of ocean habitats, microplastic debris may affect most marine plant and animal life to some limited degree. Yet such observations alone yield little actionable wisdom. The key to informed action lies in better understanding which rare and endangered species are most impacted across the Baltic Sea – and how.

Our foundational text has been the HELCOM Red List of Baltic Sea species in danger of becoming extinct (2013). This list is a comprehensive threat assessment for Baltic Sea species that covers all marine mammals, fish, birds, macrophytes (aquatic plants), and benthic invertebrates, and follows the Red List criteria of the IUCN. In this list we examined Baltic species that qualified as at risk (Vulnerable, Endangered or Critically Endangered) now or in the past. Yet to illustrate importance, we also selected species for which there is: evidence of plastic pollution; belonging to the same family of the endangered or vulnerable ones; residency in the Baltic or neighboring seas; and with both an ecological and economic importance to humans. Even if the some selected species on which the researchers found evidence of microplastics impacts are not directly listed as endangered or vulnerable, we can assume that, since they belong to the same class of the threatened ones, plastic pollution is also affecting species from the HELCOM and/or IUCN Red List database.

The following groupings, and profiles, highlight the impacts of microplastics on several species grouped in five different classes. We move up the marine food web in order of rising complexity from macrophytes, to benthic invertebrates, to fishes, birds and, ultimately, mammals. In the assessment of each class, we note the kinds of plastic pollution impacts that pose threats from: entanglement, ingestion, smothering, hazardous substances and invasive species.

Macrophytes

The source of food and shelter often begins with the diverse species of large aquatic red brown and green macroalgae, vascular plants, seagrass and mosses: macrophytes. As photosynthetic (sunlight converting) organisms, these are restricted to surface zones, where light intensity enables growth. There are few exclusively brackish species in the Baltic Sea, due to its geological youth; and its salinity gradient means the number of macrophyte species increases from the northern and eastern waters towards south and west.

Of seven threatened species, three are endangered. *Hippuris tetraphylla,* commonly

known as Fourleaf mare's tail, is a brackish aquatic plant 15-40 cm long once found in shallows along most of the Finland and Swedish coastlines. *Lamprothamnium papulosum*, or Foxtail stonewort, favored the shallow gravel and silty bottoms of sheltered bays, fjords and coastal lagoons along the Danish, German and Swedish west coast. *Persicaria foliosa* has also declined from its former abundance in rocky parts of Sweden, Finland and Russia. Each of these sensitive and vital plants have long suffered from dredging, shipping, biological pollution and tourism. The increased turbidity and new pollution sources lower the sunlight required for photosynthesis while burying vegetation in sediment and silt. The leakage of microplastics in coastal areas adds to the pressures on these protected endangered species.

Their newest and primary risks from polymer pollution come from smothering. Much like wood, stone, and other debris, small amount of marine plastic may provide shelter or habitat. Yet derelict fishing gear, bags and large (agricultural) foils are known to cover parts of the seafloor at all depths. These plastic layers decrease new shoot densities. Their weight causes blades to become abraded or crushed into the underlying anoxic sediments.

According to HELCOM researchers, plastics also alter the faunal community underneath as thin, hard durable coatings and layers reduce the exchange of pore water with overlying water. Dragged along the seafloor, large plastic litter can cause further damage to fragile habitat engineers (coral, plants) and change biogeochemical seafloor properties. The result is likely suffocating the plants, reducing photosynthetic rates and leading to eventual senescence of above-ground biomass.

Benthic invertebrates

Bottom-dwelling invertebrates are by far the most diverse of the groups assessed in the Baltic Sea, involving hundreds of species of segmented worms (Annelida), molluscs (Mollusca) and arthropods (Arthropoda), such as crustaceans

Source: Helcom http://www.helcom.fi/Lists/Publications/BSEP140.pdf

and aquatic insects. Through bioturbation, benthic species oxygenate the bottoms and fuel important processes like nitrogen turnover, to create a unique seascape for natural ecosystems and human economies alike.

The amphipod *Haploops tenuis* is classified as endangered, with 18 other vulnerable species. Most are restricted to the western Kattegat region, with some harvested for food. Edible species include crustaceans like nephrops or Norway lobsters, (pictured), Chinese mitten crab, brown shrimp, and mysid shrimps; bivalves like bay mussel, blue mussel, and Pacific oyster; and the mollusc Dun sentinel.

For these species, and possibly the humans who devour them, the key risk from plastic pollution comes from accidental and secondary ingestion.

Filter-feeding marine organisms may be especially prone to plastic ingestion. The large volumes of water they process may contain debris in addition to the targeted food source. Although non-food items can be ejected before passage into the digestive system, this is not always the case. Plastic intake is hardly unique to filter feeders, nor is it entirely accidental. Norway lobsters may eat plastic during passive feeding but may also arguably mistake fibres for favoured benthic polychaete prey. Opportunistic feeders, like two-thirds of assessed brown shrimp, consume synthetic fibres ranging from 200 µm up to 1000 µm size, with uptake was significantly higher in October than March. It

appears microplastics >20 µm are not able to translocate into the tissues. One 2017 North Sea field analysis found microplastics in 8 of 9 tested invertebrate species, with a thousand-fold higher concentration of plastic particles than it found in sediment and surface samples from the same location.

The small size and ubiquitous distribution of marine microplastics are available to species in both pelagic and benthic habitats, and their ingestion and bioaccumulation suggest a potential impact on food safety. People typically eat these invertebrates whole, without removing the gut. Depending on how recently the animal had fed (and ingested microplastics) before harvest, consumption may increase health risks, as the microplastics mostly stay in the gastrointestinal tract of the crustacean or shellfish before being egested.

Along Poland's coast, a study on plastic ingestion by the highly invasive and commercially fished Chinese mitten crab showed that 13% of the 302 analysed males and females contained microplastic strands and balls. Most were transparent fragments of fishing gears. A further study recovered microplastics from the soft tissues of farmed bivalve species, exposing the diet of European shellfish consumers to 11,000 microplastics per year, a level of potential toxicity risk that has not been estimated – yet.

Other research set 450 bay mussels in cages near a municipal wastewater plant's discharge pipe, a potential plastic gateway near Hanko, Finland. Microlitter was found in two thirds of the mussels, with polymer beads, shards and threads (polyester, polyethylene, polystyrene, polyvinyl chloride, polypropylene, and polyacrylic) accounting for 22% of all the analysed particles (the rest were non-synthetic cotton, linen, wool and viscose). Beyond potential human risks, ingestion of microplastics has been linked with immunity-weakening problems in mussels, lowered reproductive levels in oysters, and reproductive disorders in the snail *Assiminea grayana*.

Source: Helcom http://www.helcom.fi/Lists/Publications/BSEP140.pdf

Ingestion triggers a chain reaction through bioaccumulation. By ingesting plastics, marine biota accidentally support and catalyse the global distribution of plastic through bio-transportation. Also, some crustaceans reshape and redistribute plastics: a study in 2012 showed that boring crustaceans could release into the environment thousands of small particles per burrow.

Crangon crangon

Entanglement in macro plastic litter poses another risk. Crabs and octopuses are caught in derelict traps on the seafloor and die from stress, injuries or starvation, as well as the species and plastic both then being potentially ingested by larger animals. The size and shape of the microplastics allow some to be trapped in the appendages of mysid shrimp; entanglement by plastics may cause a nuisance for the animals via hampered swimming, filtering, or prey capture.

Plastics may also expose organisms to a third risk from various hazardous substances: toxic metals, plasticizers and other, persistent organic pollutants (POPs). These substances are either added upon manufacturing or adsorbed from the surrounding water. The concentrations of microplastics found in Baltic sea's invertebrate species were considerably low compared to reported concentrations in commercial mussels (Mytilus edulis) collected along the coastline of China, but on the same level as what has

been found in other Mytilus species collected in Italy, Spain, Portugal, France, Belgium and the Netherlands.

Finally, marine litter may provide new transport vectors for invasive species. Eight sites found more than 5,000 macro-organisms inhabiting coastal litter and natural substrates, increasingly mobility of plastics across the ecosystems through dispersion. The results showed plastic litter not only can support higher densities of marine organisms and represent a new habitat in the studied coast; against expectations, the artificial litter structures also revealed three times more *diverse* than natural rock substrates. Thus plastics significantly alter the biotic composition of coastal ecosystem, representing a shelter for invasive species.

Fish and lamprey species

More than 70% of the fishes in Baltic originate at sea, 20% are freshwater, and the rest are diadromous – migrating during their lifespan between river and ocean. Most of the 208 fish and lamprey species are Actinopterygii, ray-finned fishes. Of these, grayling, eel, porbeagle shark and spurdog shark are critically endangered; the Atlantic wolf-fish, whitefish, and ling are endangered; and the sea lamprey, tope shark, thornback ray, cod, whiting, salmon and trout are vulnerable. An overlap with edible species of concern focuses on cod, whiting, haddock, trait shad, and Atlantic mackerel. Finally, while not threatened, sardines and anchovies have ecological and economic importance, with potential risks for human health.

