

Full length article

## Governance implications for the implementation of biodegradable gillnets in Norway

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## ABSTRACT

Gillnets are among the most widely used fishing gear in global fisheries because of their simplicity, high operability, catch efficiency and low entrance cost for fishermen. In Norway, the Northeast Atlantic (NEA) cod (*Gadus morhua*) fishing industry represents the most important economic single species fishery and the gillnet fishery accounts for 24% of the national total allowable catch (TAC) of NEA cod. Despite the importance of the gillnet fishery in Norway, significant amounts of gillnets are lost at sea each year. As gillnets are made of synthetic materials (i.e. nylon) with high breaking strength and durability, lost, abandoned and/or discarded fishing gear (LADFG) continues catching target and non-target species for years. This phenomenon, known as "ghost fishing", cause negative impact on the benthic marine environment and to the fisheries management. Over the last years, the development of biodegradable gillnets to replace traditional nylon gillnets has become particularly sought after in fisheries worldwide. However, biodegradable gillnets are less efficient and more expensive than traditional nylon gillnets. As the urgency to eliminate the negative environmental impacts of LADFG increases, a crucial question remains how to successfully implement biodegradable gillnets to replace the more efficient nylon gillnets currently used in commercial fisheries. In this article we investigate how central elements of fisheries management may be used to implement biodegradable gillnets and how this may challenge the current resource allocation policy among different gear- and vessel groups.

### 1. Introduction

Globally, gillnets are among the most common fishing gear adopted in both developing- and industrialized countries [1]. Gillnets may be used for demersal- and pelagic fisheries, and by vessels ranging from artisanal- to deep-sea vessels. The popularity of gillnets is determined by their simple- and open technology and low entrance cost to commercial fisheries. Therefore, gillnets are often considered an essential component for the maintenance of especially coastal fisheries, local value-chains and employment systems in fisheries-dependent areas [2,3].

Gillnets are also widely used in commercial fisheries throughout the North-east Atlantic Ocean (NEA), especially by the coastal fleet. In Norway, the NEA cod (*Gadus morhua*) fishery represents the most important economic single species fishery. For the coastal fleet, gillnets accounted for 24% of the national total allowable catch (TAC) of NEA cod in 2019 [4]. Coastal- and inshore fisheries are especially adapted to

the NEA cod's migrating pattern. During the winter season (January–April), most of the adult population of the NEA cod stock migrate to adjacent waters off the Lofoten archipelago (northern Norway) for spawning. As cod is easily available in this period, gillnet fisheries are generally viewed as a low cost, catch- and fuel-efficient activities [5–7], contributing to the large seasonality of the fishery [8]. In addition, the gillnet fishery also represents the potential to produce low quality fish, which impact the value creation throughout industrial value-chains [9] (i.e. if the soaking-time for gillnets is too long, the fish quality may be heavily reduced [10]).

However, despite the popularity of gillnet fisheries, grave environmental concerns arise from the significant number of gillnets lost at sea every year [11,12].<sup>1</sup> This lost, abandoned and/or discarded fishing gear (LADFG) continues catching target and non-target species, a phenomenon known as "ghost fishing", and causes negative impacts on the benthic environment. The exact figure that quantifies the impact of

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E-mail address: [Dag.Standal@sintef.no](mailto:Dag.Standal@sintef.no) (D. Standal).<sup>1</sup> The Norwegian Environment Agency [11] suggests that more than 13,700 gillnets are lost each year, while the Fisheries Directorate [12] suggests that around 1000 gillnets are lost per year.<https://doi.org/10.1016/j.marpol.2020.104238>

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unintended capture by LADFG is not known, but it is widely acknowledged that ghost fishing increase the fishing mortality (F), contributes to alternative economic losses and undermine the principles for a sustainable fisheries management [12]. LADFG also contributes to plastic pollution entering the marine trophic chain, which requires additional costs related to clean-up operations and ultimately has a negative cascading effect on other business- and social activities [13].

The extent and gravity of the problem increased significantly with the introduction of synthetic fibers made of polyamide (nylon), a technological advancement that augmented fishing capacity and economic profitability of fisheries worldwide [13]. As gillnets are made of synthetic materials with high breaking strength and durability and are placed at strategic points on the migration routes of target species (NEA cod), LADFG may fish significant amounts of fish for years at sea.

The international recognition of the challenge posed by LADFG is demonstrated by the large number of international organizations and agreements that focus on LADFG [13–15]. Efforts to assess the environmental impact of LADFG are extensively documented in the literature [13,16,17] and several initiatives to reduce the negative effects of LADFG (e.g., collection of used gillnets, measures to trace/track LADFG and the development of biodegradable fishing gear) have gained increased interest and popularity [13]. Over the last decade, the development of biodegradable gillnets to replace traditional nylon gillnets has become particularly sought after in fisheries worldwide [13]. The basic idea is that biodegradable gillnets break down and, if lost, disappear after a specific amount of time at sea, thus, preventing the occurrence of ghost fishing and the impacts related to LADFG.

However, extensive fishing trials for NEA cod, carried out in Norwegian waters have proven biodegradable gillnets to be less efficient in terms of catch per unit effort (CPUE) than traditional gillnets made of nylon [18–20]. In addition, biodegradable gillnets are more expensive than nylon gillnets. The use of biodegradable gillnets, thus, represents an initial extra cost for small-scale gillnet fisheries. However, in a long term perspective, the removal of LADFG may contribute to a collective gain in terms of a better fisheries management, larger fish stocks and quotas for all gear- and vessel groups (trawl, line, demersal seining, jigging, etc.) harvesting the NEA cod stock.

