INdIGO

INnovative fIshing Gear for Ocean

T1.1.3 - The Economic Impacts of ALDFG and Ghost Fishing: the Role of Biodegradable Fishing Gear as a Mitigation Measure

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Contents

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Executive Summary

Marine litter is estimated to have large and wide-ranging impacts on the marine environment. However, few studies have attempted to address the economic costs of marine litter. The few examples that are available tend to address impacts and costs either globally (e.g. Beaumont et al., 2019) or by economic region (e.g. Mcllgorm, Raubenheimer and Mcllgorm, 2020). While global commitments are needed to address the marine litter problem, and progress is being made in this regard, mitigation measures will be delivered at the national level.

Abandoned, lost or otherwise discarded fishing gear (ALDFG) is a global problem. However, the level of ALDFG and the resultant impacts (environmental, economic and social) vary, being dependent on various factors e.g. the size of fleets, fishing activity and options for the disposal of end of life fishing gear. In the EU, it is estimated that fishing gear accounts for 27% of all marine litter. In those fisheries classified as 'data poor' the level of ALDFG could be much higher.

Ghost fishing represents one of the main impacts of ALDFG. It is created by fishermen themselves and impacts directly on their livelihood. Ghosting fishing is, therefore, in direct competition with commercial fishing. In this study, we addressed the role of biodegradable fishing gear (BFG) as a mitigation measure to address ALDFG and ghost fishing by developing an economic model to estimate the cost of ghost fishing and the costs and benefits of BFG as a mitigation measure. We found that under most scenarios modelled, the use of financial incentives would be essential to facilitate the uptake of BFG in the fishery we studied. The vessel level analysis provides value as it demonstrates the impacts of ALDFG, ghost fishing and the role of BFG is affected by vessel characteristics. For example, in one scenario modelled the level of financial incentive required to maintain profitability was £90,000 for an over 10m gillnetter, while it was £30,000 for an under 10m potter. In another scenario modelled, we demonstrate an increase in profitability from BFG use. On the whole, as the majority of the incentive is required to offset declines in fishing efficiency (i.e. BFG catches less fish per unit of effort); we demonstrate that integrating BFG into a circular economy for fishing gear is a technical problem and not an economic one.

Overall, our research has demonstrated the potential for BFG to mitigate ghost fishing, which is a significant problem in fisheries around the world.

1. Introduction

This report has been prepared for Work Package 1 – Task 1.1.3. The purpose of the report is to provide a resource base to support fishermen in their decision to invest in Biodegradable Fishing Gear (BFG) to mitigate the ghost fishing impact caused by Abandoned, Lost, or otherwise Discarded Fishing Gear (ALDFG), which has a direct economic impact on fishermen in the Programme Area.

1.1 Background and context

Global seafood production has grown at an average annual rate of 3.1% since 1961, reaching 179 million tonnes in 2018 (FAO, 2020). While production from capture fisheries has stagnated since the 1980s, growth in aquaculture (which now accounts for more than 50% of global fish production) has resulted in a year on year increase in seafood production. The sustainability of fisheries is measured against various metrics (that fall broadly under environmental, economic and social criteria) with 70% of stocks fished at their maximum sustainable limit (FAO, 2020). However, the demands of a growing global population, which is expected to reach almost 10 billion by 2050 (UN, 2019[1]), means that fish will become an ever more important source of food, both for developing and developed countries. From a resource exploitation perspective, this increases the potential for further pressure on fish stocks e.g. IUU fishing.

Alongside overfishing, the increasing stock of marine litter in the world's oceans represents a growing concern. The increasing stock of plastic in the world's oceans is correlated with the phenomenal growth in global plastic production, which has fostered a plastic dependent economy. From the 1960s, the production of plastic has grown exponentially, especially in the last two decades. Since 2004, the world has produced as much plastic as it did in the previous 50 years. In 2015, 322 million tonnes of plastic is estimated to have been produced globally (Lusher, Hollman and Mendoza-Hill, 2017). The growth in plastic production has created more than 6 billion tonnes of plastic waste. While (in theory) most plastics are recyclable, (in practice) most is disposed in landfill (largely due to the economic costs associated with recycling, which creates a 'value gap' in that the costs of recycling are not met with the raw material produced). Rhodes (2018) estimate that as much as 79% is disposed in landfill, 12% is incinerated and only 9% is recycled. According to Jambeck et al., (2015), 275 million tonnes of land-based plastic waste was generated in 192 coastal countries in 2010 alone, with somewhere between 4.8 and 12.7 million tonnes estimated to end up in the world's oceans every year. Furthermore, the IUCN[2] report at least 8 million tonnes of plastic enters the oceans every year, which equates to 80% of all marine debris. While various estimates are available for the annual production of plastic, plastic waste and the amount of plastic that finds its way into the world's ocean, most estimate an exponential growth rate in the coming years (at a greater rate than seen previously). Lusher, Hollman and Mendoza-Hill (2017) discuss the possibility of a doubling in plastic production to 600 million tonnes by 2025 and more than 1 billion tonnes by 2050. At the current rates of recycling, coupled with inefficient land based waste management systems (which are responsible for plastic leakage in to the oceans), the marine environment will be overwhelmed by plastic. For example, the

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[1] https://www.un.org/development/desa/en/news/population/world-population-prospects-2019.html

[2] See: https://www.iucn.org/resources/issues-briefs/marine-plastics

recent global increase in the use of facemasks during the current pandemic has resulted in an immediate increase in the reports of facemasks in the ocean. Bondaroff and Cooke (2020), estimate that as many as 1.56 billion masks entered the oceans in 2020 alone.

Marine litter represents one of the biggest threats to the health of oceans, considering its accumulation and dissemination from both land-based and ocean-based sources (EU, 2021[3]). Marine litter is, therefore, one of the biggest threats to fisheries and the livelihood of fishermen. In fact, the fishing industry is directly impacted by its own contribution (through ALDFG) to the stock of plastic in the oceans. The European Commission[4] estimate that as much as 27% of marine litter in EU sea basins is caused by the fishing industry[5]. ALDFG refers to fishing gear that is not under the management of fishermen for whatsoever reason (whether deliberate e.g. discarded or by accident e.g. lost through gear conflict). This is the crux of the problem that is being addressed in the INdIGO project. The fishing industry are contributing (by either design or accident) to a problem that it is also directly affecting the fishing industry. Given ALDFG is a significant source of plastic waste in the marine environment, and that it can cause a variety of environmental problems (perhaps for hundreds of years) after becoming ALDFG (e.g. ghost fishing, habitat/ecosystem damage, navigation hazard, livelihood impact etc.), before breaking down into the arguably more damaging microplastic (Napper and Thompson, 2020), much effort (including several research projects) is currently directed towards finding solutions[6].

However, there is a general recognition that resolving the plastics problem is not a simple matter of banning plastics use. In fact, the complete replacement of plastic in the world economy is not currently a realistic (or even desirable) solution. Rather, research and development is required to integrate plastic into a circular economy, with a clear focus on the 'reduce' and 'reuse' elements before the end of life recycling. A circular economy for fishing gear could help solve the economic impacts of ALDFG – e.g. ghost fishing - and there is a growing body of research that focuses on the need to 1 – reduce ALDFG in the marine environment and; 2 - remove as much ALDFG from the marine environment as possible. To address this one of the objectives of the INdIGO project is to review the development of a circular economy for fishing gear.

The main objective of INdIGO is to develop new BFG, focussing on the 'reduce' element of the circular economy for fishing gear. Fishing gear, which has a reduced lifespan in the marine environment can help address the environmental impacts of ghost fishing, along with other negative externalities of ALDFG, such as habitat damage, navigation hazards and ecosystem services provision e.g. food security.

[3] https://ec.europa.eu/environment/marine/good-environmental-status/descriptor-10/index_en.htm
[4] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52018PC0340&rid=9
[5] https://www.europarl.europa.eu/news/en/press-room/20210322IPR00525/parliament-urges-eu-to-take-drastic-action-to-reduce-marine-litter
[6] See: https://www.b4plastics.com/projects/glaukos/
https://www.sintef.no/en/projects/2016/bio-gillnets/
https://uit.no/research/dsolve-en?p_document_id=704783
https://pub.norden.org/temanord2020-509/temanord2020-509.pdf

However, research into biodegradability as a circularity aspect is sparse (albeit growing). The main theme that emerges from past research (Brown et al., 2005; MRAG 2020, OSPAR, 2020) suggests that biodegradability is not a 'key' circularity aspect to address the impacts of ALDFG (e.g. ghost fishing). Further, most (if not all) research that has focussed on the technical aspects of biodegradability (see e.g. Bae et al., 2012; Cerbule et al., 2022; Grimaldo et al., 2018b; Grimaldo et al., 2019; Kim, Park and Lee, 2014) as a design feature of fishing gear has concluded issues around strength and flexibility and their impact on fishing efficiency (catch rate of target species per unit of effort). In short, BFG is not put forward as a "silver bullet solution" when compared to alternatives (Wilcox and Hardesty, 2016). Having said that, as the stock of ALDFG continues to increase, it is not clear that BFG is competing against any other mitigation measure that could be considered the panacea to mitigate ALDFG and the associated impacts. Therefore, BFG deserves renewed and further attention – particularly regarding mitigation efforts for ghost fishing, as this could help fishermen in their decision to invest in BFG.

Research engaging industry stakeholders on this topic is also limited. However, what is available (Brown et al., 2005; MRAG 2020, OSPAR, 2020) suggests that fishermen have reservations about the role of biodegradability as a management response to marine litter – particularly concerning the creation of ALDFG[7]. As a result, one (or a combination of) of three scenarios is required for fishermen to invest in BFG. (1). A regulation mandating its use; (2). Consumer awareness of sustainable fishing methods, coupled with a willingness to pay for sustainably caught fish; (3). Demand from fishermen.

Notably, there is no regulation (or anticipation of a regulation in the short term) to mandate the use of BFG (1). A large scale willingness to pay study to understand the publics' willingness to pay more for fish caught using BFG (2) would likely risk confusion between lower impact fishing methods (e.g. the pot type/gill type gears that are addressed in our study) and these types of fishing methods being unsustainable. Alternatively, it could be perceived this is a study about the sustainability of fishing (in general) and the role of biodegradability in improving sustainability (when in fact the study is about biodegradability as a currently in use[8] and Extended Producer Responsibility (EPR) for fishing gear, which will be a requirement for EU Member States[9] by the end of 2024, only BFG and gear retrieval can actually prevent the long-term impacts of ghost fishing (given some level of gear loss in unavoidable).

1.2 Objective

The primary objective of this report is to provide a "resource base" to facilitate the uptake of BFG, which we consider is essential because: (1) Investing in BFG will result in an economic cost to fishermen (which may be quite substantial – depending on gear type and quantity of gear fished). (2) Further, if it is perceived that ongoing costs will also be borne by fishermen (e.g. reduced catch of target species resulting from reduced fishing efficiency), then fishermen will need to see evidence of the potential benefits in order to

[7] However, as reported in Task 1.3.2 Market Analysis, fishermen engaged in the INdIGO project have been more receptive to the idea of BFG.

[8] https://www.gov.uk/guidance/marking-of-fishing-gear-retrieval-and-notification-of-lost-gear

[9] EPR is currently being considered by UK fisheries administrations (see Defra ME5240 "end of life fishing and aquaculture gear policy options"

make an informed decision about investing in BFG. (3) Economic incentives will be required to encourage fishermen to invest in BFG. The use of economic incentives in fisheries policy previously has been damaging to the marine environment e.g. in creating perverse incentives that contribute to resource exploitation (Sumalia et al., 2013). Therefore, demonstrating the 'need' and 'correct' use of economic incentives is important for BFG.

To provide a resource base, the report will focus on the economic aspects/costs of marine litter from current and past research. This helps in providing some context and scale of the problem. We then focus on the economic and social costs of ALDFG, developing a case study on the economic impacts of ghost fishing to the fishing industry. The economic model will estimate the cost of ghost fishing and consider BFG as a management response. Engagement of the fishing industry represents a significant part of our work – particularity in validating the approach and data used in our analysis. The model will build upon the economic impacts work developed by Brown et al., (2005), which addresses economic costs to the fishing industry from lost gear. The Channel fishery is a good study area to address economic impacts, as it is home to some high value and growing fisheries. Further, static gear use is commonplace, which is considered high risk in terms of becoming lost and the resultant impacts when unmanaged by fishermen (see Gilman et al., 2021). Therefore, even with a low level of ALFDG, the economic impact (in terms of the commercial value of fish lost to ghost fishing) could be substantial. The model will utilise (largely) the value transfer method and collect data from secondary sources (mainly published research outputs as well as databases from the MMO and Seafish). This data will then be supplemented by interviews with industry representatives and fishermen (the model can largely be constructed and then verified and improved with fishermen based on various scenarios). As well as the direct economic costs (e.g. investment in gear replacement), this report will consider the indirect economic and social costs of ghost fishing, but also the economic and social benefits of BFG replacing traditional gear.

management response to ALDFG, which is only part of the marine litter problem). While we consider that there is potential for BFG to improve the sustainability of fisheries (coupled with the potential to attract higher market prices), the focus of our study is demand from fishermen (3). The objective is thus to provide a resource base to justify the potential role of BFG to address ALDFG – focussing on an economic impact ALDFG – ghost fishing.

Part of providing a resource base on the potential benefits of using BFG requires consideration of other management measures. The main management response to date has been gear retrieval. While other alternatives such as gear marking and mapping are

Therefore, the overall purpose of this report is to demonstrate that the status quo i.e. continued use of traditional fishing gear and the associated impacts i.e. ghost fishing, can be improved upon (as the status quo in not the economic optimum). This may also be important considering that consumers are becoming ever more demanding that the food they consume is sourced sustainably. Therefore, we also consider the potential (attributed) benefits that can be attained by the fishing industry through using BFG. For example, the potential to achieve higher market prices for sustainable fish caught using BFGs, as some fishermen have demonstrated possible by developing new supply chains in response to the coronavirus pandemic e.g. selling catch directly to customers.

1.3 Report structure

The remainder of this report is laid out as follows. Section 2 considers the impacts and costs of marine litter, focussing on studies that attempt to estimate the cost of marine litter before moving the focus to fisheries. In Section 3, we focus on the impacts of ALDFG and ghost fishing – particularly studies that attempt to address the economic costs. Section 3 also provides context for the scenarios addressed in the economic model (Section 5). Section 4 reviews the management approaches to address ADLFG and ghost fishing. The economic model is presented in Section 5 along with a discussion on the relevance of the model outputs in supporting uptake of BFG by fishermen in the Programme Area. Section 6 details the rationale for economic instruments to support the uptake of BFG including an indication of the level and use of economic incentives supported by our analysis (Section 5). Finally, Section 7 concludes.

2. Impacts and costs of marine litter

2.1 Introduction

The impacts of marine litter are complex and dynamic, including economic costs to expenditure, welfare (social costs) and lost revenue (Newman et al., 2015). Considering marine litter as a source of environmental pollution, management responses are needed to mitigate the negative externalities, which are significant, wide ranging and not (fully) borne by the producer/polluters. This is true even in situations where the producer is directly impacted by the externality e.g. ghost fishing caused by ALDFG. While fishermen bear the cost of lost catch caused by ALDFG, there are a myriad of environmental impacts caused by ALDFG that are not borne by fishermen alone. Therefore, the use of economic instruments (e.g. incentives) or government policy (regulation) is required to address the marine litter problem.

For fishing gear, which is a significant contributor (FAO, 2016) and one of the main sources of marine litter (through ALDFG) preventative measures are preferable to curative ones. This is because it would not be feasible to remove ALDFG from all oceans and prevent new sources completely, as some gear loss is unavoidable. Further, as there are a number of serious environmental threats caused by ALDFG, it is likely that a mixed policy framework including preventative (e.g. innovations such as BFG) and curative (e.g. taxes, extended producer responsibility) measures will be required.

Developing policy to address marine litter is not straightforward and requires the definition of economics costs (direct, indirect and social) for specific sectors. Overall, there have been limited attempts to address the economic and social costs, with most focussing on the costs to one or two industries in a few regions (Harding, 2016). Therefore, it can be difficult to contextualise the scale of the problem.

Marine litter either originates from land-based sources (e.g. through poor waste management systems) or it originates from maritime sources (e.g. shipping, fishing). Further, different types of marine litter have different impacts. For example, discarded fishing gear can ghost fish, affecting society through higher market prices from reduced catches. Ghost fishing may also affect society in other ways influencing sectors that derive a livelihood from the marine environment, such as tourism and activities including recreational angling and diving. Ultimately, ghost fishing may influence ecosystem provisioning and the range of services that flow from ecosystems, such as food security. Other types of marine litter that originate from land-based sources, such as plastic food packaging may also lead to species mortality through entanglement, for instance. There may also be impacts on human health (Woods et al., 2021).

Overall, there is a lack of information on all of these impacts – particularly the impact of marine litter on the provision of ecosystem services. Where estimates exist they are very large (see e.g. Beaumont et al., 2019). Most focus in the literature has been on the costs and impacts of marine litter on various marine sectors, with a particular focus on fisheries and tourism (Hall, 2000; Mouat et al., 2010; Mcllgorm, Raubenheimer and Mcllgorm, 2009; Mcllgorm, Raubenheimer and Mcllgorm 2020). Some of the economic impacts generated are discussed below. Economic costs relating to ALDFG, ghost fishing and fisheries is presented in the next section of the report.

2.2 Estimating the costs of marine litter

Estimating the full range of economic costs caused by marine litter has generated wide ranging estimates (see e.g. Deloitte, 2019; Beaumont et al., 2019). Given the difficulty in obtaining data on the impacts, only few attempts have been made to put a value on the 'overall' impact of marine litter (Deloitte, 2019; Beaumont et al., 2019), with larger scale studies focussing on economic regions (Harding, 2016). However, a clear message emerges - the impact of plastics waste in the marine environment is both large and growing, coupled with the rapid increase in plastics production and use since the 1960s. A recent report by Mcllgorm, Raubenheimer and Mcllgorm, (2020) estimated the direct economic cost of marine debris to APEC[10] economies was almost US$ 11 billion in 2015 (not accounting for indirect costs and impacts on the provision of ecosystem services), an eight fold increase since 2009 (when the authors conducted a similar study in the region). On a global scale, they estimate damage to equate to an US$ 18.3 billion "avoidable cost". Taking values from 2020, the study estimates that a business as usual scenario will result in global economic damage costs of US$ 197 billion in 2030 and US$ 434 billion in 2050 (if the predicted increases in plastic production eventuate (Mcllgorm, Raubenheimer and Mcllgorm, 2020). As concluded by the authors "business as usual is not an option if SGD 14.1 is to be met by 2030. Dealing with marine litter is critical – especially for countries that rely heavily on the maritime sector. For example, the marine economy in Thailand accounts for 29.4% of total economic output. The APEC report also warns against expectations of an improving situation as countries become more affluent resulting from the rapid economic growth in recent years. Evidence suggests (EKC[11] theory) that growth in income per capita leads to increased environmental awareness and preference for abatement (i.e. as income per capita increases a better environment is demanded). However, Mcllgorm, Raubenheimer and Mcllgorm, (2020) suggest this would have little effect given the predicted increase in plastic production by 2050. Further, as noted by Deloitte, (2019), more than 80% of the global plastic waste that flows from land into oceans (estimated by waste density in rivers) originates from 17 Asian countries. This leads to a clean-up cost of up to $14 billion and a revenue loss up to $2.3 billion per year. As such, Asia bears up to 86% of the 'initial' costs of marine litter.

