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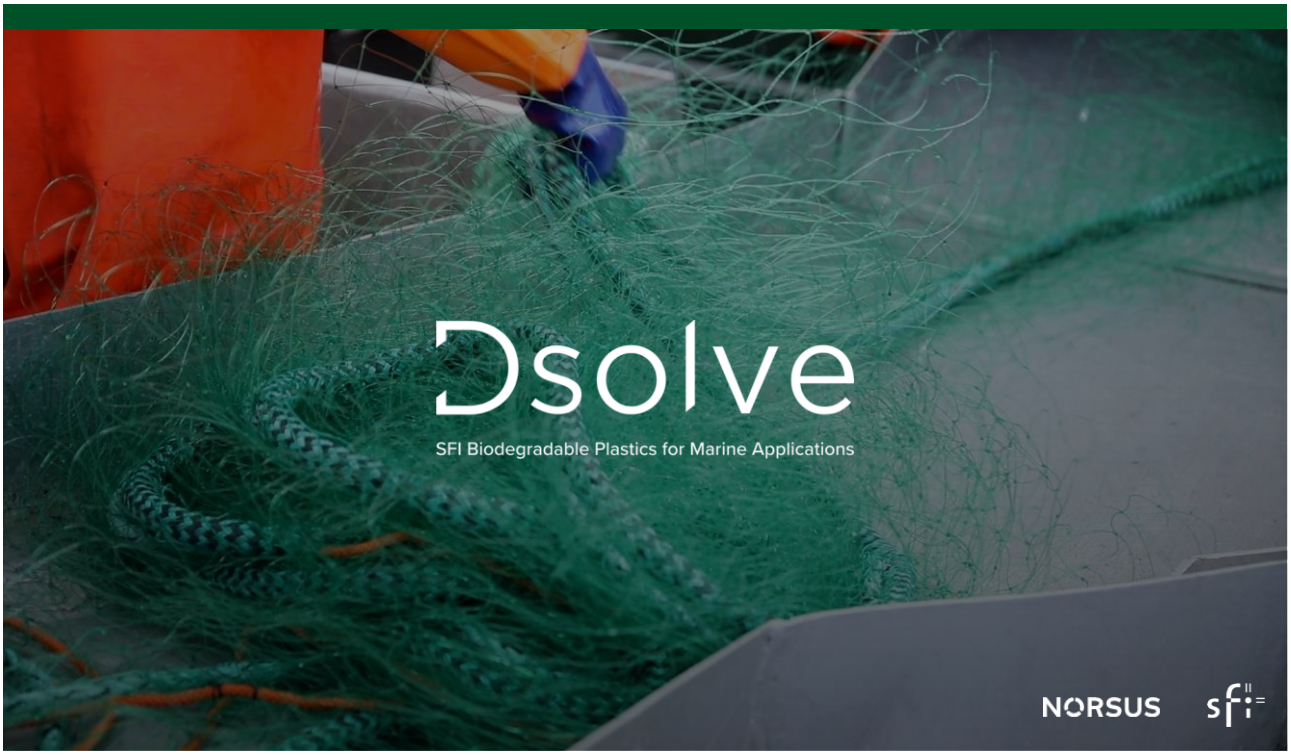
Defining status quo for the material flow of fishing gear on a national and regional level



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Abbreviations

ALDFG	Abandoned, lost or discarded fishing gear
CRI	Centre for Research-based Innovation
HDPE	High density polyethylene
IUCN	International Union for Conservation of Nature
IUU	Illegal, unreported and unregulated
LR	Littering Rate
MFA	Material flow analysis
MWI	Mismanaged Waste Index
PA	Polyamide
PE	Polyethylene
PLP	Plastic Leak Project
PP	Polypropylene
RR	Release Rate
UNEP	United Nations Environmental Programme
UV	Ultraviolet

Summary

This report is a deliverable for the Dsolve Centre for Research-based Innovation (CRI), Work Area 5 *Circularity of bio-based, biodegradable, and non-degradable plastics.* More specifically, this report documents Tasks 5.1.1 and 5.3.2.

The existing mass flow research concerning the fate of plastics in fishing gear used in the Norwegian commercial fishing and aquaculture industry is summarised in this report. Loss of fishing gear and aquaculture equipment can lead to ghost fishing and emission of microplastics affecting life below water. Plastic flows in commercial fishing gear and aquaculture can be categorized in four groups: a) new fishing gear, b) repaired materials, c) collected gear delivered to waste treatment, and d) lost equipment separated into loss from wear and tear, documented loss, and undocumented loss. Figure 1 gives an overview of the quantified and unquantified flows of plastics in the commercial fishing and aquaculture industry.

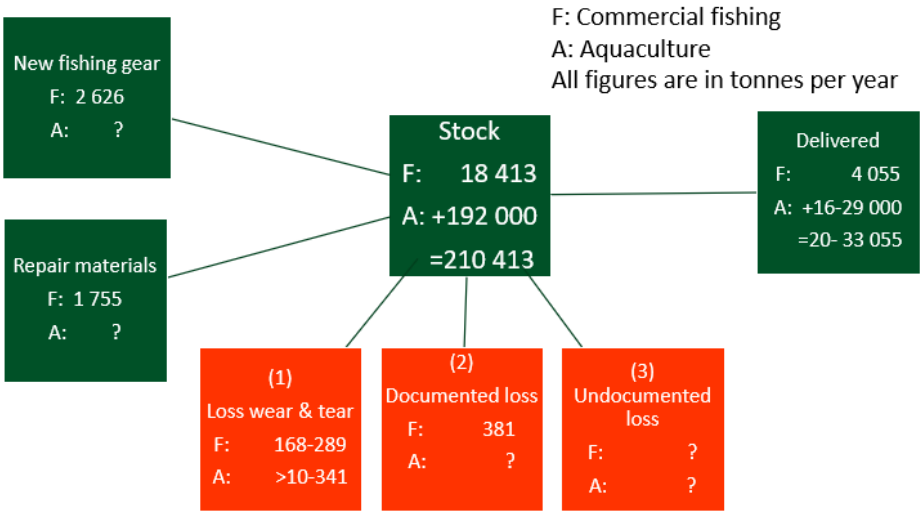


Figure 1: Quantified mass of plastics and knowledge gaps for commercial fishing and aquaculture, numbers in tons per year. Based on: Deshpande et al. (2020a), Hognes and Skaar (2017), Tore Syversen (2020), Vangelsten (2019) and Gomiero et al. (2020).