Despite the negative impacts derived from ghost fishing, the extensive use of gillnets by the coastal fleet constitutes a strong position among fishers and in the political landscape. Maintenance of a large coastal fleet to support the social fabric in fisheries dependent areas are prioritized policy goals in Norway. An initial public decree to heavily restrict or prohibit gillnet fisheries, are thus not a viable political option. Instead, as technological alternatives are available, public authorities, the gear-industry and research and development institutions seek to find incentives to stimulate the fishers towards more sustainable alternatives, which can replace the use of nylon gillnets.

In this article, our main research question is to what extent an institutional approach may effectively favour the implementation of biodegradable gillnets in NEA cod fisheries. We investigate how central elements of fisheries management (i.e. use of quota resource allocation regime) may be used to achieve specific policy goals such as implementing biodegradable gillnets and how this may challenge the current resource allocation policy among different gear- and vessel groups. The article is organized in the following sections: in Section 2, we present a framework aimed at understanding the central position of coastal gillnet fisheries in Norway and how new stakeholders introduce new values and norms to the sustainability discourse. In Section 3, we outline the impact of lost gillnets, the catch rates and potential value losses for commercial gillnet fisheries. In Section 4, we discuss how fish quotas may be used as governance initiatives to stimulate the transition towards the use of biodegradable gillnets. We outline how the individual and collective gains oppose each other and how the principles of resource allocation regime may be used to implement biodegradable gillnets and avoid ghost fishing.

## 2. Conceptual framework

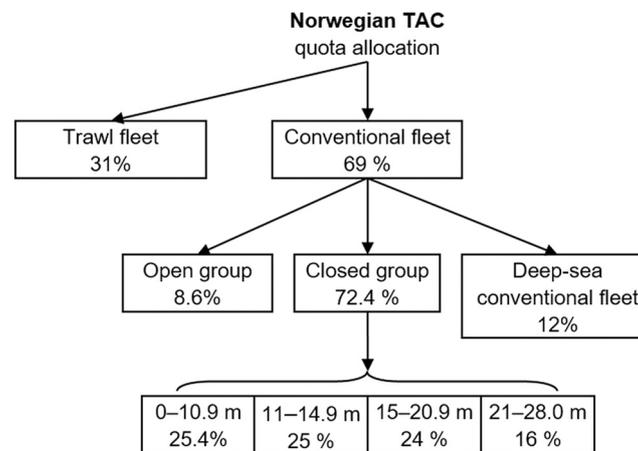
In Norway, discussions about technological adaptations of fishing gear and their effects on biological, economic, and social sustainability have always been a priority on fisheries' political agendas [21–24]. The common property theory's fundamental assumption is that fish resources are a common property and they are limited. For the individual fisherman it is rational to maximize the economic values derived from their allocated quotas. Since the introduction of a TAC regime in 1977, technological adaptations to fisheries have been a controversial subject, resulting in severe resource allocation conflicts among different gear and vessel groups [25]. Industrial stakeholders, such as the land-based fillet processing industry, argue that coastal seasonal fisheries are not able to provide the processing industry with a stable fish supply. The industry thus advocates deep-sea trawling to secure year-round supplies to maintain employment and meet the demand of international markets [26]. Opposing the industrial approach, stakeholders from fisheries dependent regions and local communities support coastal fisheries and small-scale entrepreneurs, viewing them as the most sustainable business model. Coastal fisheries' seasonal activity, which is based on NEA cod's migrating pattern, supports the basic structures of fisheries-dependent regions, especially in the northern Norway. Therefore, fishing with gillnets and other conventional gear (i.e., lines, pots, and seine), represents a natural adaptation, necessary to maintain a decentralized production system, while large-scale industrial structures are perceived as a threat to the way of living of local fishing communities [27].

Discourses and divergent views about the use of specific technologies, often mirror how different stakeholders define problems and address solutions in society. Such processes can be described as a *framing process*. According to Bijker [28], a frame is a boundary and framing is the process of producing this boundary. The concept of technological frames refers to the ways in which relevant social groups (e.g., industry, coastal fishermen, fisheries authorities, or local communities) evaluate the effects of different technological adaptations. Relevant for harvesting limited fish resources, the concept of technological frames is a way of interpreting the technological adaptations regarding sustainability, the appropriate structures for solving the problems and the institutional requirements a solution may meet. In this context, a technological frame is a socially constructed combination, reflecting current theories, tacit knowledge, engineering practices and bargaining among different stakeholders.

The theory that defines technology as a social construct suggests that the reasons for the acceptance or rejection of specific technologies (e.g., those employed in coastal vessel and gillnet fisheries) reside in society itself [28,29]. Based on this concept, actors within the field of *social constructivism* are engaged in dissociating the primary cause from the individual inventor (or technical "genius"), by removing the boundaries between technical, social, economic and political processes connected to technological adaptations.

Within this framework, one cannot explain the success of specific technological adaptations by saying that they are merely "the best" or isolated achievements of skillful engineering. Instead, one must investigate how the criteria of "being the best" are defined and how they reflect society. It is necessary to consider which groups and stakeholders participate in creating the definitions by which success or failures are measured. Consequently, in a social constructivist perspective, technology is not decoupled or isolated from factors related to law, economics, politics and institutions operating within society [28].

For generations, coastal fisheries and the use of conventional gear, such as gillnets, seines, lines and pots, also known as the conventional fleet, have represented a simple, cheap and highly efficient technology adaptation to the local environment, essential to maintain employment in fisheries-dependent communities and small-scale production systems [7]. The central position of coastal fisheries wanting to maintain local ownership in these regions is also supported by the Norwegian Fishermen's Association (NFA), which states that coastal fisheries shall be the



**Fig. 1.** The NEA cod quota allocation system,<sup>21</sup> different gear- and vessel groups in 2018. Source: Fisheries Directorate [33].

profound backbone of the national fishing fleet [30]. The strong position of coastal fisheries is also reflected in public policy goals and expressed in the important resource allocation keys of TAC's among different gear- and vessel groups; particularly for the important and most valuable NEA cod fisheries in the high north [25,31,32]. Fig. 1 shows how the Fisheries Directorate [33] divided the national TAC of NEA cod (376,575 tonnes) among groups in 2018.