In addition to the study in the APEC region, a study by Deloitte (2019) valued the cost of marine litter in Europe at €250-700 billion. However, as noted by the authors, this is an underestimate, as some economic values are not available for some forms of damage. The main (direct) economic costs of marine litter are borne by tourism, fisheries and aquaculture with the estimates of cost of inaction significantly higher than the cost of action. For example, the economic cost to tourism from beaches polluted with waste fishing gear. Deloitte (2019), estimate the cost of clean-up and impact on marine sectors to be around $1.2 billion while Beaumont et al., (2019) estimate that the global cost of

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[10] Asia Pacific Economic Cooperation - https://www.apec.org/docs/default-source/publications/2020/3/update-of-2009-apec-report-on-economic-costs-of-marine-debris-to-apec-economies/220_ofwg_update-of-2009-apec-report-on-economic-costs-of-marine-debris-to-apec-economies.pdf?sfvrsn=9ab2a66c_1

[11] The *Environmental Kuznets Curve* (*EKC*) hypothesis postulates an inverted-U-shaped relationship between different pollutants and per capita income, i.e., environmental pressure increases up to a certain level as income goes up; after that, it decreases. See: Dinda (2004).

marine litter could be as high as $2.5 trillion factoring in the loss of ecosystem service provision. Beaumont et al., (2019) also consider that the impact of each additional tonne of plastic entering the ocean will grow exponentially (each additional unit of marine litter will have a greater impact - and thus cost - than the one before) quantified at between $3,300 and $33,000 per tonne. The impact on ecosystem service provision may represent the greatest cost given the role of the marine environment in climate regulation. While only a few studies are available, Beaumont et al., (2007); Beaumount et al., 2019; Costanza et al., (1997) and Galparsoro et al., (2014) all estimate that only a small effect on the provision of ecosystem services caused by marine litter would be substantial. Further, direct costs and indirect costs spread across marine sectors affecting both producers and consumers - causing further direct and indirect economic costs.

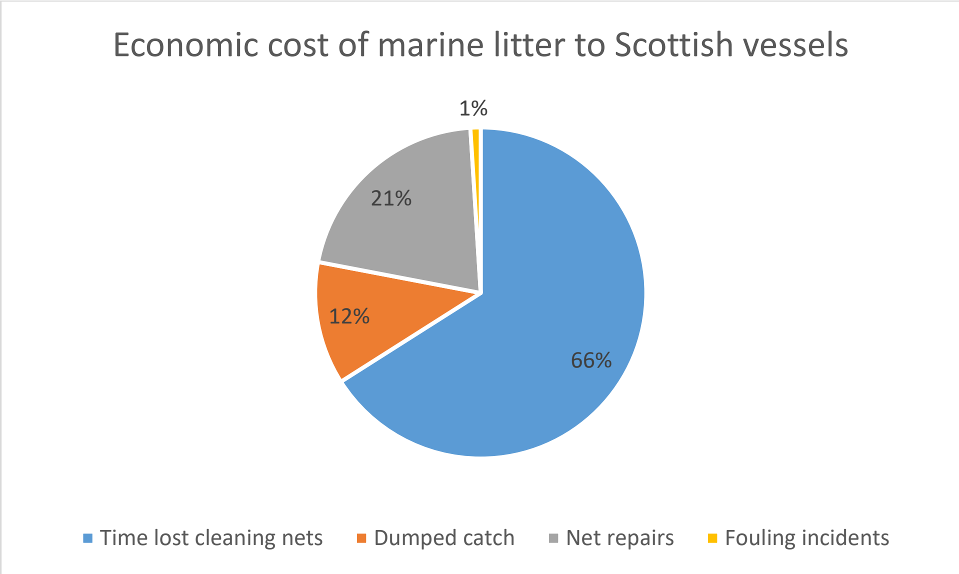
Finally, focussing on direct costs (where information is easier to access e.g. revenue lost through marine litter) is likely to represent the 'smaller' impacts. The indirect costs, viewed in terms of economic value together with long-term impacts to ecosystems is more severe than the financial implications (Deloitte, 2019). For example, those indirect costs that refer to the biological functioning of ecosystems may be substantial and difficult to assess financially. For instance, from cases of animal entanglement from ALDFG to the risk of species extinction through ingestion of plastics and microplastic and the links to impacts on human health.

2.2.1. Economic cost to fisheries

Estimates on the economic costs of marine litter at the sector level in the marine economy are also sparse. What is available largely focuses on estimates of costs to fisheries and tourism. For fisheries, the earliest attempts to address the economic cost of marine litter can be traced back to 1990 in Japan, based on a damage estimation method developed by Takehama (1990). Takehama (1990) estimated the damage of marine debris to equate to a cost to 0.3% of Japan's fish catch (based on insurance payouts from marine litter damage e.g. to propellers). The earlier study mentioned above by Mcllgorm, Raubenheimer and Mcllgorm (2020), uses the value transfer function from Takehama (1990) to estimate the economic costs of marine litter in the APEC region. They update Takehama (1990) on the basis that plastic production has increased from 100 million tonnes in 1990 to 332 million tonnes in 2015, representing a compounded annual increase rate of 4.5%. Further, Mcllgorm, Raubenheimer and Mcllgorm (2020), consider that damage (caused by marine litter) is a linear function of plastic production. Therefore, the damage function calculated by Takehama (1990) will have risen by a factor of 3.22 – i.e. increasing the economic cost in Takehama's estimate to about 1%. Utilising this methodology, Mcllgorm, Raubenheimer and Mcllgorm (2020) utilise a 1% GDP damage function in their estimate of the economic cost of marine litter on the fishing industry in countries in the APEC region. However, it may be better to assume a non-linear exponential relationship between marine litter and impacts on fisheries i.e. an increase in marine litter has a greater impact for every additional piece of marine litter (Beaumont et al., 2019).

Hall (2000) reported that a combination of the costs could cost a vessel up to £30,000 per year. A study a decade later by Mouat et al., (2010) identified that 86% of fishermen reported reduced catches due to marine litter, 82% had reported contaminated catch and 95% had snagged gear on debris on the seabed. Gear impacts aside, incidences of marine litter fouling propellers or blocking intake pipes were reported on average one time per vessel in the Scottish fishing industry (Mouat et al., 2010). In sum, the costs of marine litter are reported to be somewhere between €11.7 million and €13 million per year, which equates to 5% of total revenue from fishing in Scotland.

Fig 1: Share of economic costs associated with marine litter to Scottish vessels



Source: Mouat et al., (2010).

For other sectors, where more research has been conducted, notably tourism – studies by Mouat et al., (2010) and Trucost (2016) have attributed the cost of marine litter at between 2-5% of GDP[12]. In short, a global commitment is required to address the marine litter problem – and progress is being made in this regard[13]. However, as marine, maritime and land-based sectors are impacted to differing extents by marine litter (including by geographic location), actions to mitigate are likely to be delivered at the country level, with different interventions for different sources of plastic pollution.

3. The impacts of ALDFG and ghost fishing

3.1 Introduction

Early research on ALDFG and ghost fishing began in the 1970s (see e.g. High, 1976; Pecci, 1978) in response to the banning of dumping fishing gear by the International Maritime Organisation convention for the prevention of pollution from shipping. It was

[12] Generated by the tourism sector.

[13] https://www.bbc.co.uk/news/science-environment-60590515

around this time that the biodegradable materials used to make fishing gear, such as cotton and wood, changed to plastic. Since then the stock of ALDFG has increased (FAO, 2016). Coupled with a lack of economical fishing gear recycling, plastic based fishing gear is one of the biggest environmental threats to have developed over the last decades (WWF, 2020). While most recognise and accept (see e.g. UNEP, FAO) that most ALDFG is not of the kind that is purposely discarded at sea, the creation of ALDFG (and the resultant impacts) is getting worse at an increasing rate. This is attributed to: (1) the increase in global fishing operations and (2) the persistence of fishing gear in the marine environment when it becomes ALDFG.

3.2 ALDFG estimates

It is not debateable that ALDFG is created in global fisheries. While the widely cited FAO (2016) estimate of 640,000 tonnes per year is contested (Richardson et al., 2021), vast amounts are created around the world annually. It is also not debated that fishing gear no longer under the control of a fishermen can indiscriminately ghost fish (although there are wide ranges in the reported levels by gear types, fisheries etc., as reported in Section 3.3). Richardson, Hardesty and Wilcox (2019) conducted a meta-analysis to estimate the number of gear losses by gear type. Unsurprisingly, the research reported an overall increasing trend of gear loss overtime, which can be attributed to a number of factors (increased number of vessels and gear, for instance). The headline results of this first attempt at analysing a range of studies (68 in total) over a 42-year period (1975-2017) detail annual losses of 5.7% for nets, 8.6% for traps (pots) and 29% of all lines for 2017 around the world. However, the authors note the wide-ranging estimates in the studies analysed, ranging from 0% to 79.8% for nets, 0% to 88% for traps and 0.1% to 79.2% for lines. While there is a general lack of data on ALDFG (and no standardised measures for the collection and reporting of data) and ghost fishing, Richardson, Hardesty and Wilcox (2019) found line fisheries and fisheries using fish aggregating devices (FADs) to be the worst offenders (in terms of volume of ALDFG). Regarding the latter, there are thousands of drifting FADs deployed each year by tuna purse seine fisheries (Gershman, Nickson and O'Toole, 2015). Therefore, even a small amount of loss could have a significant impact on the level of ghost fishing. There are different regulations around the world regarding the reporting of lost gear, which makes cross-country comparisons difficult (Drinkwin, 2022; FAO, 2016). Richardson, Hardesty and Wilcox (2019) found that certain basic information is not always accessible, such as level of uncertainty, the amount of gear used, number of vessels per fleet (as well as detailed information on fishing effort to assist in efforts to estimate the impact of ghost fishing in fishing mortality). Finally, the authors point to the lack of geographic coverage in the literature on gear loss and ghost fishing, noting that there are significant data gaps in Africa, Asia and South America.

The level of reported ALDFG is often derived from the amount of fishing gear found in beach cleans. Fishing gear can travel long distances traversing oceans via winds and ocean currents before either sinking or accumulating on shorelines and beaches (Brown et al., 2005; Macfadyen et al., 2009). Walker, Grant and Archambault (2006) found that ghost gear can contribute up to 76% of marine debris found during beach clean ups. The EU estimate that 27% of all marine litter found on beaches originates from the fishing waste. In Australia, Edyvane and Penny (2017) found that foreign fishing debris is a major source of marine debris (63%) on Australia's northern shores. During the period 2003-2015, 89% of the 2,305 derelict fishing nets washed ashore were of foreign origin (i.e. manufacture), with IUU fishing the likely source. Kim, Lee and Moon (2014) estimate the gross quantity of discarded fishing traps and gill nets in the coastal waters of South Korea at 11,436 tonnes for traps and 38,535 tonnes for gill nets. Havens et al., (2008) estimate that 160,000 blue crab traps were lost each year in Chesapeake Bay between 2004 and 2008. Treble and Stewart (2010) report over 70km of lost gillnets were generated in Canada's Greenland Halibut fishery in just 5 years. Szulk et al., (2015) estimate between 5,500 and 10,000 gillnet pieces were lost each year in the Baltic Sea (between 2005-2008). Escalle et al., (2019) suggest that more than 1,300 FADs are abandoned in the Western Central Pacific Ocean each year. Brown et al., (2005) estimate that over 25,000 nets may be lost or discarded in the north east Atlantic deepwater fishery totalling 1,250km in length. Gear loss is estimated to be as high as 50% in the trap fishery around Guadeloupe (Burke and Maidens, 2004). In Florida Keys, an estimated 10-28% of lobster traps are lost east year (Matthews and Uhrin, 2009).

Ultimately, there is limited knowledge about the amount of ALDFG that is created – as well as why it is created and how it can be prevented. Discarded gear is a significant challenge in some fisheries, such as those where IUU fishing prevails. However, lost gear is also created in fisheries considered to be well managed due to gear conflict and the high financial costs of dealing with end of life fishing gear. As suggested by Brown et al., (2005), each fishery is very different and should be judged on its own merit, because the causes and extent of gear loss vary considerably.

3.3 Ghost fishing efficiency

Similarly, to the sparse literature on the amount of ALDFG created in fisheries, there are limited studies that focus on the level of ghost fishing, although experimental trials have identified the potential scope for ghost fishing mortality by gear types in various fisheries (discussed below). Ghost fishing by lost gear is indiscriminate, catching both target and non-target species, other marine organisms, seabirds etc. The entanglement of marine taxa by marine litter is constantly rising (Welden, 2020) and results in either reduced mobility (due to carrying a piece of marine debris) or direct or indirect mortality through starvation, exposure or drowning. Lost gear can be particularly efficient at catching target species (which it is designed to do) especially in fisheries where lots of gear is set and lost. However, there are also concerns of the capture of non-target species, some of which are classified as vulnerable, such as North Atlantic deepwater sharks (Allsopp et al., 2006) and Hawaiian monk seals (Derraik, 2002). The catching efficiency of fishing gear is dependent of both the gear type and the environmental conditions. The low levels of ghost fishing as reported in some studies (e.g. Godoy, Furevik and Stiansen, 2003) is to some extent not that relevant today[14] given the vast amounts of ALDFG already in the world's oceans (with the stock of ALDFG expected

[14] In other words, even very low levels of ghost fishing are significant given the sheer amount of ALDFG estimated to be present in the world's oceans.

to continue increasing – as issues such as IUU fishing have not been adequately addressed).

Guillory (1993) evaluated ghost fishing by unmanaged pots in the Louisiana blue crab fishery and found ghost fishing continued beyond initial baiting and setting of gear (similar to the process followed by a commercial fishermen) but that crab continued to enter unbaited pots. Two-thirds of the crabs in the pots either died or escaped within two weeks, with smaller crabs more likely to escape while larger crabs tended to remain in the pots and eventually die. Maselko, Bishop and Murphy (2013) found that derelict crab pots ghost fished for at least seven years, suggesting there are long term consequences on fishing mortality of commercially valuable species. The study estimates that instantaneous entrapment represents 1% of the commercial crab harvest in the southeastern Alaska Dungeness crab fishery with a cumulative annual loss of 3% of the regional commercial crab harvest. Bilkovic et al., (2014) reported that derelict crab pot loss in the Virginia waters of Chesapeake Bay is widespread. During 2008-2012 over 32,000 crab pots were recovered capturing over 40 species and 31,000 marine organisms. In terms of the target species, each derelict pot caught on average 18 crabs each year resulting in a lost value of more than US$ 300,000. This is not inclusive of the other commercially important fish caught by the ghost gear. However, other studies e.g. Godoy, Furevik and Stiansen (2003) have shown very low levels of fishing mortality in (experimental) lost pots, from periods of 5 days to one year. Nevertheless, as pots can become self-baiting, studies have regularly observed crab entering both active (managed) and derelict pots (Eggleston, Etherington and Ellis, 1998; Sturdivant and Clark, 2011).

A range of simulated ghost fishing efficiency studies have been conducted since the early 1980s. These are reported fully in Appendix 1 (taken from the Gilman et al., 2016). Most studies identify a reduction in fishing efficiency overtime. For example, Tschernij and Larsson, (2003) conducted a simulated ghost fishing trail using gillnets targeting cod in Hano Bay, Sweden. They found fishing efficiency was similar to managed gear initially, but declined to 5-7% of the initial level after 3 months. However, some fishing efficiency was maintained after 27 months, suggesting that some level of ghost fishing continues for a long time after gear loss. A similar study by Ayaz et al., (2006) using gillnets in Izmir Bay, Turkey reported that gear ceased to catch fish after 106 days for multifilament nets and 112 days for monofilament nets. The monofilament caught significantly more fish (115) than the multifilament (62). The loss of shape of the net (resulting in a reduction in area of the net that could catch fish) caused declining ghost catches overtime. This may suggest that ghost fishing efficiency could be higher in environmental conditions where the integrity of gear lost could be maintained for longer. This assertion is supported by MacMullen et al., (2003) who developed a trammel net and gillnet study in the south of France. Nets set in open ground continued to retain some fishing efficiency after 18 months, although nets set on wrecks no longer retained catch efficiency 6 months after deployment. Some older studies, e.g. Carr, Blott and Caruso (1992) report higher rates of ghost catch efficiency (gill type nets) for long periods. This may suggest improvements in gear management by fishermen overtime (with newer studies generally reporting lower levels of ghost fishing catch efficiency). In Norway, where gillnet use is commonplace, Humborstad et al., (2003) reported that nets retained catch efficiency throughout a 68 day trial, reaching 30% of initial efficiency between 21 and 45 days, with no drop off between 45 and 68 days. Kaiser et al., (1996) report on a simulated gillnet and trammel net trial in Wales. They found the ghost catch efficiency of gillnets to approach zero at 70 days after deployment and at 22 days after deployment for trammel nets. However, both nets continued to catch crustaceans (at low levels) at 9 months after initial deployment. A simulated trial by Macmullen et al., (2003) in southwest England was unable to report on the ghost fishing efficiency of trialled gillnets as they were lost when checked at 14 weeks after deployment. Nakashima and Matsuoka (2004) conducted a study on ghost fishing efficiency using gillnets and found that efficiency had declined to 5% after 142 days. In a trial in 2005, Nakashima and Matsuoka (also using gill nets) found no decline in fishing efficiency.

In the EU, ghost fishing is not believed to account for more than 5% of commercial EU landings for gillnet and tangle net fisheries (Committee on the effectiveness of international and national measures to prevent and reduce marine debris and its impacts, 2008). Brown et al., (2005) report on a ghost fishing rate of less than 1.5% of commercial landings of monkfish in the Cantabrian sea. The FANTARED 2[15] project set nets to experimentally investigate gear evolution and catch rates, showing a decline from initial catch rates to 20% after three months. Catch rates of 5-6% were reported 27 months after initial deployment, and was estimated to persist for several years. The project concluded that up to 3.2% of the commercial cod catch was represented by ghost catches. Baeta, Costa and Cabral (2009) report similar results from fixed net fisheries in Portugal to other studies focussing on trammel gear (as reported above). Specifically, in their study, the catching ability of lost gear reduced over time, reaching about 40% after 30 days with a gradual decline thereafter in line with gear deterioration reaching less than 1% after 11 months (rocky bottom) and 8 months (sandy bottom). However, in offshore, deep-water fisheries, ghost fishing can be more problematic, as nets can keep fishing for many years – with long-term catch rates of 6-20% (see e.g. Szulc et al., 2015). Hardesty et al., (2015) developed a model to predict the long-term impact of ghost fishing efficiency. Based on the removal of 4,500 nets from the Salish Sea during 2002-2009, the authors estimate a ghost catch of 800,000 fish (and 20,000 seabirds).

Ghost catch efficiency has also been reported for trap type gear. Trap gear is thought to be more effective at ghost fishing as; (1) it is self-baiting and (2) gear is rigid thus it retains its integrity. Therefore, both catch efficiency and duration of ghost fishing is higher, particularly in high intensity fisheries (and at the same efficiency as managed gear in some cases, see e.g. Bilkovic et al., 2012).