The primary polymer risk to Baltic Sea fish comes from ingestion, with plastics linked to foraging strategies. Large, predatory cod inspect plastic debris and take bites out of larger plastic items. Tint matters: specific plastics attract predators by resembling the smell or colour of their prey; white, clear, blue plastics are primarily ingested by planktivorous fish; black particles are most prevalent in stomachs of both pelagic and demersal fish.

Herrings and mackerels feed by filtering large volumes of water, with debris mixed in with the targeted food source. Commercially valuable cod, herring, sprat, and flounder are 90% of the Baltic's fish catch, and the most studied species. The most microplastic found in herring was 4 particles; in a sampling of cod (1,091 individuals) the highest percentage of ingestion in cod in the offshore Baltic Sea and coastal Baltic Sea was 26% and 16% respectively. Some 30.8% of pelagic mackerel sampled from the Baltic Sea contained microplastics, with a similar amount for whiting from Kattegat. In a 2016 study, 290 gastrointestinal tracts of demersals (cod, dab and flounder) and pelagic herring and mackerel from the North and Baltic Sea were investigated plastic ingestion. Predominantly polyethylene microplastics were detected in 5.5% of all investigated fishes, especially 10.7% of pelagic species. A Baltic study of 120 threespined sticklebacks found microplastics in 12.5% of them; synthetic fibers showed up in the digestive tracts of twait shad collected off Lithuania.

Ingested plastic may block and injure digestive tracts, reduce feeding, and cause toxic effects from the absorption of polychlorinated biphenyls. The Vistula River is the source of plastic debris in the Gulf of Gdansk, in which twaite shad stomachs revealed Diptera (3.4%), the remains of plants (1.7%), small stones, wood (6.8%), and plastic (3.4%) totaling 16.4% together.

Various species differ in diet, feeding behavior, and size. In herring, filter feeding allows only particles smaller than 1.5 mm in the intestine; larger plastics are found in fish-eating cod, haddock and whiting. The most exposed species were sardines, whose large filtration area and the closest gill rakers meant they ingested more fibers and smaller fragments. Another study found relatively large microplastics, mainly polyethylene, translocated into 80% of the livers of anchovy, ranging from 124 µm to 438 µm, showing a high level of contamination, and suggesting two pathways: (i) agglomeration of smaller pieces into large particles found in the liver; and/or (ii) plastics simply pass through the intestinal barrier.

Again, a lesser risk comes from entanglement. Prey fish, which use plastic debris as a shelter, can increase entanglement risks for predators, such as sharks and fish. Effects of entanglement: a ring from a plastic bottle became fixed around the operculum of a juvenile axillary sea bream, inflicted a deep cut in the anterior part of the fish, eventually killing it. Discarded plastic lines and fishing gear, even if not directly drowning the animal, may cause complications in proper foraging or surfacing to breathe. Fish carcasses rot, while synthetic plastic nets, lines and hooks endure for decades; fishing gear is often the lethal gift that keeps on killing.

Baltic breeding and wintering birds

Western Palaearctic seabird and coastal bird species depend heavily on the wide diversity of Baltic Sea habitats. Grebes and dabbling ducks breed in its brackish lagoons; sea ducks favour its rocky and shrubby archipelagos; waders and terns prefer open sand or gravel habitats or low grass vegetation; gulls occupy roofs of buildings or auks reproduce on rocky islands and skerries. Then come the truly marine, pelagic species: northern fulmars, black-legged kittiwakes, and auks.

The Red List assessment includes 56 breeding and 58 wintering bird species. Of these the critically endangered Kentish plover, red-throated diver and the black-throated diver have in recent years decreased dramatically. The breeding dunlin, Terek sandpiper, Mediterranean gull and the black-legged kittiwake join seven wintering birds, including five sea duck species, as endangered.

Foraging seabirds face a constant risk of plastic ingestion. Pursuit-diving birds, such as the shearwaters have the highest frequency of plastic uptake, followed by surface-seizing and dipping seabirds. Marine birds, feeding on crustaceans and cephalopods ingest more plastic than piscivorous seabirds, and those omnivores are most likely to confuse prey and plastic. Seabirds with specialized diets are less likely to misidentify plastic, unless its shape, consistency, smell and colour resembles their prey – as believe with shearwaters. Gulls frequent rubbish bins and landfill areas, yet ingested debris rarely shows up in their stomachs during dissections because they clear them daily by regurgitating hard prey remains. Tubenose birds mostly retain plastic and hard prey items because they possess two stomachs with a constriction between the glandular proventriculus and the muscular gizzard. Even when spitting stomach oil to defend themselves or when feeding their chicks, only plastics from the proventriculus are regurgitated but items from the gizzard are retained.

Age is a factor. Younger northern fulmars, and short-tailed shearwater, have more plastic in their stomachs than adults. The reasons for this elevated load may be due to both parents transferring its own bioaccumulated plastic load to the chicks, delivering polymer-infused food by regurgitation at the nest. Younger birds may also lack the grinding action in the gizzards, slowing the mechanical break-down of plastic and removal through the intestines. A third hypothesis is that, young animals are less efficient at foraging, and therefore less specific in their prey selection.

A case of unintentional, secondary plastic ingestion occurs when birds eat plastic-ingesting prey, whole or while scavenging. Skuas forage on smaller seabirds that consume plastic. In northern fulmars, intact stomachs from scavenged fulmars or black-legged kittiwakes were occasionally found, containing plastic. This aspect of the food web cuts in both directions. A spectacular example of secondary ingestion arose in a 2013 study, which reported a ball of nylon fishing line in the stomach of a little auk, which was in turn found in the stomach of a goose fish.

Escalating observations of plastics ingested by sea birds trace back to the 1960s, reaching levels that may at first seem to have possibly stabilized over time. A closer look suggests shifting dynamics. Initial monitoring schemes focused on the most obvious and visible plastic items, like bottlecaps and bags, rather than microplastics smaller than 1 mm. Today's analysis show

more complex interactions. More recently, the chemical compound dimethyl sulphide (DMS) is associated with marine plastic, producing a scent that can be picked up by marine organisms including seabirds and may represent a biological cue for the presence of food. Furthermore, birds feeding on crustaceans and cephalopods had more plastics than piscivorous seabirds, perhaps because they are likely to confuse prey with plastics.

Blockage and damage to the gastrointestinal tract can bring rapid death. Even small pieces can harm bird intestines, if orientated in the wrong way. Plastic ingestion has been documented in over 100 species of seabird. Of these, the omnivorous, ocean-foraging northern fulmar is particularly vulnerable to plastic ingestion, with fragments remaining in its muscular stomach until they are broken down to a size that can pass through the gut, a process requiring one month. The species' high abundance and wide distribution make the fulmar an optimal candidate – and recognized European indicator species – for monitoring marine plastic pollution. An 'acceptable level' finds no more than 10% of fulmars exceed a critical level of 0.1 g of plastic in the stomach. During 2003-2007, 95% of 1295 fulmars sampled in the North Sea had on average 35 pieces weighing 0.31 g in the stomach. The origins of polymer found in fulmar stomachs has changed over time: in the 1980s, plastics were evenly divided between industrial and consumers; today consumer plastics outnumber industrial by a factor of 10.

Given their abundance, plastics that do not kill the individual may still cripple the health of an entire species. Tubenose seabird species regularly ingest plastic, raising urgent questions concerning the cumulative physical and chemical impacts at the population level. Sub-lethal physical impacts may have various and chain-linked consequences. Stomachs filled with plastic limit optimal intake of real food, which may only be sporadically available. Reduced storage affects optimal foraging ability. Efficiency of digestive processes are reduced when sheet-like plastics or fragments cover parts of the intestinal wall, causing ulcerations. Ingested plastics trick brains into a feeling of satiation, which may reduce the appetite and drive to search for food. All these factors may lead to a deterioration of the body condition.

Perhaps more than any other taxa, seabirds facilitate and catalyse the global distribution of plastic through bio-transportation. In short, they accidentally spread plastic to otherwise pristine habitats, and unwittingly force feed polymers to their otherwise healthy offspring. Fulmar and thick-billed murres, after overwintering in more polluted regions, excreted smaller plastic particles in breeding grounds, where they become available to other trophic levels in marine and terrestrial habitats. A 2011 study suggests northern fulmars annually reshape and redistribute ~630 million pieces or 6 tonnes of plastic, allowing widespread secondary distribution of plastics and associated chemicals to occur.

Seabirds are also well known to become entangled around the bill, wings and feet with rope-like materials, which constrains their ability to fly or forage properly. Gannets and others that use seaweed to build their nests, are known to frequently incorporate ropes, nets and other anthropogenic debris. Marine debris used in nest construction increases the risk of mortal entanglement for both adult birds and chicks. As a 'plunge-diver' the gannet is endangered by drifting plastic-debris and 'ghost-nets'.