In 2018, 69% of the NEA cod TAC (259,837 tonnes) was allocated to vessels fishing with conventional gear, such as gillnets (96,766 tonnes), longlines (79,576 tonnes) and demersal seines (87,838 tonnes), while 31% was allocated to the trawler fleet (112,125 tonnes). Other fishing gears (purse seine, pots and traps) accounted for the rest of the TAC [4]. Within the conventional fleet, the year-round coastal fleet (closed group) was allocated the largest share among all groups (72.4% of the conventional fleet), while the open group (part-time fishermen) was allocated 8.6% of the conventional fleets' group quota. The deep-sea conventional fleet, mainly fishing with longline, was allocated 12% of the quota. In the last decade, the numbers of deep-sea vessel (over 28 m) within the coastal fleet has increased rapidly, from 17 vessels in 2008 to 64 vessels in 2014, with these vessels having quotas from steadily smaller coastal vessel groups, even below 11 m [34]. Likewise, there is a tendency that deep-sea conventional vessels gradually change from the use of long-line and gillnets to long-line and demersal seines, e.g. the vessel M/S Atlantic [35]. The landing of the conventional fleet in the last 20 years is shown in Fig. 2.

According to Armstrong [36], resource allocation among gear and vessel groups is not based on science, (i.e., on which technological adaptations or fleet structures fulfil specific requirements). Instead, it is based on political goals to maintain a diverse fleet structure and on historical catch shares among different gear and vessel groups prior to the closing of the commons in 1991 [37]. In order to establish a stable and predictable quota allocation regime the Norwegian Fishermen's Association (NFA) proposed the introduction of allocation keys among groups. First, the system outlined a simple group division of cod quotas between the fleet fishing with conventional gears and the trawler fleet. When the individual vessel quota system (IVQ) was introduced to the coastal fleet and the deep-sea long line fleet during the early 1990's, the resource allocation regime became more detailed. In this setting the trawler fleet, the coastal fleet and the deep-sea long line fleet were allocated specific percentage shares of a given TAC of NEA cod [25].

In a long-term, resource allocation keys are essential to secure coastal fisheries and local production systems. Transfer of quotas across the deep-sea fleet and coastal vessels, due to the ITQ's, is thus forbidden. While LADFG has not traditionally been a cause of concern, due to the historic traditions of using gillnets the negative impact on marine

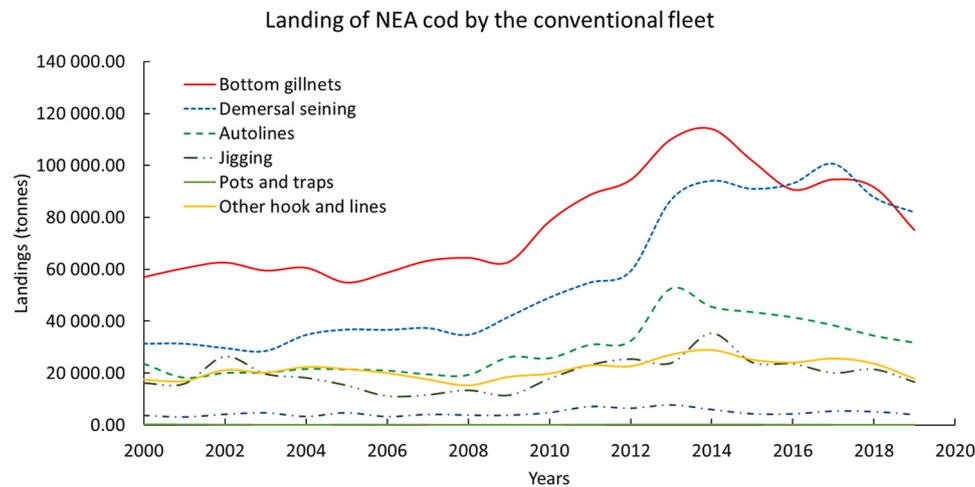
ecosystems have now gained increased attention. New stakeholders, such as environmental NGOs, joined the debate and brought new perspectives to gillnet fisheries and to the sustainability discourse. In addition, the ecosystem management approach outlined by the Ocean resources Act [38] have gained increased momentum. The employment of gillnets, once accepted as a natural adaptation to the local environment, is now challenged by new sustainability imperatives, which were not previously part of the traditional coastal fisheries' attributes.

As new stakeholders join the discourse, it is essential to understand how different actors or social groups seek to impose- and defend different interests, values and norms in the sustainability discourse. In this setting, stakeholders with a stronger environmental perspective view gillnet fishery as a source of LADFG and consequently see ghost fishing as a threat to the management of fish resources, causing negative impacts on marine ecosystems [15]. The various ways of evaluating specific technologies also reflect how different interests interpret different understandings of artefacts, their technical characteristics and ultimately their effects on the environment and society. In this context, the choice of a technology that are accepted or rejected in society, does not necessarily need to be based on "true" or objective values (i.e. most efficient, most profitable, easiest to handle, most environmentally friendly); it also depends on which stakeholders manage to gain acceptance of their business views, by promoting a strategy, defining the problems and presenting the right solutions to fulfil their self-interest in the political landscape. In the recent years, due to the increased focus on fisheries to fulfill environmental sustainability attributes (i.e. Marine Stewardship Council (MSC) standards [15]), the implementation of biodegradable gillnets to avoid ghost fishing has gained increased importance.

