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Fishing and fish farming as sources of plastic litter and microplastics — a case study from Finland

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A country-specific assessment of the role of fishing and fish farming as sources of marine littering was carried out in Finland. The calculations were based on data from fishery statistics, mass loss estimates for different plastics, cloud-based and postal surveys, and telephone interviews. The annual input of plastics to the Baltic Sea directly related to fishing activities and gear was estimated to be close to 16 tonnes, and to fish farming 27–36 tonnes, when potential plastic emissions from the vessel's hull were excluded. Microplastics constituted more than 90% of the emissions of plastics. Results from the survey and interviews revealed that commercial fishers considered marine litter a slight nuisance to fishing, whereas fish farmers did not find it harmful to fish farming.

Introduction

Marine litter is a significant global environmental problem (UNEP 2016). Most, up to 90% or more, of all marine litter consists of plastic items or their remnants (Thompson *et al*. 2004, Andrady 2011, 2015, Eriksen *et al*. 2014, Galgani *et al*. 2015, UNEP and GRID-Arendal 2016, Consoli *et al*. 2018, Oztekin *et al*. 2020, Büyükdevecia and Gündoğdub 2021, Abelouah *et al*. 2021, Compa *et al*. 2022). Plastics made from one or more polymers are versatile materials that offer a wide range of societal benefits, applications in industry, construction, pharmaceuticals, and food preservation (Andrady and Neal 2009). The amount of plastic waste can be expected to increase as more and more plastic is produced (PlasticsEurope 2015, 2019, Geyer 2020).

All marine litter is the result of human activities, either on land or at sea. While land-based marine waste is transported to the receiving water bodies along various pathways, especially rivers (Lebreton *et al.* 2017, Boucher and Friot 2017, Lebreton and Andrady 2019), activities at sea directly affect the marine environment. It has previously been assessed that about a fifth of marine littering is caused by activities at sea, such as fishing, aquaculture, shipping, and dumping (UNEP 2016). Regionally, the amount of plastic waste turning into marine litter depends both on the amount of plastics used and the level of the local waste management infrastructure. Marine plastic litter poses an enduring environmental hazard in the form of macro- and microplastics. Plastic items or their parts and remains can cause serious harm to marine animals such as various species of birds,

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fish, mammals, and turtles through entanglement and plastic ingestion, potentially leading to death because of injury, starvation, or suffocation (Butterwort *et al.* 2012, Setälä *et al*. 2014, 2016a, Kühn *et al*. 2015, Galloway *et al*. 2017, Panti et al. 2019, Domènech *et al*. 2019, Anastasopoulou and Fortibuoni 2019, Napper and Thompson 2020, Guerrera *et al*. 2021).

Plastics in the environment are subjected to weathering and degrade with time. The degradation process is enhanced in favourable conditions by exposure to UV light, heat (temperature changes), waves, and bacterial activity, and is most effective on beaches and water surfaces, while on the seabed fragmentation is slow (Andrady 2011, GESAMP 2015). Like all plastics found outdoors, plastic materials commonly used in fishing gear or in aquaculture fragment into smaller micro- and nanoplastics. Microplastics found in the marine environment are of concern especially because of their ubiquitous distribution in the world's oceans and their bioavailability to a wide range of marine organisms across trophic levels (Tanaka *et al*. 2013, Cole *et al.* 2013, 2015, Fossi *et al.* 2014, Lusher *et al.* 2015, 2017, Sainio *et al.* 2021).

Finland is one of the most important fishing countries in the Baltic Sea area. The total commercial fish catch in the sea area was 112 500 tonnes in 2020. The catch consisted principally of herring (*Clupea harengus*) and sprat (*Sprattus sprattus*), both of which were caught mainly by trawling from open sea areas. Coastal fishers catch freshwater species, anadromous species, and herring with traps and gillnets. In the winter, gillnet fishing takes place mainly under the ice. In 2020, there were 2276 commercial fishers in the Finnish sea area (Official Statistics of Finland (OSF): Marine fishery). In addition to commercial fishers, around 300 000 recreational fishers fish in the Finnish sea area every year. Their most popular fishing methods are angling and gillnet fishing (Official Statistics of Finland (OSF): Recreational fishing).

In Finland, fish farming is mainly carried out in net cages in the Baltic Sea region. In 2020, there were 37 fish farming companies in the Finnish sea area (Official Statistics of Finland (OSF): Aquaculture). There were 100 fish farming offshore units and a total of 570 cages. The cage's total volume was 863 600 cubic metres. Food fish production in the Finnish sea area was 11 823 tonnes. Rainbow trout accounted for about 95% of the total food fish produced at sea (Official Statistics of Finland (OSF): Aquaculture).