Mammals

Marine mammals, while not a distinct biological group, are united by their reliance on the sea for feeding. Whales and dolphins depend utterly on the marine environment, while seals breed on land or on ice. At risk are the vulnerable ringed and harbour seal species, the critically endangered harbour porpoise, and the near threatened Eurasian otter. This assessment also selects the vulnerable sperm whale, endangered fin whale and endangered North Atlantic right whale, as well as the Minke, Humpback, Cuviers beaked whale, and white-beaked dolphin.

Research has found 54 and 62 % of the baleen and toothed whales, respectively, ingest plastics. Marine mammals may see plastic as a curiosity and, while investigating it, swallow or become entrapped in it. Again, age plays an important role in the ingestion of plastic debris, as younger harbour seals had significantly higher levels of plastics in their stomach than older ones.

In 654 harbour porpoises sampled between 2003 and 2013, the frequency of occurrence of plastic litter was 7% (in 47 stomachs) with less than 0.5% additional non-synthetic man-made litter (paper, non-synthetic rope, fishing hook). Polyethylene and polypropylene were the most common plastic types encountered. A more recent and rigorous detection standard found more than twice that level 15% of 81 harbour porpoise stomachs from 2010–2013 of plastic litter. Methodology matters, and the occurrence of litter with other non-food remains suggest plastic was often ingested accidentally when the animals foraged close to the bottom. Most items were small and had no major health impacts.

In some cases, plastic impact can be severe. On March 18, 2019 a marine biologist in the Philippines received a phone call about a young Cuvier's beaked whale that was reportedly weak and vomiting blood; after its death, a necropsy found the whales stomach "full of plastic – nothing but nonstop plastic." Among the 88 pounds of plastic were 16 rice sacks, and bags still identifiable by their grocery chains. Within the last decade this was just one of 57 whales in the Davao Gulf alone to have died from ingesting plastic debris and likely suffering not for days but months or even a year.

As with fish and invertebrates, filter-feeding mammals appear more prone to plastic ingestion. Large baleen whales have been long known to occasionally ingest debris. According to recent research, "marine filter feeders are exposed to microplastic because of their selection of small particles as food source. Baleen whales feed by filtering small particles from large water volumes. That same study found microplastic in intestines of a baleen whale, with several polymer types (polyethylene, polypropylene, polyvinylchloride, polyethylene terephthalate, nylon) found in varying particle shapes: sheets, fragments and threads with a size of 1 mm to 17 cm. The diversity in polymer types and particle shapes can be interpreted as a representation of the varying characteristics of marine plastic and the unselective way of ingestion.

Beyond filter feeders, plastics found in harbour seals were considered to have been accidentally ingested when catching prey fishes. Unintentional secondary ingestion also occurs when animals feed on prey, which had already ingested debris; small plastic particles in the faeces of fur seals has been attributed to their eating myctophid fishes – a stable food with high abundance of small plastics.

Data on Nordic mammals are infrequent, qualitative, and rarely focus on plastic ingestion. But they show it happens often enough, and at disturbing levels. In 1985 off Iceland, one sperm whale and 6 out of 82 fin whales sampled contained "synthetics". A Cuvier's beaked whale stranded near Bergen, West Norway, contained about 35 plastic bags, food packaging and larger plastic sheets. And a White-beaked dolphin stranded off Hvaler in the Kattegat, had a "ball" of entangled plastic in its stomach.

In the winter of 2016, 30 sperm whales stranded in five countries over six weeks; of 27 necropsied and/ or sampled, all appeared in fair to good nutritional condition with no evidence of disease or trauma. Infectious agents were found, including various parasite species, several bacterial and fungal pathogens. In gastro-intestinal tracts of 22 carcasses, nine revealed marine debris including netting, ropes, foils, packaging material and a part of a car. None directly caused death, but the findings demonstrate the high level of exposure, with up to 25 kg of debris collected from a single animal. Fishing related debris represented a high proportion of the findings, while general litter consisted of items of daily use (coffee capsule, chocolate wrappings).

Whales and dolphins can become entangled around flippers and flukes, often in several types of fishing gear. Seals become frequently entangled

in synthetic fishing gear, packing straps or other loop-shaped items that create problems during growth. Behavioural traits can be important factors. The 'playful' behaviour of marine mammals may increase risk of entanglement, in combination with lack of experience and a foraging habit closer to the water surface. Age plays a significant role in pinnipeds, as younger seals are more often entangled than adults, and can disturb growth over time. In 1992, a dead grey seal found in the Baltic Sea was discovered with deformations. The size of the rubber trawl roller suggested that it had been entangled as a juvenile five years before.

Examples of plastic entanglement, ingestions, and other negative effects on individuals are abundant. Yet given their range, it is rarely possible to assess the proportional damage to populations. One exception in 2012 was a study of 626 photo-identified individuals of the North Atlantic right whale, 83 % of which showed evidence of entanglements in ropes and nets. On average, 26 % of adequately photographed animals acquired new wounds or scars every year. Entanglement reduces the longer-term survival of grey seals, suggesting the potential impact of plastics on wild populations.

Over a quarter century along the German coast (from 1990 and 2014), researchers collected records of marine debris in and attached to 6,587 carcasses of stranded harbour porpoises and harbour seals. The decomposition state allowed for necropsy in 1,622 cases and recorded marine debris items in 31 carcasses including 14 entanglements (5 harbour porpoises, 6 harbour seals, 3 grey seals) and 17 cases of ingestion (4 harbour porpoises, 10 harbour seals, 3 grey seals). Objects comprised general debris (35.1%) and fishing related debris (64.9%). Injuries associated with marine debris included lesions, surface ulcers, holes in the digestive tract, abscesses, suppurative peritonitis and septicaemia. This investigation demonstrates marine debris impacts, including severe suffering and death, and inform Baltic management directives, such as the Marine Strategy Framework Directive (MSFD).

Looking ahead

Worldwide, over the last two decades, the number of species that suffer from entanglement has doubled. The weight and size of this footprint is heavy and vast. All seven marine turtle species, two-thirds of all seal species, 31 % of all whale species and a quarter of all seabirds have become entangled. In the Baltic studies show plastic restricts movement, feeding, and breathing to the point of drowning or starvation. That death may by itself be slow and painful in isolation, but a more insidious horror of plastic comes from ingestion, which is less visible but more common. Plastic shapes and colors often mimic a favored food, send signals to brain receptors that trick animals into feeling sated, then lead them to carry the polymers back to nests, and shove fragments and filaments to open beaks of their young.

The least obvious risk comes as polymer sinks to the bottom and layers the seabed. Smothering weakens the plant fabric that links the fixed habitat stage with so many species actors. Plastics may continue to smother Baltic Sea surfaces where effects may range from suffocating organisms to offering new habitats for species that are otherwise unable to settle. Especially sessile organisms are most vulnerable to smothering since they are immobile and cannot escape when their habitat changes. By inhibiting gas exchange between the sediment and overlying water, plastic triggers local hypoxia or anoxia in the benthos. In fact, anoxic conditions have been observed in the sediments under a single sunken plastic bag.

To be sure, plastic is far from the only, biggest, or even worst threat to Baltic Sea species. Yet it exacerbates, builds on, and compounds the damage from centuries-old contaminants, toxic farm runoff, fishing pressure, and greenhouse gas impacts. Many of the hazardous substances are buried in sediments and present in water and biota. Since the Baltic Sea still seems to have a burden of hazardous substances, the increasing plastic pollution may aggravate the situation by leaching out harmful additives, monomers and other substances. Plastics can also adsorb

persistent organic pollutants (POPs) from the surrounding water, which may impact animals able to ingest these plastics and attached pollutants together.

Many areas in the Baltic Sea are classified as being disturbed by hazardous substances, and the most contaminated areas according to HELCOM are the main basin of the Baltic Sea including Northern Baltic Proper and Western and Eastern Gotland basins as well as the Kiel and Mecklenburg Bights outside the main basin area. Since the combined effects of multiple stressors are not easy to predict in advance, particularly the biota living in areas with already high concentrations of hazardous substances may be at risk regarding plastic pollution.

Finally, polymers last longer than driftwood, animal carcasses or seaweed, which quickly become decayed or consumed. Thus, plastic as a rafting platform, or pathway, once floating in the Baltic Sea may support more long-lived communities and cover greater distances than natural flotsam. Plastic litter has been observed to enable both long distance and short distance dispersal of motile and sessile invertebrates, which are regularly encountered “hitch-hiking” on plastic litter. Nearly three quarters of the rafters are suspension feeders, which acquire their nutrition from the surrounding seawater. After litter is fouled by various micro- and macro-sized organisms, they attract also predators, scavengers, grazers and borers on their surface.

Any animal of any size can become the victim of plastic entanglement or ingestion. So, research must continue to record impacts of plastic pollution on Baltic Sea biodiversity until all marine species – especially filter-feeders at lower trophic levels – are documented. Only through future assessments of the various impacts, including frequency and quantity, can we ultimately gain a real understanding of the many deleterious effects of marine plastic debris on marine wildlife in the Baltic Sea.