As different fisheries technologies represent different properties due to i.e. efficiency, handling and operating cost, choices of technologies may also reflect conflicting goals. In this context, fishing with i.e. nylon gillnets may benefit the coastal fishermen but may be less sustainable than degradable gillnets, due to ghost fishing. Hence, as different technologies are available, choices of technologies may also correspond to the "prisoner's dilemma". In this perspective, specific choices may benefit individuals or specific groups, but may not benefit the commons or all gear- and vessel groups harvesting NEA cod [39].

### 3. Gillnet fisheries in Norway

In 2019, the coastal fleet comprised 5 712 vessels smaller than 27.9 m. Of these, 96% were smaller than 14.9 m [4] and freely allowed to choose between conventional gears (gillnet, lines, longlines, seines, pots). Since most of the vessels are smaller than 14.9 m are unable to



**Fig. 2.** Landing of NEA cod by the Norwegian conventional fleet in the period 2000–2019.  
Source: Fisheries Directorate [4].

**Table 1**

Gillnet landings of NEA cod (tonnes) and first-hand value (1000 NOK)<sup>a</sup> divided by the total coastal fleet's length groups.

Length group	2016		2017		2018		2019	
	Landing	Value	Landing	Value	Landing	Value	Landing	Value
Under 11 m	34,068	444,122	36,261	529,977	39,087	647,274	30,319	622,283
11–14.9 m	35,403	481,216	37,408	568,935	35,245	601,762	29,314	618,568
15–20.9 m	8068	112,469	7594	114,944	6210	106,635	6400	136,707
21–27.9 m	8,281	132,156	6833	114,776	5320	101,673	4202	95,164
Over 28 m	4,441	75,958	6096	114,011	5315	117,649	4328	106,609
Other <sup>b</sup>	4,635	69,101	5736	100,838	5589	112,986	4540	104,135
SUM	94,896	1,315,022	99,928	1 543,481	96,766	1,687,979	79,119	1,683,466

<sup>a</sup> The statistics are based on landing and final data submitted by the Norwegian fish sales organizations to the Fisheries Directorate.

<sup>b</sup> These numbers include landings of drift gillnets and from not-defined vessel's length groups. Also include recruitment and research quotas.

Source: Fisheries Directorate [4].

operate demersal seines, they use gillnets, which are a very efficient, cheap, and easy to handle fishing gear. In 2019, vessels smaller than 27.9 m were responsible for 89% of the gillnet landings (79,119 tonnes) of NEA cod and a first-hand value of 1.68 billion NOK (Table 1). The NEA cod fishery is highly seasonal, with the largest catches during the winter season (January–April) [8].

The standard operating procedure of a gillnetter is that vessels leave the port before dawn and head for the fishing grounds close to the mainland, where gillnets are organized in different sets and positioned at various locations. Commonly, gillnets are hauled in the morning and deployed during the middle of the day or afternoon. Normally, gillnets are hauled after a maximum soaking time of 24 h to enhance efficiency and fish quality. Today, coastal vessels are equipped with electronic navigation systems and acoustic fish detection devices (i.e., sonars and echosounders), and gillnetters use automatic net haulers and net clearers that allow vessels to be operated efficiently by small crews. The number of gillnets used by the coastal fleet varies according to the size of the vessel. Vessels smaller than 11 m, normally operated by one or two persons, use 80–100 gillnets<sup>3</sup> per fishing trip, while vessels between 20 and 27.9 m, with four to five crew members, operate 180–220 nets. As gillnet fisheries for NEA cod target the adult population migrating during the winter season, coastal fisheries are described as energy efficient, due to low fuel consumption per kg of caught fish [40].

Furthermore, according to the Fisheries Directorate [41], the coastal fleet also showed positive operating profits over the last few years.

