frequent cyanobacterial blooms, oxygen deficiency in bottom waters, changes in fish stocks and loss of marine biodiversity all decrease the environmental benefits from the Baltic Sea in terms of both use-related values and non-use values (Ahtiainen *et al.* 2016). Examples include increased costs of cleaning, reduced income from tourism, damage to fishing gear and lost fishing possibilities, increased travel costs to reach unaffected areas, and reduced cultural and historical values. Reaching good eutrophication status for the Baltic Sea is foreseen to increase human well-being significantly and bring economic benefits to society.

Sources of nutrient inputs

The majority of nutrient inputs to the Baltic Sea originate from human activities on land and at sea. Waterborne inputs enter via rivers and direct discharge from coastal areas. The main point sources of waterborne inputs are wastewater treatment plants (Figure 4.6), industries and aquaculture. The main diffuse sources are agriculture, managed forestry, scattered dwellings and storm water overflows. In addition, natural background sources contribute to the input.

The main sectors contributing to atmospheric inputs are energy production (combustion) and industry, as well as the transportation of oxidized nitrogen, and agriculture is also a source of reduced nitrogen. A large portion of the atmospheric inputs originate from sources outside the Baltic Sea region. Emissions from shipping in the Baltic and North Seas contribute significantly to atmospheric inputs of nitrogen.

Excess nutrients stored in bottom sediments can re-enter the water column and again enhance primary production. In oxygen-depleted areas, phosphorus can leak out and be used by cyanobacteria that can make use of inert nitrogen. Other habitats have a strong capacity to store and sequester nutrients, such as coastal habitats with rooted plants and long-lived macroalgae (HELCOM 2023d).

Regulations and needs

Minimizing the input of nutrients from human activities is a central management objective of the Baltic Sea Action Plan.

Regional targets for nutrient inputs are defined by the Maximum Allowable Inputs (MAI) and Nutrient Input Ceilings (NIC) in the Baltic Sea Action Plan. Fulfilling these targets for all sub-basins is a key prerequisite for achieving a Baltic Sea unaffected by eutrophication.

Reducing the agreed levels of nutrient inputs is expected to improve eutrophication status at sea, even though the responses at sea may take time (HELCOM ACTION 2021a). Model simulations indicate that significant improvements in eutrophication status can be expected roughly one or two decades after nutrient inputs are reduced to the target levels, and that it could take half a century or more to reach the environmental objectives. In coastal areas, the responses could be faster, if significant direct point sources are removed. This is probably also the case in the eastern part of the Gulf of Finland (HELCOM 2023f).

Measures to restore the natural functioning of Baltic Sea food webs are expected to enhance the natural capacity of the ecosystem to counterbalance eutrophication symptoms. Strengthening trophic control in the food web can curtail the overproduction of fast-growing filamentous algae, for example (see section 3.3).

Measures to strengthen coastal habitats with a strong capacity for nutrient uptake and storage, such as rooted plants and long-lived macroalgae, are expected to strengthen the ecosystem's natural capacity to sequester nutrients at sea.

Climate change is expected to worsen the negative impacts of eutrophication. Climate change effects could enhance algal blooms or oxygen consumption, for example.