Kentish Plover
(*Charadrius alexandrinus*)


2018

PART VI
Private collective action: the Baltic Sea business response

Recently, a small portion of leading plastic-dependent corporations announced a $1.8 billion initiative to help end plastic leakage into nature. What should the private sector do, where should it focus energy, how should it invest resources, and what is motivating action (beyond public relations) to shape value chains in the global economy? To answer these questions in a regional context, in this chapter IUCN has teamed up with the Netherlands based social enterprise, Searious Business. Our goal was to help manufacturers in the Baltic Sea basin 'close the plastic loop' by tackling loss and leakages into our environment. More focused objectives were to help the private sector address plastic pollution and potential solutions; define their voluntary commitments; determine how governmental policies can encourage frontrunners; and streamline business policies with government policies to address gaps in an inclusive approach.

In the quest for solutions, polymer pathways reveal economic forces at work. If industrial production and popular consumption had to take account of the externalized costs imposed on natural marine ecosystems, plastic would no longer be regarded as 'cheap.' Accounting for these costs, through extended life cycle analysis, help quantify the plastic footprint for each product, industry, country and source. And if those who most benefit financially from linear polymer usage transitioned to assume legal responsibility for these negative impacts, they would quickly find ways to reduce, reuse, and recycle plastics into a closed loop ecosystem, bringing the world closer to a circular economy. The question this section explores is how much of that transition may be driven by voluntary incentives, and how other stakeholders can encourage companies to make that change.

Following the September 1, 2017 merger of industry giants Dow Chemical and DuPont, the combined DowDupont became the world's largest chemical company by sales of $62.5 billion. Nestlé sold nearly $90 billion worth of products, and Unilever $60 billion. Beverage industry giant, the Coca-Cola Company, took in $35.4 billion, while its rival Pepsico nearly doubled that revenue at $64.6 billion.

Those figures hint at the global scale, and what's at stake. Just five global producers rank among the world's largest manufacturers and distributors of plastic-encased items, food, drink and personal goods that get shipped to and used by billions. These behemoths set the agenda for millions of large, medium and small enterprises at regional and local levels. Yet even alone, this handful of brands controls a plastic-dependent economy greater than the gross national product of more than a hundred and fifty entire countries, including the Baltic states of Denmark, Finland, Latvia, Lithuania and Estonia. The high-profile combination of money and plastic suggests one extent to which the private sector holds real potential to alter the polymer

pathways through the global marketplace – a marketplace of both goods and ideas.

With immense market power comes immense market responsibility. Promisingly, recent years offer signs that even the most competitive companies have begun taking their central roles – as purveyors of plastic-wrapped, plastic-infused, plastic-contained, and plastic bonded goods – more seriously, and shifting the gears of their operations, marketing and investments in the direction of a circular economy. In mid-January of 2019, the global Alliance to End Plastic Waste – a collective action effort that consists of nearly thirty companies from North and South America, Europe, Asia, Southeast Asia, Africa, and the Middle East – has committed to a goal of investing $1.8 billion over the next five years to help end leakage into natural environments, like the Baltic Sea basin.

Against the massive global and trillion-dollar scale of our complex polymer economy, that particular effort by a portion of the plastics-dependent industry is tiny. Still, it's a start. More important is the kind of leadership that follows: how will the private sector move forward, what's on its agenda, and why are any companies motivated to generate not superficial hype but quiet and substantial transformation? The consumer goods industry claims to be "working in a pre-competitive and collaborative space to make a real impact." Amidst these hairy ambitions, originating from increased consumer and media pressure, it is vital to keep an eye out for actual results coming from real actions.

Before decision-makers could reach any conclusions on which to base public policies or put measures in place, it was important to first acknowledge how private sector sees its role in moving away from linear, polymer-based economy.

Private sector priorities

In choosing industry players, our approach focused on leaders in the field of textiles, tyres, fisheries & packaging, since these sectors play the most important role in the Baltic basin's plastic pollution. Within Europe, the furniture and consumer electronics industries also have big potential impact, with high volumes and possibilities for circular use of plastics. To better understand linkages in the Baltic Sea, we also included public sector in water, waste, and road infrastructure management, governmental oversight, non-governmental organisations, and research institutions. In the summer of 2018, Searious Business reached out to more than 150 organizations (in Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland and Sweden), which generate the bulk of plastic waste and account for 5% of the GDP in the Baltic region. Except for the remarkably silent fishing industry, responses from 26% captured a representative microcosm of the region's key players. While far from exhaustive, the new research provides an elaborate overview of involvement of private sector to help prevent plastic pollution in the Baltic, and related gaps in policies and activities from other stakeholders, and of the preconditions to achieve better economic, environmental and social outcomes.

Building on earlier causal and consequential elements – linking the plastic footprint through habitat and biodiversity impacts – teams delivered outcomes in four interrelated areas that brought the Baltic's major industry players, from the margins of discussion to the heart of debate:

- First, we analysed crossovers between research on plastic sources broken down by countries and sectors. Stakeholder mapping identified the current activities of major companies in the Baltic that can try to do to alter the course and volume of polymer pathways.
- We then engaged with industry associations from the region in the way they use plastics, ranked the ten most prominent and effective measures the private sector should take to close the plastic tap in the Baltic, and took an inventory how willing and ambitious

these businesses would be to take bold actions in reducing polymer leakage.

- Furthermore, we captured valuable insights and experiences of these businesses in an overview of the issues to be addressed, the barriers and potential solutions. This included both a systemic change and a change within the businesses and value chains themselves.

- Finally, we drafted policy recommendations for countries in the Baltic on how to close the plastic tap. Instruments include coercing legislation but also setting up initiatives based on voluntary commitments, building on expertise and knowledge of research and NGO's and involving consumer stakeholder organizations.

What motivates businesses to act on the root causes of plastic pollution?

No decisions, good or bad, take place in a vacuum. Cynics may dismiss outward advances by businesses as simply an effort to enhance corporate image, avoid reputational risk, insulate shareholders from liability, or minimize damage to their brand. To be sure, there are indeed external legal and political forces at work. Some companies may be guilty of 'green-washing' their image, while doing nothing; more laggards will simply 'free-ride,' or take advantage of real investments and hard efforts by leaders.

Skepticism, while understandable, misses the more expansive and fast-evolving picture. There has been a deep paradigm shift in the context for industry-wide recognition of problem: plastic waste is increasingly seen as a sign of lost potential, and the focus of innovation. Those industry laggards or shameless superficial advertisers are likely to be left behind, losing market share or going out of business, unless they too can learn to capture the flip side of the polymer crisis, which is a futureproof business opportunity.

The advantages won't always be immediate or obvious, say economists. Yet there is significant untapped long-term potential moving away from virgin plastics. This includes advantages in avoiding materials, but also in processing used plastics, in terms of increasing volumes, quality and yield of reprocessed plastic. Improvements are partly driven by technical innovations, including automated and robotics-powered collection and sorting, and novel chemical recycling methods to obtain virgin-grade plastics. Another important value-retaining driver is harmonization of collection systems, while allowing adaption to local conditions.

At scale, looking ahead (and admittedly in some cases after decades of resistance), progressive manufacturing companies in the Baltic basin have begun to recognize the potential economic gains from re-integrating used polymers into their economies – even, or especially, in countries that don't yet have the capacity to do so through public governance. As they are nudged toward a more circular economy model, manufacturers in the region earn dividends to the extent they can:

- increase recyclability of packaging increases license to operate;
- reduce costs through avoiding plastics;
- find alternatives that have a lower total cost;
- eliminate plastic waste from their operations;
- increase margins through added value for customers and increased brand loyalty;
- score higher when competing for public tenders;
- realize a substantial CO_2 reduction by using recycled instead of virgin content.

Incentives for innovation

We often tend to look for guidance and leadership from the giants of plastics. They can, as noted above, leverage tremendous human and economic resources at their disposal. Yet with rising incentives, new innovations for reducing the volume and leakage of polymers may be just

as likely to arise from small, medium and start-up enterprises, which can move nimbly, have more to gain and less to lose.

Up to now, past research, development and innovations have often focused on improving a single issue, like barrier properties or conversion of a specific biomass, rather than taking the entire plastics system into account. Teams work in silos, in isolation. Yet only a systemic, interdisciplinary, collaborative approach can integrate innovation with other steps in the wider supply chain. For example, breakthroughs in bio-based and compostable plastics may be considered both technically successful and scientifically important. Yet few lab breakthroughs ever say how they fits into the reality of the European material economy, with suitable applications, required infrastructure, regulatory framework, and availability of feedstock. Systems thinking helps embed innovations within cross-value chain collaboration, yet this rarely happens in the polymer economy, due in part to challenges in tracking, collection, sorting and recycling of used plastics.