Plastics are widely used materials in both fisheries and aquaculture. Polyamide (PA, nylon) and polyethylene (PE) netting is commonly used in gillnets, fish traps, seines, and trawls. The net lines are made of PE. The fish farming units used in the sea area are mainly built of floating, flexible frames, nylon cages, anchoring ropes, and buoys (Kankainen and Mikalsen 2014). In Finland, floating frames are used, most of which are made of PE pipes. In some cases, especially near the coast, steel structures and e.g. aluminium pontoons can also be used. Floating PE structures are usually round, and in Finland, in more sheltered archipelago zones, the circumference of the cage frames is 60–90 metres and in open sea even 120 metres. Cages are commonly made of nylon netting. They are light to handle and relatively durable: the estimated service life for nylon netting is 4–7 years. The depth of cages in open sea areas is about 20 metres; near the coast, it is about 10 metres (Kankainen *et al*. 2014). Water-soluble antifouling agents (e.g. Notorius A-net paint/Scandi Net and Aqua-Net/Steen-Hansen Making A/S) are used in fish farming to prevent organisms from infecting the netting of farming cages. Antifouling paints are also sources of microplastics, as the share of plastic compounds in them is ca. 20% (Loriot *et al*. 2017).

The distribution of microplastics in the Baltic Sea has been investigated in the last decade (Magnusson and Norén 2011, Magnusson 2014, Norén *et al*. 2014, 2015, Gorokhova 2015, Stolte *et al*. 2015, Talvitie *et al*. 2015, Setälä *et al*. 2016b, Gewert *et al*. 2017, Hengstmann *et al.* 2017, Zobkov and Esiukova 2016, Tamminga *et al.* 2018, Zobkov *et al.* 2018, Uurasjärvi *et al.* 2021). The common conclusion in the studies is that the information on the significance of different sources and the amount of microplastics in the environmental matrices remains limited and uncertain and is related to the varying sampling and processing methods (Gewert *et al*. 2017).

This study's main aim was to produce preliminary estimates of the plastic load of Finnish marine fishery and aquaculture on the Baltic Sea. The study focused on both macro- and microplastics. Estimates of the amount of microplastics released from fishing gear and net cages were mainly based on a combination of existing data on fishing, fish farming, the plastics used in them, and their fate in the sea. In addition, we made some observations about the effects of marine litter on fishery and aquaculture.

Material and methods

Commercial fishers are obliged to report their catches, fishing areas, gear, and fishing efforts to the fishery authorities. Natural Resources Institute Finland (Luke) collates this data into statistics for commercial marine fishery (Official Statistics of Finland (OSF): Marine fishery). Data on recreational fishery are collected by postal surveys, and the statistics are published biennially by Luke. The statistics include rough estimates of annual fishing efforts (average number of gears used by a fisher multiplied by number of his/her active fishing days, and finally summed over all fishers) by gears, including gillnets, which are widely used by recreational fishers (Official Statistics of Finland (OSF): Recreational fishing). Luke also produces annual statistics for aquaculture, including data on production, the number of units, number of cages, and the total volume of net cages (Official Statistics of Finland (OSF): Aquaculture). The data of fishing efforts and aquaculture cages, with mass loss values for different plastics, were used to calculate the annual microplastic load directly from the gear or cages. Potential plastic emissions from the vessel's hull were not calculated.

According to experiments of Welden and Cowie (2017), the mass loss percentages per year in seawater for thin ropes (diameter: 10 mm) of the three common plastic polymers, nylon, PP, and PE, were 12.24%, 4.68%, and 5.40%, respectively. Gillnets are made of nylon or polyethylene. Fish traps used in Finland consist of several plastic materials: nylon nettings; PE fences; and seal-resistant Dyneema fishing line, mainly at the end of the trap (Esa Lehtonen/Luke). An annual mass loss percentage of 8.5% (mean of nylon and PP, from Welden and Cowie, 2017) was used for gillnets and trap nets. The main material of trawls and aquaculture cages is nylon netting, and the annual mass loss percentage of 12.2% was used. The annual mass loss percentages were transformed into mass loss percentages for 100 days, and the calculations covered only the mass loss during active fishing days or during days when the cages were kept at the sea. The average weight of the plastic parts of a gillnet was estimated to be 0.5 kg (total weight of a standard 30 meters long gillnet is almost 1.0 kg, including the lead or other heavy material in the lower rope), of a trap 260 kg (Esa Lehtonen pers. comm.), and of a trawl 1500 kg (based on interviews with trawler skippers). According to information received from fish farming companies, the average weight of the plastic parts of one cage was 800 kg. There are certainly differences in the properties of gear and cages used, but the averages used here appear realistic.