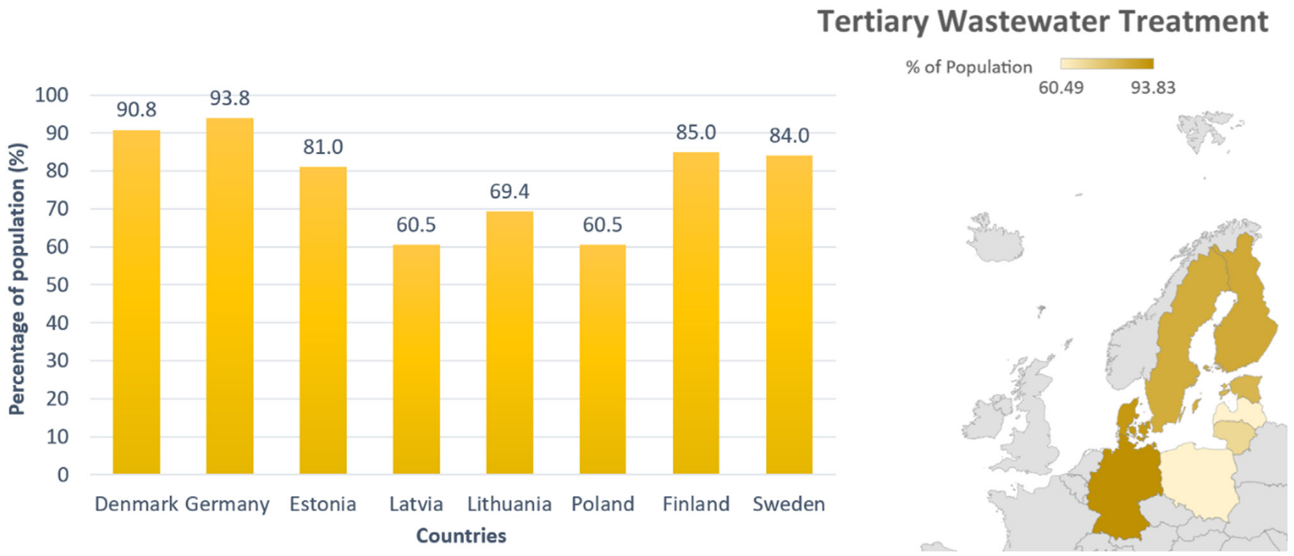

Figure 4.6. Various drivers determine the extent and efficiency of wastewater treatment in the Baltic Sea region, including political will, investment, regulations and the adoption of technology. Overall, 72% of the Baltic Sea catchment area population is connected to tertiary wastewater treatment plants (Eurostat 2022). The bar charts show the percentage of the total population connected to tertiary wastewater treatment plants in Baltic Sea countries in 2020. The chart does not include data from Russia or any non-HELCOM countries. Source: HELCOM 2023d.

4.2.2 Hazardous substances

The status of hazardous substances shows some signs of improvement during the assessment period, however it is still clearly not good (Figure 4.7). The integrated contamination status of the Baltic Sea remained above acceptable minimum levels during 2016-2021. The contamination status was assessed as either bad or poor in roughly 80% of the 57 assessed spatial units, including the majority of the open sea sub-basins. Only one assessment unit in the open sea had good status. The results partly reflect the prevailing monitoring regimes, because units achieving better status tend to be represented by fewer parameters being evaluated or key drivers of the overall status being absent.