The recycling sector's increasing complexity and slim profit margins make it hard to adapt to new material streams, which risk adds costs and can reduce performance. It's also hard for the well-meaning end-user to know what's good or bad for the plastics system, or whether their ethical deliberations at multiple waste bins will be combined, undermined, incinerated, or recycled once hauled away in an opaque system. This worry or confusion reduces collection rates and sorting yields. Even the R&D process faces drawbacks. Peer reviewed initiatives tend to emphasize how the material or technology performs, not whether it challenges the underlying logic of cheap, single-use applications. As a result, limited efforts go into determining whether new product designs encourage a circular economy. In theory, a business model innovation that enables digital technologies to prevent plastics from becoming waste. By, say, embedding data trackers, or cameras identifying shapes, or tracing responsibility from purchase to disposal and thus improve transparency would directly address one root cause of plastic pollution. Yet, examples of such bottom-up innovations are limited.

When approached with results, some businesses indicated they want to contribute to solutions by working in public-private partnerships aimed at education and thus preventing marine debris. These partnerships seek to raise awareness with consumers about the nature of the problem and highlight steps people are taking to combat it. They envision such commitments can help change the user behavior that leads to marine litter.

Others seek to work with the scientific community and university researchers to better understand and evaluate the scope, origins and impact of and solutions to marine litter. They collaborate with independent facilities on plastic pollution, provide researcher with (some of) the necessary funds to carry out investigations, and empower consumers to return end-of-life products to the loop.

Education can help, if linked to incentives. Starting in primary school, every European child (and, indeed, parent) should know the 7 major types of plastic. And municipal or national chambers of commerce should be encouraged to share non-proprietary lessons learned, research outcomes, building more diverse players and expertise. Companies reach out to specific target groups and stakeholders like Sustainable Brands, WBCSD, PlasticsEurope and sector leaders. Optimal results may emerge most equitably under a rigorous framework of local or national policies.

Those policies are, alas, often slow to take shape. The private sector need not wait for legislative or executive decisions to be enacted and enforced. There are prominent and effective steps that individual companies of any size can take, right now, to close the plastic tap in the Baltic. Among the top ten measures, business executives and directors could:

1. Define strategy on plastics use, e.g. goal on zero waste

2. Design for recyclability / Design products to be repurposed, repaired, reused, resold or recycled
3. Increase use of recycled plastics (or biobased plastics)
4. Reduce use of virgin plastics
5. Collaborate across the whole value chain
6. Phase out or replace single-use plastics
7. Closed loop recycled content
8. Avoid plastic waste
9. Reverse logistics (e.g. take-back schemes)
10. Encourage effective recycling with recyclers and consumers

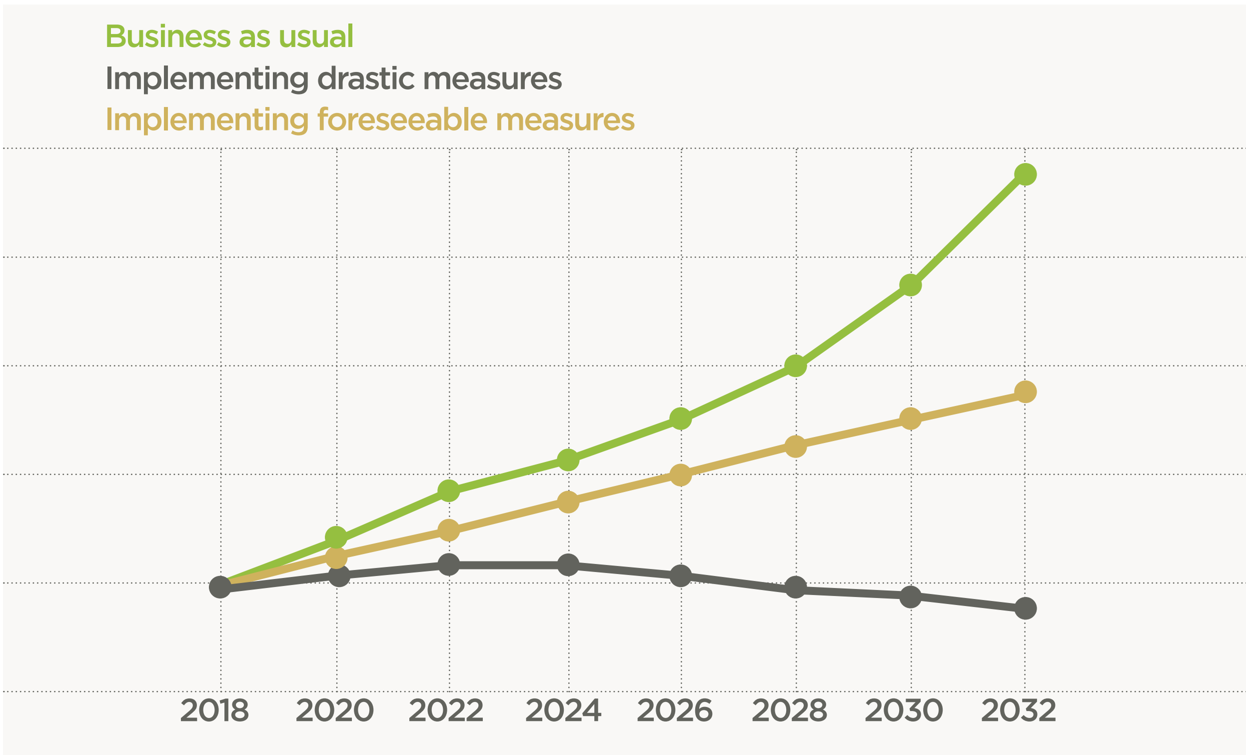
Next steps

The challenges posed by the current plastics system demand fundamental change, for which innovation, reinforced by policymaking, plays a crucial role. While plastic brings benefits as a functional material, the current system has severe unintended drawbacks, including economic loss and environmental damage, such as marine litter. To break the current stalemate, and move the entire plastics economy in the Baltic, incremental progress will not suffice – a systemic change is the only long-term solution. While such change benefits from the joint effect of multiple small steps, it also requires big leaps forward.

After conducting research with the stakeholders from private sectors and other stakeholders, it is striking how much alignment there is across the different players. It is easy to reach conclusions of the kind that much more needs to be and can be done to prevent plastic pollution. Different stakeholders seem to wait for each other. Decisive measures are lacking, although most opinions point into the same directions.

Although there are always the odd exemptions, our outreach and research has been extensive enough to determine a general state of mind and sense of directions. Based on many different conversations, there is broad consensus around the following issues.

The first is the need for voluntary foresight and leadership. Barriers to change, stakeholder agree, are never just technological. Often, organizational or marketing barriers are even



Bending the Arc of History: To break the current stalemate, and move the entire plastics economy in the Baltic, incremental progress will not suffice – a systemic change is the only long-term solution.

more important. A company's culture ("there's too much uncertainty," "that's not our problem," "we've never done something like that") is likely to get in the way of shifting behavior within the private sector.

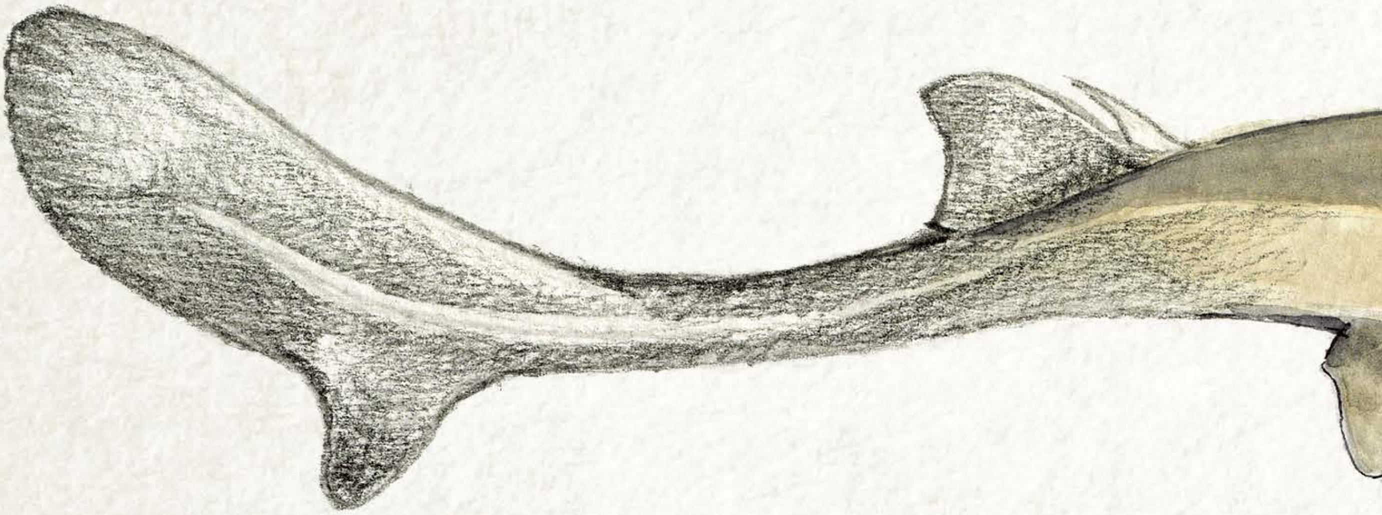
The second is that incentives matter. Companies clearly state that they simply lack real financial motivations to make the shift toward more sustainable production. For real change, the entire private sector would be transformed if it began to compete under flat, universally applied measures like a meaningful carbon tax rising from 21-100% over a decade, or a front-end value add tax on raw crude or virgin plastics. Doing so would allow recycled plastics to compete, mitigate oil that gets 'dumped' onto the European market, not to mention reducing the risks of climate change and ocean acidification. In countries implementing extended producer responsibility schemes, you can immediately see more companies taking action due to measures like differentiated tax schemes on packaging material.