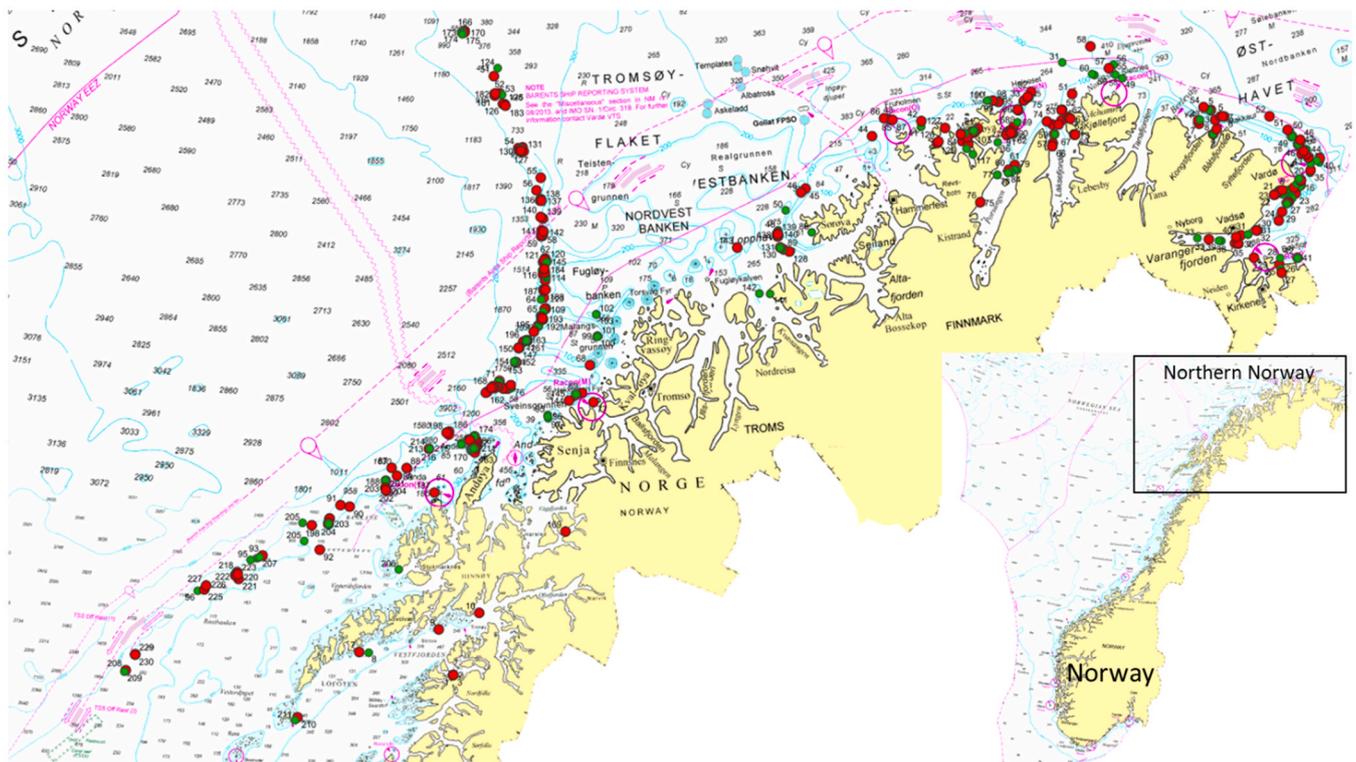
However, despite the GPS systems used for accurate gillnet localization, a significant proportion of gillnets is lost at sea every year. Deshpandea et al. [42] provided estimates of the annual loss rates of six types of fishing gear in Norway and identified gillnets as the primary source of LADFG. Although fisheries authorities lack an exact figure for the amount of lost gillnets, estimates from the Norwegian Environment Agency [11] suggest that more than 13,700 gillnets are lost each year,<sup>4</sup> while estimates from the Fisheries Directorate [12] suggest that the number is closer to 1000 gillnets per year.<sup>5</sup> Norway is one of the few countries that has a program in place to systematically retrieve lost gear from high fishing pressure areas. Since 1983, more than 22,000 gillnets (and associated buoy-lines) have been retrieved. The annual number varied between 106 and 1180 retrieved gillnets, with a mean number ( $\pm$ SD) of  $583 \pm 279$  gillnets per year. As gillnets are located in abundant fishing grounds, retrieved ghost gear often contains large amounts of fish and other benthic species. The variable number of retrieved gillnets is mainly associated with uncertainties about their position and highly demanding retrieval operations [12] (Fig. 3). It is important to mention that the majority of gillnet fisheries harvesting NEA cod operate at great depths and in areas affected by strong currents. In the event a gillnet breaks near the surface (or the buoy-line near the gillnet), it may drift

<sup>2</sup> For a detailed review of resource allocation discourse, see [25,31,32].

<sup>3</sup> Each assembled gillnet is 27.5 m long and depending on the number of meshes in height, that varies between 30 and 50 meshes, it could be between 3 and 5 m high [19,20].

<sup>4</sup> Based on interviews to coastal fishermen conducted by NTNU-Sustainability in the summer–autumn 2017 [11].

<sup>5</sup> Based on the number of reported lost gillnets (Gjermund Langedal, Fisheries Directorate 2020, pers. comm).



**Fig. 3.** Position of retrieved gillnets along the coast of northern Norway, 2017–2019. The red circles indicate retrieved lost gear and the green circles indicate reported lost, but not found, gear. Source: Fisheries Directorate [12].

over a long distance before settling again and its position will be lost. Similarly, in the event of gear collisions, gillnets may be displaced and drift far from their original position, and it would be impossible to locate them.

Gillnets are lost every year in key fishing grounds for commercially important fish species and the magnitude of the losses each year is cumulative. Considering that only 50–60% of the reported lost gillnets are retrieved every year, the remaining lost gear continues accumulating at sea and may ghost fish for decades (Fig. 4). Many studies attempted to estimate the fish mortality rates and the extent of ghost fishing, but the majority contain significant levels of uncertainty [13]. Carr and Cooper [43] estimated that groundfish gillnets with a soaking time of at least four years could catch approximately 15% of the commercial catch rates. In Norway, Humborstad et al. [44] estimated that the catch efficiency of lost gillnets tended to stabilize after 21–45 days at sea, maintaining 20–30% of the initial efficiency and continuing fishing at this rate for several years.

To illustrate the extent and magnitude of NEA cod ghost fishing in Norway, we provide in Table 2 a rough estimate of the accumulated number of lost gillnets using the estimates from the Fisheries Directorate [12] and those from the Norwegian Environment Agency [11], the amount of NEA cod caught by the lost gear over a period of one, five and ten years and today's first-hand value of this unintended catch. The estimate is based on the landings per vessel-length group (Table 1) and assuming that: (i) the mean number of fishing days at sea is 30, during the winter season (January–April); (ii) the mean number of gillnets used by a coastal vessel is 151; (iii) the number of reported lost gillnets per year is around 1 000 units and they are lost in commercially important fishing grounds; (iv) 50% of reported lost gillnets are successfully retrieved every year, (v) lost gillnets maintain at least 15% of the catch efficiency that new gillnets have; (vi) the catch efficiency of lost gillnets is fairly stable for at least ten years.

Based on the Fisheries Directorate's data, the results of this estimation report a potential accumulated number of 5 000 lost gillnets over a

period of ten years, and an accumulated volume of 24 288 tonnes of NEA cod caught by ghost fishing. This volume is equivalent to almost 3.1% of the TAC of NEA cod for 2019. Today's first-hand value of a catch resulting from ten years of ghost fishing would be equivalent to 517 million NOK (Table 2). When using the Norwegian Environmental Agency's data, the potential accumulated number of lost gillnets reaches 137,000 over a period of ten years, with an accumulated volume of 666 458 tonnes of NEA cod caught by ghost fishing. Since it is uncertain for how long gillnets keep ghost fishing and at which catch rates after 1, 5 and 10 years, the results from 5 and 10 years in particular, should be taken cautiously. Despite the uncertainties in our estimate, we observe that the accumulated number of lost gillnets, catch rates from ghost fishing and the potential first-hand value are substantial and highly significant. These figures illustrate that ghost fishing has a negative impact on the NEA cod fish stocks and on the economic efficiency of the fishery.