Hebert et al., (2001) noted that the loss of only 1,000 crab pots would ghost catch more than 80,000 crabs per year. Anderson and Alford (2013) quantified the impact of ghost fishing during crab trap clean-ups in 2012 and 2013. Of the 3,607 derelict traps removed in the Louisiana blue crab fishery 65% of traps analysed were actively ghost fishing at rates between 2.4 and 3.5 crabs per trap. Welden (2020) reports a simulated derelict pot trial in the Gulf of Oman with a ghost catch of 1.34kg per trap per day

[15] https://www.seafish.org/document/?id=55615b7b-bfee-40f5-8f64-29529b12bfb6

decreasing over time. In the Barents Sea crab fishery, Humborstad et al., (2021) report the lost crab pots have a huge potential for ghost fishing, with 430 out of 1,000 catching an average of three crabs per pot. In Chesapeake Bay, which is an intensively fished area, it is estimated that 10-30% of the millions of pots set annually are lost, resulting in the ghost catch of as many as 1.9 million blue crab (alone) in some fisheries (Boilermaker, 2015). This is supported by DelBene, Bilkovic and Scheld (2019) who simulated ghost fishing in the Chesapeake Bay blue crab fishery by setting derelict pots near actively fishing pots. They found that the derelict pots reduced harvests by 30% during the summer, but not later in the season. The study also found that the catch of female crabs was reduced where derelict pots were present, but males were not negatively affected by derelict pots. This suggests that seasonal differences in the movements of female and male crabs may cause variable levels of ghost fishing throughout the season and off-season (suggesting removal efforts should be targeted at certain times throughout the year). This assertion is supported in several studies (Al-Masroori et al., 2009; Ayaz et al., 2010; Bilkovic et al., 2014; Hareide et al., 2005; Maufroy et al., 2015; Uhrin, 2016).

Some studies that focussed on crab ghost catch reported starvation after bait exhaustion as the main reason for mortality. Campbell and Sumpton, (2009) found that dead crabs were eaten or decayed within one week of being found dead. Generally, the level of ghost fishing is correlated with amount of gear deployed, gear design and fishery intensity. In the Channel fisheries, where effort for trap type gear has increased in recent years, this suggests that ghost fishing has become more problematic over time. As noted by Siikavuopio et al., (2019) crab ghost fishing efficiency does not reflect starvation and predation in self-baiting fishing gear, which leads to underestimates due to unaccounted mortality.

Textbox 1: Gear types and fishing efficiency

Most studies show that ghost fishing efficiency decreases overtime, compared with managed fishing gear (e.g. a lobster pot under the control of a fishermen that is baited, set and fished on a regular basis), with some studies estimating the drop off in fishing efficiency to be quite rapid. The decrease in efficiency can be attributed to several factors. The **type of gear** is thought to be a significant factor – as the fishing efficiency of long trawl **nets** lost in deep waters will be different to long trawl nets lost in shallow waters – as nets lost in shallower water lose shape quickly, become entangled and act more like a fish aggregating device than a ghost net. However, nets lost in deeper waters may retain their shape, structure etc. and fish similarly to a net towed by a vessel. However, this type of fishing efficiency is estimated to be short term, as nets ultimately lose their integrity characteristics e.g. shape and become fouled so that they become visible and easier for marine life to avoid. Further, once nets have ghost fished for a period of time, they may sink to lower depths and not ghost fish significantly (although they may rise again and ghost fish). **Static gear** e.g. pots, however, might be more of a significant problem, largely as they are self-baiting. This means they continue to ghost fish for longer periods, particularly in high intensity fisheries (i.e. where large amounts of gear are deployed).

The ultimate fate of ALDFG in fisheries is subject to several factors e.g. environmental conditions, fishery intensity, type of gear used etc. The efficiency of ghost fishing is generally shown to decline over time. However, some studies have shown that certain types of gear can fish at similar levels years after becoming ALDFG. Deepwater gill net fisheries are especially problematic, as these waters are not subject to strong tides allowing gear to retain its shape and fishing efficiency for longer (Brown et al., (2005). For trap type gear that can self-bait, even low levels of ghost fishing could be significant given ALDFG persists in the marine environment. In addition, in some data poor fisheries (e.g. the Mediterranean) ghost fishing may be a problem simply given the large numbers of fishermen involved in static gear fisheries. Brown et al., (2005) concluded that in the Channel fisheries, levels of gear loss are not thought to be significant due to the high degree of communication, gear value, industry awareness and the relatively small number of vessels involved. However, in the last 20 years or so, vessel numbers have increased (with a shift from active to static gears – particular crab potters). The INdIGO surveys indicated that gear loss through gear conflict was reasonably commonplace. Finally, it should be noted there has been limited research into the cause and level of ALDFG, and the level of ghost fishing in the Channel fisheries.

3.4 Economic impacts

As shown in Table 1, there are a number of direct and indirect economic costs, as well as social costs, which result from the creation of ALDFG by the fishing industry. In this section, we detail the economic costs associated with ghost fishing to develop a baseline for our analysis (as well as discussing the sparse literature that has assigned economic costs to ghost fishing mortality). In Section 5, we develop a vessel level analysis to demonstrate the cost of ghost fishing to individual fishermen (which is aggregated in various ways to represent fleet segments in the Channel fisheries). We then consider the potential for BFG to mitigate ghost fishing in these static gear fisheries.

Table 1: Economic costs of ALDFG[16]

Economic costs of ALDFG
Direct economic costs:
Cost of time spent disentangling vessels whose gear/engine has become tangled in ALDFG, which results in less fishing time
Cost of lost gear/vessels because of entanglement as well as replacement
Cost of emergency rescue operations because of entanglement

[16] The costs highlighted are those either directly or indirectly included in our vessel level analysis.

Cost of time and fuel spent searching for lost gear, which also results in lost fishing time
Costs of retrieval programmes/activities to remove lost gear, or other potential management measures (e.g. cost of communication, cost of gear marking, cost of monitoring regulations intended to reduce ALDFG)
Indirect economic costs:
Reduced income/value-added from ghost fishing mortality
Lost future income from the removal of small fish from ghost fishing mortality
Reduced multiplier effect from reduced fishing income, including spillovers into other sectors and local/regional economic development
Cost of research into reducing ALDFG (and redirection of research to ALDFG)
Cost of reduced consumer demand because of consumer concerns about ALDFG and ghost fishing
Social costs:
Reduced employment opportunities in fishing, resulting from increased mortality from ghost fishing, leading to reduced catching opportunities (e.g. reduced TACs)
Reduced employment opportunities, resulting from reduced catches because of unintended mortality (ALDFG and ghost fishing)
Reduced tourism (recreation, diving, beaches) from lost gear offshore and onshore
Safety risks for fishermen and other marine stakeholders from reduced vessel manoeuvrability if compromised by entanglement or navigational hazards

Source: Macfadyen, Huntington and Cappell (2009)

The economic impacts of ALDFG can be disaggregated to direct economic costs, indirect economic costs and social costs. Only some of these economic costs are relevant for our study on the economic impacts of ghost fishing. There are direct costs, but the main cost associated with ghost fishing mortality (i.e. catch foregone) is an indirect cost. However, if nothing is done to combat ghost fishing, government regulation may impose direct costs (e.g. mandating the use of BFG, or gear modified in some way to reduce the potential for gear to ghost fish). Other indirect costs include the loss of future income from the removal of juvenile fish (and other food web interactions). A significant (future) indirect cost may relate to consumer awareness and reduced consumer demand due to concerns about the impact of ghost fishing (whether the concern derives from impacts to commercial fish stocks or marine mammals entangled in fishing gear). The redirection of research and innovation away from sustainable fisheries to a sole focus on ALDFG and ghost fishing represents a future (potential) indirect cost. The potential for reduced employment due to ghost fishing may also represent a future significant social cost. However, there is a lack of data to address these costs in this study.

The main 'tangible' economic cost of focus in ghost fishing studies has been the potential for reduced income from ghost fishing mortality. Factoring in the economic viability of management responses represents a gap in the literature – hence our study is building on the work of Brown et al., (2005) to develop real life scenarios of ghost fishing in the Channel fisheries (static gear) while also comparing BFG against gear retrieval programmes (as management responses).

There is a limited (albeit growing) resource base on the economic cost of ghost fishing. A study by Watson and Bryson (2003) estimated the cost of ALDFG to a single fisherman at US$ 21,000 in lost gear and US$ 38,000 in fishing time in one year. Scheld, Bilkovic and Havens (2016) conduct a global analysis of derelict fishing gear, reporting on the high gear loss in many of the world's crustacean fisheries. In fisheries where gear loss estimates exist, loss rates between 10 and 70 percent (table 2) are suggested by Bilkovic et al., (2012). In the world's major crustacean fisheries (defined by Scheld, Bilkovic and Havens, 2016 as fisheries with commercial catches exceeded US$ 20 million per year), a total 615,560MT catch is worth around US 2.5 billion. This involves the setting of tens of millions of pots each year, with millions of set posts becoming ALDFG.

Table 2 – Gear loss from crab and lobster fisheries

Species	Annual Gear Loss (% Deployed)*	Landings (MT)	Revenues (US$)	Major Producers
Blue swimmer crab *Portunus pelagicus*	70	173,647	$199M†	China, Philippines, Indonesia, Thailand, Vietnam
American lobster *Homarus americanus*	20–25	100,837	$948M	Canada, USA
Blue crab *Callinectes sapidus*	10–50	98,418	$152M	USA
Queen crab/snow crab *Chionoecetes opilio*	NA	113,709	$401M	Canada, St. Pierre and Miquelon (France), USA
Edible crab *Cancer pagurus*	NA	45,783	$49M‡	United Kingdom, Ireland, Norway, France
Dungeness crab *Metacarcinus magister*	11	35,659	$169M	USA, Canada
Spiny lobster *Panulirus argus*	10–28	34,868	$500M§	Bahamas, Brazil, Cuba, Nicaragua, Honduras, USA
King crab *Paralithodes camtschaticus*	10	10,137	$99M	USA
Stone crab *Menippe mercenaria*‖	NA	2,502	$24M	USA
TOTAL		615,560	$2.5B	

Source: Scheld, Bilkovic and Havens (2016).

In the USA, an estimated $250million worth of marketable lobster is lost to ghost fishing annually (Allsopp et al., 2006) and between 4-10million blue crabs are trapped in ghost fishing gear each year in Louisiana (Macfadyen, Huntington and Cappell, 2009). Scheld, Bilkovic and Havens (2016) report that in one of the world's largest crustacean fisheries in Chesapeake Bay, which was declared a commercial fishery failure by the US Department of Commerce, a gear retrieval that removed more than 34,000 pots over six years (which was estimated to represent a 9% removal), increased the harvest by 13,504 MT. Extrapolating this study to a global analysis of derelict gear (i.e. 9% derelict pot removal from the world's most valuable crustacean fisheries) would increase landings by 293,000 MT at a value of US$ 831 million. However, the net economic benefits in terms of increased future catches from derelict pot removal would be minus the costs of gear retrieval. A study by Sukhsangchan et al., (2020) focussing on fishing grounds near Suan Son Beach (Thailland) simulated a ghost fishing exercise by monitoring set derelict pots and reported the economic cost of ghost fishing (during two separate experiments) to be between 5302 Thai baht and 6318 Thai baht from 27 traps (approx. US$150 to US$180). The SeaDoc Society[17] estimate that just one abandoned net could ghost catch almost US$ 20,000 of Dungeness crab over 10 years. The Virginia Institute of Marine Science has estimated abandoned or lost crab pots in the Chesapeake Bay area capture 1.25 million blue crabs annually (approx. US$ 4.5 million[18]). The NOAA (2015) estimated that ghost traps kill about US$ 750,000 worth of Dungeness crabs each year. Antonelis et al., (2011) estimated that 178,874 harvestable crabs valued at US$ 744,292 were lost to ghost fishing in one season in the Puget Sound (approx. 4.5% of the harvest). Brown et al., (2005) developed a case study based on a hypothetical gillnet fishery in the English Channel that indicated the cost of ghost fishing to be around €10,000 per vessel. They also demonstrated that the cost of a gear retrieval programme would be economically unviable.

[17] Cited in: https://www.theguardian.com/sustainable-business/2015/sep/10/fishing-industry-vows-to-tackle-wildlife-deaths-from-ghost-gear

[18] Based on 84 crabs per bushel costing US$ 300.

However, none of the studies that address the economic cost of ghost fishing account for mortality of non-market species, or the impacts on market species that are not managed effectively in fisheries around the world (e.g. by catch and discarding). Therefore, an accurate assessment of the economic impact cannot be made. As stated previously, basing studies on the widely cited FAO 640,000 tonnes of ALDFG created annually may lead to arbitrary estimates. Richardson et al., (2021), summarise that the state of knowledge on lost gear remains poorly understood (and the FAO 640,000 tonne figure may only loosely relate to the actual amount of ALDFG created in global fisheries). Further, as noted by Sheavly and Register (2007), estimates (such as the ones presented here) are only reflective of lost catch. The longer-term impact of ghost fishing on conservation and the recovery of vulnerable stocks may represent deeper economic effects. As the ICC suggests "in the Chesapeake Bay and its tributaries, where the blue crab population has crashed, every crab lost means one step further away from recovery for a species that provides economic support for entire communities" (ICC 2009: 17) "and the viability of other vulnerable species may be similarly affected" (Sheavly and Register 2007).

According to the FAO (2016), there remain several important information gaps regarding the economic assessment of ghost fishing and its wider impacts. These can be summarised as high dispersion of estimates (fishing efficiency, fishing mortality etc.) and relatively few studies that estimate the impact of ghost fishing. In addition, most estimates (and experimental work) are based on fixed gear e.g. gillnets and pots/traps, with less research focussing on the impact of towed gear in different environments (e.g. inshore vs. offshore). As such, the predictive powers of these studies is low and possibly fisheries specific. There is underrepresentation by oceans and regions around the world. While there are some comprehensive studies that cover certain oceans (e.g. the APEC report covering the Pacific Ocean[19]) that are publicly accessible, there is a lack of studies in other regions e.g. the EU. Further, there is a lack of knowledge on the amount of fishing gear in use globally (FAO, 2016). Finally, as noted by the FAO study, there is no standardised method to estimate ghost-fishing mortality – different assessments are used in different regions/oceans. Therefore, comparisons between fisheries and the types of mitigation responses would be difficult to compare across fisheries. As such, the collection of primary data from fishermen to develop vessel level analysis is important to better understand the amount of ALDFG created in fisheries, the extent to which ghost fishing occurs and the associated economic costs (to inform mitigation strategies at the fishery level).

[19] https://www.apec.org/docs/default-source/publications/2020/3/update-of-2009-apec-report-on-economic-costs-of-marine-debris-to-apec-economies/220_ofwg_update-of-2009-apec-report-on-economic-costs-of-marine-debris-to-apec-economies.pdf?sfvrsn=9ab2a66c_1

4 Management approaches to address ALDFG and ghost fishing

4.1 Introduction

This section deals with the management responses to sustainably deal with ALDFG and the resultant ghost fishing – considering both preventative and curative options. We focus on the environmental and economic considerations, both in reducing the contribution of fishing gear to the marine litter base and demonstrating the potential of BFG (for fishermen) in both preventative and curative measures (over 1. the status quo and 2. alternative management responses). The section that follows presents a case study on the role of biodegradability in mitigating ghost fishing, which will increase in severity as the stock of ALDFG continues to increase.

4.2 Traditional approach: Gear retrieval programmes[20]

Gear retrieval represents the main response to address the impacts of ALDFG in the marine environment. In terms of cost, Deloitte (2019) report gear retrieval- along with beach cleans (land based) – account for the main (curative) mitigation efforts. In terms of action, preventative measures are always preferable to curative ones, especially in the case of ALDFG, because it can persist for a long time in the marine environment. Prevention of ALDFG would eliminate[21] the environmental, economic and social costs e.g. the impacts of ghost fishing, entanglement of other marine life, entanglement with vessels, reduced commercial fish catches, damage to corals etc. Given the sheer volumes of ALDFG estimated to be present (see FAO, 2016) gear retrieval will remain important. However, countries around the world have embarked on these programmes in the absence of information on their economic viability, including assessments of alternative measures to mitigate or prevent ALDFG (Brown et al., 2005). While forms of legislation exist in some fisheries, such as gear marking, reporting of gear loss and voluntary measures including communication to prevent gear conflict[22], there is a lack of policy or assistance in place to change the behaviour of fishermen to adequately prevent ALDFG. For instance, gear recycling facilities were largely absent from fishing ports until recently, with recent pilots in fishing ports around the UK demonstrating that there is a value gap in the current fishing gear recycling value chain (i.e. the cost of recycling is not met with value addition activities). Similarly, while small-scale recycling collection points are available across ports in the programme area, in other ports visited as part of our stakeholder engagement (e.g. Bridlington and Cromer) no such recycling facilities are available. Further, discussions with fishermen and their representatives (e.g. the Holderness Fishing Industry Group) demonstrated that fishermen are unaware of what happens to end of life fishing gear generated in their fishery.

As noted by Brown et al., (2005), there are a lack of studies that focus on the economic feasibility of gear retrieval programmes. What has been done is largely restricted to estimations of the costs of ghost fishing (and hence the cost of having no retrieval programme) in terms of the volume and value of ghost catch, (e.g. Al-Masroori, 2002; Al-Masroori et al; 2004; Mathews et al, 1987) and, separately, the cost of gear

[20] This section is taken from T.1.3.2 Market Analysis.

[21] Some level of ALDFG would be generated in fisheries. As such, the removal of all ALDFG would not be the economic optimum, as the costs would outweigh the benefits (at a given point).

[22] https://www.gov.uk/guidance/marking-of-fishing-gear-retrieval-and-notification-of-lost-gear

retrieval programmes (e.g. Brown et al., 2005; Drinkwin, 2022; Tschernij et al, unpublished). There is also a lack of literature on the relative costs/benefits of different management measures as a basis for prioritisation. There is also limited research to understand how measures may also change the behaviour of consumers (e.g. WTP studies to reveal preferences for sustainable fisheries). UK consumers, for example, have been accepting of policy to address the reduced use of plastic carrier bags through the disposable carrier bag charge. The EU[23] estimate that the carrier bag charge, since the 2015 Plastic Bags Directive, brought about a rapid change in consumer behaviour that will lead to a reduction in 3.4 million tonnes of CO_2 emissions, avoid environmental damage, which could cost the equivalent of €22 billion by 2030 and save consumers an estimated €6.5 billion.