It may at first sound odd that businesses seek to grow more competitive and sustainable by making the raw materials they depend on cost more. Yet simple taxation avoids the danger of perverse incentives of selective regulation, while rewarding innovation. It reflects consensus that the private sector needs that kind of shock, to make the sharp bend from a linear model to a circular economy. To that end, a third step is to set bold, strict minimum percentages (starting at 25%, annually rising 10%) of recycled content for every sector. To prevent 'leakage' or unfair advantages, a single policy could by 2020 limit types of plastic produced or imported, or even ban single-use plastics in multilayer packaging – not just in a few cities or nations, but throughout Europe.

Public efforts raise the bar high and firm; private efforts must discover how to clear it. At that point, there was consensus and trust that the market will think of and find new ways to adapt. There are enough smart people in Europe willing to ReThink & ReDesign the system, together with major producers converters, recyclers, designers, etc. In addition to the stick, make room for carrots. Public and philanthropic vouchers for innovators, a kind of X prize for plastics, can act as seed fund and accelerate change.

Finally, highlight what works through benchmarking policies. If Germany has the best waste recycling in Europe, other countries can adapt lessons and copy this, bringing their infrastructure up to speed right away, without the need for extensive ponderous and duplicative studies. Likewise, just as France prohibited many single-use items, like plastic cutlery, other countries can learn from its successes, and avoid early missteps. Just as Nordic countries thrive at engaging consumers, Southern Europeans can benefit from this approach, too. Governments can even make a list of best practices like this every year, setting new standards within their country.

Recalling those plastic-dependent giants, the opportunities and obligations for private sector action are real. Yet even with billion-dollar budgets, celebrity CEOs, far-reaching networks, and ambitious agendas, there may be limits to what commercial efforts like the Alliance to End Plastic Waste can accomplish on their own. As the next section illustrates, it often takes smart and coordinated public tax or regulatory policies to level the playing field, reward innovative models, encourage investment in R&D, and spur collaboration within the plastics value chain. In the Baltic Sea, there is an opportunity to align the interests of businesses and governments, forging a symbiotic relationship between private incentives and public goals.



Spiny Dogfish
(*Squalus acanthias*)

Graça Lagrifa
2018

Part VII
Public collective action: harmonizing policy, governance and investment

Marine plastic pollution is exactly the kind of complex wicked problem for which IUCN was established to address. For this global crisis, there is no single source, no optimal level of governance, no simple solution. To the contrary, we have seen how any pragmatic solutions will demand broad understanding through peer-reviewed science, dissemination of knowledge through institutional channels, strategic analysis and creative thinking by impartial leaders, collaborative research in new fields, and a keen grasp of economic incentives. Above all, in this chapter we appreciate the need for pragmatic and coordinated policies that can link the most responsive and effective action from the local to trans-national levels. In a regional setting, like the Baltic Sea basin, the IUCN EU office's convening power can continue to help bring stakeholders in various hierarchies to see clearly where they fit into the policy mosaic, and how their own efforts can work and nest with – rather than against -- the most progressive approaches developed by their neighbors.

With deeper understanding and rising concern over the many causes and consequences of plastic waste on marine ecosystems, political leaders struggle over how to develop and advance the right public policy responses. One risk is that since every company or resident – even those upstream in landlocked countries – contribute to marine plastic pollution, responsibility is scattered or not easy to feel individually. Another risk is that the desire to do something might have not desired effects such as distortion of growth and development; therefore, it could result in unintended consequences, like generating backlash from industries.

As we have seen, private companies are hardly silent about their interests. Many are in principle opposed to officials imposing new fees, bans, restrictions, or regulations. Paperwork and compliance demands additional time, people, and money to sort through, imposing new burdens and eroding margins. Some may have the opposite outcome than desired. But more importantly, what companies do seek, through internal or external governance, is *business certainty*: a reliable and uniform set of transparent rules that apply equally to all sectors, all industries, all employers, all jurisdictions and all firms regardless of size. That certainty does not currently exist throughout the Baltic Sea basin. There are, instead, overlapping laws, at various levels, which could breed distrust, send mixed signals, or raise barriers to automated sorting or de-polymerization. The lack of certainty and clarity inhibits the kind

of informed and focused multi-stakeholder collaboration needed for long-term systemic transformation across the plastics supply chain. To be sure, transparency is improving, and broad targets have been set. Dedicated officials at various levels of governance try to reduce damage, whether via beach cleanups or proposed bans. And many precedents and frameworks exist, thus setting the stage. But effective, coordinated and transformative action remains elusive, uneven, or too slow to arrive.

Global to local governance policies

In the international arena, there are of course the Sustainable Development Goals. SDG 14 aims to "conserve and sustainably use the oceans, seas and marine resources." This includes Target 14.1, "to prevent and significantly reduce marine pollution of all kinds." The UN Environment has also established a #CleanSeas campaign, and the UN Environment Assembly (UNEA) adopted a resolution on Marine plastic litter and microplastic. Elsewhere, the 2012 Global Partnership on Marine Litter (GPML) was launched at Rio + 20 in Brazil. The G7 Summit and G20 have both adopted action plans to address the problem of marine litter.

The European Commission's goal is "reducing marine litter by 30% by 2020 for the ten most common types of litter found on beaches, as well as for the fishing gear found at sea." For the Baltic Sea (and others shared by European Union member states) the EU has developed the circular economy-oriented Strategy on Plastics. It has also defined qualitative criteria for plastic under the Marine Strategy Framework Directive (MSFD). These MSFDs demand that "properties and quantities of marine litter do not cause harm to the coastal and marine environment" to qualify as Good Environmental Status (GES). More specifically, one EU Directive aims to harmonize national measures concerning management of packaging and packaging waste to prevent or reduce its impact on the environment, and its amendment includes measures on reducing the consumption of lightweight plastic carrier bags. Indeed, plastic bags and bottles have in some countries, including Sweden, become a government target of federal, provincial or even municipal measures, laws, policies, action plans, and product bans in order to address lost litter, leakage of microplastics, and polymer pathways from land to sea. In May 2018 the European Commission proposed new EU-wide rules to target the 10 single-use plastic products most often found on Europe's beaches and seas, as well as lost and abandoned fishing gear. Together these items constitute 70% of all marine litter. The new rules are proportionate and tailored to get the best results, with distinct measures applied to different products. So, where alternatives are readily available and affordable, single-use plastic products will be banned; those products without straightforward alternatives will be reduced through design and labelling requirements and waste management/clean-up obligations for producers.

The unifying and crosscutting word in all these international, EU, national, provincial and local efforts is the overriding need to "harmonize."

Harmonic convergence

Due its terrestrial origins, transboundary drainage, and high mobility once at sea, marine plastic litter is a challenge that Baltic Sea stakeholders must tackle in concert. Indeed, when it comes to addressing polymer pathways, no industry or country or city is ever truly an island. No single agency, study, target, business plan or state policy can ever really succeed on its own. To the contrary, real and enduring promise lies in science-based regional coordination efforts, standardization, and interrelated polices (e.g. on waste or packaging), e.g. through the European Regional Sea Convention (HELCOM), aiming at addressing marine litter, including related Regional Action Plans, both in force or in a preparatory phase.

To support and strengthen regional collaboration to reach these global and regional goals, and “close the plastic tap,” the IUCN European Regional Office has been leveraging its research authority and convening power to elevate “policy solutions considering plastics and products over their whole lifecycle to reduce plastic losses during production, use, maintenance or end of life of products and releases to the world ocean.” To that end, IUCN elaborated an overview of national legal instruments in all EU Member States related to protection of the marine environment from plastic pollution. Although this report does not claim to be comprehensive, it is the first of its kind, and serves as a first European overview of existing related policies (in 2017). IUCN drew also on the work of the Regional Seas Conventions from the Black Sea to the Mediterranean to the Baltic, most of them quite active in the matter. For example, the Helsinki Commission (HELCOM) has developed and in 2015 adopted a regional action plan to significantly reduce Baltic Sea marine litter by 2025 and to prevent harm to the coastal and marine environment. It also builds on work by the Nordic Council of Ministers for the Environment programme to reduce the impact of plastics.