To prevent the negative effect of LADFG, the development and use of biodegradable gillnets to replace nylon gillnets has been proposed and has gained significant attention. Biodegradable gillnets maintain similar mechanical properties as conventional nylon gillnets during fishing operations, but are completely degraded in seawater by naturally occurring microorganisms, such as bacteria, fungi and algae, when dispersed in the marine environment [45]. Hence, replacing traditional nylon gillnets with biodegradable alternatives can significantly reduce ghost fishing and marine plastic litter (from macro- to microplastics) caused by non-degradable lost gillnets [46]. In the last decade, biodegradable gillnets have been widely studied [47–54] and are currently being used in commercial fisheries in South Korea, China, and Japan. Since 2016, biodegradable gillnets have also been intensively tested in Norwegian gillnet fisheries targeting NEA cod (*Gadus morhua*), saithe (*Pollachius virens*) and Greenland halibut (*Reinhardtius hippoglossoides*) to reduce the negative impacts of LADFG [18–20]. However, commercial fishing trials show that biodegradable gillnets are 21% less efficient and twice as expensive as conventional nylon gillnets [20]. To illustrate the



**Fig. 4.** Photograph showing a 30–40-year-old lost gillnet retrieved off the coast of Tromsø (Northern Norway) with newly caught NEA cod and saithe (*Pollachius virens*). The use of plastic rings to provide buoyancy to the gillnets was a technique used in the 1980s. Since the early 1990s, ropes containing floating elements are commonly used as float lines.

Source: Roger B. Larsen, the Arctic University of Norway, 2017.

effect of replacing nylon with biodegradable gillnets on the economy of a coastal gillnetter, it is worth considering an example provided by Grimaldo et al. [20] of a 10.9 m coastal vessel fishing for NEA cod with gillnets during the winter season in northern Norway. If all his six sets of nylon gillnets (120 in total) were replaced by biodegradable gillnets, fishing operations would have led to a 21% reduction of the total catch of NEA cod, decreasing from 97 to 77 tonnes, which corresponds to approximately a 0.51 million NOK loss in gross revenue. Moreover, as biodegradable gillnets are twice as expensive as nylon gillnets, the additional cost of using 120 biodegradable gillnets would amount to 36,000 NOK.

Overall, the total increased costs due to the 21% reduction in catch efficiency and the higher cost of biodegradable gillnets, equal 0.54 million NOK. In order to maintain the same gross catch rates usually obtained with nylon gillnets, vessels would need to increase either the number of gillnets deployed (by 25 gillnets) or the amount of time spent

fishing at sea (an extra 5.4 days). This compensation strategy would not only increase fuel consumption per kg of caught fish for the vessel using biodegradable gillnets, but it would also limit fishing operations and potential alternative income for other fisheries using traditional nylon gillnets. From an economic perspective, this example shows that biodegradable gillnets cannot compete with traditional nylon gillnets in terms of efficiency. Lower catch efficiency and increased costs, thus, represent the main reason why fishermen are unwilling to replace traditional nylon gillnets with biodegradable ones. In addition, the operational costs are low in this fleet during the peak season. As they also may have free operating days, due to limited quotas, there may be limited alternative costs at this part of the year. In addition, a lower CPUE may contribute positively for the society, as it reduces the seasonality and adds capacity to improve the fish quality.

#### 4. Discussion

For fishermen, the use of nylon gillnets represents the most efficient adaptation, while biodegradable gillnets yield reduced catches, require extra costs, and increase fuel consumption per kg. of caught fish. However, while being the most efficient fishing gear, nylon gillnets that remain dispersed at sea for years contribute to the NEA cod stock depletion and ultimately impose collective costs to all gear and vessel groups harvesting this species (between 517 and 1 418 million NOK annually as estimated in Table 2). Additionally, ghost fishing introduces uncertainties in resource management because fish mortality becomes more complicated to calculate.

The short-term individual gains from using nylon gillnets and the long-term collective costs imposed by ghost fishing reveal how the individual- and collective rationalities work against each other, when managing limited and common fish resources. This conflict is described as the "prisoners dilemma" in game theory and in the common property theory [39,55]. As the employment of either nylon or biodegradable gillnets is optional in Norway under the current policy, the use of biodegradable gillnets is generally disregarded by individual fishermen, as it is less efficient and more expensive than nylon gillnets. Moreover, for the individual gillnet fishermen considering using biodegradable gillnets, they do not know the other fishermen's willingness to use biodegradable gillnets. Hence, the potential effects from using biodegradable gillnets, are not only a matter of their own individual choices but also depends on other fishers behaviour. Therefore, the collective effects derived from each individual choice to employ this gear remain uncertain.

Compared to nylon gillnets, fishermen who are willing to use biodegradable gillnets, also risk facing economic losses. Hence, as long as the individual fishermen have no guarantee that they will obtain a reward because of their own self-imposed limitations, they are unwilling to voluntarily replace nylon gillnets with biodegradable ones. Decisive action aimed at the removal of ghost fishing and the consequent decrease in fishing mortality (F), are thus hard to achieve. On the contrary, the single fisherman finds it rational to use the most effective fishing gear. The reason is that harvesting with nylon gillnets benefits the individual fisherman, while the costs of overfishing, due to ghost

**Table 2**

Estimated number of lost gillnets, volume of NEA cod (tonnes) caught by ghost fishing and the catch value (million NOK) for a 1, 5, and 10-year prediction.<sup>61</sup> The estimates of lost gillnets provided by the Fisheries Directorate and Norwegian Environmental Agency are used in the prediction.