As espoused by Brown et al., (2005), there is little or no evidence to support the economic viability of gear retrieval. They find the benefits of gear retrieval do not outweigh the costs in their hypothetical gillnet study in the Channel. Even so, countries invest millions in gear retrieval. For example, the Canadian Department of Fisheries have allocated more than US$ 8.3 million to reduce the amount of ALDFG, as well as implementing a sustainable fisheries solutions and retrieval support contribution fund (Walker, Goodman and Brown, 2020). Gear retrieval has been undertaken annually since the 1980s in the Norwegian gill net fishery. Sundt et al., (2018) and the NDF, (2019) report on the removal of 20,450 (gill type) nets, although estimate gear loss at 35,000 (Sundt et al., 2018) and 490,000 (NDF, 2019). Furthermore, no information regarding the costs and benefits of the programmes is available[24]. Large et al., (2009) conducted several gear retrieval exercises as part of EU DEEPCLEAN project in 2005 and 2006 in deepwater gillnet fisheries in the Northeast Atlantic. The purpose was to estimate the extent of ALDFG and the level of ghost fishing. One exercise towed creeper type retrieval gear for 228km and retrieved no lost or abandoned fleets (or whole/complete gillnet panels), but did recover parts of equipment such as fragments of gillnet. As such, no ghost catch was identified. Another exercise completed 54 tows at depths of 400-1300m for a total distance of 320km. In this exercise, 648 gillnet panels were recovered with an estimated length of 35-40km. Considerable ghost catch of a mixture of fish and crustaceans weighing 14.3 tonnes (approx. 50% were commercial species) was recorded. A further exercise recovered fragments of gillnets (no whole panels or fleets) totalling almost 34km in length with low levels of ghost catch. As noted by the authors, part of the cause of retrieving mostly fragments of gear (rather than whole panels/fleets) may have been due to the stresses of towing and hauling. For example, gillnet panels may have been located but the panels may have disintegrated by the time they were hauled. Overall, the exercises demonstrated that gear retrieval success is highly dependent on gear type and understanding of where lost gear may be located. The study reported nothing on the cost of the retrieval exercises.

[23] https://ec.europa.eu/commission/presscorner/detail/de/STATEMENT_19_1873

[24] The cost saving from the resultant reduction in ghost fishing. Furthermore, there may be environmental issues with retrieving lost nets e.g. damage to the benthic environment if gear becomes embedded on the ocean floor. Ghost nets and pots may act as food sources for scavengers. Generally, studies focus solely on the economic cost of ghost fishing as a starting point.

Locating lost gear is especially problematic in countries where the reporting of lost gear is not mandatory. As noted by Drinkwin (2022) even basic preventative measures (e.g. gear marking) are not required in some fisheries (noted in 2/3 of 25 countries reported in Drinkwin, 2022) with no mandatory retrieval efforts for lost gear. In addition, more than 80% of the countries study were found to have waste reception facilities that were not adequate.

Drinkwin (2022) represents an important contribution to knowledge providing a synthesis reports of various gear retrieval programmes, including information on costs. For example[25], the fishing for litter programme operates 16 projects in 11 EU countries (60 ports and 670 vessels) where fishermen are provided with bags or bins in order to keep ALDFG they encounter, which has led to the removal of 600 tonnes of ALDFG since 2013. Regarding costs, Darwin (2022) reports an average cost of around €150,000 per 12 participating ports (equates to €2,500 per port with an estimated removal cost of €1,250[26] per tonne of ALDFG). Some modest income is generated through the selling of recyclable materials, although no information is given. The Enaleia Mediterranean Cleanup Programme works with 23 ports in Greece and Italy (around 250 vessels) and collects around 1 tonne of ALDFG per year and around 20-30 tonnes of end of life fishing gear. Most of the costs associated with the programme are met through sponsorship and grants, although fishermen are paid around €100 per month to retrieve ALDFG, which resulted in a seven-fold increase in participation. This demonstrates the role of positive incentives (discussed in Section 5) on behavioural change. Fishermen benefit by way of an improved public image and intrinsic satisfaction from removing waste from their fishing grounds (such satisfaction received as resource custodians came through strongly in the INdIGO surveys conducted earlier in the project).

The "Fishing Net Gains Africa" project operates an ALDFG retrieval programme in the coastal areas of Nigeria. A relatively small-scale programme, 700kg of ALDFG has been removed by 523 fishermen. An incentive is paid to fishermen for nets brought ashore, which benefits the fishing community through the reduction of ghost fishing. NGOs and the Canadian Government currently fund the programme.

The Washington Coast crab tag programme is a voluntary programme operated in a high intensity fishery. Around 90,000 pots are set annually with approx. 9,000 lost each year. Retrieval rates of between 1 and 10% occur each year. As recovered gear is expensive, fishermen are allowed to keep the gear they recover (representing a form of financial incentive for retrieving lost gear encountered).

A gear retrieval programme operates in the Canadian Dungeness crab fishery. In 2020, 119 traps were recovered at a cost of US$ 13,500 (equates to US$ 113 per trap) leading to a reduction in gear conflict (with the lost gear) and ghost fishing.

[25] This section is largely taken from Drinkwin (2022).

[26] Estimate based on €12,500 per 12 ports, which equates to €750,000 for all 60 ports that engage in the programme. Removal of 600 tonnes equates to €1,250 per tonne of ALDFG removed.

Textbox 2: Ghost fishing efficiency

Locating lost gear represents a significant barrier to the success of gear retrieval. In the absence of GPS tracking of all fishing equipment, fisheries authorities have largely relied on fishermen reporting gear loss[27] (which is a requirement in all UK fisheries). Gear loss in inshore fisheries tends to be less problematic, as it is easier to locate and recover. In addition, gear loss is thought to be less problematic in inshore fisheries (in terms of ghost fishing) as fishing efficiency declines through tidal action, fouling etc. (Brown et al., 2005). However, in offshore, deep-water fisheries, ghost fishing can represent more of a problem as nets can keep fishing for many years – with catch rates of 6-20% (see e.g. Szulc and Kasperek, 2015).

Therefore, the benefits (from an economic perspective regarding ghost fishing) may be minimal if gear is not retrieved quickly in inshore fisheries. Finally, if annual gear retrieval resulted in the removal of the majority of ALDFG – say 80% - the stock of ALDFG would continue to increase each year.

On the one hand, the literature suggests that gear retrieval programmes can be efficient under certain circumstances. They are possibly most successful and economically efficient (although there remains limited information to support this) in high intensity fixed gear fisheries (mainly inshore). Lobster and crab fishing in Chesapeake Bay are one such example where it is reported to be economically viable to retrieve lost gear (Bilkovic et al., 2012). In these fisheries, economic benefits accrue through retrieval to fishermen themselves. For instance, the cost of lost gear, the cost of ghost catch, reduced gear conflict between active and lost gear (resulting in further lost gear) and lost fishing time. The role of biodegradability in these fisheries requires further attention, as it can address the economic costs to fishermen – especially ghost fishing as fishing efficiency in these fisheries is thought to be of concern.

On the other hand, there is little evidence to demonstrate the economic viability of gear retrieval in other fisheries from the viewpoint of economic benefit to fishermen. However, the environmental impact of lost gear on the marine environment (and other sectors like shipping and tourism) is not factored into this assertion[28]. Furthermore, there may be environmental issues with retrieving lost nets e.g. damage to the benthic environment if gear is deeply embedded on the ocean floor. Ghost nets and pots may act as food sources for scavengers. Bio fouled gear may act as a Fish aggregating devices (FADS) rather than actively catch fish.

4.3 Contemporary approaches: BFG

This section of the report reviews the experimental research[29] on the development and use of BFG, either as a substitute (i.e. replacement to traditional gear) or complement (e.g. partial replacement to traditional gear – for instance, biodegradable escape hatches on trap gear) to conventional fishing gear. The objective is to synthesise

[27] However, as lost gear is not stationary, if not done quickly gear retrieval success may be limited. In addition, as fishing gear is expensive, fishermen will tend to exert significant effort in retrieving it themselves.
[28] However, this report is about creating a resource base to support the uptake of BFG by fishermen, hence the consideration of the costs and benefits to fishermen from this perspective.
[29] This will include outputs published in academic journal articles and research organisation reports.

the research to develop understanding of the potential barriers and opportunities for BFG and how these should factor into our analysis (Section 5 - particularly scenario development and the level of incentives required to support fishermen in their decision to invest in BFG).

4.3.1 What are the barriers and opportunities[30]?

The development of fishing gears made of biodegradable plastic materials e.g. PBSTAT resin, is a potential solution to reduce the environmental impacts of ALDFG with a particular focus on ghost fishing and plastic pollution (see e.g. Brown and Macfadyen, 2007; Large et al, 2009; Macfadyen, Huntington and Cappell, 2009; Gilman, 2015; Gilman et al, 2016). As noted by Grimaldo et al., (2018) it is important to evidence the environmentally safe application of such biodegradable plastics e.g. ecotoxicological effects on the ecosystem during degradation (currently undertaken for the BFG produced in INdIGO). In addition, BFG should be at least as efficient (cost, lifespan etc.) as conventional fishing gear to not impact profitability. We will focus largely on studies that consider the impacts of BFG on fishing efficiency[31] (also known as catchability) as well as studies that have engaged the fishing sector. The latter mostly focus on the wider issue of integrating fishing gear into a circular economy (to determine the key circularity aspects and the relevant barriers and opportunities for BFG).

The majority of experimental work on developing and testing BFG has focussed on fixed gear - mainly gillnets[32] and traps/pots. Around the world, gillnets are commonly used to catch a variety of demersal and pelagic species, as well as some shellfish species (FAO, 2016). The size of gillnet operations can vary greatly, from small single crewed vessels (in developed and developing countries) to large-scale industrial vessels (Grimaldo et al., 2020). While data are not available to estimate the number of gillnetters in the Channel fisheries, 50% of respondents in the technical survey conducted in INdIGO reported gillnetting as a primary or secondary fishing activity. In the last decade or so, the recognition of the harmful impacts of ALDFG has been noted by international organisations (FAO, 2016; GGGI, 2020[33], MSC[34] 2020), with the development of BFG, particularly for gillnet fisheries, increasing around the world (FAO, 2016). Biodegradability serves two main functions. Firstly, as the gear degrades completely in the marine environment, lost gear would have limited capacity to ghost fish (and for a significantly reduced time). Secondly, the vast reduction of plastics degrading to microplastic, compared with the loss of non-BFG.

Biodegradable gillnets are currently used in commercial fisheries in China, Norway, Japan and South Korea and trap type gear in the USA and South Korea. The majority of research (as represented in the academic literature) has been (and is currently) conducted in Norway, South Korea and the USA. There is nothing available in the literature that documents the development of biodegradability in active gear types

[30] This section is taken from T 1.3.2. Market Analysis – and is based on a literature review of development in BFG.
[31] A full cost-benefit analysis is being developed in T 2.3.1.
[32] Including entangling nets, drift nets, trammel nets and encircling gillnets.
[33] See: https://www.ghostgear.org/resources
[34] See: https://www.msc.org/what-we-are-doing/preventing-lost-gear-and-ghost-fishing

e.g. trawls and seines. However, as revealed in the stakeholder engagement work conducted for our task, there is growing interest in the use of BFG for sacrificial parts of trawl nets e.g. the dolly ropes that are designed to protect trawl nets. Biodegradable versions of dolly rope are currently being produced and tested in EU fisheries[35]. Further, biodegradable ropes have been tested for use with Fish Aggregating Devices (FADs) in tuna fisheries showing similar aggregative patterns of fish for conventional and biodegradable FADs (Moreno, Orue and Restrepo, 2017).

In South Korea, BFG has been studied across 13 different fisheries focussing on gillnetting and potting targeting a variety of species. A type of trap gear that is used to catch Octopus minor in South Korea was compared against a biodegradable trap, as both a direct substitute (complete replacement of conventional material) and as a complement (e.g. partial replacement) in a study by Kim, Park and Lee (2014). The trap gear used to catch Octopus minor comprises two parts – a funnel and a body. Kim, Park and Lee (2014) produced three experimental designs. First, a trap made 100% of biodegradable plastic. Second, a trap with a funnel made of biodegradable plastic and a body made of conventional material. Third, a trap with a funnel made of conventional material and a body made of biodegradable plastic. The study concluded that biodegradability is not a suitable substitute for gear made of conventional materials, as the 100% BFG has a reduced fishing efficiency of 60%, having a great impact on profitability. However, the authors note that biodegradability offers considerable potential as a partial design feature of the trap gear studied to catch Octopus minor. The gear with a biodegradable funnel and conventional body performed slightly better than the 100% BFG (with a 50% lower fishing efficiency over the conventional gear). However, the gear designed with a conventional funnel and biodegradable body returned almost the same catch efficiency as the conventional gear (Kim, Park and Lee, 2014).

Biodegradability is used as a design feature of gear in the Maine lobster fishery in the USA. Pots in this fishery must be designed in such a way to allow undersize lobsters to escape. Pots must also be fitted with a biodegradable panel[36] to reduce ghost fishing should they become lost. However, as noted by Bilkovic et al., (2012), escape mechanisms on pots often rely on hinges or degradable attachment points that can fail due to encrustation of bio-fouling organisms, which can prevent the escape mechanism operating. Bilkovic et al., (2012) developed a mechanism that is fully biodegradable and dissolves, thus not relying on hinges or detachable components. In Chesapeake Bay (USA), the authors tested their biodegradable panel with a cull (escape ring). The cull is placed on the side of crab pots and completely degrades after one year. The study notes that the escape panel and cull are relatively inexpensive and easy to install (including retrospectively). The authors found no statistical difference in catch rates of the target catch (or any increase in bycatch). The developmental phase of the panel and cull was supported by fishermen, who were paid to fish with the gear for a season. Chesapeake Bay is an intensively fished area, where it is estimated that 10-30% of the millions of pots

[35] https://www.senbis.com/products/marine-degradable-fishing-net-protection-dolly-rope/
[36] This was a requirement for MSC certification.

set annually are lost, resulting in the ghost catch of as many as 1.9 million blue crab (alone) in some fisheries (Boilermaker, 2015).

Of the options to address ALDFG in trap fisheries in the USA e.g. improved port reception facilities, behaviour changing, gear retrieval and the use of biodegradable escape panels have grown in popularity. The use of biodegradable escape panels (and its acceptance) is mainly attributed to the panels not causing a decline in catchability (Boilermaker, 2015). In other fisheries, particularly the Alaskan Dungeness crab fishery, the use of BFG is common, with biodegradable escape cords used on all pots. However, studies have shown (Boutson et al, 2009) that the position of escape devices is dependent on target species and likely bycatch, as the latter may prevent escape from ghost gear. For example, escape hatches at the top of a pot are less likely to allow the easy release of crabs, who are more likely to crawl out of a pot than swim upwards to escape from the top. The utilisation of biodegradable escape panels means that should pots become lost they can act as valuable habitats for other marine life (e.g. nursery area), rather than be damaging to them. While some studies report that implementing biodegradability as a design feature of trap-type gear is relatively inexpensive, others (see e.g. Kim et al. 2014) suggest that in fact the main disadvantage is that the biodegradable pots are more expensive, so it is unlikely they will be widely used by the fishing industry without financial incentives. Further, as noted by Bilkovic et al., (2012) and Boilermaker (2015), many fisheries in the USA claim to use BFG, when in fact it is only degradable, meaning it can degrade into microplastic.

Rather than having a sole focus on the relative catch efficiency of different BFGs, most studies have now evolved to address the outputs of earlier studies on BFG that documented such shortcomings – most related to strength, flexibility and durability. For example, a study by Bae et al., (2012) found that biodegradable gillnets in the South Korean Flounder fishery were 45% less effective (in terms of catching efficiency), but this was not correlated to soak time (issues relating to reduced strength) - rather it was correlated to wave height. A further study by Bae et al., (2013) compared flexibility with soak time, finding a positive correlation between soak time and catch efficiency. Overtime the BFG becomes relatively less efficient for all of the 15 species targeted ranging from 10-45%. A study by Kim et al., (2016) demonstrated the dry breaking strength of a nylon gillnet exhibited a greater breaking strength than a biodegradable monofilament of the same diameter, which when wet revealed a stiffness of around 1.5 times the nylon net. As demonstrated by other studies (some reported here), these characteristics (less flexibility and strength) should correlate to lower catching efficiency. However, as demonstrated by Kim et al., (2016), similar catch efficiency was noted for the experimental BFG in the Yellow Croaker fishery in South Korea.

Demonstrating both the technical and economic feasibility remains one of the main challenges for BFG implementation. A study by Park, Park and Kwon (2010), estimated the economic benefits to the fishing industry adopting BFG using a contingent valuation technique. The study looked at the role of consumer willingness to pay for BFG to address marine litter. While the average willingness to pay (household level) was less than £5 (currency equivalent), extrapolating to the national level gives a willingness to pay of around £52 million for biodegradable fishing net development and supply. This could be translated as consumers' willingness to pay higher prices for sustainable low impact fisheries – and thus has relevance for BFG implementation. Brown et al., (2005) also addressed the role of consumers in BFG implementation. While BFG ranked low as a management response to reduce the impact of lost fishing gear, the role of consumer awareness and acceptance was suggested as a potential benefit of using BFG. Other studies (Whitmarsh and Wattage, 2006) also demonstrate the role of consumer awareness, acceptance and willingness to pay for sustainably produced fish. Drinkwin (2022) reports on the improvement in public image as a driving force for fishermen recovering ALDFG.

Taking into consideration the current challenges around developing BFG (e.g. strength, durability), the role of consumer awareness and consumer acceptance is perhaps one of the greatest opportunities for BFG implementation. A number of studies (Kershaw, 2015; Tsai, Lin and Chang, 2019) have shown that a variety of factors are responsible for differing attitudes towards the marine environment (age, education, gender, cultural background). While very few studies have been conducted on attitudes towards marine litter (Kershaw, 2015), a study on attitudes of European populations found that Governments and policy were considered responsible for the reduction of marine litter. There is also some evidence to suggest that human perceptions influence behaviour and that some people are attracted to technological solutions as an alternative to changing behaviour (Klockner, 2013). While this could be seen as positive for BFG – e.g. a new technology that reduces the need for behavioural change to correct an environmental externality caused by ALDFG, it may also be seen as negative, as a perceived lower responsibility could result in a reluctance to take action e.g. BFG that become ALDFG also has environmental impacts.

Norway dominates BFG research for fixed nets. Gillnet fisheries are particularly popular in Norway with more than 5,500 vessels using them (Grimaldo et al., 2020). While some studies in South Korea have shown comparable fishing efficiency between conventional and experimental BFG, most studies in Norway have shown a consistently lower catch efficiency, which has been attributed to the weaker monofilaments used (11-16% weaker monofilaments than nylon monofilaments of the same diameter (Grimaldo et al., 2020)). However, increasing the diameter of the monofilament did not have a significant impact in Grimaldo et al., (2020), who tested larger diameter monofilaments in the north Norwegian cod and saithe fishery. Therefore, Grimaldo et al., (2020) conclude that strength does not explain the difference in catch efficiency, but the elasticity and stiffness (that relate to monofilament strength) may be responsible for reduced catch efficiency. Further, larger diameters of monofilaments cause a decrease in fishing efficiency, as gear becomes more visible (and thus available) to fish.

Grimaldo et al., (2019) compared biodegradable gillnets to nylon gillnets and found the traditional gear caught 21% more of the target catch (cod), with better catch rates for most size classes. The number of deployments resulted in lower catch rates. Although less efficient, the biodegradable nets offer considerable potential for the reduction of ghost fishing and plastic pollution caused at sea by the fishery.

A study by Cerbule et al., (2022) found a similar decline in catch rate (25%) in the Norwegian cod gillnet fishery, declining with each deployment. Grimaldo et al., (2020) noted that the long term use of biodegradable gillnets negatively affects catch performance, with an aging test showing signs of deterioration after just 200 hours of exposure. Cerbule et al (2022a) also conducted a study on the use of biodegradable materials in longline comparing nylon vs. biodegradable snoods finding no difference in either the loss of snoods (nylon vs. biodegradable) or catch efficiency.