The Baltic Sea is on average just thirty fathoms (55m) deep, with only 3% of its brackish water replaced each year. Due its primarily terrestrial origins, transboundary river drainage, and high ocean mobility, marine plastic litter is a challenge for 90 million basin inhabitants to tackle in concert. Indeed, when it comes to addressing polymer pathways, no Baltic industry or even country can ever regard itself an island. No single national or municipal study, agency, target, private sector plan or policy can succeed in isolation. To the contrary, real and enduring promise comes from science-based regional coordination efforts, standardization, and interrelated polices (e.g. on waste or packaging), aimed at addressing marine litter (European regional seas Conventions, Regional Action Plans) both in force or in the works.

This section digests and follows the structure of national reports elaborated in the framework of the mentioned 2017 IUCN report on national policies tackling marine plastic litter in EU Member States, plus an additional report prepared ad-hoc for Russia (as this country was not included in this EU-focused report). This also means that this (not intended to be comprehensive) information is updated as of July 2017 for EU Member States, while it will be more updated (early 2019) for Russia. This section has been organized in the same four parts considered in that report: targets and strategies; policies tackling plastic production and use impacting the oceans; policies tackling plastic waste disposal in the oceans; and policies tackling marine plastic waste already in the oceans. We further distill the lessons and scope by focusing primarily on Baltic Sea members states.

1. Targets and strategies

Most Baltic basin countries that developed marine litter targets did so as part of a program and strategy to implement the EU MSFD leading up to 2020. In Denmark, Germany, Latvia, Lithuania national targets aim simply to reduce the amount of marine litter that is threatening marine life on their shores and at sea. Lithuania and Germany have an overall general target for marine litter as well as more specific sub-targets. Germany also sets a specific target to reduce the quantity of litter in marine organisms. Finland still plans to set targets and measures for reducing marine litter.

Some countries include more specific targets, linking reduced marine plastic avoid entanglement by loggerhead sea turtles, or ingestion by northern fulmar. Lithuania has quantitative targets related to marine litter, e.g. to have the trend of the annual average volume of litter deposited on the seafloor to remain stable compared to the initial quantity, which is 1.3 units/ha. Specificity often leads countries to develop indicators for monitoring trends, survey programs, and amounts of marine litter and microplastics in the water column. These, in turn, help shape action plans and strategies.

For example, Estonia is committed to develop a national action plan for managing marine litter in harbours specifically as well as at municipal level.

Specific targets and strategies can also lead to legislative measures. Poland has a broadly defined measure to increase the effectiveness of the fight against pollution at sea. Other measures are not necessarily legislative or policy-driven, but rather information-based (such as research or awareness raising) related to marine litter in general as well. Estonia, for instance, seeks to raise environmental awareness regarding marine litter generally and hence curb the sheer volume of plastic packages from entering the sea. Sweden has stressed its engagement in promoting awareness amongst the general public on the importance of tackling marine litter, with specific activities for schools and fishermen. Finally, Latvia has defined five measures and will use marine litter on beaches as an indicator until 2030.

Other relevant voluntary commitments emerged at the UN Ocean Conference in New York in June 2017. There, Estonia committed to build a marine litter action plan for ports and harbours and declared it would launch a public awareness and information campaign on marine litter and on prevention of plastics in the sea. Germany promised to implement a ten-point Plan of Action for Marine Conservation and Sustainable Fisheries within German Development Cooperation, which has a field of actions on the reduction of land-based marine littering. And Denmark pledged to reduce plastic marine debris in Indonesia and has allocated 3 million DKK for financing an information campaign on reducing marine litter on beaches. Second only to Belgium's 11 pledges, the country that made the second highest number of commitments related to marine litter at the UN Ocean Conference was Sweden with five commitments, followed by Estonia, with four.

Nations also act as contracting parties to Regional Seas Conventions like HELCOM. Denmark, Estonia, Finland, Germany, Sweden have each mentioned their commitment to develop and/or implement Regional Marine Litter Action Plans at national level. Germany has established a National Round Table on Marine Litter in 2016 in order to facilitate implementation of the MSFD at national level as well as the implementation of the Regional Marine Litter Action Plan. Estonia has undertaken the implementation of HELCOM recommendations 36/1 on Regional Action Plan on Marine Litter (RAP ML) but also on recommendations 29/2 on Marine litter within the Baltic Sea region.

2. Policies tackling plastic production and use impacting the oceans

Whether for human or natural health, the priority for any measure is prevention: slowing or stopping the flow of polymer pathways before they can pollute marine environments like the Baltic Sea.

In most cases, and guided by the EU Directive on packaging waste, national mitigation policies tend to involve either bans or taxes on plastic items, like single use carrier bags. In Finland the Ministry of Environment and the Federation of Finnish Commerce concluded an agreement to reduce the consumption of the single use plastic carrier bag. Other countries, like Denmark, have passed a tax or fee on plastic bags.

According to a recent Surfrider Foundation report, Estonia, Germany, Lithuania, and Sweden have also adopted a tax or fee. This report also mentions a successful German voluntary agreement to impose tax on plastic bags, as well as Poland's intention to impose a tax by 2019.

France made a commitment, at the UN Ocean Conference in New York in June 2017, to reinforce a global coalition (with UN Environment) on marine litter, in which the Swedish government is also partner. This coalition members commit to eliminate single-use plastic bags in a

consistent manner with existing international instruments and policies.

From a plastic production and use perspective, policies on microbeads and microplastics in cosmetics have been highlighted in a certain number of countries. The Danish Marine Strategy mentions that, through the Finance Act, Denmark has allocated funding to study the sources, scope and impacts of microplastics coming from cosmetic products. Germany has also initiated a dialogue in 2014 with the cosmetic industry promoting a voluntary phasing out of the use of microbeads in rinse-off products.

Governments also made a certain number of voluntary commitments during the UN Ocean Conference in New York related to the use of microplastics in cosmetic products. For instance, Sweden, Finland, committed to ban the placing on the market of rinse-off cosmetic products that contains plastic microbeads by June 2020. Germany's Program of Measures (PoM) to reduce microplastic particles aim "to identify items of particular concern with regard to risks to the marine environment in the German parts of the North and Baltic Seas by assessing the findings of beach litter monitoring, contents of fulmar stomachs".

Considering other plastic items, Denmark's Marine Strategy highlights the introduction of deposits on plastic bottles as legislation it has enacted tackling marine litter. Deposit systems are present in countries such as Sweden (for plastic bottles and metal cans) and Lithuania (for plastic bottles). More generally, some policies focus on plastic packaging. Finland, Estonia, and Poland have regulations on Packaging and Waste Packaging that set general requirements for the packaging produced and placed on the market and for the collection, recycling, recovery and disposal of the packaging waste in order to reduce its harmful impact on the environment.

A few countries, like Sweden, have introduced "principal producer responsibility" initiatives for waste products such as electronics, batteries, plastic packaging, end-of-life vehicles and tyres.

3. Policies tackling plastic waste disposal entering the oceans

There is a distinction between disposal and management of waste coming from land and waste coming from sea-based sources, namely ships and fishing vessels. Most EU Member States seek to control and prevention of marine pollution from sea-based sources. Several, including Denmark and Lithuania, have a "no-special-fee" system or "indirect fee" instruments, in which ships can empty waste in ports without having to pay an extra fee. Poland plans to introduce this system as a new measure under the MSFD.

Similarly, Estonia, Finland, Germany have begun implementing the MarPol Convention 73/78, and especially Annex V, which controls and prevents garbage and solids pollution, including plastic waste. Without specifically mentioning MARPOL, Sweden has two general regulations to address ship-source pollution, including plastic waste. Germany bans the dumping of waste in the high seas as an existing measure under the MSFD. Denmark and Lithuania require ships at national ports to report and submit their waste. Under Lithuania's Law on Protection of the Marine Environment, all ships registered under the country's flag shall not dispose or incinerate waste in the Baltic Sea. Denmark's Marine Environment Act bans disposal of disposing of litter in Danish marine areas. Germany has also applied at national level the EU Directive 2000/59/EC on port reception facilities for ship-generated waste and cargo residues, and Poland plans to develop and supervise port reception facilities for waste and cargo residues.

In the fisheries sector, Denmark requires all fishing gear to be reported if lost. Poland is planning to tackle ghost nets in its PoM by marking fishing gear.

Regarding land-based sources of waste, some countries have indicated policies related to landfills. It is interesting to note that these policies have an impact on management at municipal level as they tackle the landfilling system. Throughout the Baltic, nations have waste legislation or plans that take plastic into account, such as Denmark, Estonia, Germany, Finland (in the National Waste Plan, Waste Act and Waste Decree), Lithuania, Latvia (in their National Waste Management Plan). The Swedish Environmental Protection Agency carries out strategic work by including marine plastic litter in relevant waste management plans and programmes, including the municipal waste plans.

Regional and international conventions also shape legal instruments for reducing marine litter from sea-based sources. Finland cites the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, and Protocol (London Convention), regulating the disposal of waste at sea.

4. Policies tackling marine plastic waste already in the oceans

Measures don't stop after plastic has made its way into the Baltic Sea. Policies can still try to reduce the amount of litter already present, through research and monitoring initiatives as well as clean-up activities.