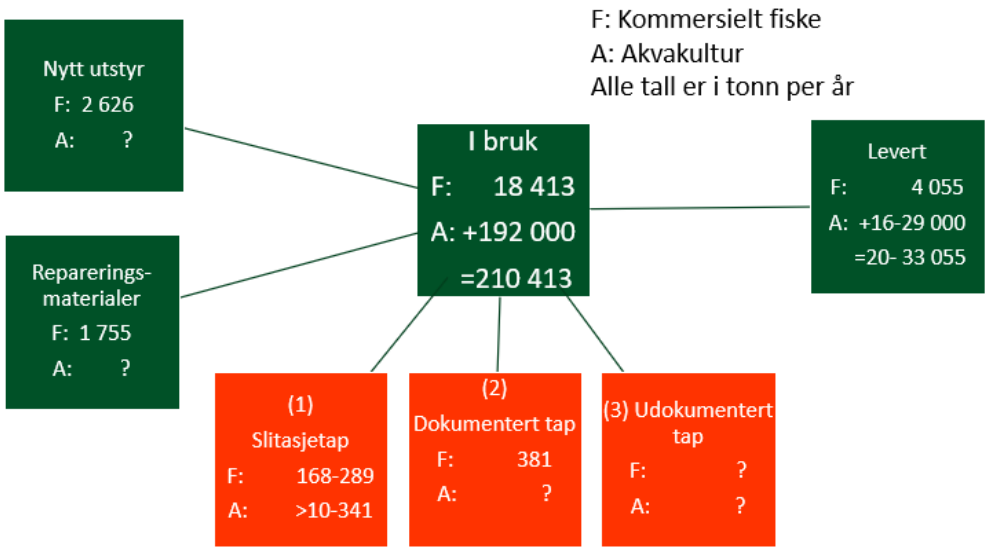
The plastics in gear from the commercial fishing sector are quantified in one study, which used a static material flow analysis for 2016. It shows that 381 tons of fishing gear is assumed lost each year, this accounts for 2% of the fishing gear stock. However, this number does not account for undocumented losses and wear & tear. The study also showed that 4,381 tons of plastic in fishing gear entered the market, 18,413 tons were in use and 4055 tons were collected and delivered for further end-of-life processing. An experiment on common polymer ropes showed an average loss of mass at 0.62% a month, and the result was used in a rapport that estimated wear losses from fishing gear to be 168-289 tonnes per year. For the aquaculture industry, there are fewer sources of data for quantification of plastic flows and little quantification of loss of gear. 16-29 thousand tons are collected and delivered to end-of-life processing each year and the stock in use is estimated to 192 thousand tons. Additional estimates show that feeding pipes emit 10-431 tons of microplastic per year.

There are several missing data points one would need to complete the material flow analysis of the Norwegian fishing and aquaculture sector. The Plastic Leak Project (PLP) and the UNEP/IUCN Plastic Pollution Hotspotting and shaping action project represent existing methods for quantifying plastic leakage. The projects are

evaluated to see if they can fill the relevant data gaps. The conclusion from the evaluation is that the data gaps for fishing gear cannot be adequately filled by the PLP and UNEP/IUCN plastic hotspotting methods. An ideal overview would provide amounts of the different types of fishing gear lost, as well as geographical variations.

Sammendrag

Denne rapporten sammenstiller eksisterende data for massestrømmen av plast for fiskeutstyr i fiskeri- og havbruksnæringen i Norge. Tapt utstyr fra disse næringene kan føre til spøkelsesfiske og utslipp av mikroplast som påvirker livet under vann. Plaststrømmene kan deles inn i fire kategorier: a) nytt utstyr solgt til industrien, b) reparert materiale, c) innsamlet og levert utstyr til avfallshåndtering, d) tapt utstyr, inndelt i slitasjetap, dokumentert tap og udokumentert tap. Figur 2 gir oversikt over de kvantifiserte og ikke-kvantifiserte massestrømmene av plast i fiskeri- og akvakulturnæringen i Norge.



Figur 2: Kvantifiserte plastmengder og kunnskapshull for kommersielt fiske og akvakultur, alle tall er i tonn per år. Figuren er basert på: Deshpande et al. (2020a), Hognes and Skaar (2017), Tore Syversen (2020), Vangelsten (2019) og Gomiero et al. (2020)

Plastmengden i den kommersielle fiskerinæringen er kvantifisert i en studie som brukte en statisk materialstrømsanalyse for 2016. Studien viser at 381 tonn med plast i fiskeutstyr er antatt tapt hvert år som tilsvarer 2% av fiskeutstyret i bruk. Tallet inkluderer verken udokumenterte tap eller tap fra slitasje. Videre oppga studien at 4 381 tonn plast i fiskeutstyr ble tilsatt markedet i 2016, 18 413 tonn var i bruk og 4 055 tonn ble samlet inn og levert til avfallshåndtering. Et forsøk på vanlige polymertau fant et gjennomsnittlig massetap på 0,62% i året, resultatet inngikk i en rapport som anslo slitasjetap fra fiskeutstyr i Norge på 168-289 tonn i året. Innen akvakulturindustrien er det mindre kvantifisering av plastmengdene og lite tall på tapt utstyr. 16-29 tusen tonn blir samlet og levert til avfallshåndtering hvert år og det er estimert at utstyret i bruk tilsvarer 192 tusen tonn plast. I tillegg er det estimert at fôringsrør avgir 10-341 tonn med mikroplast i året.

Det mangler flere data som er nødvendige for å gjennomføre en omfattende materialstrømsanalyse av hele fiskeri- og havbrukssektoren i Norge. Gjennom de internasjonale prosjektene Plastic Leak Project og UNEP/IUCN Plastic Pollution Hotspotting and Shaping Action Project er det utviklet metoder for å kvantifisere plastforurensing til naturen. Det er blitt vurdert om metodene fra disse prosjektene kan fylle de presenterte datahullene presentert i denne studien, men det konkluderes med at metodene ikke er egnet for dette formålet da de ikke omfatter spesifikke data nok for fiskeri- og havbruksnæringen. Ideelt ville en oversikt vært tilgjengelig over tap av ulike utstyrstyper med geografisk variasjon.

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1 Introduction

This report is a deliverable for the Dsolve project, Work Area 5 *Circularity of bio-based, biodegradable, and non-degradable plastics.* More specifically, this report documents Tasks 5.1.1 and 5.3.2:

> *Task 5.1.1 Define the status quo for the material flow of fishing gear on a national and regional level with goals to document:*
>
> i. *The proportion of used fishing gear delivered for further processing and depositing,*
> ii. *Loss of mass due to wear,*
> iii. *Documented loss of gear,*
> iv. *Undocumented loss of gear*.

> *5.3.2 Assess the Plastic Leakage Project and UNEP/IUCN national guidelines for plastic hotspotting and shaping action and other relevant international initiatives for relevance in closing the data gaps*

This report presents an attempt to define the status quo for the material flow of commercial fishing gear and aquaculture for Norway, based on existing scientific literature. The resolution of data in the literature was not suitable for a comprehensive analysis at the regional level, therefore this report focusses on the national level.

Existing methodologies for quantifying plastic leakage, namely the Plastic Leak Project and the Plastic Pollution Hotspotting and Shaping Action project are scrutinized to evaluate if the underlying data can be used for filling the data gaps identified in the status quo.

Chapter 2 presents background, introducing the topic of marine plastic pollution (2.1), followed by a review of causes of marine pollution from fishing gear (2.2), and presents an overview of the fishing gear in use in Norway (2.3).

Chapter 3 presents an overview of the material flow in the commercial fishing industry (3.1) and the aquaculture industry (3.2), followed by a discussion on estimates of the fishing gear losses (3.3). Further, the relevance of existing methodologies for quantifying plastic leakage, namely the Plastic Leak Project and the Plastic Pollution Hotspotting and Shaping Action project are scrutinized, to evaluate if the underlying data can be used for filling the data gaps identified (3.4). Finally, an overview of the missing data needed to perform a comprehensive material flow analysis is presented (3.5).