Profitability is the main drawback to reduced fishing efficiency. However, there are other factors that may also reduce profitability e.g. strength – as gear will more likely break during the active fishing phase (Wilcox and Hardesty, 2016). Further, less strength and flexibility may increase the time (and expense) of gear repair and maintenance. As strength is correlated with soak time (Wang et al., 2020), then further trails in commercial conditions to test gear characteristics. For example, breaking strength during degradation, which may highlight a shorter commercial lifespan increasing costs and reducing profitability. Moreover, the impact of BFG on ghost fishing could also be limited, with some studies suggesting that the degradation time of BFG far exceeds the (likely) ghost fishing time. Other studies also demonstrate that fishing efficiency of lost gear is a function of time since becoming lost in the marine environment, with sharp declines in fishing efficiency. For example, Brown et al., (2005) found a negative exponential function with rapidly declining ghost catches, so that after 90 days, a ghost gillnet would fish at less than 5% the capacity of the same net under the control of a fisherman. However, given the time that conventional non-biodegradable nets can persist in the marine environment (before breaking down into the arguably more harmful microplastic), catches at only 5% of a managed net will likely be significant.

Evidence from the FANTARED 2 project[37] (which is extensively reported on in Brown et al., 2005) suggested (based on interviews with fishermen) that net loss in the Channel fisheries is not extensive and is mainly a result of gear conflict, with trawlers often cited as the culprit. The FANTARED 2 project concluded that in the Channel it was unlikely that lost gillnets had any great impact on fishing mortality. This is (somewhat) supported by the technical questionnaire conducted in INdIGO, which reports low levels of gear loss with some apparent cause/effect relationship with gear conflict. We found similar from the stakeholder engagement undertaken with fixed net and trap fishermen, suggesting better communication between fishermen (often facilitated by POs for cross Channel communication) has resulted in less gear loss compared to a decade ago. In deep water offshore fisheries, the impact of lost nets on fishing mortality may be significantly higher with long soak times and greater environmental pressures.

Ghost fishing, however, is only one negative impact of ALDFG. Reducing ALDFG may deliver significant reductions in the environmental damage to benthic fauna and corals (Clare Eno et al., 2001; Meurer, 2020) that could benefit from BFG implementation. In any case, a major barrier would likely be the increased cost of investing in new BFG. This investment cost would likely need supporting with incentives (Wilcox and Hardesty, 2016).

[37] https://cordis.europa.eu/project/id/FAIR984338

Overall, there are a number of challenges that need to be addressed and overcome for the use of BFG to become commonplace in fisheries in the programme area, the EU and global fisheries. While the idea of biodegradation to tackle the environmental impacts of ALDFG is by no means a new idea, there is a paucity of literature on the role of biodegradability in the circular design of fishing gear. Combining BFG with an EPR programme could lead to better outcomes than developing EPR for traditional gear (and deserves further attention). However, research that has engaged stakeholders on the better management of fishing gear has tended to rank BFG low against alternatives to address ALDFG. Brown et al, (2005) note that several alternatives e.g. gear marking, communication, recycling supply chain development were ranked higher as key circularity aspects to address ALDFG and ghost fishing. Brown et al., (2005) report on a lack of faith in the concept of biodegradability in the Channel as well as Baltic and Mediterranean fisheries. MRAG (2020) report little interest from stakeholders in the use of biodegradable materials. OSPAR (2020) report on mixed responses to biodegradable materials for fishing gear with responses ranging from "promising" to "concerns raised about the functionality" and "time to degradation concerns". Therefore, there is a real need for research into the economic impacts as conducted here (and linking with technical shortcomings) – otherwise the uptake of BFG by industry is unlikely to become commonplace.

While most of what is available in the literature points to negative aspects, such as strength and flexibility resulting in reduced fishing efficiency (and the knock-on effects e.g. increased costs), further research is required to address the challenges. Importantly, there has been a shift in this direction in recent research (e.g. Grimaldo et al., 2020). While INdIGO is addressing some of the challenges around biodegradability, other EU funded projects also focus on biodegradability and the circular economy for fishing gear. For example, the Glaukos[38] project focuses on developing eco-friendly fishing gear, the BIO gillnets project is attempting to address fishing efficiency reductions in BFG[39], the Dsolve project[40] and the Clean Nordic Oceans Project[41] are addressing some of the common challenges of developing BFG that is comparable to traditional fishing gear to meet fishermen's expectations. Projects are also developing bio-based solutions for aquaculture, such as the recently funded BIOGEARS project[42].

The use of BFG in commercial fisheries is confined largely to South Korea (gillnets) and the USA (crab and lobster pots) – with experimental work growing in Norway. Most research refers to the common challenges outlined here – and the need for further research to address these challenges (noting that fishermen are unlikely to adopt gear that is perceived to be less effective than current standards). One major link is often made between BFG and the elimination of ghost fishing. Several studies though have shown that the impact of ghost fishing is reduced significantly overtime, resulting from a large decline in fishing efficiency (compared with managed gear) (see e.g. Pawson, 2003; Brown et al., 2005). However, this is dependent on the type of gear and environmental

[38] See: https://www.b4plastics.com/projects/glaukos/
[39] See: https://www.sintef.no/en/projects/2016/bio-gillnets/
[40] See: https://uit.no/research/dsolve-en?p_document_id=704783
[41] See: https://pub.norden.org/temanord2020-509/temanord2020-509.pdf
[42] See: https://biogears.eu/

conditions (e.g. water depth, tides). For example, in some gillnet fisheries, catch rates at 5% of commercial catch rates have been noted more than two years after net loss (MRAG, 2020). Trap fisheries may be even more problematic in terms of ghost catch, as traps can be self-bait (thus retaining a higher fishing efficiency for a longer period). Taking into account that there are wide variations in the estimation of ALDFG (and ghost fishing) local level studies are important to provide an indication of the scale of the problem to prioritise mitigation measures (at the fishery level).

Perhaps one of the greatest opportunities for BFG– as there is little research that refers to BFG as a technically feasible and economically viable alternative – is to link BFG with consumer awareness and willingness to pay more for fish caught from sustainable low impact fisheries (see e.g. Jaffry et al, 2016; Vitale et al. 2020).

4.4 Extended producer responsibility

Extended Producer Responsibility (EPR) essentially builds on the polluter pays principle. The Environment Act 2021[43] provides a framework for a new and enhanced EPR, building on existing waste laws and bringing in new industries and products (PWC[44], 2021). Thomas Lindhqvist developed the concept in the early 1990s - a method that places the producer at the heart of the negative externalities created by waste placing emphasis on redirected waste destined for landfill into a circular economy focusing on the reduce and reuse elements. EPR was first implemented in Germany in 1991[45], dictating that manufacturers assume the responsibility for recycling and disposing of the packaging material they sold. In placing the responsibility for end of life management firmly with producers the three goals of EPR are realised. (1) provide incentives for eco-design through innovation in the production process to minimise environmental impact; (2) create a sustainable production and consumption policy. This encourages separate waste collection and recycling to help countries reach their recycling targets and; (3) reduce landfilling and develop recycling channels. EPR schemes have proven successful in diverting waste from landfill to prevent waste and increase recycling (EXPRA, 2013[46]).

EPR schemes thus force the development of a circular economy, especially end of life recycling. Where the producer is the sole liable member of the supply chain that is responsible for management of end of life products, they are incentivised to innovate and ensure that products they produce are (technically) easy and (economically) viable to recycle. Criticisms of EPR include over concentration on the safe disposal of harmful products (e.g. by incineration) rather than reducing use. This may be a concern for fishing gear if too much focus is attached to developing recycling at the cost of the reduce and reuse elements of a circular economy. There is clear scope for BFG as part of an EPR programme, providing end of life recycling is ensured.

[43] https://www.legislation.gov.uk/ukpga/2021/30/contents/enacted
[44] https://www.pwc.co.uk/services/legal/insights/update-on-extended-producer-responsibility-changes-in-uk.html
[45] https://prevent-waste.net/wp-content/uploads/2020/09/Germany.pdf
[46] https://www.expra.eu/uploads/downloads/EXPRA%20EPR%20Paper_March_2016.pdf

4.4.1 Extended producer responsibility in fisheries

The EU Directive on single use plastics updates the existing legal requirements, which as stated in the Directive 2000/59/EC and Directive 2008/98/EC "do not provide sufficient incentives to return such fishing gear to the shore for collection and treatment". The 2019 Directive (EU) 2019/904[47] dictates that "as plastic components of fishing gear have high recycling potential, Member States should, in line with the polluter-pays principle, introduce extended producer responsibility for fishing gear". Research into developing EPR schemes for fishing gear is growing (see e.g. Powell, Jarvis and Worth, 2021). In terms of fisheries policy, EPR would represent a form of environmental policy, where the producer of fishing gear (e.g. of a crab pot) becomes responsible for the entire life cycle from design to end of life.

The establishment of an EPR policy for fishing gear represents a clear and actionable response to address one major vector of potential plastic pollution derived from fishing activities (IUCN, 2021). Under an EPR scheme for fishing gear, it is the role (responsibility) of the gear producer to ensure safe disposal/recycling of end of life gear. As such, it is hoped that EPR schemes would internalise the environmental costs of marine litter, incentivise the development of fishing gear with more sustainable materials (e.g. BFG) and provide much needed stimulation for the development of commercial recycling supply chains. However, there are significant barriers to overcome to increase recycling rates of fishing gear from the current low of 1.5%[48] (of the 640,000 tonnes of fishing gear that become ALDFG each year).

Similar to the voluntary nature of some gear retrieval efforts (Section 4.2), voluntary EPR schemes already exist for some forms of plastic use e.g. The Plastic Pact, Textile 2030[49] and the voluntary EPR pilot for fishing gear in France developed by the PECHPROPRE project[50] (Powell, Jarvis and Worth, 2021). Similar to other fisheries regulations (e.g. the EU landing obligation[51]), managing ALDFG by direct regulation of fishermen may prove unfeasible due to the expense and effort required in the large scale monitoring and enforcement required at sea. However, engaging fishermen in the design of sustainable fishing gear that meets their expectations e.g. BFG, would improve buy in for developing manageable EPR schemes. Financial incentives to support the implementation of EPR would be essential, particularly during the voluntary/experimental phase (IUCN, 2021). We consider the same for BFG use.

Defra committed to reviewing EPR for fishing gear in the 2018 Resources and Waste Strategy for England[52] and in 2019 commissioned a study to address EPR and other policy measures regarding the sustainable management of end of life fishing gear. An EPR scheme focussing on a mandatory EPR with take back was proposed as offering

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[47] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0904&from=EN
[48] https://www.europarl.europa.eu/news/en/press-room/20210322IPR00525/parliament-urges-eu-to-take-drastic-action-to-reduce-marine-litter
[49] https://wrap.org.uk/resources/guide/textiles-2030-roadmap
[50] https://www.pechpropre.fr/en/english-presentation/
[51] https://ec.europa.eu/oceans-and-fisheries/fisheries/rules/discarding-fisheries_en#:~:text=The%20EU's%20common%20fisheries%20policy,and%20to%20avoid%20unwanted%20catches.
[52] https://www.gov.uk/government/publications/resources-and-waste-strategy-for-england

the best benefit/cost measure. The EU Commission Directive on single use plastics and EPR for fishing gear dictates a harmonisation between the implementation of an EPR across all Member States (as well as Iceland, Norway and the UK). This is a particularly important consideration for the development of EPR in the UK fishing industry, as the EU is the main market for UK caught fish (Zych, 2020).

Some EU Member States have already enacted EPR into national legislation and others have until the end of 2024 to implement the policy. Iceland has already published a related law and Norway and the UK (as noted earlier) are planning similar policies[53]. While an EPR scheme for fishing is not a "silver bullet" solution, in the same way that gear retrieval and BFG are not, there may be considerable potential to incorporate BFG within an EPR scheme.

4.5 Section summary

The development of a circular economy for fishing gear, particularly the sustainable management of end of life fishing gear, is essential to mitigate the environmental, economic and social impacts of fishing gear. However, a circular economy adopting the reduce, re-use and recycle method cannot (by itself) mitigate (and eventually prevent) ALDFG in the marine environment. Previous research (Brown et al., 2005; FAO, 2016; MRAG, 2020; OSPAR, 2020) has identified a number of solutions regarding the "better" management of fishing gear, such as gear marking, gear mapping (to reduce gear conflict), identification and reporting of lost gears. Further, various citizen science projects, including beach cleans and Apps for the reporting of marine litter (including fishing gear) on beaches (e.g. the Fish&Click App developed by INdIGO) have developed to address the growing amounts of ALDFG. However, a clear message from the stakeholder engagement work conducted for our research, which is common in the literature (e.g. Chamber, Jarvis and Powell, 2021) is that fishermen do not lose gear on purpose. Gear, irrespective of type, (e.g. pots, fixed nets, trawl nets, dredges etc.) is expensive and is repaired and reused wherever possible. Further, in cases of gear loss considerable effort to recover gear is noted in some fisheries. For example, the Holderness Fishing Industry Group (per comms) report incidences of several attempts (over long periods) to recover lost gear – simply because of the financial impacts of gear replacement. For example, while a traditional parlour pot may cost as little as £70, a lost string of 100 pots (typical gear set up for this fishery) would result in a cost of £7,000.

The next section presents our analysis of ghost fishing in the Programme Area and considers the role of BFG as a mitigation measure to address ghost fishing to support fishermen in their decision to invest in the development phase of BFG in their fishery.

[53] https://landbell-group.com/news/another-country-introduces-epr-for-fishing-gear/

5. Addressing the economic impacts of ghost fishing and the role of BFG as a mitigation measure

5.1 Introduction

As previously discussed, there is a sparse (albeit growing) resource base on ALDFG and related impacts. During analysis of the literature and surveys already undertaken as part of this project it was identified that fishermen's assessment of the impact of losing gear, and time lost searching for and retrieving it, within their fishery was a gap. The collection of data to fill this gap would allow for an economic assessment of the impact of this for fishermen in the Programme Area. The model follows the assertion made in several studies (e.g. Arthur et al., 2014; Bilkovic et al., 2014; Butler et al., 2013) that fisheries incur losses in revenue due to a reduction in their potential harvestable catch through ghost fishing. In other words, ghost fishing is in direct competition with commercial fishing and uncontrolled ghost fishing represents an ongoing and increasing economic cost to commercial fishermen[54].

The model can be specified under various scenarios (and levels of sensitivity analysis), which is particularly useful to demonstrate to fishermen the potential gains from using BFG. For example, the model can be constructed at the fleet and fishery level (based on sample data – i.e. extrapolating data collected from a sample of fishermen to represent the population). However, it can also be constructed at the vessel level. Given the business model of a 6m potter (e.g. amount of gear, landings, outgoings and incomings etc.) is different to that of a 10m potter (or larger or any size in between) vessel level analysis is critical to demonstrate the role of BFG in mitigating ghost fishing to individual fishermen.

This analysis builds on work done in by Brown et al., (2005) on the impacts of ghost fishing on a hypothetical fishing fleet with data collected from active static gear fishermen and therefore provides an updated and tangible assessment of the impact that can be scaled. While Brown et al., (2005) assessed the role of gear retrieval programmes to mitigate ghost fishing, we consider the role of BFG as a mitigation response to ghost fishing for the INdIGO project. The section that follows (Section 6) considers the incentives required to facilitate BFG uptake.

Following the serviceable obtainable market for BFG in T1.3.2. Market Analysis, we focus on static gear fisheries. Considering both gear types, the Channel fishery is home to around 1,170 vessels, with almost 95% of these vessels being 10m and under. Of these, approx. 45% hold a shellfish licence. While data is not available to estimate the number of set net fishermen in the fishery (we estimate this in the analysis to provide scale), around 40% of the fishermen interviewed who use set net gear fished vessels 10m and under. However, as we also collected data for over 10m vessels we are also able to demonstrate the role of BFG in mitigating ghost fishing for these vessels and draw comparisons to other studies in Europe.

[54] As the stock of ALDFG continues to increase. Further, as noted by Beaumont et al., (2019) the cumulative effect of increases in marine litter mean that the impact of each additional piece of marine litter is worse than the one before.

5.2 Stakeholder engagement[55]

Fishing organisations, representatives, authorities and private enterprises were invited to take part in our research through phone calls, emails and contact made at the quayside. While several fishermen's organisations and associations (and authorities e.g. IFCAs) were contacted[56], the Cornish Fish Producers Organisation (CFPO) engaged heavily with the project and we were able to engage 23 of their members providing 71.9% of respondents. In total there were 29 respondents representing 48 vessels of which 31 fished using static gear. These came from the following ports from West to East: Newlyn, Helford, Newquay, Padstow, Mevagissey, Clovelly, Plymouth, Bideford, Portsmouth and Shoreham. Respondents were interviewed for 15-20 minutes on their fishing activity, interaction with ALDFG and experience of BFG (Appendix 2).

5.3 Data analysis

The model is built in Excel[57] and provides a basis for the assessment of the economic costs of ghost fishing and potential mitigation measures and can be presented at the vessel, fleet and fishery levels. This is considered important as vessels that may appear to be the same (e.g. size, gear type, species targeted) may operate under different business models. A report by the New Economics Foundation[58] (published in 2018) reveals significant variance in economic performance in the UK fleet. Based on net profit margins, larger scale vessels are more profitable overall with an average profit margin of 19%, although there is significant variation among both fleets and gear types. However, average profit margins are 0% for some of the <10m fleet segments. The data presented in the NEF report[59] suggests that some fleet segments are even operating with negative profits – reflecting the fact that for some smaller scale fishermen, fishing is as much a recreational activity as a commercial one (Appendix 3).

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[55] Full ethical approval was granted from the University of Portsmouth Ethics Committee Reference: **BA/2021/39/DRAKEFORD** before stakeholder engagement commenced.

[56] Fishermen's representatives were also contacted in North Norfolk, as well as outside of the Programme Area in Bridlington. We had also planned a joint stakeholder workshop with the Blue Marine Foundation in Berwickshire (home to a large shellfish fishery) but pandemic restrictions delayed the workshop beyond the feasible inclusion in this work.

[57] The spreadsheets used for the models development are available on request from the authors.

[58] See: https://neweconomics.org/uploads/files/Not-in-the-Same-Boat-PDF.pdf

[59] Based on: Scientific, Technical and Economic Committee for Fisheries. (2017). The 2017 Annual Economic Report on the EU Fishing Fleet (STECF-17-12). Luxembourg: Publications Office of the European Union. Retrieved from: https://stecf.jrc.ec.europa.eu/reports/economic

5.3.1 Vessel level analysis

The table below shows an example of a vessel level analysis (please see notes below for information).