Indicative information on the amount of fishing gear lost from commercial fishing was obtained by contacting the coastal fisheries insurance associations. A rough estimate of the number of gillnets lost at sea by recreational fishers was obtained from a nationwide postal survey conducted in 2016. A question concerning the disappearance of gillnets during the previous year was included in the survey, which was sent to 7500 people, sampled from the database of the Population Register Centre. The results of the survey were extrapolated to represent all recreational fishers fishing in the sea area. When fishing, various ropes, floats, and flags can also be lost, even if the gear itself is not lost. Calculations of the number of ropes, canisters, and flags released from fishing gear were also made, based on fishing effort data and information gathered from interviews with commercial fishers.

Data on fishing were refined through an online survey using Webropol tool. In the survey, the views of commercial fishers on marine litter were also assessed. The survey was conducted in Finnish, Swedish, and English. It was sent to a total of 1189 commercial fishers, and the response rate was 10%. Fishers were asked about their views on the impact of marine litter on their fishing, the quantity of debris of human origin getting entangled in the fishing gear, and their waste management practices related to fishing activities.

The views of fish farming entrepreneurs on litter in the marine environment were clarified through semi-structured telephone interviews, which involved a total of ten entrepreneurs, i.e. about a quarter of fish farming companies active at sea. The entrepreneurs were asked about the impact of visible marine littering on their fish farming activities and observations on the quantity of debris sticking to farming structures, as well as the impact of fish farming activities on marine littering.

Results and discussion

Estimates of the amount of microplastic released from the fishing gear

The estimated mass loss for the commercial fishing gear (gillnet, trap fishing, trawl fishing) used by the Finnish fleet in 2020 was ca. 14 tonnes (Table 1). Most of the mass loss took place in trap net and trawl fishery. The mass loss estimates are rough, mainly due to the limited data of properties and material of the gears used and due to scarcity of published data of the mass loss processes in sea water. Antifouling agents are expensive, their total use in fishing gears in the Finnish sea area is minimal (Esa Lehtonen/Luke), and most fishers wash their traps repeatedly during the fishing season to maintain their fishing characteristics. The potential plastic load from antifouling paints in fishing gears was therefore ignored.

This estimate of microplastic load from fishing gear is at the same level (4–46 tonnes per year), as was previously estimated in Sweden (Magnusson *et al*. 2016). The Swedish estimate was based on the total amount of fishing gear taken out of service each year, and on the assumption that 1% to 10% of the plastic originally contained in the gear ended up at sea (as mass loss) before being taken out of service.

The estimated annual mass loss for the commercial gillnet fishing was 0.2 tonnes (Table 1). Recreational fishers' gillnet days in the sea area (1 086 000 gillnet days; Official Statistics of Finland (OSF): Recreational fishing) were about half the gillnet days for commercial fishing (Table 1), so the calculated mass loss for recreational fishing gillnets was estimated to be ca. 0.1 tonnes per year.

Lost fishing gear as sources of plastic waste

According to information received from two coastal fisheries insurance associations, only a few applications for compensation for the loss of gillnets (i.e. estimated at a few dozen gillnets a year) are received from commercial fishers each year. Based on a question related to the disappearance of gillnets in the 2016 recreational fisheries survey, approximately 2000 gillnets were estimated to be lost at sea each year due to storms, ice shift, or other similar causes. However, this estimate is very uncertain, because its

Table 1. Average dry weight (plastic parts) of fishing gear, fishing gear specific mass loss estimates per 100 fishing days, fishing gear specific fishing days per year (Official Statistics of Finland (OSF): Marine fishery), and the estimated mass loss for different gear types per year. Commercial marine fishery.

	Dry weight (kg)	Mass loss of one gear (kg per 100 days)	Fishing days per year	Mass loss (tonnes per year)
Gillnet	0.5	0.01	1 716 509	0.2
Fish trap	260.0	6.50	117 572	7.6
Trawl	1500.0	45.00	13 500	6.1
Total				13.9

*n.b.: These estimates do not take the use antifouling paints in some of the traps into account, which reduces the number of plastic fragments released from the fish trap into the sea.

Fig 1. Fishing in the Baltic Sea: a push-up trap with plastic canisters and flags (Photo: Mikael Lindholm).

95% confidence intervals, about 3500, are larger than the estimate itself. The total weight of the plastic parts of the recreational fishing gillnet being 0.5 kg, about one tonne of macroplastic would be left by recreational fishing each year in the form of lost gillnets at sea and on coasts.