Appendix 1 gives a description and illustrates the different kinds of fishing gear presented in this report.

2 Background

2.1 Marine plastic pollution and fishing gear

Marine littering is defined as any persistent, manufactured or processed solid refuse discarded, disposed of or abandoned in the marine or coastal environment through human activity (UNEP, 2017). Plastics have an apparent predominance amongst marine litter, contributing 60% – 80% of total marine debris around the globe (Moore, 2008). The annual influx has been estimated to between 4.8 - 12.7 million tons of plastic waste to the ocean (Jambeck, 2015), forming the notable garbage patches in global waters (Lebreton et al., 2018). It has also been estimated that 80 percent of marine litter comes from land, usually from uncollected waste, with the remaining 20 percent directly generated at sea, through marine activities (UNEP, 2016).

UNEP (2016) has identified 5 sources of plastic loss to the ocean from sea-based sources: the fishing and the aquaculture industry, commercial shipping, tourism and recreational users. This report will focus on fisheries and aquaculture, which is the scope of the Dsolve project. Aquaculture encompasses the production of all aquatic organisms, i.e. both plants and animals living in water. From these sectors, the release of plastic products to the environment occurs due to abandoned, lost or discarded fishing gear (ALDFG), or due to misfunctioning waste and wastewater management systems (UNEP, 2016).

Combined data from visual surveys in the Pacific, South Atlantic, Indian Ocean and Mediterranean Sea suggest that fishing gear from commercial fishing makes up the greatest share of macroplastics (>200 millimetres) in the oceans. Buoys accounted for 58% by weight, followed by lines (11,1%) and nets (0,9%) (Eriksen et al., 2014). See Appendix 1 for an illustration of the different types of fishing gear. A significant proportion of the objects found during beach clean-up operations come from the maritime and fishing sector, with objects such as ropes, fishing nets, buckets, and styrofoam used for fish boxes. These products are significant both when the calculation is based on weight and on number (Sundt, 2014). Fishing gear on European beaches accounts for about a quarter of the litter found (European Commission, 2019). The same types of fishing gear are lost from the aquaculture industry, but this sector is assumed to account for a smaller share of the litter (UNEP, 2016).

2.2 Reasons for abandoned, lost or discarded fishing gear

Abandoned, Lost or otherwise Discarded Fishing Gear (ALDFG) leads to harmful effects for the coastal and marine environment and human activities (Gall and Thompson, 2015, Joint Research Centre, 2016), and has been identified as one of the most biologically threatening types of marine litter (Kühn, 2015).

The causes of ALDFG are rather difficult to assess. According to Viool (2018), ALDFG in the marine environment has to be understood as an accumulation of (1) loss due to wear and tear, (2) loss of gear and gear parts which cannot be retrieved or are too risky to retrieve, and (3) unintentional and intentional dumping (e.g. with net pieces from net mending washed overboard, or intentional discarding of gear and gear parts). Equipment loss has also been assumed to mainly happen upon deployment (Deshpande et al., 2020a) for a variety of reasons

including (but not limited to) adverse weather conditions, irregular topography, gear conflicts and failures, ship collisions, abandonment, human error, and vandalism (Richardson et al., 2019).

Figure 3 gives an overview of the reasons for fishing gear losses at sea, based on Macfayden & Huntington (2009). They categorize the losses in three groups: abandoned gear, discarded gear (intentional) and gear losses (unintentional). The reasons for losses include four kinds of pressure:

- Enforcement pressure, which often entails the abandonment of gear. This type of loss includes having illegal gear onboard or illegal, unreported and unregulated (IUU in Figure 3) fishing.
- Operational and/or economic pressure, which often entails the abandonment of gear or the discarding of gear. This reason for loss can include having too much gear onboard.
- Spatial pressure, which often entails deliberatly discarded or lost gear. The reasons for loss include the presence of damaged gear thrown overboard, gear conflicts or misplaced gear.
- Environmental conditions, which often entails the unintentional loss of gear, due to for instance poor ground conditions and extreme weather.

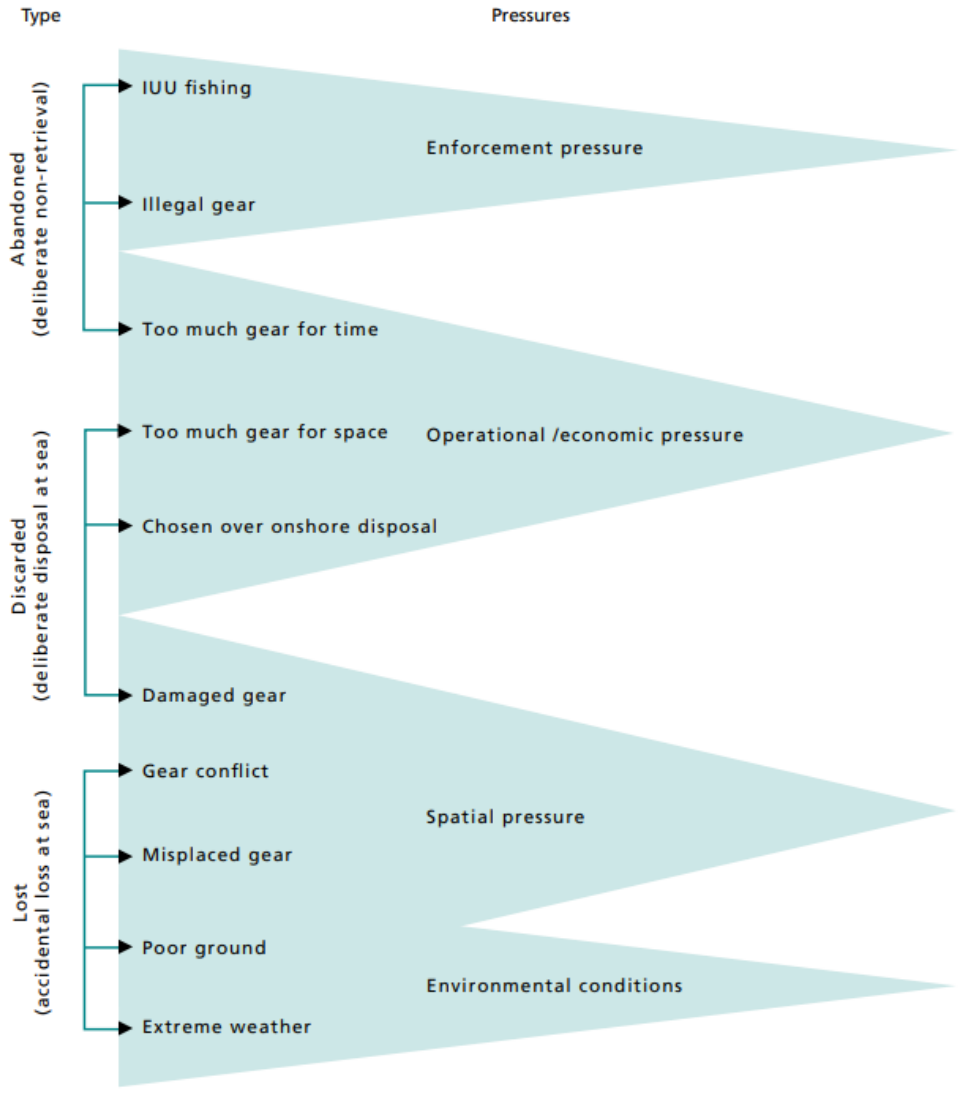

Figure 3: Reasons why fishing gear is abandoned, lost or otherwise discarded. Source: Macfayden & Huntington (2009)