Table 3 – Vessel level analysis: the cost of ghost fishing

		Pot u10m	Net u10m
		10m	9.98m
	Gear data		
1	Pots used/net length used (m)	1,000	41,062
2	Pots per string/nets per tier	50	24
3	Number of strings/tiers	20	19
4	Average soak time (hrs)	Year round	60
5	Cost of each pot/net panel	£84	£100 per 100yd (91.44m)
6	Cost of pots per string/ nets per tier	£1,680	Not provided
7	Cost of pots/nets used	£84,000	Not provided
8	Cost of markers & floats per pot/net	Not provided	Not provided
9	Cost of markers & floats used per string/tier	£10	Not provided
10	Cost of markers & floats used	£200	Not provided
11	Total cost of pots/nets and markers/floats	£84,200	£44,906
12	Average life span of pots/nets (months)	90	48
13	Average life span of markers/floats (months)	Not provided	Some ropes 20-25 years old
	Cost and earnings (per year)		
14	Landings (tonnes)	57.59	68.60
15	Revenue	£200,000	£200,000
16	Average value of landings (£per tonne)	£3,473	£2,915
17	Fishing expenses	£99,092	£97,373
18	Non fishing expenses	£43,095	£24,967
19	Total expenses	£142,187	£121,841
20	Net profit	£57,813	£78,159
21	Crew earnings	£59,016	£59,422
22	Value-added (crew earnings + profit)	£116,829	£137,581
23	Number of crew	3.0	3.5
24	Crew earnings per man	£19,672	£16,978

25	% of catch not quota controlled	100%	5%
26	Days fished	200	200
27	Hours fished	1,600	1,600
28	Value-added per hour	£73	£86
29	Crew earnings per hour	£37	£37
30	Value of non quota catch per hour	£125	£119
31	Value added as % of revenue	61%	69%
32	Value added per tonne fish caught	£2,112	£2,002
33	Catch per string/tier (tonnes)	2.879	3.579
34	Catch per string/tier per day (tonnes)	0.014	0.018
	Data on lost fleets and associated costs		
35	Gear lost per year	30/50 pots a year	2.5 tiers
36	Cost of gear lost	£3,360	£2,343
37	Time spent looking for nets (hrs)	8	24
38	% of time spent looking that would otherwise be fishing time	100%	100%
39	% of time spent looking that would otherwise be leisure time	0%	0%
40	Cost of lost leisure time		
41	Cost of lost value added from fishing time lost	£584	£2,064
42	Ghost fishing catch as % of total active catch	5%	5%
43	Value added lost from fish caught in ghost nets rather than by active gear	£6,080	£6,866
44	***Total cost of ghost fishing (lost nets, fish ghost caught and time spent by fishermen)***	£10,050	£11,268

Notes on model specification[60]:

1. The data required to populate the table and provide the result came from four sources:
    a. Primary data collected from surveys – Cells 1-7, 9-13, 15, 23, 25-27, 35-39, 41;
    b. Seafish multi annual UK fishing fleet estimates 2009-2019 – Cells 14, 17-21;
    c. Prices from online chandlery Coastal Nets (https://www.coastalnets.co.uk/) were used for cells 5-11 where the information was not provided – Cell 5-11;
    d. Calculated cells within the table – Cells 9-11, 16, 22, 24, 28-34, 40-41, 43-44;
    e. Cell 42, Ghost fishing catch as % of total active catch is a variable. This was not derived directly from the primary data but based on estimates derived

[60] Spreadsheets with full data and complete calculations are available from the authors if required.

from previous studies and assumptions based on the qualitative data collected in the surveys.

2. The data from Seafish allowed for the creation of estimates for a given vessel size band and gear type. This was then adjusted based on the yearly revenue provided in the primary data. This data was not collected in the primary data for two reasons:
    a. It was assessed that this would not be held by the respondents for recollection during the short interview due to the level of detail required;
    b. The data is of such a high level of commercial sensitivity that the respondents would be either unwilling to supply the data or it would present a barrier to their participation.

3. Cells 5 to 11 dealt with the cost of the nets. The respondents understood the cost of their nets in a variety of ways e.g. cost of replacement over time, whole cost, cost per net inclusive or exclusive of rigging. Therefore, these cells are populated/ unpopulated based on the information provided and some assumptions have been made to derive the figure in Cell 11.
    a. The data from the online chandlery was used to provide an estimate of an average figure of £84 per pot and £100 per 100yd of fully rigged net with £10 of accessories (floats, ropes, markers) per string used with the fishing gear where this was not information that the respondents were able to provide.

4. Cell 44, Total cost of ghost fishing (lost nets, fish ghost caught and time spent by fishermen), is the output from the calculations. It brings together the costs associated with replacing any lost gear, the value of any fishing lost due to the effects of ghost fishing and the cost of time lost to searching for and recovering lost gear.

5.3.2 Fleet level analysis

Following the vessel level analysis, which can be undertaken for each of the vessels[61] represented in each interview, the data from the 31 static gear vessels provided an average figure for vessels above and below 10m in length and whether they used pots, static nets or both. These headline figures, which are used for the sensitivity analysis, are presented below.

[61] The vessel number is higher than the number of interviews conducted as some interviewees owned multiple vessels.

Table 4 – Fleet level analysis disaggregated by fleet segment

	Pots u10m (n=7)	Pots o10m (n=1)	Nets u10m (n=8)	Nets o10m (n=6)	Net and Pot u10m (n=8)	Net and Pot o10m (n=1)
Pots used/net length used (m)	950	840	14,328	40,447	791 pots 12406m net	1200 pots 12,000m net
Total cost of pots/nets and markers/floats	£75,069	£67,410	£15,669	£44,234	£80,589	£114,063
Ave. lifespan pots (months)	86	96			60	81
Ave. lifespan nets (months)			18	13	12	14
Revenue	£147,917	£60,000	£91,667	£456,250	£170,000	£285,000
Total expenses	£105,159	£36,270	£55,844	£402,373	£114,725	£235,569
Crew earnings	£43,647	£11,349	£27,235	£147,211	£50,286	£84,365
Net profit	£42,757	£23,730	£35,823	£53,877	£55,275	£49,431
Value-added (crew earnings + profit)	£86,405	£35,079	£63,058	£201,088	£105,561	£133,795
Value-added per hour	£56	£44	£43	£126	£68	£84
Cost of gear lost	£2,992	£480	£513	£17	£6,177	£13,104
Cost of lost value added from fishing time lost	£792	£175	£258	£0	£990	£1,305
Ghost fishing catch as % of total active catch	5%	5%	5%	5%	5%	5%
Value added lost from fish caught in ghost nets rather than by active gear	£4,320	£1,754	£3,153	£10,054	£5,278	£6,690
Total cost of ghost fishing (lost nets, fish ghost caught and time spent by fishermen)	£8,105	£2,409	£3,924	£10,071	£12,445	£21,098

Table 5 - Fleet level analysis aggregated by vessel size

	All static gear u10 (n=23)	All static gear o10 (n=8)		All static gear (n=31)
Pots used/net length used (m)				
Total cost of pots/nets and markers/floats	£51,559	£178,576		£56,207
Ave. lifespan pots (months)	72	88		74
Ave. lifespan nets (months)	15	13		14
Revenue	£136,033	£385,313		£200,363
Total expenses	£91,333	£335,760		£154,411
Crew earnings	£40,248	£122,373		£61,441
Net profit	£44,699	£49,553		£45,952
Value-added (crew earnings + profit)	£84,947	£171,925		£107,393
Value-added per hour	£56	£110		£70
Cost of gear lost	£3,238	£1,711		£2,844
Cost of lost value added from fishing time lost	£675	£185		£549
Ghost fishing catch as % of total active catch	5%	5%		5%
Value added lost from fish caught in ghost nets rather than by active gear	£4,247	£8,596		£5,370
Total cost of ghost fishing (lost nets, fish ghost caught and time spent by fishermen)	£8,160	£10,492		£8,762

5.3.3 Sensitivity analysis

The data collected allowed a sensitivity analysis to be undertaken by manipulating the following key variables:

- The value of potential catch lost to ghost fishing at different intensities;
- The impact of a loss of revenue associated with a reduction in fishing efficiency of biodegradable gear versus current gear;
- The impact of increased costs associated with biodegradable gear versus current gear;
- Increased revenue from an increase in market price for fish marketed as caught with biodegradable gear.

5.3.3.1 Ghost fishing

The cost of ghost fishing comes from the cost of lost gear, time lost searching for and retrieving gear plus the potential lost value added (profits plus crew earnings) from reduced catch in the fishery. The lost value added was set at four levels (2.5%, 5%, 7.5% and 10%) of ghost fishing intensity with the values shown in the table below.

Table 6 – Cost of ghost fishing (vessel level)

Ghost fishing		Pots u10m (n=7)	Pots o10m (n=1)	Nets u10m (n=8)	Nets o10m (n=6)	Net and Pot u10m (n=8)	Net and Pot o10m (n=1)
2.5%	Total cost of ghost fishing (lost nets, fish ghost caught and time spent by fishermen)	£5,945	£1,544	£2,347	£5,044	£9,806	£17,753
5%		£8,105	£2,421	£3,924	£10,071	£12,445	£21,098
7.5%		£10,265	£3,298	£5,500	£15,098	£15,084	£24,443
10%		£12,425	£4,175	£7,076	£20,125	£17,723	£27,788

Table 7 – Cost of ghost fishing (aggregated by vessel size)

Ghost fishing		All static gear u10 (n=23)	All static gear o10 (n=8)		All static gear (n=31)
2.5%	Total cost of ghost fishing (lost nets, fish ghost caught and time spent by fishermen)	£6,036	£6,195		£6,077
5%		£8,160	£10,493		£8,762
7.5%		£10,284	£14,791		£11,447
10%		£12,407	£19,089		£14,132

5.3.3.2 Fishing efficiency

Any reduction in fishing efficiency of biodegradable gear versus current gear will reduce the revenue associated with fishing activity. The assumption made for this analysis is that there would be no additional fishing effort applied in order to return revenue to its former level and that all other costs remain fixed. Ghost fishing activity is assumed to remain at the original level for this analysis.

The analysis was performed using a decline in fishing efficiency of 5%, 10% and 20% with the results shown for revenue and net profit. There is some offsetting from a reduced cost of lost catch to ghost fishing as revenue reduces so this is included in the results.

Table 8 – Impact of fishing efficiency (vessel level)

Fishing efficiency		Pots u10m (n=7)	Pots o10m (n=1)	Nets u10m (n=8)	Nets o10m (n=6)	Net and Pot u10m (n=8)	Net and Pot o10m (n=1)
0%	Revenue	£147,917	£60,000	£91,667	£456,250	£170,000	£285,000
-5%		£140,521	£57,000	£87,083	£433,438	£161,500	£270,750
-10%		£133,125	£54,000	£82,500	£410,625	£153,000	£256,500
-20%		£118,333	£48,000	£73,333	£365,000	£136,000	£228,000
0%	Net profit	£42,757	£23,730	£35,823	£53,877	£55,275	£49,431
-5%		£35,361	£20,730	£31,240	£31,064	£46,775	£35,181
-10%		£27,966	£17,730	£26,656	£8,252	£38,275	£20,931
-20%		£13,174	£11,730	£17,490	-£37,373	£21,275	-£7,569
0%	Total cost of GF	£8,105	£2,409	£3,924	£10,071	£12,445	£21,098
-5%		£7,667	£2,244	£3,676	£8,930	£11,940	£20,247
-10%		£7,229	£2,079	£3,428	£7,790	£11,436	£19,395
-20%		£6,354	£1,749	£2,932	£5,509	£10,426	£17,693

Table 9 – Impact of fishing efficiency (aggregated by vessel size)

Fishing efficiency		All static gear u10 (n=23)	All static gear o10 (n=8)		All static gear (n=31)
0%	Revenue	£136,033	£385,313		£200,363
-5%		£129,231	£366,047		£190,345
-10%		£122,429	£346,781		£180,327
-20%		£108,826	£308,250		£160,290
0%	Net profit	£44,699	£49,553		£45,952
-5%		£37,898	£30,287		£35,934
-10%		£31,096	£11,021		£25,916
-20%		£17,493	-£27,510		£5,879
0%	Total cost of GF	£8,160	£10,492		£8,762
-5%		£7,766	£9,508		£8,210
-10%		£7,372	£8,524		£7,658
-20%		£6,584	£6,556		£6,553

5.3.3.3 BFG cost

Any increase in the cost of gear on a per unit basis over current gear will reduce net profit assuming that fishing activity remains consistent with revenue and other costs unchanged. Ghost fishing activity is assumed to remain at the original level for this analysis.

The analysis was performed using an increase of 5%, 10% and 20% with the results shown for revenue and net profit. There is some fluctuation in the cost of lost catch to ghost fishing as net profit and therefore value-added declines, reducing the value of lost fishing time, while the increased gear cost raises the value of the gear lost.

Table 10 – Impact of BFG cost (vessel level)

Cost increase		Pots u10m (n=7)	Pots o10m (n=1)	Nets u10m (n=8)	Nets o10m (n=6)	Net and Pot u10m (n=8)	Net and Pot o10m (n=1)
0%	Yearly gear cost	£10,475	£8,426	£10,544	£40,212	£26,526	£26,272
5%		£10,998	£8,848	£11,071	£42,223	£27,852	£27,586
10%		£11,522	£9,269	£11,598	£44,234	£29,178	£28,899
20%		£12,570	£10,112	£12,653	£48,255	£31,831	£31,526
0%	Net profit	£42,757	£23,730	£35,823	£53,877	£55,275	£49,431
5%		£42,234	£23,308	£35,296	£51,866	£53,949	£48,117
10%		£41,710	£22,887	£34,768	£49,856	£52,623	£46,803
20%		£40,662	£22,044	£33,714	£45,834	£49,970	£44,176
0%	Total cost of GF	£8,105	£2,409	£3,924	£10,071	£12,445	£21,098
5%		£8,223	£2,410	£3,921	£9,971	£12,675	£21,675
10%		£8,342	£2,411	£3,918	£9,872	£12,905	£22,252
20%		£8,579	£2,413	£3,912	£9,672	£13,366	£23,405

Table 11 – Impact of BFG cost (aggregated by vessel size)

Cost increase		All static gear u10 (n=23)	All static gear o10 (n=8)		All static gear (n=31)
0%	Yearly gear cost	£16,082	£34,497		£20,834
5%		£16,886	£36,221		£21,876
10%		£17,690	£37,946		£22,917
20%		£19,298	£41,396		£25,001
0%	Net profit	£44,699	£49,553		£45,952
5%		£43,895	£47,828		£44,910
10%		£43,091	£46,103		£43,868
20%		£41,483	£42,653		£41,785
0%	Total cost of GF	£8,120	£10,441		£8,762
5%		£8,275	£10,489		£8,847
10%		£8,391	£10,487		£8,931
20%		£8,621	£10,481		£9,101

5.3.3.4 Sales price increase

The final sensitivity analysis relates to any potential improvement in the market price of fish landed due to any positive consumer response to fish products marketed as landed using biodegradable gear. The values used were 1%, 2% and 5%. This small improvement to revenue has a significant effect on net profit while also raising the cost of ghost fishing as the catch lost is worth more.

Table 12 – Impact of sales price increase (vessel level)

Price increase		Pots u10m (n=7)	Pots o10m (n=1)	Nets u10m (n=8)	Nets o10m (n=6)	Net and Pot u10m (n=8)	Net and Pot o10m (n=1)
0%	Revenue	£147,917	£60,000	£91,667	£456,250	£170,000	£285,000
1%		£149,396	£60,600	£92,583	£460,813	£171,700	£287,850
2%		£150,875	£61,200	£93,500	£465,375	£173,400	£290,700
5%		£155,313	£63,000	£96,250	£479,063	£178,500	£299,250
0%	Net profit	£42,757	£23,730	£35,823	£53,877	£55,275	£49,431
1%		£44,236	£24,330	£36,740	£58,439	£56,975	£52,281
2%		£45,716	£24,930	£37,656	£63,002	£58,675	£55,131
5%		£50,153	£26,730	£40,406	£76,689	£63,775	£63,681
0%	Total cost of GF	£8,105	£2,409	£3,924	£10,071	£12,445	£21,098
1%		£8,192	£2,442	£3,973	£10,299	£12,546	£21,269
2%		£8,280	£2,475	£4,023	£10,527	£12,647	£21,439
5%		£8,542	£2,574	£4,171	£11,212	£12,950	£21,950

Table 13 – Impact of sales price increase (aggregated by vessel size)

Price increase		All static gear u10 (n=23)	All static gear o10 (n=8)		All static gear (n=31)
0%	Revenue	£136,033	£385,313		£200,363
1%		£137,393	£389,166		£202,367
2%		£138,753	£393,019		£204,370
5%		£142,834	£404,578		£210,381
0%	Net profit	£44,699	£49,553		£45,952
1%		£46,060	£53,406		£47,955
2%		£47,420	£57,259		£49,959
5%		£51,501	£68,818		£55,970
0%	Total cost of GF	£8,160	£10,492		£8,762
1%		£8,239	£10,689		£8,872
2%		£8,318	£10,885		£8,983
5%		£8,554	£11,476		£9,314

5.4 Scenario development

These sensitivity analyses were used to create scenarios for a modelled 10m and under vessel and an over 10m vessel. Scenario 1A was low impact using a 5% reduction in fishing efficiency and a 5% increase in gear cost. Scenario 2A was a high impact scenario using a 20% decrease in fishing efficiency and 20% increase in gear cost. Scenario 1B and 2B were then created with a 1% increase in the market price.

Table 14 – Scenario 1A: Low impact with no price increase

		All static gear u10 (n=23)	All static gear o10 (n=8)
Ghost fishing	**5%**	£8,067	£10,163
Fishing efficiency	**-5%**	-£6,802	-£19,266
Cost increase	**5%**	-£804	-£1,725
Price increase	**0%**	£0	£0
Costs		-£7,606	-£20,990
Benefits		£8,067	£10,163
Total		£461	-£10,828

Table 15 - Scenario 1B: Low impact with 1% price increase

		All static gear u10 (n=23)	All static gear o10 (n=8)
Ghost fishing	**5%**	£8,093	£10,228
Fishing efficiency	**-5%**	-£6,802	-£19,266
Cost increase	**5%**	-£804	-£1,725
Price increase	**1%**	£1,360	£3,853
Costs		-£7,606	-£20,990
Benefits		£9,454	£14,082
Total		£1,848	-£6,909

Table 16 - Scenario 2A: High impact with no market price increase

		All static gear u10 (n=23)	All static gear o10 (n=8)
Ghost fishing	**5%**	£7,788	£9,176
Fishing efficiency	**-20%**	-£27,207	-£77,063
Cost increase	**20%**	-£3,216	-£6,899
Price increase	**0%**	£0	£0
Costs		-£30,423	-£83,962
Benefits		£7,788	£9,176
Total		-£22,635	-£74,786

Table 17 - Scenario 2B: High impact with 1% market price increase

		All static gear u10 (n=23)	All static gear o10 (n=8)
Ghost fishing	**5%**	£7,815	£9,242
Fishing efficiency	**-20%**	-£27,207	-£77,063
Cost increase	**20%**	-£3,216	-£6,899
Price increase	**1%**	£1,360	£3,853
Costs		-£30,423	-£83,962
Benefits		£9,175	£13,095
Total		-£21,248	-£70,867

The scenarios show that even at low impact, the loss of profit is large and only in the 10m and under vessel would this be offset by eliminating ghost fishing entirely. As this would be unlikely from the start, as already lost gear would continue to ghost fish for a period of time, the costs form the basis of the impact on the fleet from day one of biodegradable gear adoption.

5.4.1 Fleet size estimate

As seen in the market analysis achieving an accurate figure for the number of vessels operating in the Channel area is not possible. Therefore, the figure for static gear vessels in the UK is taken from the 2019 Seafish fleet report which shows 1,391 10m and under (excluding low activity) and 311 over 10m static gear vessels. The Channel area has ~20% of the UK's static gear vessels which gives a crude estimate of 274 10m and under and 61 over 10m vessels.