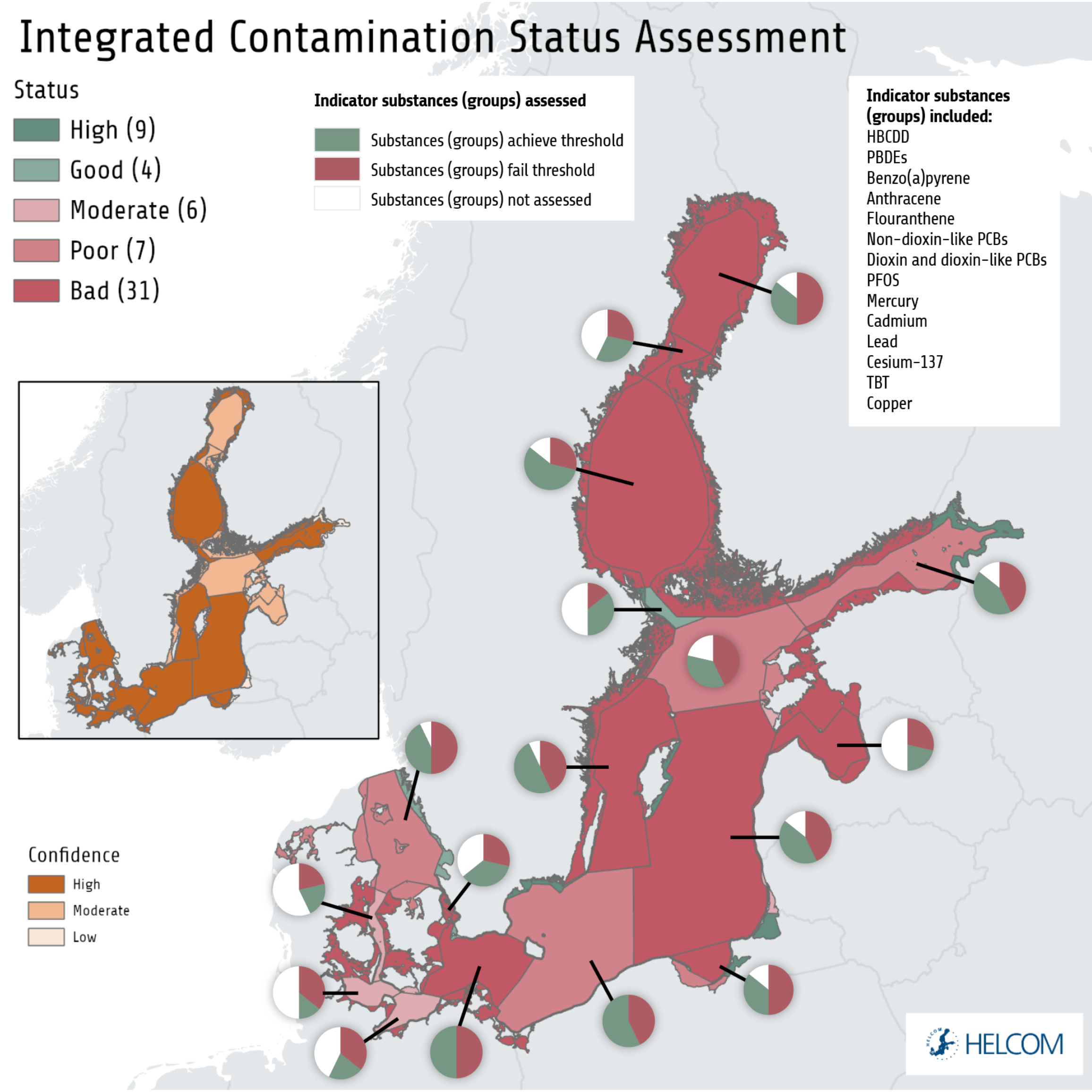

Figure 4.7. The integrated assessment of hazardous substances status in the Baltic Sea, assessed using the CHASE integrated assessment tool. The assessment shows that hazardous substances are a cause for concern in almost all assessed units, and those showing good status generally lack a full and adequate assessment. The integrated assessment is based on 11 core indicators. It integrates concentrations to threshold-derived values (contamination ratios) for fourteen individual hazardous substances or substance groups. The overall assessment is moderated by a parallel assessment of confidence (see inset map on the left) that can be considered an appraisal of the data coverage and assessment quality in any given assessment unit. Source: HELCOM 2023c.

Furthermore, only a small fraction of all potentially hazardous substances is measured and included in the indicator evaluations that make up the integrated assessment (Box 4.3).

There are some encouraging signs, however. Six open sea sub-basins have improved their status category since the previous assessment (HELCOM 2018), although they are still not in good status. Furthermore, at the level of individual monitoring stations, there are more substances with downward concentration trends than upward trends (Figure 4.8).

The assessment results are mostly driven by elevated concentrations of polybrominated diphenyl ethers (PBDEs) in biota, tributyltin (TBT) in sediments, mercury in biota, and copper in sediments. Cadmium concentrations in biota and sediments also contribute, as do lead concentrations in biota (Figure 4.9).

Monitoring and assessment currently focus on a relatively small number of priority substances which are known to have persistent and widespread negative impacts on the Baltic Sea environment. Work to address additional substances and develop a regional strategy for hazardous substances (towards BSAP action HL1) are ongoing in HELCOM. A pilot assessment shows that approaches to detect the biological effects of contaminants (signatures of exposure) and screening a wide array of substances could complement existing methods. An initial regional screening listed roughly 130 substances that regularly occur across the region, of which around 40 exceeded available environmental risk values. These substances include, for example, pharmaceuticals, industrial chemicals, personal-care products and tobacco/coffee-related contaminants, and they may require dedicated follow-up actions.

Impacts of hazardous substances in the Baltic Sea ecosystem

Hazardous substances can have both direct and indirect harmful impacts on species, habitats, and the environment as a whole, and they remain among the most widespread and impactful pressures in the Baltic Sea today (HELCOM 2023c). Hazardous substances are often persistent, bioaccumulative and toxic. They affect the function or viability of biota when they occur at concentrations above safe limits. Many hazardous substances have the potential to interfere with biota even at very low levels. Furthermore, impacts from several contaminants can occur together (multiple mixture effects) or can coincide with other types of pressure, potentially enhancing and increasing the susceptibility of the system. Examples of impacts range from acute pollution events, such as oil spills to the slow accumulation of hazardous substances in top predators via biomagnification in the food web. Hazardous substances also affect the suitability of fish as food for humans and other animals.