The majority of nets lost in Norwegian fisheries tend to be those used in offshore operations, especially those targeting spawning saithe (Macfayden & Huntington, 2009). Strietman (2021) examined the reasons for the loss of fishing nets in more depth, by examining nets found on the coastline of the Artic and North-East Atlantic. Strietman estimated that most pieces of fishing net bigger than 50cm originate from vessels operating in fishing areas relatively close to the beaches where the littered pieces were collected, and that the transport of nets to beaches does not happen over large distances. Only gillnets nets were transported, whereas trawl nets were found to sink. This was explained by the fact that trawl nets operate on the sea floor, requiring low buoyancy, whereas gill nets have a higher buoyancy and float (Strietman, 2021). This is in line with findings from other studies, revealing that most of the plastic waste sinks (e.g. EUNOMIA, 2016). In the Barents Sea and the Norwegian Sea, the mean density of litter was found to be 202 and 279 items/km2 respectively, based on video mapping of the sea floor for different marine landscapes, at different depths and distances from the coast (Buhl-Mortensen and Buhl-Mortensen, 2017). Fishing gear was the dominating type of litter, with higher density (items per unit area) closer to the coast and in troughs and canyons (Buhl-Mortensen and Buhl-Mortensen, 2017).

It was further found that the net litter washed up on beaches was in the form of pieces, rather than complete nets. These were trawl net pieces originating from bottom trawl fisheries, as the result of damage during trawling, and predominantly, the mismanagement of net cuttings during mending on deck. The net cuttings reach the sea as there is no effective waste management system in place for the collection and disposal of such waste material. The net cuttings are either unintentionally washed overboard or deliberately discarded (Strietman, 2021). This is in line with the results from Hareide (2005), who concluded that the amount of lost and discarded nets is poorly estimated, and has evidence from one shark vessel discarding approximately 30 km of damaged nets on a typical 45-day trip (Macfayden & Huntington, 2009).

According to Clean Nordic Oceans, it is the smaller coastal vessels that are in the greatest danger of losing fishing gear. The main reason for the losses seems to be that the fishing gear is moved by strong currents to deeper areas, ship traffic (the buoys are cut), gear conflicts, getting stuck in previously lost fishing gear on the seabed, and human attitudes.

Wear and tear losses are hard to assess. UV light, wave action, abrasion and temperature changes are factors that can contribute to embrittlement and fragmentation of plastics (Lusher et al., 2017). For aquaculture, other additional potential sources of wear and tear loss are mechanical stress on feeding pipes and washing of nets to remove biofouling. Due to added weight from water and biomass, quantifying loss from wear and tear of fishing gear is challenging.

2.3 Fishing and fishing gear in the Norwegian context

Although commercial fishing is a primary activity in most EU-EEA member states, Norway alone contributes to around one-third of the total catch, owing to its resource-rich coastline and advanced fishing fleet. The Norwegian fishing fleet consists of approx. 6000 fishing vessels, most of them less than 15 meters in length. For fishing vessels operating at sea, the main types of fishing gear used are trawls and purse seines, as well as some lines, nets and pots. For the medium-sized fishing fleet and the coastal fishing fleet, fishing gear such as trawls, purse seines, Danish seine, nets, pots and lines in various forms are used (Clean Nordic Oceans, 2021). See Appendix 1 for descriptions and illustrations of the different types of fishing gear.

In addition to electronic catch reporting, Norway has a system where fixed, also called passive, fishing gear (nets, lines and pots) placed in the sea must be reported to the Coast Guard Centre. The subsequent hauling of this fishing gear must also be reported. Such an arrangement has significantly contributed to reduced gear conflicts with a consequently lower risk of loss. Fishing vessels that lose fishing gear are required to try to recover it, but if this fails, the loss must be reported to the Coast Guard. The losses reported to the Coast Guard Centre are included in the database for the annual clean-up (Clean Nordic Oceans, 2021).

The aquaculture industry is of increasing importance, both in terms of size and revenue. The equipment in use is rather different than equipment used for commercial fishing. Plastic equipment used in aquaculture includes: ropes and buoys for mooring rings and feed raft, floating rings, bottom rings, nets, and ropes (Skaar and Hognes, 2017). See Appendix 1 for descriptions and illustrations of the different types of aquaculture equipment.

All aquaculture facilities have systems registering the equipment in use, which must be certified and have a maintenance plan. The largest components are therefore registered, but smaller equipment, such as ropes,

are not registered. None of the facilities analysed by Skaar and Hognes (2017) had systems in place for tracking all of the materials and equipment in use, and their waste management. In other words, the facilities had no overview of the entire mass balance of the equipment in use at the facility (Skaar and Hognes, 2017).

In addition to commercial fishing and the aquaculture industry, recreational fishing activities in saltwater are quite extensive in Norway, especially in the southern part of the country. The use of fishing gear in recreational fishing is limited to hand lines, fishing rods and similar handheld equipment, machine-driven cheat or troll, nets with a total length of up to 210 m, lines with up to 300 anglers, and up to 20 pots or traps. The gear restrictions apply to all fishing that takes place from land or from vessels that are not registered in the Directorate of Fisheries' register of fishing vessels (Clean Nordic Oceans, 2021).

The Norwegian Directorate of Fisheries uses an online notification system for gear lost during recreational fishing, which has provided insight to which fishing gear is most often lost and the reasons for the losses. Pots are by far the most lost type of recreational fishing equipment. The reasons for the losses are complex, but lack of knowledge about fishing is an important reason (Langedal et al. 2020). The findings from the database correlate well with the findings from Kleiven (2021). Recreational fishing is, however, not in the scope of the Dsolve project.

3 Material flow of fishing gear on a national level

An attempt was made to quantify the material flows of fishing gear in Norway, based on literature data. This chapter presents the status for Norwegian commercial fishing first, and then the Norwegian aquaculture industry. Estimates about the amounts of fishing gear lost are provided, together with an overview of the reasons for the losses. A summary of the data gaps that need to be addressed before conducting a full material flow analysis (MFA) is presented.

3.1 Material flow of fishing gear in commercial fishing

Figure 4 illustrates the material flows for typical types of fishing gear used in the Norwegian commercial fishing fleet in 2016. It shows the data for the combined amounts of the most commonly used fishing gear types: trawl nets, Danish seines, purse seines, longlines, gillnets and traps. These are mainly made of polypropylene (PP), polyethylene (PE), and nylon (PA), which are the main materials used in advanced fishing gear. It was, however, not possible to present this overview for each gear type separately. The data is based on the interviews by Deshpande et al. (2020a, 2020b) with several gear producers, suppliers, fishers, waste collectors, authorities, and waste management facilities.