	1 years		5 years		10 years	
	Fisheries Directorate	N. Env. Agency	Fisheries Directorate	N. Env. Agency	Fisheries Directorate	N. Env. Agency
Accumulated number of lost gillnets	500	13,700	2500	68,600	5000	137,000
Catch efficiency (%)	15	15	15	15	15	15
Ghost fishing of NEA cod (tonnes)	2429	66,646	12,144	333,229	24 288	666,458
21.3 NOK per kg <sup>a</sup>	21.3	21.3	21.3	21.3	21.3	21.3
First-hand value (million NOK)	51.7	1 418	258.4	7 091	517	14,182

<sup>a</sup> Average price per kg of cod landed by the coastal gillnets fleet in 2019.

fishing, are shared with the entire fishing fleet harvesting the NEA cod stock. Consequently, gillnet fisheries lack economic incentives to replace nylon gillnets with less efficient biodegradable gillnets. Collective action among gear and vessels groups and an institutional framework are needed to provide those incentives, which would promote the use of more environmentally sustainable gillnets.

Similar to other gear- and vessel groups, such as trawlers, long-line etc, coastal vessels (gillnet included) are allocated individual vessel quotas from a national TAC (cf. Fig. 1). Hence, the use of nylon gillnets and the consequent negative effects of ghost fishing, related to a higher fishing mortality (F), represent an extra cost for all groups harvesting the NEA cod stock. Due to the strong political position of coastal fisheries, especially in the high north, the problem posed by ghost fishing is not only a question of technology (i.e. type of fishing gear). It is also directly connected to the institutional framework of the management system. As modern fisheries are managed by- and through institutions [56], a central question is to what extent an institutional approach may effectively favour the implementation of biodegradable gillnets in NEA cod fisheries.

According to Ostrom [55], common property theory puts forth fundamental strategies within the fisheries sector; it proposes the establishment of an external sphere of authority with the right to rule over common fish resources, but also to implement incentives and/or restrictions to the management regime. For the strategic options to successfully reduce ghost fishing, institutional change may be required to transform the individual fishers' basic context of rationality towards a more collective rationality of resource sustainability. Hence, the successful or poor performance of fisheries management and the ability to address future sustainability issues (i.e., ghost fishing), may be a question of institutional design.

In South Korea, the use of biodegradable gillnets is promoted by the government and fishermen get monetary subsidies to compensate for using biodegradable nets with a lower catch efficiency and at higher costs [57]. However, public financial support to fisheries using specific fishing gear, is not a relevant approach in Norway.<sup>7</sup> Other public initiatives may be relevant, such as e.g. fees or area regulations according to access to relevant fishing grounds. However, the latter would undermine the profound idea of coastal fisheries while fees could be complex to administer.

Replacing nylon gillnets for environmentally friendly biodegradable gillnets is not a technical problem. It is a management problem that demands an institutional approach. As different gear- and vessel groups are allocated vessel-quotas from a common TAC, addressing the problem of gillnet substitution and institutional change, may be connected to the use of quota resource allocation regime to achieve specific policy goals. To support the decision-making process, a better data collection of lost gillnets, should thus be prioritized.

Especially within the Norwegian NEA cod fishery, a tradition exists of using specific quota-shares actively as incentives to promote specific policy goals outlined by the government. For 2018, such policy goals refer for example to a specific quota-bonus (4 000 tonnes) to stimulate catch-based aquaculture (CBA) for live storage of wild-caught NEA cod [8], specific NEA cod quotas (7 000 tonnes) to stimulate recreational fisheries and the recruitment of young fishermen, quotas for research and development at research institutions (703 tonnes) and a significant quota of NEA cod (17,200 tonnes) as bycatch quota to increase harvest of the allocated haddock (*Melanogrammus aeglefinus*) quotas within the coastal fleet. An important element is that all these NEA cod quotas are

deducted directly from the national TAC, before sharing among groups. However, the bycatch quota (17,200 tonnes) specifically earmarked for the coastal fleet (closed group), is earmarked directly from the closed group's specific group quota. The allocated quota shares for the three first policy goals are thus collectively financed by all gear- and vessel groups, as outlined in Fig. 1, while the bycatch quota for the coastal fleet is deducted from the coastal fleets' own group quota.<sup>8</sup>

In a regulative institutional perspective, measures such as the quota-bonus to increase CBA, could parallel a public incentive to stimulate an increased use of biodegradable gillnets. In this scenario (alternative 1), gillnet fisheries using biodegradable gillnets would, thus, be allocated an extra quota-bonus to compensate for the use of less efficient and more expensive gear. With the support of a full compensation, fishermen will not suffer economic losses. However, as the quota-bonus earmarked for CBA is deducted directly from the total TAC before sharing among groups, this alternative would imply that all the other groups (such as the trawlers, long-liners etc.) would contribute with quotas to promote the use of biodegradable gillnets. Therefore, this approach leads to a reallocation of quotas among groups and lower the trawlers' and long-liners' relative quota shares of NEA cod stock to promote the use of biodegradable gillnets.

Another approach (alternative 2), that does not involve resource allocations or quota subsidies from all other gear and vessel groups, can be described as a zero-sum game within the specific gillnet fishery. Here, quota shares may be reduced for fisheries employing nylon gillnets and reallocated to the users of biodegradable gillnets.

For both alternatives, if fishing with biodegradable gillnets is awarded a full compensation for potential economic losses, this compensation in terms of extra quota-shares, should equal 21% of the efficiency loss and of the extra cost of biodegradable gillnets, as described in Grimaldo et al. [20].