Clear examples of hazardous substance leading to reproductive failure occurred recently in the history of the Baltic Sea. Widespread use of persistent organochlorines, such as DDT and PCBs, until the 1980s resulted in their spread into the Baltic Sea environment. They accumulated in the food web and severely reduced the fertility and population growth of ringed and grey seals, as well as the white-tailed eagle, all top predators in Baltic Sea food webs (Helle 1980, Helle *et al.* 1976, Bergmann 1999, Helander *et al.* 2008). There are also indications of a link between elevated organochlorine concentrations and lower pregnancy rates in harbour porpoises (Murphy *et al.* 2010). At the point when impacts are detected on top predators, such as marine mammals, the road to recovery is often long and complex. However, because certain persistent chemicals accumulate in the food web, new emerging pollutants that are below detection limits in other biota may be detected in the tissues of top predators, giving an early warning signal.

Sources of hazardous substances

Hazardous substances enter the Baltic Sea through various pathways. Key sources of hazardous substances include wastewater treatment plants, rivers, atmospheric deposition, redispersal of substances from dredged material (or other dumped material, such as dumped munitions) and discharge from maritime activities. Certain direct inputs also occur (or have occurred), such as in relation to biofouling treatment using TBT or copper. More examples are presented in the HELCOM (2023c).

Wastewater treatment plants are a key point source of contaminants to the Baltic Sea. Households and industries in the Baltic

BOX 4.3.

What are hazardous substances?

Hazardous substances are synthetic or natural substances that enter the Baltic Sea at elevated concentrations because of human activities and can cause various types of damage to species and habitats in the ecosystem. Hazardous substances range from those that are highly visible in the form of oil-spills to others that can remain unnoticed until signs of detrimental impacts on the ecosystem or organisms become apparent. Many contaminants degrade slowly, and their impacts can magnify as they accumulate within aquatic food webs. Because hazardous substances are difficult or impossible to remove once they are in the system, the key measure is to limit the risk of their entry into the environment.

The Baltic Sea Action Plan has the following ecological objectives for hazardous substances:

- **Marine life is healthy**
- **Concentrations of hazardous substances are close to natural levels**
- **All sea food is safe to eat**
- **Minimal risk to humans and the environment from radioactivity**

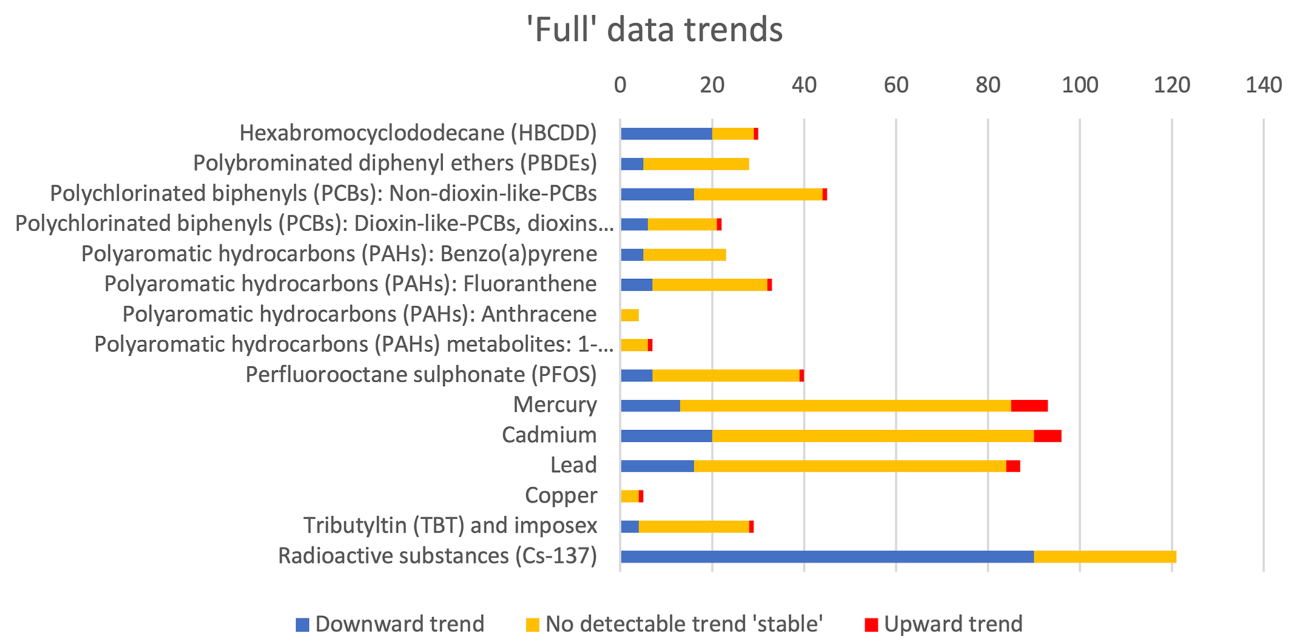

Figure 4.8. Trends in indicator substances or substance groups based on stations where "full" data series were available (i.e. longer-term data series with more than three years of data). The number of stations with suitable time series data available (horizontal axis) is divided into trend categories. Downward trends reflect a decrease in concentrations (i.e. improving status), whereas the opposite is true for upward trends, and other stations show no detectable trend ("stable" concentrations). Source: HELCOM 2023c.