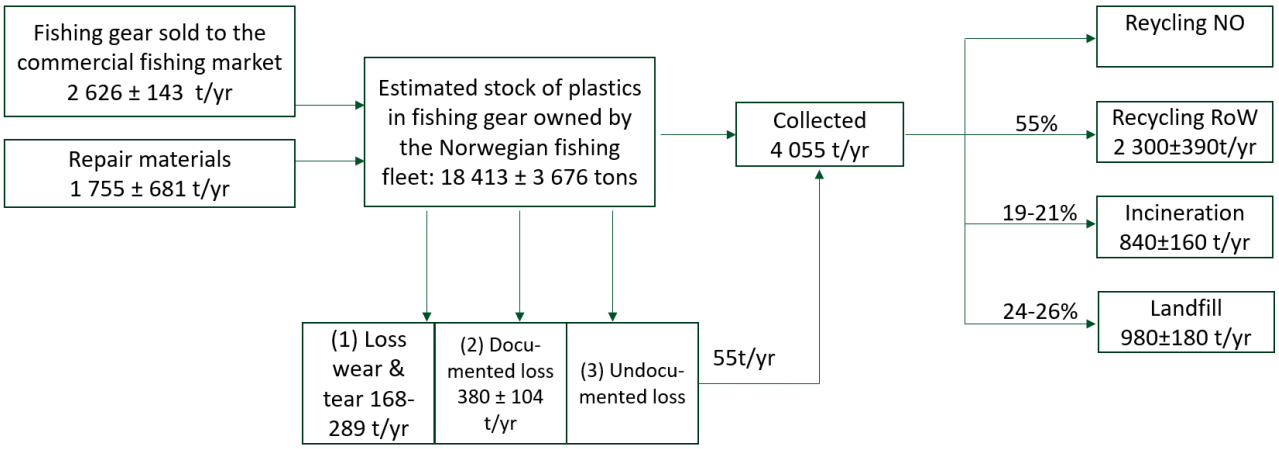

Figure 4: Illustration of the PA, PP and PE plastic mass flows in fishing gear from the commercial Norwegian fishing fleet. Sources: Deshpande et al. (2020a), Deshpande et al. (2020b) and Tore Syversen (2020).

As seen in the figure, 2,626 tonnes of new commercial fishing gear were placed on the market in Norway in 2016, as well as 1,755 tonnes for repair purposes (4,381 tonnes in total). The stock of plastic fishing gear was estimated to be over 18,000 tonnes in the fishing fleet. About 4,000 tonnes were sent to waste management every year (Deshpande et al. 2020a), whereof 55% were sent to recycling abroad, 19-21% to incineration and 24-26% to landfill (Deshpande et al. 2020b). The remaining 381 tonnes of gear is assumed lost during operation at sea, which accounts for 2% of the fishing gear stock, of which 55 tonnes are recollected for proper waste management. The gear lost at sea represents accidents happening during gear deployment or due to operational damage (reported as documented loss, numbered 1 in Figure 1). Deliberate losses (undocumented loss, numbered 2) and wear and tear (numbered 3) were not accounted for. This indicates that the real amount of lost fishing gear is higher than 381 tonnes per year (or 8.7% of the amount of fishing gear and repair materials sold to commercial fishing activities).

there are only a handful of studies that attempt to quantify losses from wear and tear. One of the studies is on degradation of common polymer ropes in benthic conditions (Welden and Cowie, 2017). The study found through experiments that ropes of PA, PP and PE lost respectively 1.20%, 0.39% and 0.45% of its mass each month, amounting toan average degradation rate of 0.62% a month. Syversen et al. (2020) aims to quantify wear and tear losses for different fishing gear in Norway using 2019 as the reference year. Wear is quantified based on the estimated mass of different equipment in use, possible causes of wear, expected lifetimes, and percentwise losses. Degradation rates from Welden and Cowie (2017) are part of the basis for the calculation. The report's average wear estimates are presented in **Feil! Fant ikke referansekilden.** and sums to a plastic loss from wear at 229 tonnes/year. High uncertainties are related to the figures, and they range from a total at 168 to 289 tonnes per year.

Table 1: Average estimates for the mass of plastic lost by wear in tonnes per year (reference year 2019) for different commercial fishing gear in Norway. Source: Syversen (2020)

Nets (t/yr)	Longline (t/yr)		Autoline (t/yr)		Traps (t/yr)				Seine (t/yr)		Trawl (t/yr)		
Average	Bottom	Floating	Coast	Sea	Snow crab	King crab	Crab	Lobster	Danish	Purse	Bottom	Shrimp	Pelagic
9.2	9.2	0.4	10.7	4.4	21.7	3.4	3.4	0.3	102.0	12.0	40.0	9.0	3.0

3.2 Material flow of fishing gear in the aquaculture industry

Figure 5 is an illustration of the material flows for the main types of fishing gear used in the Norwegian aquaculture industry. The data is based on values gathered from aquaculture companies, which were scaled up to represent 5 500 fish cages, which was the estimated numbers of cages in the Norwegian sea-based aquaculture in 2017 (Skaar & Hognes 2017). Note that these values are only based on data from salmon aquaculture, which represents 75% of the total aquaculture locations in Norway in 2019 (Fiskeridirektoratet, 2021). In addition to salmon aquaculture there are facilities for other fish 5%, molluscs, crustaceans and echinoderms 13% and algae 7%.

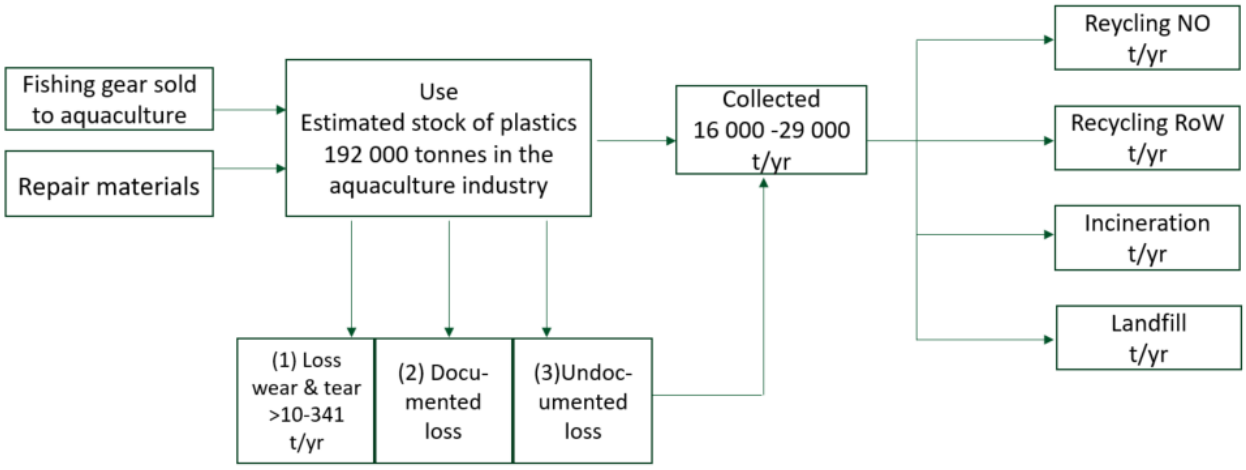

Figure 5: Illustration of the plastic mass flows in the Norwegian aquaculture industry. Data sources: Hognes and Skaar (2017), Vangelsten (2019) and Gomiero et al. (2020).