Table 18 - 10m and under

	All static gear u10 (n=23)	Channel area	UK
Vessel numbers	**Single vessel**	**274**	**1,391**
Scenario 1a			
No Ghost fishing	£461	£126,466	£641,763
Ghost fishing	-£7,606	-£2,084,815	-£10,579,549
Scenario 1b			
No Ghost fishing	£1,848	£506,550	£2,570,526
Ghost fishing	-£6,245	-£1,711,934	-£8,687,336
Scenario 2a			
No Ghost fishing	-£22,635	-£6,204,413	-£31,484,754
Ghost fishing	-£30,423	-£8,339,261	-£42,318,198
Scenario 2b			
No Ghost fishing	-£21,248	-£5,824,329	-£29,555,991
Ghost fishing	-£29,063	-£7,966,380	-£40,425,984

Table 19 - Over 10m

	All static gear o10 (n=8)	Channel area	UK
Vessel numbers	**Single vessel**	**61**	**311**
Scenario 1a			
No Ghost fishing	-£10,828	-£663,577	-£3,367,373
Ghost fishing	-£20,990	-£1,286,420	-£6,528,032
Scenario 1b			
No Ghost fishing	-£6,909	-£423,415	-£2,148,649
Ghost fishing	-£17,137	-£1,050,277	-£5,329,710
Scenario 2a			
No Ghost fishing	-£74,786	-£4,583,300	-£23,258,297
Ghost fishing	-£83,962	-£5,145,679	-£26,112,128
Scenario 2b			
No Ghost fishing	-£70,867	-£4,343,138	-£22,039,573
Ghost fishing	-£80,109	-£4,909,537	-£24,913,807

Using the figures from the scenarios to derive figures at a static gear fleet Channel area and UK level shows that, assuming that ghost fishing cannot be eliminated from the start, the sums involved for individual vessels and the fleet are substantial. The Channel area range for 10m and Under vessels of £1.7m to £8m and over 10m of £400k to £5m in these scenarios suggests a significant investment would be required to keep the fleet profitable during any transition.

Declines in fishing efficiency appear to be the most significant potential issue. For instance, in the scenarios if fishing efficiency declines are removed for the 10m and under Channel area fleet the impact estimate drops from £1.7m to £8m down to -£150k (i.e a positive benefit) to £880k.

Overall, our work supports the literature on the potential role of biodegradable gear in mitigating ghost fishing impacts of ALDFG[62].

[62] In the full cost benefit analysis, the costs and benefits for lost gear retrieval will be factored in. A study carried out in 2005 estimated the return on investment of the schemes to be 0.49 and to provide minimal benefits at a vessel level (€ 567).

6. Policy - using economic instruments to address ALDFG and ghost fishing[63]

6.1 Introduction and context

The functionality and low price of plastic has resulted in two outcomes. (1). An exponential increase in plastics use in the global economy. Under the business as usual scenario, plastic will become even more persistent in the everyday lives of people around the world. (2). The low cost of virgin plastic has precluded the development of plastics recycling around the world. Without intervention, both of these outcomes will continue on an upward trajectory.

The rationale for policy intervention is to mitigate problems that would otherwise remain unaddressed – essentially internalising negative externalities to bring about better outcomes for society. However, there is currently no policy intervention to mitigate ALDFG and ghost fishing. As noted by Chambers, Jarvis and Powell (2021), in the absence of a policy intervention, there is reduced incentive for fishermen to act in the interest of the common good for all users (not only other fishermen but all users of the marine environment that ALDFG impacts upon). Further, other actors in the supply chain for fishing gear e.g. gear makers perhaps have even less incentive to act as they are further detached from the impacts of ALDFG and the financial cost of damage to the marine environment (than direct users of the marine environment) (Cole et al., 2021). Solutions to the overexploitation of common pool resources like fisheries, forestry and clean air therefore requires some form of government intervention – usually in the form of property rights, regulation or collective action to change behaviour. The use of traditional (plastic based) fishing gear is a result of the Commons problem. This arises as the benefits of **some** fishermen investing in BFG would be distributed among **all** fishermen (in the form of reduced ALDFG and ghost fishing). However, the costs are borne **only** by the fishermen that adopt BFG (through investment costs and reduced fishing efficiency of BFG over traditional fishing gear). In a wider sense, as ALDFG (and marine litter in general) effects on the provision of ecosystem services flowing from the world's oceans, all of society are affected (Arabi and Nahman, 2020). In short, while the direct economic impacts of environmental damage are felt most by those that derive their livelihood from the environment that is being damaged, the range of indirect economic and social costs that result from environmental damage impact on all of society. This is in both the short term (e.g. impact of dirty beaches on visitors) and the long term (e.g. long term impacts on the provision of ecosystem services).

The creation of ALDFG is thus a market failure. The role of policy intervention in the case of ALDFG is to realign incentives so that actions to address ALDFG do not penalise the individual. According to Chen, (2015), there are four types of management approaches that can be implemented to address marine litter. Firstly, preventative measures - essentially legislation and regulations that ultimately aim to prevent marine litter from entering the ocean. By integrating elements of marine litter (e.g. fishing gear) into the circular economy by reusing before recycling (and preventing land-based waste entering oceans), the level of marine litter would naturally decrease. With regards to waste fishing gear, two key improvements can be made. One is the upgrading of port

[63] This section is largely taken from T1.1.2 Market Analysis. It has been updated to take into account our analysis (Section 5) and the indication from the results of the type of economic incentives required.

reception facilities (which are almost non-existent at most ports in the EU) for dealing with end of life fishing gear (Chen, 2015). The other option is to make producer responsibility mandatory. This is commonplace in the EU for environmentally damaging production processes e.g. car batteries, where the producer has responsibility for financing the collection, recycling and responsible end of life disposal. In the EU, extended producer responsibility is considered a cornerstone of waste policy (Pouikli, 2020). For example, the EU Single-Use Plastics Directive covers fishing gear as well as tackling the 10 single use plastics most commonly found washed up on beaches. From the end of 2024, an extended producer responsibility will be applied to fishing gear, bringing fishing gear in line with other damaging sources of environmental pollution in the EU.

Secondly, mitigation measures - essentially attempting to dilute the impact of marine litter (Chen, 2015), given some type/amount of marine litter is unavoidable. There is a close link with preventative measures, where command and control regulations are attempting to prevent the pollution in the first instance. Mitigation measures, that link to port reception facilities, for instance, are relevant to fishing gear waste.

Thirdly, removal measures - essentially activities that take place to remove marine litter. For example, beach clean-ups and gear retrieval programmes. There is some link to preventative measures e.g. extended producer responsibility.

Fourthly, behaviour changing – essentially the use of educational tools to change behaviours and reduce marine litter. A significant element here is the use of economic incentive tools to bring about the required behavioural changes to address the problem (in the hope that once the behaviour has changed the incentive is withdrawn).

Nations are faced with two broad (although not mutually exclusive) options to manage ALDFG – command and control regulations or incentive based approaches (so called market based mechanisms[64]). Historically, the effectiveness of the command and control approach is strongly linked with the ability to enforce the regulation set – significantly more difficult for ocean based activities compared with land based activities. While significant improvements in the way fisheries management regulations are enforced have been made (e.g. technological advances such as GPS vessel monitoring), the task remains challenging. For example, Illegal, Unreported and Unregulated (IUU) fishing is considered to be "one of the greatest threats to marine ecosystems for its potent ability to undermine national and regional efforts to manage fisheries sustainably as well as endeavours to conserve marine biodiversity" (FAO, 2021[65]).

However, the use of incentive based approaches also presents problems. For example, subsidies, a commonly used incentive measure, can lead to perverse outcomes that contribute to resource depletion (i.e. contributing to the problem addressed). There is concern that the use of BFG (if aligned with incentives) could also create a perverse

[64] In addition, there are other systems, like community based management or voluntary measures (such as no take zones, or voluntary agreements on gear use) and other initiatives like the Blue Marine Foundation Lyme Bay fisheries.

[65] The FAO (2021) estimate that up to 26 million tonnes of fish caught annually (valued at USD 10 to USD 23 billion) is lost to IUU fishing.

incentive to intentionally discard more gear into the marine environment and could lead to leakage of microplastics (OSPAR, 2020). However, in certain cases financial incentives are needed to assist the transition to sustainable practice. This was evident in the INdIGO surveys and the stakeholder engagement work conducted for this report.

6.2 Command and control

Command and control measures can be implemented to control parts of a production process that are causing environmental impact that left alone would get worse[66]. A regulation mandating BFG to address the impacts of ALDFG e.g. ghost fishing could be implemented. However, given the current technical shortcomings identified (e.g. Cerbule et al., 2022; Grimaldo et al., 2019) low uptake by industry is a risk (OSPAR, 2020). Therefore, more research is required to ensure the status quo in terms of functionality and environmental impact is maintained. INdIGO and other projects (Section 4.2.1) are addressing these issues – as clear themes emerge in the literature, particularly declines in fishing efficiency. As a result, we do not consider regulation in any further detail here.

6.3 Incentive based measures

From a theoretical viewpoint, incentives refer to economic instruments of cost internalisation. The incentive-based approach is preferable providing it delivers what it promises - that being, it incentivises/rewards greater reduction in the level of environmental impact. Connecting environmental objectives with financial incentives effectively incentivises producers to find alternatives to reduce pollution[67] and invest in such technology if it is cost effective (the incentive can be implemented to ensure the short-term cost effectiveness, or to facilitate engaging in fishing gear trials, for example). As a result, (although there are caveats – as outlined below), the social cost of incentive-based approaches tends to be less, as society as a whole benefit from better environmental performance of firms. It is also clear that society will benefit from reductions in marine litter. The traditional economic viewpoint of incentive-based approaches is that they will achieve at the least the same outcome as the command and control regulation, as well as (incentivising) reduction beyond the "command" level – leading to lower levels of environmental impact (the externality that the incentive based approach is targeting). However, in some cases, a mixed policy framework (command and control with incentives) may lead to a better outcome – especially in cases where monitoring compliance and enforcement is difficult.

Incentive based approaches also have drawbacks. Subsidies, a commonly used market based measure to address market failure can be damaging to the environment (Sumalia et al., 2013). This is (in part) because they may create perverse incentives that lead to unintended outcomes. The worst-case scenario is that a subsidy to decrease the level of a negative environmental impact can actually result in an increase in the negative environmental impact. While subsidies should incentivise improvements in reducing pollution overtime they may (if poorly implemented) in practice, create inefficient

[66] A description of command and control measures is provided in T 1.3.2. Market Analysis. Given there is no expectation of a regulation around BFG (rather EPR appears to be the preferred measure by UK Government), it was not felt necessary to include a full overview of command and control measures here.
[67] In a similar way to EPR.

production processes and have the opposite effect. For example, most fisheries subsidies are estimated to be harmful to the environment, particularly fuel subsidies that make it affordable for vessels to spend longer at sea and catch more fish from already depleted stocks. The literature is littered with examples of 'harmful fisheries subsidies' (Arthur et al., 2019; Cisneros_Montemayor and Sumaila, 2019; Skerritt and Sumaila; 2021; Sumaila et al., 2016). Added to that, it is estimated that the use of subsidies in developed countries is far greater than developing countries (accounting for 65% of total subsidies transferred by governments to the fishing industry), with EU fisheries alone (including the UK) accounting for 25% of global subsidies (Sumalia et al., 2013). A further drawback is that market based instruments may be negatively received by society (Fullerton, Leicester and Smith, 2007), as part of their transaction cost is to incentivise producers to reduce their environmental impact - consumers may consider that the responsibility of the producer (and/or government). As such, there may be a higher moral value assigned to command and control approaches, or extended producer responsibility schemes.

6.3.1 Incentives required for BFG uptakes in the Programme area

There are limited examples in the literature of the type/amount of incentive that would be required for fishermen to engage with BFG. There are several references to the use of government financial incentives to mitigate impacts of ALDFG (including the role of BFG to address ghost fishing). For example, Cho (2009) discusses incentive schemes for ALDFG removal with different rates paid for the type and volume of gear retrieved. Kim, Lee and Moon (2014) discuss the need for financial incentives to stimulate BFG use (and the importance of public education to emphasise the need to address gear discarding at sea). Kim et al., (2015) report on the use of government financial incentives for biodegradable gillnet use as compensation for lower catch efficiency and higher gear costs.

A study by Standal, Grimaldo and Larsen (2020) discussed the options for type and level of incentives required for BFG use in the Norwegian cod gillnet fishery. Standal, Grimaldo and Larsen (2020) report on a 10.9M gillnetter working a fleet of six nets (120 panels in total). Replacing all gear with biodegradable gillnets would result in a 21% decline in catch (approx. 20 tonnes) resulting in almost £40,000[68] of lost revenue. Given biodegradable gillnets are twice as expensive in Norway as traditional gear the investment would be almost £3,000. Therefore, a total cost (lost catch and gear investment) of £43,000. In the lack of government assistance e.g. financial incentive, the gillnetter would either have to set more gear (higher investment cost) or spend more time fishing (higher variable costs e.g. fuel). Therefore, everything else remaining constant, the gillnetter would need to be compensated for the reduced catch and extra gear investment cost. This study does not factor in higher market prices from BFG use (as we do in our analysis). However, what this study does show is that the use of BFG is a technical challenge and not an economic one. The majority of incentive (more than 90%) is to compensate for fishing efficiency and less than 10% for the cost of gear.

Our analysis highlights various scenarios where the use of financial incentives would be essential for BFG uptake. The incentives required for decreases in fishing

[68] Figures adjusted to GBP at 2022 values.

efficiency (especially for >10m gillnetters) are the greatest. We found that for these vessels a 20% decline in fishing efficiency (as consistently reported in Norwegian experimental trials[69]) would yield negative profits of more than £37,000. Therefore, if BFG was given to these fishermen free of cost a financial incentive of £37,000 would be needed to breakeven. As the current profitability for this vessel is around £53,000, an incentive for a "no change" scenario to the fishermen would be £90,000. However, under the same scenario an incentive of less than £30,000 would be required for an <10m potter. Extrapolating to the Channel area (7D/7E) the impact of fishing efficiency would require financial incentives as high as £8 million (the worst-case scenario as presented in our analysis) to maintain a profitable fleet. If the issue of fishing efficiency could be addressed, a positive benefit of £880,000 could be realised.

Our analysis demonstrates the importance of a vessel level analysis showing that the cost of using BFG is dependent of the fleet characteristics of various vessels operating in a fishery. However, it does further demonstrate that integrating BFG into a fishery is a technical rather than an economic problem. In this respect, we found similar to Standal, Grimaldo and Larsen (2020) – most of the financial incentive is required to offset declines in fishing efficiency. While subsidising the cost of BFG, as well as assuming that fishermen may be able to attract higher prices for fish caught using BFG, it is not enough to address the impact on profitability of declines in fishing efficiency. However, our research also supports the role of BFG in ghost fishing mitigation and helps to identify the vessels that could be incentivised to engage in experimental work (to better understand and address functionality issues in fisheries in the Programme area).

Along with the use of incentives for BFG, fishermen will continue to play an important role in retrieving lost gear. Perhaps more so if fishermen were using BFG. Drinkwin (2022) notes that "requiring" fishermen to retrieve gear if it is lost as a critical measure to avoid impacts from ALDFG. Most fishermen make a great deal of effort to retrieve gear (even illegal fishing activity) as the purchase and maintenance of fishing gear is a major expense and investment for fishermen. Incentivising fishermen to do so will be important, otherwise retrieval attempts that divert attention from lucrative fishing, costing time and fuel, fishermen may abandon lost gear in order to carry on fishing. An incentive to ensure that vessels carry the necessary equipment to recover gear would be useful in this respect (Drinkwin, 2022). Finally, coupling this with policy to establish new regulations would likely yield the best chance of success.

[69] We refer to Norway as this is where most BFG experimental work has been undertaken for gill (type) nets.

7. Conclusion

Biodegradability as a design feature for fishing gear is not a new idea (Grimaldo et al., 2020; Wilcox and Hardesty, 2016). The research that has developed on BFG has not considered the innovation a key 'circularity aspect' with studies reporting a lack of faith in the concept by fishermen, or reservations around BFG as it is not like-for-like in terms of functionality and cost (Brown et al., 2005; MRAG, 2020; OSPAR, 2020). The fishing industry, however, is one of the main contributors to marine litter through ALDFG, with the EU (2018) estimating that 27% of all marine litter in the EU is fishing waste. As such, urgent action is required to develop a circular economy for fishing gear to address the myriad of environmental impacts.

In this report, we have focused on the ghost fishing impact of ALDFG developing an economic model to address the cost of ghost fishing to the fishing industry and assess BFG as a management response. For an innovation to be accepted by end users, it must be demonstrated to be technically and economically feasible. Our analysis indicates that integrating BFG in to the fishing industry is a technical challenge and not necessarily an economic one. We assert this given the various scenarios modelled in our analysis demonstrate that the majority on incentive (to engage fishermen) is needed to offset the decline in fishing efficiency (i.e. technical issue). In other words, the cost of ghost fishing prevented by BFG is not sufficient to offset the economic cost of declined catches by fishermen using BFG.

Conducting a vessel level analysis of the fleets identified in the market analysis[70], we show that in one scenario a vessel could benefit economically from the use of BFG[71]. In all other scenarios, some level of financial incentive would be required. In some cases, the level of incentive may be prohibitive – especially in the developmental phase of BFG. This is supported by Standal, Grimaldo and Larsen (2020) who show that more than 90% of the incentive required to assist fishermen in their decision to invest in BFG is needed to offset revenue from declining catches and less than 10% for investment in the new gear. Similar to Standal, Grimaldo and Larsen (2020), we consider incentives such as increased fishing effort or the deployment of more gear to offset fishing efficiency decline incompatible with sustainable management objectives. For example, there are concerns regarding the increase in static gear use in the Channel fisheries.

For the most part, our analysis supports the role of BFG in mitigating ghost fishing. Stakeholder engagement in INdIGO (the two surveys developed by SMEL and CEFAS) found that fishermen were generally receptive to the role of BFG in mitigating the environmental impacts of ALDFG. We found similar in our own discussions with fishermen (conducted for this task) – they were generally interested in the role of biodegradability in their fishery and could see the wider benefits (such as BFG being viewed positively by consumers). In some cases, fishermen would be prepared to pay a higher price for BFG given its potential role in sustainable fisheries (helping to offset

[70] The serviceable obtainable market for BFG i.e. the fleet segments identified where BFG implementation is likely to be most successful.
[71] This includes an assumption of a modest increase in market prices rewarding the use of sustainable BFG.

some of the incentive required for larger vessels where decline in revenue from BFG use would be higher than smaller vessels). However, a common theme was the need for financial assistance to engage in the developmental stage of BFG.

Ultimately, commercial use of BFG in the development phase is essential, so that functionality can be assessed and research targeted to address issues identified. While some studies have identified reduced fishing efficiency (Cerbule et al., 2022; Grimaldo et al., 2019; Grimaldo et al., 2020; Wang et al., 2020), other studies show similar efficiency (Bilkovic et al., 2012; Kim et al., 2016). Nevertheless, issues around fishing efficiency need to be better understood in the Programme area to facilitate the successful implementation of BFG in these fisheries to improve the sustainable management of fishing gear.

This research demonstrates the potential role of BFG in the Programme Area to combat ghost fishing and provides insights on how that might be best achieved[72].

[72] In some cases, fishermen offered to trial gear being produced in INdIGO (in fisheries inside and outside the Programme area).