However, regardless of the model or approach to reduce nylon gillnets and stimulate the use of biodegradable gillnets with extra quotas, a transfer of quotas will create severe resource allocation conflicts among different gear and vessel groups (alternative 1) or within the gillnet fishery sector alone (alternative 2). In the short term, an annual-based reallocation of quotas will be perceived as an instant quota-loss by other fisheries, while biodegradable gillnet fisheries will gain extra quotas. However, in the long term, the use of biodegradable gillnets, will decrease the amount of adult NEA cod caught by ghost fishing, contributing to a potential larger stock biomass. Hence, elimination of ghost fishing, will benefit all gear and vessel groups harvesting NEA cod.

With a better understanding of how smart technologies can improve materials, it is expected that future biodegradable gillnets will reach an efficiency closer to today's nylon nets. Therefore, the compensation for lost efficiency and higher costs associated with biodegradable gillnets may be gradually phased out in the future. However, during the transition period it is obviously necessary to provide effective incentives for the introduction of biodegradable gillnets, and the gradual replacement of nylon nets.

In this context, the powerful organization, the Norwegian Fishermen's Association organizes both coastal- and deep-sea vessels, and thus constitute a major position to unite different fishers towards collective gains [32].

Another alternative (alternative 3) could be to impose a taxation to the use of nylon gillnets that equals to the lack of efficiency when using biodegradable gillnets, a strategy which would remove the economic benefit from using nylon gillnets. Decision makers, such as central authorities and politicians, also constitute the power to simply ban the use specific technologies, e.g. nylon gillnets, especially when alternative technologies exist. However, due to the strong position of gillnets to maintain the smallest coastal fleet, a ban would impact the structure of

<sup>6</sup> Based on the annual number of reported lost gillnets per year in commercially important fishing grounds for NEA cod [30] and the mean price per kg of NEA cod landed by the gillnet fishery in 2019 [41].

<sup>7</sup> The public financial support regime, known as the Main Agreement between the government and The Norwegian Fishermen's Association, was ended in 2000 [58].

<sup>8</sup> For a detailed overview of NEA cod resource allocation for 2018–2019, see [32].

coastal fleet adaptations. A large part of the coastal fleet is too small to operate alternative fishing gears, e.g. demersal seine or automatic line systems. As such, vessel must be rebuilt or replaced by larger- and more capital-intensive vessels, an approach which may demand a larger quota-base and increased market orientation of the quota regime.<sup>9</sup>

As nylon gillnets have proven more catch-efficient than biodegradable gillnets, this article discusses the possibility to reallocate fish resources to reduce the use of nylon gillnets and stimulate the use of less catch-efficient biodegradable gillnets, to avoid ghost fishing. However, the discourse about different fishing gears that prevail in society should not only correspond to which fishing gear are the most catch efficient. In a larger context the potential use of the resource allocation regime to achieve specific policy goals, other sustainability attributes, such as e.g. fish quality or fuel intensity are vital for economic performance and value-adding of available fish resources. The use of resource allocation among different gear- and vessel groups could thus be expanded from a "narrow" discussion between nylon- and biodegradable gillnets, to a larger debate about the use of alternative technologies to reduce the use of gillnets in general. However, such an approach would trigger a debate where different stakeholders will address different sustainability attributes and technological choices, depending on their fixed place in society. Also, area regulations of different fishing gears and vessel size are widely used in modern fisheries management to achieve specific policy goals, e.g. catch profiles and organize fisheries between different gear- and vessel groups.<sup>10</sup> Hence, such management measures could also be more specifically implemented to the gillnet fishery, e.g. a ban or restriction to the use of nylon gillnets in weather exposed areas or where the losses of gillnets are significantly higher than in other areas (c.f. Fig. 3). As the resource allocation regime connects to technical input regulations, resource sharing among fishermen thus represents a powerful management tool to address specific policy goals. While resource allocation has traditionally been a question exclusively between the Fishermen's Association and the fisheries department in a corporative bargaining model, relatively newcomers such as environmental NGOs and sustainability labels (e.g., the MSC), have gained significant roles in the sustainability discourse. The MSC holds a powerful position in regards to sustainable approval and market access for the most important global commercial fisheries (www.msc.org). While the MSC-certification standards originally corresponded to sole biological management principles (such as maximum sustainable yield (MSY), precautionary approach (PA) criteria determined by safe limits for size of spawning biomass, productiveness and limits for fishing mortality, LADFG is now being gradually included as a supplementary sustainability attribute. According to MSC: [15].

"We are working with NGOs, fishery managers and scientists to see how we (MSC) can improve the MSC Fisheries Standard's requirements around ghost gear. We want our Standard to reflect the current best practice in management of abandoned, lost- or discarded fishing gear. *If any part of the Standard is revised, a new version will be released in March 2022.*"

This means that aspects related to LADFG may be implemented as sustainability attributes in MSC Fisheries Standards by 2022. The maintenance of the MSC-certification and best available market-access for the NEA cod fishery should encourage gillnet fisheries to see a clear advantage in using biodegradable gillnets. However, what will be the acceptable standards related to LADFG within the frame of MSC, may be subject to debate among legitimate stakeholders. In this context, sustainability labels and the best market access may impact the transition towards the use of biodegradable gillnets. However, a quota compensation for the use of less efficient biodegradable gillnets, will

ease the transition. Here, the options may include a full compensation, a public decree to ban nylon gillnets and a control system to enforce the use of biodegradable gillnets, a partial quota-compensation, or a voluntarily approach. The future status of the gillnet fisheries depends on negotiations and interpretations of values and norms based on the principles of sustainability and on the ability of stakeholders to address the problem and find a future solution.

#### CRediT authorship contribution statement

**Dag Standal:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing. **Eduardo Grimaldo:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Funding acquisition. **Roger B. Larsen:** Writing - original draft, Funding acquisition.

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#### Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.marpol.2020.104238](https://doi.org/10.1016/j.marpol.2020.104238).

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<sup>10</sup> For a survey of area regulation in the Lofoten NEA cod fisheries [60].

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