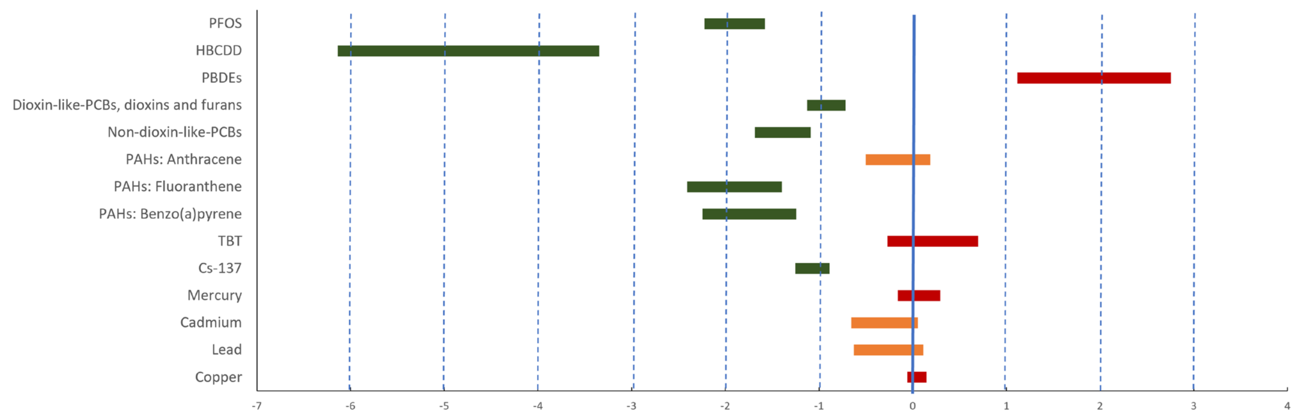

Figure 4.9. The range of contamination ratios of the evaluated hazardous substances. The ratios are the observed concentration value divided by the threshold value, based on the mean concentrations for the assessment period 2016–2021. The horizontal bars show the range of contamination ratios from the 20th to 75th percentile for each substance on a log-transformed scale. Red bars indicate that the median value fails the threshold value, which is indicated by the solid blue line. Orange bars represent a situation where the median value achieves the threshold value but not some of the stations (in the 75th percentile). The figure is based on the coastal and open sea data used in the integrated assessment. Source: HELCOM 2023c.

Sea catchment area are generally well connected to wastewater treatment systems, which results in a large number of hazardous or potentially hazardous substances occurring at elevated concentrations in their sludge and effluent. Some substances are depleted or transformed in the wastewater treatment process, while others remain relatively unaffected (HELCOM 2021). Phenolic substances appear to be frequently occurring, based on available measurements, although they generally are at levels below current environmental quality standards. Polyfluoroalkyl substances (PFASs), in particular PFOS and PFOA, are detected regularly, and many are not removed. Pharmaceuticals have also been shown to remain relatively unaffected by wastewater treatment processes, and levels exceed current environmental quality standards (HELCOM 2021).

Information on riverine and atmospheric sources are available for a few selected priority substances (HELCOM 2021). Data for the period 2015-2017 suggest that inputs of cadmium come mainly through rivers, while mercury and lead are predominantly introduced through atmospheric deposition. The total amount of input differs markedly between the substances, with 27, 5.3 and 356 tonnes per year being recorded for cadmium, mercury and lead, respectively. Only a small amount is estimated to come from point sources. Atmospheric deposition of these substances has generally declined since the 1990s (HELCOM 2020e and HELCOM 2021). The volume and location of dredged material in the Baltic Sea varies between years (e.g. HELCOM 2020b). For example, around nine million tonnes were deposited at 106 sites in 2020, with a little over half of this material being from capital dredging and the rest from maintenance dredging. Around seven million tonnes came from harbours and river estuaries, and most of the dredged material was deposited at locations offshore. Levels of mercury, lead, copper, tributyltin and polycyclic aromatic hydrocarbons in the dredged material were similar to or lower than corresponding values recorded in 2014 or before. However, cadmium levels had increased.