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9. Appendices

Appendix 1: Ghost fishing efficiency studies

Methods and estimates of ghost fishing mortality rates and duration of ghost fishing efficiency of ALDFG from gillnet and trammel net fisheries

UNEP Regional Seas[1]	FAO Major Marine Fishing Area[2]	Fishery or study site location	Method[3]	Ghost fishing mortality rates	Ghost fishing duration	Citation
Baltic	27	Simulated derelict demersal cod gillnets, Hano Bay, Swedish	a,c,d,e,h,i	NA	Fishing efficiency declined to 5–7% of the initial level after 3 months. Retained some fishing efficiency at 27 months.	Tschernij and Larsson, 2003
Mediterranean	37	Simulated derelict demersal gillnets, Izmir Bay, eastern Aegean Sea, Turkey	a,d,f,g,k,l	Multifilament gillnets: 62 fish in three 33 m × 2.8 m gillnets for duration of fish fishing efficiency. Monofilament gillnets: 115 fish in three 33 m × 2.8 m gillnets for duration of fish fishing efficiency.	Multifilament and monofilament gillnets ceased to catch fish at 106 and 112 days after deployment, respectively.	Ayaz *et al.*, 2006

Mediterranean	37	Simulated derelict demersal crawfish trammel net and hake and seabass demersal gillnet, St. Tropez Canyon and Cassis harbour, coastal France	a,c,d,e,k	Gillnet open ground: 46 hake and 36 crawfish per 5400 m^2 of net per year. Trammel net open ground: 46.25 crawfish per 2 100 m^2 of net per year.	Nets on open ground retained some catching efficiency at 18 months after deployment. Gillnet and trammel nets set on wrecks no longer retained catch efficiency by 6 months after deployment.	MacMullen *et al.*, 2003
None	21	United States of America Gulf of Maine, Jeffries Ledge and Stellwagen Bank demersal gillnet fishery	b,f,i	15% of fish catch rate of in-use gear.	NA	Carr and Cooper, 1987
None	21	Simulated derelict demersal gillnet, Cape Cod Bay, Gulf of Maine, United States of America	a,c,f	NA	Retained catching efficiency after 74 days.	Carr *et al.*, 1985

None	21	Simulated derelict demersal gillnet, Buzzards Bay, New England, United States of America	a,c,f	NA	Catch efficiency of the control and all experimental treatment nets continued after 2 years.	Carr, Blott and Caruso, 1992
None	71 and 77	Simulated derelict Japanese high seas squid drift gillnets, central Pacific Ocean near the Hawaii archipelago	a,c,d,f,k	NA	Lengths of 50 m and 100 m length nets reduced to < 5% of original in less than 0.5 day. The 350 m length net reduced to <5% of original at 2 days. The 1 km length net reduced to < 5% of original length at 10 days.	Gerrodette, Choy and Hiruki, 1987, 1990
North-East Atlantic	27	Simulated derelict demersal trammel nets, central coast of Portugal	a,c,d,f,i,k	Rocky substrate: 541 organisms per 100 m of net during study period. Sandy substrate: 257 organisms per 100 m of net during study period.	Fishing efficiency < 1% from an in-use net at 10.5 months at the site with rocky substrate, and at 8 months at the site with sandy substrate.	Baeta, Costa and Cabral, 2009

NorthEast Atlantic	27	Simulated derelict demersal gillnet and trammel net, Algarve, Faro, southern Portugal	a,c,d,f,g,k,l	Gillnet: 314 fish, 0 seabirds, Duration of fishing 0 reptiles, 0 mammals per efficiency for finfish: 15-20 240 m^2 net for duration of weeks. finfish fishing efficiency. Trammel net: 221 fish, 0 seabirds, 0 reptiles, 0 mammals per 190 m^2 net for duration of finfish fishing efficiency.		Erzini *et al.*, 1997

TABLE 2C (CONTINUED)

UNEP Regional Seas[1]	**FAO Major Marine Fishing Area**[2]	**Fishery or study site location**	**Method**[3]	**Ghost fishing mortality rates**	**Ghost fishing duration**	**Citation**
North-East Atlantic	27	Simulated derelict deep water demersal Greenland halibut gillnets, Norway	a,c,d,e,h,j	Experiment 1: 67–100 kg halibut per 4 207.5 m^2 net per day once net fishing efficiency declined to 20–30% of original. Experiment 2: 28–43 kg halibut per 4 207.5 m^2 net per day once net fishing efficiency declined to 20–30% of original.	Retained catch efficiency after 68 days. Catch rate reached 20–30% of initial efficiency between 21 and 45 days after setting and remained at that level through the remainder of the study period to 68 days after setting.	Humborstad *et al.*, 2003

North-East Atlantic	27	Simulated derelict demersal gillnet and trammel net, St. Bride's Bay, southwest Wales, United Kingdom	a,c,d,f,g,l	Gillnet: 226 fish, 839 crustaceans per 243 m^2 net for duration of fishing efficiency. Trammel net: 78 fish, 754 crustaceans per 243 m^2 net for duration of fishing efficiency.	The ghost fishing catch rate of number of fish per 24-hour period approached 0 at 70 and 22 days after deployment for the gillnet and trammel net, respectively. Crustaceans continued to be observed to be caught at low rates at 9 months after initial deployment.	Kaiser *et al.*, 1996
North-East Atlantic	27	Simulated derelict demersal hake gillnet, southwest England, United Kingdom	a,c,d	Fleet 1: 39 crustaceans and 2 fish per 400 m net during study period. Fleet 2: 30 crustaceans and 6 fish per 400 m length of net during study period.	Not known; the experimental fleets were lost when checked at 14 weeks after deployment.	MacMullen *et al.*, 2003
North-East Atlantic	27	Simulated derelict demersal gillnet, Bay of Biscay, Spain	a,c,e,h,l	7.38 kg of monkfish per 180 m^2 net for duration of fishing efficiency	Still maintained some demersal fish and invertebrate catch efficiency after 12 months of deployment.	MacMullen *et al.*, 2003

North-East Atlantic	27	Simulated derelict wreck gillnet and demersal trammel net, North Sea off northeast United Kingdom	a,c,d,f,g,k	NA	Wreck gillnet ceased finfish fishing efficiency at 45 weeks and crustacean fishing efficiency at 2 years after being set. Open ground trammel net ceased fishing efficiency at 58 days after being set.	Revill and Dunlin, 2003
North-East Atlantic	27	Simulated derelict demersal monkfish gillnet, Bay of Biscay, Basque Region, Cantabrian Sea, northern Spain	a,c,d,e,h, k,l	4.7 monkfish (17.7 kg) per 360 m^2 net for duration of fishing efficiency.	224 days until ceased to catch monkfish.	Sancho *et al.*, 2003
NorthEast Atlantic	27	Simulated derelict demersal hake gillnets, Faro, Algarve, Portugal	a,c,d,e,h,i, k,l	May-deployed fleets: 116 organisms (29.8 kg) / 9 hake (20.6 kg) per 620 m^2 net for duration of fishing efficiency. Sept.-deployed fleets: 413 organisms (90.1 kg) / 88 hake (29.9 kg) per 620 m^2 net	Ghost fishing maximum duration was estimated to be 248 days; negligible catch was predicted to be reached after 3 months.	Santos *et al.*, 2003

				for duration of fishing efficiency.		
NorthEast Atlantic	27	Simulated derelict demersal hake gillnets, Algarve, Faro, southern Portugal	a,c,d,e,h,i,l	249.9 non-hake organisms (64.4 kg) per 620 m^2 net for duration of fishing efficiency	Retained catching efficiency after 12 months. Estimated fishing capacity would end at 430 days after setting.	Santos, Gaspar and Monteiro, 2009
NorthEast Pacific	67	United States of America Puget Sound, Washington salmon driftnet fishery	b,f,g	2.119 invertebrates, 0.196 seabirds, 0.275 fish per 3 610 m^2 net per day	NA	Gilardi *et al.*, 2010

TABLE 2C (CONTINUED)

UNEP Regional Seas[1]	**FAO Major Marine Fishing Area[2]**	**Fishery or study site location**	**Method[3]**	**Ghost fishing mortality rates**	**Ghost fishing duration**	**Citation**
North-East Pacific	67	United States of America Puget Sound, Washington salmon driftnet fishery	b,f,k	NA	Fish and diving seabirds ceased to be caught after about 3 years. Crabs continued to	High, 1985

					be caught after 6 years.	
North-West Pacific	61	Simulated derelict demersal Japanese spiny lobster gillnets, Tateyama Bay, Chiba Prefecture, Japan	a,c,d,f,g,l	Artificial reef experiment 1: 44 crustaceans, 11 gastropods, 2 bony fishes, 2 sand dollars per 9.4 m^2 net during study period. Artificial reef experiment 2: 33 crustaceans, 5 gastropods, 5 bony fishes, 1 sea cucumber per 9.4 m^2 net during study period. Sandy sea bed experiment 1: 8 crustaceans, 4 gastropods, 1 bony fish per 9.4 m^2 net during study period. Sandy sea bed experiment 2: 7 crustaceans, 1 gastropod per 9.4 m^2 net	Duration of fishing efficiency derelict gillnet in an artificial reef, experiment 1: 561 days. Duration of fishing efficiency derelict gillnet in an artificial reef, experiment 2: 284 days. Duration of fishing efficiency derelict gillnet on sandy sea bed, experiment 1: 200 days. (Sandy sea bed experiment 2, no significant correlation between soak time and number of caught organisms).	Akiyama, Saito and Watanabe, 2007

				per during study period.		
North-West Pacific	61	Simulated derelict salmon drift gillnets, northwest Pacific Ocean east of Japan	a,c,d,f,k	NA	< 3 months for nets to form a solid mass.	Mio *et al.*, 1990
North-West Pacific	61	Simulated derelict demersal gillnet, coastal Japan	a,f,g,j,l	455 fish per 165.6 m^2 net until net reached 5% of original fishing efficiency.	142 days to reach 5% of initial fishing efficiency.	Nakashima and Matsuoka, 2004
North-West Pacific	61	Simulated derelict demersal gillnet wrapped on a fish aggregation device, and control fish aggregation device with no tangled gillnet, coastal Japan	a,f,g,j	191 fish per 2.25 m^2 net per year.	No declining trend in ghost fishing catch rate observed during the 1 149 day study period.	Nakashima and Matsuoka, 2005

[1] UNEP, 2005b, 2014. "None" indicates there is no UNEP Regional Sea Convention or Action Plan in the region for this study.

[2] FAO, 2014.

[3] (a) Deployed simulated derelict gillnets and/or trammel nets.

(b) Observed ALDFG from gillnet and/or trammel net fisheries.

(c) Simulated derelict gear used commercial gear design and fishing methods, in some cases modified to simulate derelict conditions.

(d) Simulated derelict gear set at conventional fishing grounds, including cases where the study site was selected in a subset of grounds to avoid disturbance, e.g. from conflict with mobile gear.

(e) Monitored catch and/or changes to gear condition via periodic retrieval of subset of gear.

(f) Monitored catch and/or changes to gear condition via in situ monitoring.

(g) Estimated short-term (hours to weeks) ghost fishing mortalities by counting the number of organisms that became newly captured since a previous observation. Marked catch to enable the identification of new catch in subsequent monitoring event.

(h) Estimated short-term (hours to weeks) ghost fishing mortalities by counting the number of recently captured organisms in 'good condition' observed present at the time of monitoring.

(i) Fishing efficiency of derelict gear/simulated derelict gear at end of study period compared to that of in-use gear during the same period and area as the study gear.

(j) Fishing efficiency of derelict gear/simulated derelict gear at end of study period compared to its initial fishing efficiency.

(k) Monitored ALDFG until cessation of ghost fishing, until cessation of fishing efficiency for target species, or until retained small proportion of initial species-specific or total catch capacity based either on observations of ghost fishing catch rates or on net condition factors that indicate catch capacity.

(l) Fit decay model to short-term ghost fishing catch rate data to: (i) estimate total ghost fishing mortality level over a study period that ended before derelict gear ceased to ghost fish, or for the estimated duration of fishing efficiency; and/or (ii) estimate the duration of fishing efficiency.

Appendix 2 – Interview questions[73]

INdIGO
INnovative fishing Gear for Ocean

EUROPEAN UNION

General:

1. Description of fishing activity
    a. What types of fishing do you do (species, gear etc.) and how much of each type?
    b. How many days per year do you fish? Is fishing your only/ main employment?
    c. How many crew do you employ?
    d. What size/type of vessel(s) do you own/operate?

Economic:

2. On average how many tonnes of each species do you land per year?
    a. Do you catch any quota species and of so what proportion of your total catch?
    b. What is the average sales price of each species?
    c. How to you sell your catch (e.g. fish market, direct to restaurant/ catering trade, direct to consumers)?

Gear:

3. How many nets/pots do you fish at any given time (nets, net panels, pots etc. – please define)? Are there seasonal fluctuations? *Include total length, nets per fleet and number of fleets. Also number of pots per string and number of strings*
    a. What are the annual maintenance/repair costs for your gear?
    b. What is the average lifespan of gear and what is the cost of replacement (nets, net panels, pots etc. please define)? *Include ropes, markers, floats and other accessories*

[73] The interview questions reflect information that was required to complete the analysis (supplementing secondary data sources as well as the two INdIGO surveys. In depth discussions with fishermen interviewed yielded further information on the views towards biodegradability and circumstances where they thought BFG use was feasible (or not).

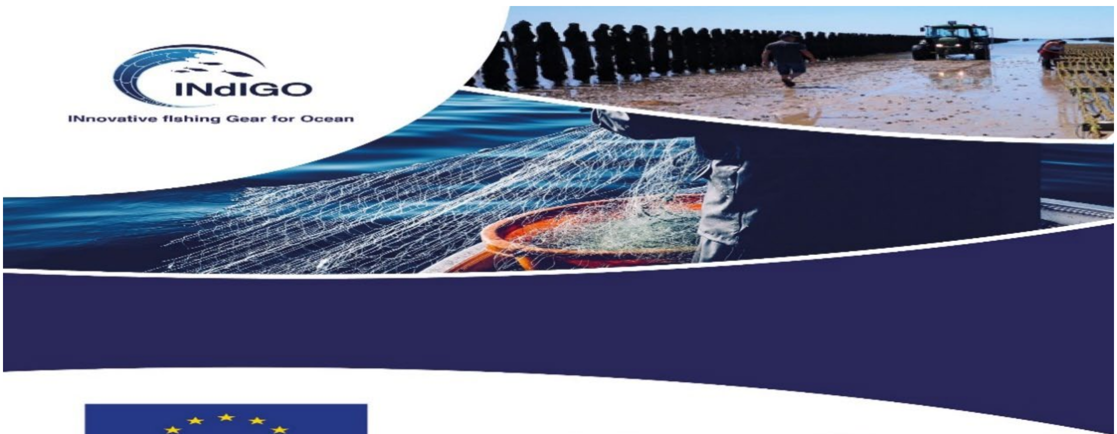
    c. What is the average soak time of gear? Does poor weather often extend this?

ALDFG:

4. How much gear do you lose per year (for whatsoever reason) and what are the main causes (e.g. gear conflict, poor weather)?
    a. How long is spent looking for lost fishing gear in hours?
        i. Of that how much of that is time you would have spent fishing?
        ii. Of that how much is time you would have spent not working?
5. What do you think are the main problems associated with Abandoned, Lost or Discarded Fishing Gear (ALDFG)?
    a. Do you think ghost fishing is an issue in your fishery? If yes, could you quantify your answer e.g. percentage of ghost fishing catch as percentage of total active catch?
    b. Do you see discarded fishing gear at sea? Do you recover it?
    c. Does it impact your activities (entanglement of props, nets, pots etc.)?
    d. Can you quantify the cost?

Biodegradable fishing gear:

6. Do you know about biodegradable gear? For example, it is used in some gillnet fisheries in Norway and some pot/trap fisheries in the USA.
    a. Do you think it could be a potential solution to reducing the impact of lost fishing gear on the marine environment and economic impacts to your business?
    b. Do you see any problems/issues with the use of biodegradable gear (e.g. fishing efficiency, purchase cost, maintenance cost etc.)?
    c. Do you see any benefits to using biodegradable gear (e.g. customer preference, higher sales price similar to diver caught scallops)?
    d. Would an incentive (e.g. subsidy) help to trial/use biodegradable fishing gear (either experiential work or commercial use)?



Appendix 3: The Economic Performance of UK Fleet Segments

Fleet segment	Number of vessels	Number of FTE fishers	Landings (tonnes)	Earnings (£)	Net profit (£)	Net profit margin
Drift/fixed net 0–10m	622	175	4,015,932	9,544,148	-583,684	-6%
Drift/fixed net 10–12m	15	75	2,348,757	4,134,734	820,645	20%
Drift/fixed net 24–40m	16	272	5,323,974	13,991,700	2,958,938	21%
Dredgers 0–10m	105	76	3,298,674	5,821,918	417,473	7%
Dredgers 10–12m	32	52	2,627,702	5,121,013	879,118	17%
Dredgers 12–18m	114	312	17,153,080	24,023,378	3,460,799	14%
Dredgers 18–24m	25	160	10,644,565	12,900,206	1,523,518	12%
Dredgers 24–40m	31	307	13,265,569	21,225,543	2,844,251	13%
Demersal trawl/seine 0–10m	257	290	4,794,036	11,206,112	405,166	4%
Demersal trawl/seine 10–12m	89	164	3,386,989	8,049,016	1,067,898	13%
Demersal	208	818		40,852,055	5,027,754	12%

trawl/seine 12–18m			17,590,155			
Demersal trawl/seine 18–24m	171	1,087	42,426,070	83,194,670	12,185,905	15%
Demersal trawl/seine 24–40m	86	909	72,135,080	126,636,917	28,800,954	23%
Demersal trawl/seine 40m+	10	137	26,513,163	39,262,660	5,131,041	13%
Pots & traps 0–10m	1,739	1,190	25,452,792	57,905,610	-50,858	0%
Pots & traps 10–12m	166	378	9,573,686	20,047,772	5,174,123	26%
Pots & traps 12–18m	81	358	15,245,745	25,341,827	3,721,884	15%
Pots & traps 18–24m	14	155	7,823,939	12,029,787	2,084,487	17%
Hook & line 0–10m	527	216	2,274,052	6,224,460	-524,932	-8%
Hook & line 10–12m	17	34	305,567	1,139,538	-220,083	-19%
Hook & line 24–40m	13	263	8,301,350	22,722,546	2,068,231	9%
Polyvalent active	30	27	2,272,339	1,606,735	52,181	3%

gear 0–10m						
Polyvalent active gear 12–18m	37	58	8,262,978	3,981,629	498,926	13%
Polyvalent passive gear 0–10m	70	22	361,899	921,199	-53,711	-6%
Beam trawl 0–10m	12	10	163,265	345,280	-2,292	-1%
Beam trawl 12–18m	10	38	815,895	1,793,639	159,571	9%
Beam trawl 18–24m	18	132	4,758,097	12,530,091	2,030,584	16%
Beam trawl 24–40m	33	365	16,782,785	36,923,838	2,102,258	6%
Pelagic trawl 40m+	28	55	380,912,449	203,487,658	55,774,390	27%
Total	4,576	8,135	708,830,584	812,965,679	137,754,533	17%

Source: NEF (2018) – calculations of GBP based on STECF (2017). Figures in 2015 constant GBP.