As seen from the figure, the stock of plastic in the Norwegian aquaculture industry was estimated to be 192,000 tonnes, of which 16,000 to 29,000 tonnes are collected for waste management each year. However, few aquaculture facilities could document the amount of waste delivered to waste management, or how it was sorted and treated at end-of-life. In addition, none of the companies logged their material use (Hognes and Skaar, 2017).

Based on an overall assessment of the interview results, current regulations and environmental certifications in the Norwegian aquaculture industry, Hognes & Skaar (2017) concluded that the Norwegian aquaculture facilities are unlikely to be a significant source of marine pollution of plastics and metals. Nonetheless, it is likely that some plastic parts disappear during storms or accidents.

Quantification of microplastic released from aquaculture feed pipes due to wear and tear has been quantified. Total mass lost has been simulated based on models for erosion as a result of sand acting on gas pipes (Vangelsten, 2019). The authors found a plastic loss of between 10 to 100 tonnes with a mean of 30 tonnes. The estimates are highly uncertain as the study is not based on empirical data and the models used (one for straight and one for curved pipes) used sand particles which are a lot smaller than feed-pellets. A later experiment on old and new feed pipes ran a total of 2 tonnes of pellets through two straight and two 10° curved HDPE pipes. The results showed significantly higher weight loss in curved pipes and higher weight loss in older pipes. The average loss was 0.10-0.40g/meter/day, which adds up to a theoretical release of 150 to 569 kg/year/aquaculture site (Gomiero et al., 2020). By multiplying with an average of 599 locations (for 2018 to 2020) (Fiskeridirektoratet, 2021), it results in an annual plastic loss from feeding pipes at 90-341 tonnes. Combining results from the studies on feed pipes, results in wear and tear losses in the range of 10-341 tonnes.

3.3 Estimates of fishing gear loss

It is estimated that at least 640,000 tonnes of fishing gear are lost or abandoned in the oceans every year (Macfayden et al., 2009), while the annual loss in European waters is estimated as 2,000 – 12,000 tonnes a year. Given the development of the European fishing fleet over the past five decades, it has been estimated that 130,000 - 550 000 tonnes might have accumulated in this region (EUNOMIA, 2016). However, these numbers are contested (Richardson et al., 2021). It has also been estimated that 4,000 tonnes of plastic from lost commercial fishing gear in Norway have been accumulating in the ocean between 2007 and 2016 (Deshpande et al., 2020).

Richardson et al. (2021) argue that weight-based metrics are irrelevant in the context of ALDFG, as they divert the attention from other relevant fishing gear metrics, such as proportions of loss from different types of gear, gear sizes, material types, gear lifespans and the potential for ghost fishing and wildlife entanglement from different gear types. For example, fishing lines generally weigh substantially less than most pots, traps and fishing nets. Thus, a weight-based comparison of the amount of line losses compared to other naturally heavier gear types is misleading in terms of how much gear is lost across different fisheries and gear types. In a meta-analysis of ALDFG, they estimated that 5.7% of all fishing nets, 8.6% of all traps and 29% of all lines are lost to the world's oceans each year (Richardson et al., 2019); they highlight the need of differentiating gear types.

It has proven challenging to estimate the losses of fishing gear from Norwegian commercial fishing and aquaculture as a whole. In fact, most estimates of fishing gear losses have been limited to specific gear types and/or geographic locations, largely due to fishing gear being tailored for target species, which can vary widely (Richardson et al., 2021) and therefore not be representative for a national sector. Another major challenge in comparing ALDFG estimates is that many studies do not report the proportion of the gear item lost (i.e. whether the entire gear item was lost, or some portion of the gear).

Beach clean ups have gathered extensive data about litter both in terms of mass, amounts and potential origin, and could be a way of collecting data on fishing gear loss. Nonetheless, it is estimated that of the plastics entering the ocean, 94% end up on the seafloor (EUNOMIA, 2016). Different densities of the polymers along with the shape of the gear are parameters that can affect where the plastics end up. Polymers denser than seawater (> 1.027 g/cm3) will sink, while those with lower density (e.g. PE and PP) will tend to float in the water column (Kershaw and Rochman, 2015). In addition, biofouling and the colonization of organisms can increase the weight of particles making them sink (Lobelle and Cunliffe, 2011).

There has been considerable effort put into gathering knowledge about marine litter on the coast, on the seafloor and from commercial fishing and aquaculture. However, there are a limited number of studies that quantify the material flow of plastics in fishing gear and aquaculture equipment. The data presented here is deemed the best available data applicable for Norway at the present time.

3.4 Assessing the Plastic Leakage Project and UNEP/IUCN National Guidelines for Plastic Pollution Hotspotting and Shaping Action for closing the data gaps

In recent years, plastic leakage methodologies have been published. These methods, namely the Plastic Leak Project and the UNEP/IUCN National Guidelines for Plastic Pollution Hotspotting and Shaping Action, were evaluated in this study in order to assess whether the data gaps could be filled with data from these methodologies. This chapter presents a short description of plastic leakage calculations and each of the aforementioned methods.

3.4.1 Plastic leakage calculations

Plastic leakage represents the plastic pollution that is released into the environment. Leakage is most often reported for plastic entering rivers and oceans, but plastic leakage also affects other environmental compartments (e.g. soils, air). Any plastic that is mismanaged is prone to leak. As illustrated in Figure 6, the leakage for a geographical area is derived from the Mismanaged Waste Index (MWI) and Littering Rates (LR) through Release Rates (RR). M_{macro} stands for *the mass of macroplastics*. For a product however, only the leakage and release rates are assessed.

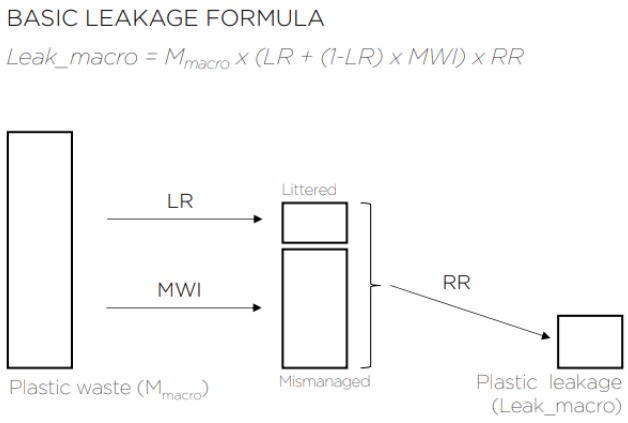

Figure 6: Overview of the plastic leakage formula. Source: Plasteax (2021)

For filling the research gaps identified in chapters 3.1 and 3.2 for the fishery sector in Norway, only the Littering Rates (LR) are of interest. It is assumed that the Mismanaged Waste Index (MWI) is not relevant for the fishing sector (i.e. the fishing gear waste delivered to treatment is managed well), and the leakage of fishing gear occurs directly at sea (not via littering on land). This makes the Release Rate (RR) as illustrated in Figure 6 superfluous. The following chapters will therefore concentrate on LR.