Gilman *et al*. (2021) presented the first quantitative assessment of gear-specific relative risks for ALDFG (fishing gear lost and left at sea). According to this study, gillnets were found to be the most problematic fishing methods globally, with the greatest risks from ALDFG. Based on the meta-analysis of a total of 68 studies (from 32 countries) on lost fishing gear (Richardson *et al*. 2019), the authors estimated that 5.7% of all fishing nets used were lost to the sea annually. On the Finnish coast, the risk of losing gillnets is probably greatly reduced by the fact that it is no longer permitted to use drifting nets in the Baltic Sea, and most gillnet fishing takes place in the shelter of the archipelago or in the inner bay areas. However, it is evident that recreational fishers are generally more careless in the use of their gillnets, and the rough estimate of 2000 gillnets lost annually in recreational use therefore sounds realistic. In a recent pilot study off the Finnish west coast (Finnish Environment Institute; unpublished) covering more than 300 km and 110 dragged transects, nearly 10% of the drags contained remnants of fishing-related gear, mostly line and gillnets. The risk of losing parts of trawls is not very high, because there is no bottom trawling in the northern Baltic Sea, as the fleet's target species, Baltic herring (*Clupea harengus*) and sprat (*Sprattus sprattus*), are pelagic.

A fish trap used by a commercial fisher typically has ca. 20 plastic canisters to keep the trap in fishing condition and to facilitate the placement and lifting of anchors (Fig. 1). The canisters are important for the effective use of the fish trap, and they should be properly attached. However, it was assumed that one canister or flag and a part of a rope (total weight 1 kg plastic) for every 200 trap fishing days would disappear (the probability of one canister/flag disappearing over 200 days is 0.05). This means approximately 0.6 tonnes of plastic were estimated to be lost each year from commercial trap fishing (see fishing days in Table 1).

Gillnets are held in a series of several nets, and ca. 0.2 canisters and flags per one gillnet are typically used to mark the nets. Assuming the probability of one canister/flag disappearing, and part of the rope (total weight 1 kg plastics) is the same as in trap fishery (0.05 over 200 fishing days), it was estimated that less than 200 kg of macro plastic (in the form of canisters and/or mooring ropes) would be lost annually from commercial gillnet fishing (see fishing days in Table 1). Similar canisters, flags, ropes, and anchors are also used in recreational gillnet fishery, but the probability of disappearance is likely to be much higher, e.g. double, than in commercial fishing. Based on the above calculations and assumptions, a realistic estimate of the lost amount of plastic in gillnet tagging devices in recreational gillnet fishing (ca. half the gillnet days in commercial fishing) was also estimated to be around 200 kg per year. This is probably an underestimate, because it does not take into account those tagging devices that disappear when gillnets are completely lost. The assumptions of the probabilities of canisters and flags to disappear both in commercial and recreational fishery are quite uncertain. However, the effect of these assumptions on the total plastic load estimate from fishery remains low.

Estimates of the amount of microplastic released from fish farming

According to information received from fish farming companies, the cages were in seawa-

Fig 2. Fish farming in the Baltic Sea. (Photo: Markus Kankainen)

ter for 140–230 days annually. Some were in seawater for up to 310 days if fish were kept in them during the winter (Fig. 2). The annual mass loss of material from the nylon cages was estimated to be 29 tonnes. Loss was calculated by multiplying the average weight of one cage (0.8 tonnes), with the annual mass loss estimate (12.2%), with an average time of a cage kept annually in water (190 days = 0.52 years) with the total number of cages used in 2020 (570 cages). (Official Statistics of Finland (OSF): Aquaculture). However, antifouling paints (see the next paragraph) reduce the wear and tear of the construction materials, and the mass loss is likely significantly lower (e.g. up to a third) than the estimated maximum mass loss of the cages. The corrected estimate for annual mass loss is therefore between 20 and 29 tonnes (Table 2). The effect of antifouling treatment on the mass loss should, however, be clarified by experimental studies. The higher mass loss estimate compared to fishing is due to the simple fact that the total mass of plastic kept in the sea on an annual level is higher in fish farming than in fishing. The mass loss estimate of fish farming did not include the amount of microplastics dissolving from the frames (made of PE, steel or aluminium) surrounding the cages at the surface. According to one fish farmer, there are no signs of wear in the PE frame, even though the structures have been in the sea for "eighteen summers".