Maritime activities, such as shipping, can emit hazardous substances through spills of oil or other substances. Operational discharges from the cleaning systems of ships are a significant source. With the use of exhaust gas cleaning systems (scrubbers), hazardous substances are released with the discharge of scrubber waters, as well as in grey and bilge waters and through the smokestack. In 2021, the total volume of discharge water from exhaust gas cleaning systems was roughly 286 million cubic metres, mainly from open loop systems. For example, open loop scrubber systems are estimated to generate as much as 8.5% of the total Baltic Sea load of the polyaromatic hydrocarbon anthracene (Ytreberg *et al.*, 2022). Discharges from these activities are increasing.

Regulations and needs

Minimizing the input and impact of hazardous substances from human activities is a key goal of the Baltic Sea Action Plan.

Management objectives relating to hazardous substances are to minimize their input from sea-based activities, enforce international regulations, achieve no illegal discharges and have safe maritime traffic without accidental pollution.

Hazardous substances that enter the aquatic environment often remain for a long time, and their impacts accumulate in the food web. Removing a contaminant once it is present at sea is far more complex and costly than preventing its release, and in several cases is impossible. Furthermore, many substances are persistent and have long recovery times even after their input has been stopped.

Finding measures to reduce or prevent the input of hazardous substances at the source is significantly more achievable and cost-effective than dealing with them once they are already present in the environment.

The complexity of human activities and regulatory levels associated with environmental contaminants makes management response and policy implementation for hazardous substances a significant challenge that warrants strategic development in itself.

Climate change is expected to have significant effects on the Baltic Sea, but there is currently no regional overview of how climate change interacts with hazardous substances (HELCOM and Baltic Earth 2021). A number of direct climate change effects are likely to affect hazardous substances, such as water temperature, atmospheric circulation, solar radiation, acidification, stratification, precipitation, river runoff and sediment transportation. Among indirect effects, factors such as changes in oxygen concentration, microbial processes, non-indigenous species and ecosystem functions could affect the presence and impact of hazardous substances in the Baltic Sea ecosystem (HELCOM 2023c).

4.2.3 Marine litter

The status of marine litter in the Baltic Sea is currently evaluated based on beach litter and litter on the seafloor (Figure 4.10, Box 4.4).

The HELCOM threshold value for beach litter is 20 litter items per 100 metres of beach. During 2016-2021, eleven out of the sixteen sub-basins that could be assessed were above this limit and did not reach good status. The subbasins with highest median values were the Sound (313 litter items per 100 m), the Gulf of Riga (156 items) and the Eastern Gotland Basin (96 items). The sub-basins achieving good status for beach litter were Kiel Bay, the Bay of Mecklenburg, the Gdansk Basin and the Western Gotland Basin. The Quark had a median value below the threshold value, but the result was evaluated as uncertain due to limited data. Plastic litter, including single-use items, was the most common litter category, accounting for between 32 and 93% of the total number of litter items (Figure 4.12). Several sub-basins showed a decrease in the total litter count over time, which correlates with a decrease in the count of single-use plastics and plastic litter items.

Data about litter on the seafloor is collected in connection with fish surveys using trawls and is available for some sub-basins (Figure 4.11). Litter in the categories “plastic” and “other” increased during the evaluation period, and these categories thus fail the preliminary threshold value, which is “no significant increase” from 2015 to 2021 in weight, number or probability of catching litter. The category “fisheries-related litter” achieved the threshold when measured in number per square kilometre but not when measured in weight. The remaining categories,

BOX 4.4.

What is marine litter?

Marine litter comes from a vast range of human sources and reaches different marine compartments. Beach litter is monitored worldwide as a proxy of human impacts on the ecosystem. Information on the amount of litter can indicate general levels of potential harm to marine biota and ecosystems, as well as societal losses in the form of aesthetic values, economic costs and hazards to human health. Litter that has accumulated on the seafloor is equally relevant and can have significant impacts on organisms at sea. Evaluation of litter types and categories helps us understand the sources of marine pollution and assess the efficiency of environmental management measures.

The Baltic Sea Action Plan states the following ecological objective for marine litter:

— No harm to marine life from litter.

Figure 4.10. The impact of marine litter on the marine environment is closely linked to human behaviour.