3.4.2 Plastic Leak Project

Quantis, a sustainability consulting group, has developed a methodology that calculates plastic leakage from a company's value chain or a product life cycle, for both micro and macro plastics, in land-based and marine environments (Peano, 2020). The approach accounts for losses from all main stages in a product's life cycle or company's value chain, namely production, processing, transport, use and waste management. Figure 7 presents the flow of the model.

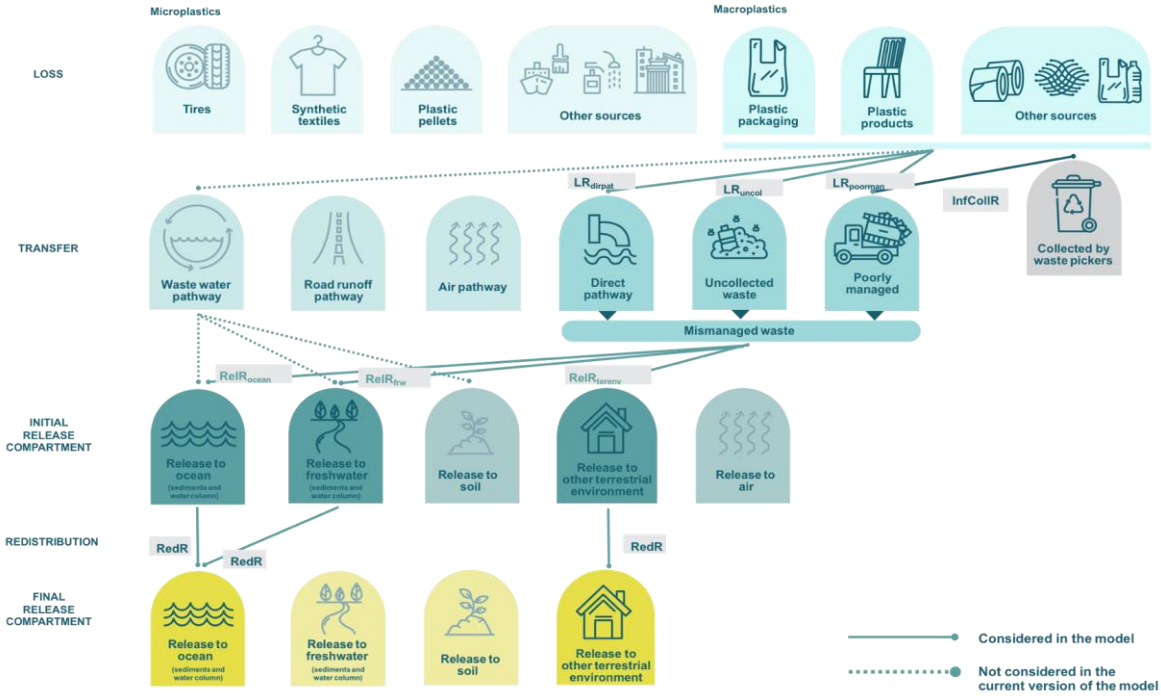

Figure 7: Main steps in the modelling of plastic leakage. Source: Peano (2020)

Quantification starts with documentation of the amounts of plastic per polymer type for a product or portfolio. The methodology includes leakage factors for different types of products and sectors, allowing quantification of product/polymers leaked in the different life cycle stages. The stray plastics are then tracked across different environmental compartments, calculated with release factors, from when they are leaked into nature until the final environmental compartment they end up in. The methodology is limited to the release of macroplastic to land-based environment and to the sea, while microplastics leakage can also be calculated as leaked to fresh water and soil. A final leakage metric can then be calculated, both to the oceans and to other environmental compartments. This leakage metric expresses the ratio between the mass of macroplastics that has leaked and the mass of used macroplastics, and provides insight into the extent of litter. In addition, the methodology allows the identification of hotspots, which can be countries, products, polymers or value chain stages, so that leaks can be reduced where they are greatest.

The Plastic Leak Project calculates LR based on a combination of product size and the location where the product is consumed (on-the-go, or in-house). However, this applies to consumer products and not to fishing gear. In its current form, this methodology and data is not relevant for assessing gear loss from the fishing and aquaculture sectors.

3.4.3 UNEP/IUCN National Guidelines for Plastic Pollution Hotspotting and Shaping Action

The national guidelines for plastic pollution hotspotting and shaping action (hereafter "guidance") have been developed by UNEP, IUCN and the Life Cycle Initiative. The basis of the guidance starts with mapping plastic leakage and its impacts across the values chain by collecting and analysing relevant data on plastic production, consumption, waste management and disposal; hotspots are then prioritised. The guidance enables governments, in collaboration with key stakeholders, to identify and implement corresponding interventions and instruments to address the prioritised hotspots. The Guidance is built on existing efforts to develop methodologies for mapping and quantifying plastic flows, leakage and impacts, including the UNEP publication (UNEP, 2018), an IUCN publication (Boucher et al., 2019) and the Plastic Leak Project (PLP, 2019). For each element of the hotspot category (a specific polymer, application or industrial sector), the guidance establishes a mass balance between plastic inputs and outputs. Generally, inputs include production and imports, while outputs encompass waste generation and export. Outputs also include the quantity of plastics leaking to the environment. This leakage is derived from the total waste generated by first applying a loss rate to assess the quantity of plastic lost along the waste management system, to which a release rate is applied in order to estimate the quantity of plastic leaking to the environment. These calculations rely on the Plastic Leak Project.

The guidance addresses all types of plastic leakage, including mismanaged waste; primary microplastics from abrasion and intentionally used; accidentally lost plastics; all plastic polymer and products, and relevant sectors. Concerning the fishing sector, a littering rate of 3.6% is presented. This seems to be a crude estimate, with no differentiation between types of fishing gear, which leads NORSUS to conclude that the data provided by the existing methodologies cannot be used to fill the data gaps identified.

3.5 Summary of the data gaps

Figure 4 and Figure 5 present the MFA for fishing gear from commercial fishing and aquaculture according to the best available literature data. Undocumented losses of gear in commercial fishing were not reported explicitly in the literature, nor complete data related to wear and tear, which would be needed for performing an MFA. Table 1 shows a summary of the data points and gaps across these two industrial sectors.

Table 2: Summary of data available for fishing gear losses for commercial fishing and aquaculture in Norway.