Antifouling agents are used in fish farming to prevent organisms infecting the netting of farming cages. The amount of antifoulants used depends on the surface area and volume. According to the interviewed fish farming entrepreneurs, the required amount of antifouling paint is approximately 160 kg per 1000 cubic metres. In 2020, there was a total of 570 net cages, with an average volume of 1500 cubic metres. Based on this information, the use of antifouling agents in fish farming at sea would have been about 137 tonnes. However, the antifouling treatment of net cages is renewed every two years, i.e. roughly, an estimated 69 tonnes of material was consumed per year. The share of plastic compounds in antifouling paints is about 20% (Loriot *et al*. 2017). Some of these plastic compounds are released directly in seawater, and some end up in the sea indirectly from the shore during treatment and storage. If about half the plastics content of the paints end up in the sea, the total amount of plastics is ca. 7 tonnes per year.

Table 2. Summary estimate of the total annual plastic input (tonnes) from fishing and fish farming to the Finnish sea area in 2020.

	Microplastics	Macroplastics	Total
Gillnet, commercial	0.2	0.2	0.4
Fish trap, commercial	7.6	0.6	8.2
Trawl, commercial	6.1	—	6.1
Gillnet, recreational	0.1	1.2	1.3
Fishing total	14.0	2.0	16.0
Fish farming cages	20–29	n/a	20–29
Antifouling paints	7	—	7
Fish farming total	27–36	—	27–36

*n/a = data not available

Observations on the disadvantages of marine litter for fishing and fish farming

42% of the 120 commercial fishers who responded to the survey reported that plastics and other debris at sea disrupted their fishing activities. Litter accumulated in the fishing gear, and it took time to remove it. At worst, entangled debris damaged the gear, especially large items moving on the water surface. Several coastal fishers reported that marine litter was detrimental to fishing, especially during river floods. According to interviews with trawler skippers, large amounts of plastic debris (up to 600–800 litres per week) accumulated in trawls hauled close to the seabed. Based on the responses, the share of plastic in the amount of litter was highest in trawl fisheries (about three quarters of the litter), while in gillnet and trap fishing, the share of plastic litter was typically estimated to be less than a quarter of all litter. However, marine litter was not generally considered a serious problem at sea, and in addition to the problems associated with litter, fishers' responses highlighted the problems linked to abundant seal and cormorant populations and the high amounts of algae attaching to gillnets and traps. Plastics or other litter in the sea was barely perceived as a disturbance to fish farming. According to the interviews, cages and other production structures did not get much litter. Minor observations of debris were usually associated with plastic debris such as plastic bags, bottle caps, and pieces of string.

A quarter of the responding fishers indicated that they were willing to cooperate to deliver litter items caught in the fishing gear to the fishing port's waste management point. The interviewed trawler skippers stated that the debris accumulating in the trawl was mostly collected. The costs of transporting the waste to the fishing port were mainly mentioned as normal operating costs. Only a few respondents also hoped to receive compensation for waste collection. However, it is possible that the results are biased because it is likely that the fishers who were already environmentally aware and interested in the topic were keener to participate in the survey.

The total input of plastic from fishery sector

The annual plastic input from fishing and fish farming to the Finnish sea area was estimated to be between 43–52 tonnes (Table 2), and two thirds of this originated from fish farming. Of these 43–52 tonnes, microplastics (mass loss from gear and cages, plastics from antifouling painting) constituted more than 90%. According to a desktop analysis, the most important point sources for microplastic emissions in Finland were traffic and artificial turf fields (Setälä and Suikkanen 2020). Microplastics emissions from traffic caused by tyre abrasion were estimated to be between 5348 and 10 528 tonnes per year. An unknown fraction of microplastics from land-based sources actually enters the marine environment via different transport routes (rivers, streams, stormwater, etc.). The estimated amount of microplastics released from the fishery sector is a few magnitudes smaller, but it is released directly into the sea.

The calculations forming the main results of this study are based on official statistics, expert judgements, several assumptions, interviews, and information on material fragmentation from a different marine environment (the Firth of Clyde on the west coast of Scotland, see Welden and Cowie 2017). The results must therefore be treated with caution. Improving the estimates would require a more in-depth study, gathering detailed information on the gear and materials used, and conducting field experiments on mass loss specifically in the conditions of the northern Baltic Sea, where the water is cooler and less salty, and the coasts are less exposed than they are off the coast of Scotland. The effects of washing the gear and cages on land, as well as processes during storage should also be regarded. Better quality initial information would also allow the use of more advanced modelling approaches. Nevertheless, we have presented the first estimates of the plastic input from fishing and fish farming in the northern Baltic Sea area and have thus provided a starting point for future studies.

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