"Fishing for litter," is an OSPAR Commission approach, that has also been adapted by Germany and Poland. It was created to work with fishermen to clear the oceans of plastic litter. As fishermen often catch litter in their nets, the scheme provides large bags to store litter on-board the ship, to be then deposited in ports and harbours. Several countries, including Finland and Sweden, encourage collection of lost or abandoned nets as well as the redesign of fishing gear.

Meanwhile, Latvia, and Poland are among those with research and monitoring programmes and measures to assess the level of marine litter and the environmental status of marine waters. Lithuania has undertaken a study on plastic pollution to determine the ways litter enters its corner of the Baltic Sea. It seeks to identify the types and amounts of litter, and assess the damage caused to the marine ecosystem.

One indication of national concern involves remedial initiatives under the MSFD. Denmark, Estonia, Poland and Sweden incorporate measures on waste from beach tourism; their efforts raise awareness to prevent littering, support voluntary beach clean-ups, and encourage collection of floating litter in waterways and ports. Lithuania's municipal acts focus on litter management of terrestrial coastal zones.

Russia's policy context

Given Russia's plastic footprint on the Baltic, what is the nature of its strategies, targets, or policy framework response, outside the EU context? One 2011 paper by Dmitry Nechiporuk, Maria Nozhenko,

And Elena Belokurova concluded that Russia is very weak on the implementation of environmental policies. This dynamic issue is quickly evolving, in particular related to plastics.

As a contracting party of the HELCOM, Russia has adopted a Regional Action Plan for the Baltic Sea on marine litter in 2015. Another article explains how the relationships between the Baltic countries were strengthened thanks to HELCOM, not only at EU level, but also with Russia. The environmental cooperation in the Baltic Sea Region is considered an outstanding case of peaceful dialogue.

Generally, Russia has in force several marine litter management related laws and regulations:

- the law on wastes of production and consumption,
- the water code act,

- the law on internal waters, territorial sea and contiguous zone regulations,
- the law of environmental protection, and
- the law of seaport.

In 2018 Russia engaged in the HELCOM Clean Beach campaign, and two years earlier noted cleanup efforts highlighted on the beaches of Kaliningrad. Another report noted a pilot to treat wastewater from small and scattered communities in the Leningrad and Kaliningrad Oblasts.

Whether in Russia, or in any other Baltic states of the EU, a useful distinction should be made between having a policy listed in the books, and ensuring compliance, enforcement, and effectively coordinated efforts in practice. Private incentives can align with public goals. And with practice, transparency, and harmonization, what happens at scattered levels or on paper to tackle plastics can be instilled in an integrated Baltic Sea culture.

Alignment with European policy recommendations

As noted above, the best policies and most pragmatic efforts can be adapted and replicated basin-wide. Yet plastic pollution is not an issue for the Baltic alone. Ideally, it should align under a common vision across the plastic value chains to trigger actions at local, national, European and global levels.

The private sector responds quickly to financial incentives and business certainty. That certainty can come only from the public sector, acting transparently. Yet given their long-term perspective, policymakers are uniquely positioned to convene, frame and drive the discussion on such fundamental systemic change. Appropriate new or existing platforms enhance our understanding of the current linear plastics economy and develop a shared vision of a more circular one – within reach. Through existing or new mechanisms, data on plastics' impacts and flows can be shared systematically.

When officials develop and enforce existing and new policy frameworks, it is important that they are guided by systems thinking. The scope of such thinking can help define: business models and product design; chemical safety and risk assessments; use and measurement of recycled content; compostability and biodegradability; and information sharing and (digital) technologies in the field of plastics.

No circular economy just happens, overnight, on its own. To build certainty and clarity to reduce Baltic Sea plastic pollution, it is important that officials work government levers to:

- support the establishment of legal frameworks through an iterative process,
- standardize terminology and assessment methodologies,
- offer clear product requirements,
- harmonize EU-wide legal structures and unify diverse pieces legislation,
- implement product stewardship systems, and
- extend producer responsibility schemes.

These steps can reduce or eliminate inconsistencies, confusion, doubt, redundancy, and gaps in coverage.

A way forward

The ecological – and potential public health-- impacts caused by marine plastics understandably generates emotional concern. Sound policy demands dispassionate analysis. It is important to from the very beginning keep in mind that polymer materials deliver significant societal benefits, including energy and resource savings, consumer protection and innovations that improve health care, reduce food spoilage and improve quality of life. Yet all too often, plastic benefits come at a cost to nature that is not just unacceptable but also unnecessary.

All stakeholders acknowledge that plastics should be responsibly used (reduce), reused, recycled and finally recovered for their energy

value. Plastic leakage is at one level a result of poor or insufficient waste management, lack of sufficient recycling / recovery and bad practices such as land and marine litter. It also comes from severe undervaluation of polymers, which find their way into manufactured consumer goods, tyres and textiles. These complex societal and economic challenges are more than any single entity, industry, or government can solve, alone. Working together, governments can do more than promote comprehensive science-based policies, encourage awareness, and enforce existing laws. To stop the plastic tap's leakage, policies can reach further, and:

- *Classify plastic as an emission under the rule of pollutant release and transfer register.*
- *Improve wastewater facilities, capability for retaining microplastics/microfibers.*
- *Collaborate with NGO's and research facilities, then engage industry to back it up with best practices.*
- *Finance cleanups and give companies incentives to prevent marine litter.*
- *Promote organic and/or biodegradable material for fishing gear and fish aggregating devices.*
- *Extend producer responsibility; take back products at end of life and keep plastic in a closed loop.*
- *Ban virgin plastic and replace with alternative bio-based or postconsumer recycled materials.*
- *Invest in opportunities to recover plastic products for recycling and energy recovery.*
- *Require the inclusion of the plastic footprint into the annual reports of publicly traded companies*

Conclusion

The time is ripe for a harmonic convergence of policies around marine plastic pollution – both in the Baltic basin and across Europe. At the foundations of civil society, studies have found that 82% of Canadians, 76% of Australians, and three quarters of all polled citizens are in favour of more aggressive action on tackling marine litter, including support for bans and deposit return schemes. Another by the University of Plymouth showed people blame global marine litter crisis on retailers, industry and government. These trends have come together in a Eurobarometer public consultation, that took place between December 2017 and February 2018. More than 1800 contributions showed that "both within the wider public and with stakeholders there is an awareness of the need for action on single-use plastics." 98.5% of respondents demanded action to tackle single-use plastic marine litter as "necessary", and 95% considered it "necessary and urgent", as did more than 70% of manufacturers and more than 80% of brands and recyclers.

In response, the current political environment has grown more favourable than ever. Leaders are promising to take meaningful action on marine plastic litter, with potential for 'high level' support not only at national levels but even at high international for a, such as the G20 agenda. On 16 January 2018 the EU adopted a Plastic Strategy to set a level playing field and defines a good level of ambition for the EU: it can also help as an example to the rest of the world on environmental standards. Yet EU leadership can only take place if EU Member States can reach consensus on direction about common priorities taken from national plans and activities.

A sound policy framework allows for systemic transformation. Public investments provide the catalytic spark to set it in motion. At every level, Baltic region governments in the Baltic region should set up, connect and fund mechanisms to coordinate the transition of plastics to a circular economy. Strategic coordination tracks activities and interventions, and investments fund both supply chain infrastructure and R&I capabilities across the plastics value chain. Grants can advance social benefits through expanding our knowledge on plastics design, production, use and after-use handling. Innovation incentives can come through public procurement, fiscal measures or equity investments. Baltic stakeholders can further reduce risk exposure by pooling funds.

Public and private co-financing of systemic innovation will ensure strategic coordination and systemic consistency in policy areas of the plastics system, including biological feedstock, eco-design, tracers and chemical recycling. It fosters agreement on knowledge, and ensures that new legislation or investments in recycling capacity are mutually reinforcing.

Incentives matter, not only in sharing industry best practices or harmonising national policies, but in linking private and public efforts, forging a culture that values the materiality of plastic. For example, this public-private collaboration has led to high deposits and processing machines located at supermarkets throughout Norway's urban areas ensure that country now recovers a whopping 97 % of its plastic bottles. It also helps explain why, after passing a bag tax in 1993, the average citizen of Denmark goes through one single-use plastic bags per season, while residents in other industrialized nations may average one per day.

Banning single-use items like plastic bags or straws, if properly planned and enforced, can effectively counter one of the causes of plastic overuse. The EU proposed Directive on Single Use, for example, will apply to plastic cotton buds, cutlery, plates, straws, drink stirrers and sticks for balloons which will all have to be made exclusively from more sustainable materials instead. Single-use drinks containers made with plastic will only be allowed on the market if their caps and lids remain attached.

Yet bans largely address symptoms, not the underlying disease. To tackle the roots of the problem, governments need to improve waste management practices, tax raw polymer materials, increase accountability and responsibility for manufacturers and retails, and introduce financial incentives that change the habits of consumers, enacting strong policies that push for a more circular model of design and production of plastics.

Haploops tenuis

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