	Commercial fishing, Tonnes per year, Reference year 2016/19	Aquaculture, Tonnes per year, Reference year 2017
Fishing gear sold to the industry sector	2 626	Unknown
Repair materials	1 755	Unknown
Total entering the market	**4 381**	**Unknown**
Collected gear – directly from industry	4 000	16 000 - 29 000
Collected during cleanup	55	Unknown
Total collected	**4 055**	**16 000 - 29 000**
Documented lost fishing gear	380	Unknown
Lost wear & tear	Unknown (168-289, uncertain)	Unknown (10-341, uncertain & incomplete)
Undocumented lost fishing gear	Unknown	Unknown

It would be ideal to have an overview of the lost fishing gear based on gear types. It was, however, not possible to present this overview for each gear type separately due to the lack of data in the assessed literature. An approach that is promising for further work is mapping the amounts of different types of fishing gear sold on the Norwegian market, to which release factors presented by Richardson et al. (2019) could be applied in order to estimate how much gear is lost at sea. The same approach could be followed for estimating wear and tear losses for different types of ropes, based on their material composition and the release factors presented by Welden and Cowie (2017). This would give a better estimate of the amounts of different types of fishing gear lost by the Norwegian fishing fleet. Partners in the Dsolve CRI will be contacted in order to collect up to date data about plastic flows in the Norwegian fishery and aquaculture industries in order to fill the data gaps outlined above.

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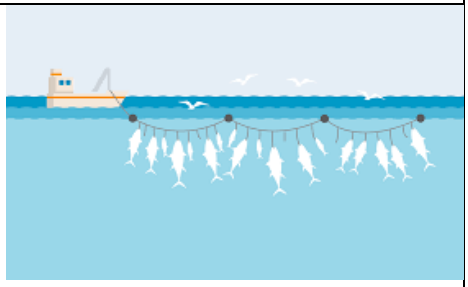
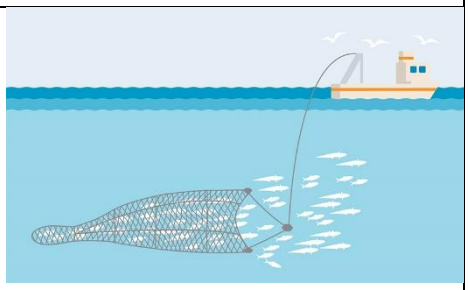
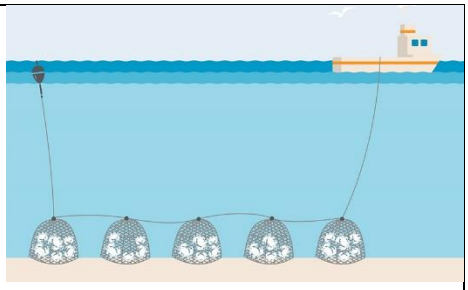
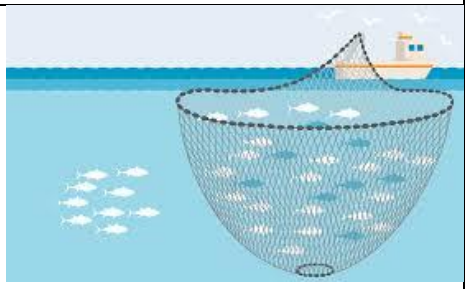
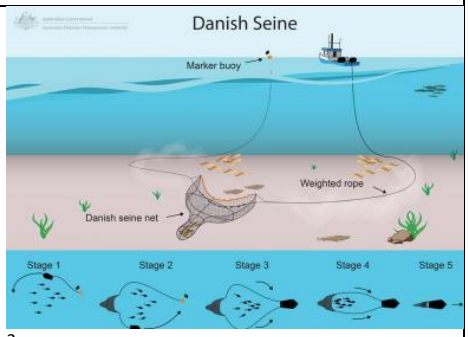
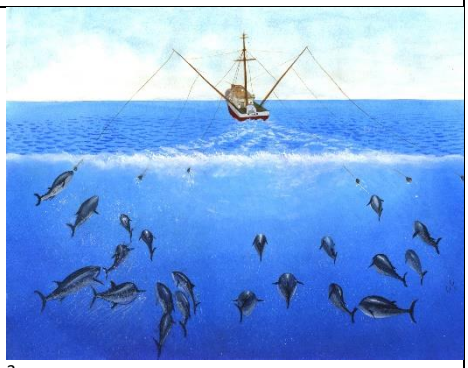
Appendix

This appendix presents descriptions and illustrations of the most commonly used fishing gear types referred to in this report.

Type of fishing gear	**Description**	**Estimated lifespan in years** (Deshpande et al., 2019), (Skaar and Hognes, 2017).	**Illustration**
Gillnets	Passive. Vertically standing wall of net, consisting of a mesh between a rope with floaters at the top and a weighted rope at the bottom. Can sit at different depths targeting different species. Components: Mesh out of monofilament nylon-line, rope, floaters, metal.	2.1 ± 1.1	
Longlines	Passive. A series of hooks attached with short ropes to a long line of rope. Bait is added to the hooks for attracting fish. Deployed at different depths.	3.0 ±2.6	 1
Trawls	Active. Bag of net attached by rope and towed by the vessel. The mouth of the net is kept open, and the species (e.g., fish or prawns) are trapped in the net as the vessel moves forward. Used at different depths. Bottom trawl and pelagic trawl.	2.8±1.8	 1

[1] www.msc.org

Traps and pots	Passive. Containers with bait attracting the species which are captured once they are inside. Designed so that juvenile or non-targeted species can escape through small holes. Includes mesh that disintegrate after a certain time to avoid further capture in case of lost gear.	6.1±4.6	 1
Purse seines	Active. Net that surrounds a shoal of fish and traps them inside the net by tightening the bottom wire (like a purse).	10.2±5.3	 1
Danish seines	Active. Firstly, a buoy with a rope is released, then the seine follows landing on the sea floor, another rope is released before the vessel runs to the buoy closing the loop. Thereafter it is towed before hauling.	3.9±1.8	 2
Machine driven troll or lure	Lines with one or more lures (hooks) that is drawn through water, eighter by driving the vessel or dragging the line. The lines can be inserted on poles attached to the vessel to avoid tangling.	-	 3

[2] https://www.afma.gov.au/fisheries-management/methods-and-gear/danish-seine

[3] Not supplied, Public domain, via Wikimedia Commons.

Buoy	Floating device. Can be used to mark location of fishing gear or equipment and keep gear afloat. At aquacultural sites it is a part of the mooring.	-	4
Hand line	Line held in hand, it has multiple hooks and a sinker at the end.	-	5
Fishing rod	Rod with a reel to store the line, the line has one or more hooks.	-	6
Mooring rings	Ring connected by rope, chains and chackles to anchor and buoy for mooring a construction, for instance fish farms.	8-10	7

[4] Image by Krista Grear from Pixabay
[5] Hentet fra https://www.baardsen.no/skarven-fiskeharpe-100-m-4-makk-2-tinnbeit-?parent=10039
[6] Santeri Viinamäki, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, vi a Wikimedia Commons
[7] Hentet fra https://www.morenot.com/upload_images/AD6C97A1325F489399258B42E29B2056.pdf

Feed raft	Feed is pumped from silos on board at the raft to the pens.	-	8
Floating and bottom ring	Floating ring: Ring of pipe to keep the net floating and in place. Bottom ring: Ring at the bottom of the pen to keep the net expanded. Consists both of plastics and metal wire.	5-25	9

[8] Hentet fra https://eidesvikhavfiske.no/en/forflate-klargjores/
[9] Hentet fra https://scaleaq.com/product/midgard-system/

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