The Greening of the Deep Blue Sea: Paradigm shift in the Capture Fishing Industry through a disruptive Circular Design Recycling Model incorporating Additive Manufacturing

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Abstract

Title: The Greening of the Deep Blue Sea: Paradigm shift in the Capture Fishing Industry through a disruptive Circular Design Recycling Model incorporating Additive Manufacturing

The ubiquitous crisis of ocean plastic pollution desperately calls for immediate action. The global fishing industry is a crucial component of the food supply but perversely also a significant contributor to the marine pollution of the world's oceans. The capture fishing nets impose high risks of microplastics from decomposing nets, and threatening marine species, the ecosystem and food supply. Present specialized recycling methods for the nets are not sufficiently scaled to reach all fishermen.

The present research aims to validate the viability of a method for sustainably transforming the capture fishing industry. This includes transformative management practices such as circular design and business model innovations. A closed-loop circular design subscription model for recycled capture fishing gear, with the utilization of distributive- and additive manufacturing, was proposed. There has not been an approach similar to this so far.

Analysis revealed the necessity of industry transformation which needs to be carefully assessed and precisely planned across multi-stakeholders to ensure successful transition from a linear to a circular business model promoting sustainability.

Author: Ferdinand Heck

Keywords: Circular Economy, Capture Fishing Industry, Additive Manufacturing, Business Model Innovation, Industry Transformation, Distributed Manufacturing

Resumo

Título*: O Ecologismo do Mar Azul Profundo: A mudança de paradigma da Indústria da Pesca de Captura através de um Modelo de Reciclagem de Desenho Circular disruptivo que incorpora a Fabricação de Aditivos*

A questão omnipresente da poluição dos oceanos derivada do plástico exige desesperadamente uma ação imediata. A indústria global da pesca é uma componente crucial do abastecimento alimentar, mas perversamente também contribui significativamente para a poluição marinha dos oceanos do mundo. As redes de pesca de captura impõem elevados riscos de microplásticos de redes em decomposição e ameaçam as espécies marinhas. Os atuais métodos de reciclagem especializados para as redes não se encontram suficientemente dimensionados para alcançar todos os pescadores.

A presente investigação visa validar a viabilidade de transformar, de forma sustentável, a indústria da pesca de captura através de práticas de gestão pivotal, tais como a concepção circular e inovações de modelos de negócio. Por esta razão, foi concebido um modelo de subscrição de desenho circular de circuito fechado para redes de pesca de captura recicladas, com a utilização de fabrico de distribuição e aditivos, uma vez que até agora não houve uma abordagem semelhante a esta.

A análise revela a necessidade de avaliar cuidadosamente e planear com precisão a transformação da indústria através de múltiplos intervenientes para assegurar uma transição bem sucedida de um modelo comercial linear para um circular.

Autor: Ferdinand Heck

Palavras-chave: Economia Circular, Indústria de Captura de Pesca, Fabrico de Aditivos, Inovação do Modelo de Negócio, Transformação da Indústria, Fabrico Distribuído

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Ferdinand Heck

Lisbon, 5th of January 2022

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List of Abbreviations

SDG	Sustainable Development Goals
ALDFG	Abandoned Lost Discarded Fishing Gear
FAO	Food and Agriculture Organization of the United Nations
C-BPF	Best Practice Framework
GGGI	Global Ghost Gear Initiative (known as the “triple GI”)
GPS	Global Positioning System
RFID	Radio-Frequency Identification
CE	Circular Economy
CO_2	Carbon Dioxid
IUCN	International Union for Conservation of Nature
AM	Additive Manufacturing
PE	Polyethylene
PA6	Nylon
PET	Polystyrene
PRF	Port Reception Facilities
EPR	Extended Producer Responsibility
EMFAF	European Maritime, Fisheries and Aquaculture Fund

1 Introduction

The global fishing industry is a crucial component of the food supply as the world's population rises to an expected 9.7 billion by 2050 (FAO - United Nations, 2018). If sustainably managed, fishing – both in capture fisheries (at sea) and in aquaculture (fish farming) – has a vital role in providing jobs and feeding the world. Global fish production amounted to some $ 401 billion in 2018, of which $ 250 billion came from aquaculture production (FAO, 2020) – a figure that will continue to rise (Fisher Projects, 2020). Perversely, the fishing industry is also a significant contributor to polluting the world's oceans. An estimated 640,000 tonnes of plastic fishing gear annually is abandoned, lost, or discarded within the oceans every year. This polluting crisis is a growing and pervasive problem, with a staggering 12 million tonnes of plastic ending up in the ocean every year, and so far without any effective recycling programs being implemented (Greenpeace, 2019). This calls for international action to reduce plastic pollution, which is deadly to marine life, and the primary goal of SDG Target 14.1 (United Nations, SDG, n.d.). While studies have shown that recycling plastics can offer significant environmental benefits, especially when compared to other waste treatment alternatives, consumer perception varies widely (Huysveld et al., 2019). The vast majority (95%) of a survey conducted in 16 European countries perceived pollution in general and plastic waste in particular as major environmental problems of this century (Hartley et al., 2018).

Marine life is dying, and oceans are being polluted extensively, with only a small proportion of ocean waste being retrieved. This thesis investigates how the present fishing industry may be sustainably transformed through a circular economy, additive manufacturing, and business model innovation. It introduces the idea of a subscription model with a circular economy design, where plastic fishing gear can be reprocessed within a technical cycle. It additionally explores how additive manufacturing (3D printing) could be part of the solution as it provides local community initiatives, low material, and energy usage plus customization. Large amounts of ocean plastic waste are not yet included in the different re-/upcycling process solutions and should be incorporated into circular economy models. Consumer accessories, footwear, clothing, recreational products, etc., may be manufactured entirely or partially from polymers obtained from the reprocessing and/or the repurposing or upcycling of fishing gear.

The tangible output of this thesis evaluates how a circular recycling system, using additive and distributed manufacturing technologies, can create eco-friendly, innovative, and impactful new economies related to fishing. Additionally, it examines how more sustainable waste management schemes can be applied to discarded plastic waste to prevent material streams from entering the ocean environment by continuously reusing them.

2 Literature Review

In the following section, a comprehensive literature review is provided. These various topics lay the foundation of the theoretical part of this thesis. This information is then used to link the different topics together in a research statement and establish the managerial and academic relevance of the thesis.

2.1 The Fishing Industry

2.1.1 Statistics of the Sector - Global Context

Global seafood production has increased fourfold in the last 50 years. Not only has the world's population more than doubled in that time, but the average person consumes almost twice as much seafood today in comparison to half a century ago (Ritchie & Roser, 2021). Thus, approximately more than 3 billion people worldwide rely on fish as their primary source of protein (Petrossian, 2019). Worldwide fish production reached an estimated 179 million tonnes in 2018 with an estimated first-sale value of $ 401 billion, of which 82 million tonnes worth $ 250 billion came from aquaculture, presented in Figure 1. Of the total, 156 million tonnes were used for human consumption, representing an estimated annual supply of 20.5 kg per capita, and consumption above average for Portugal with 56,84 kg per capita (Figure 2). Aquaculture accounted for 46 percent of total production. China remains a leading fish producer, accounting for 35 percent of global fish production in 2018 (FAO - United Nations, 2018; FAO, 2020).

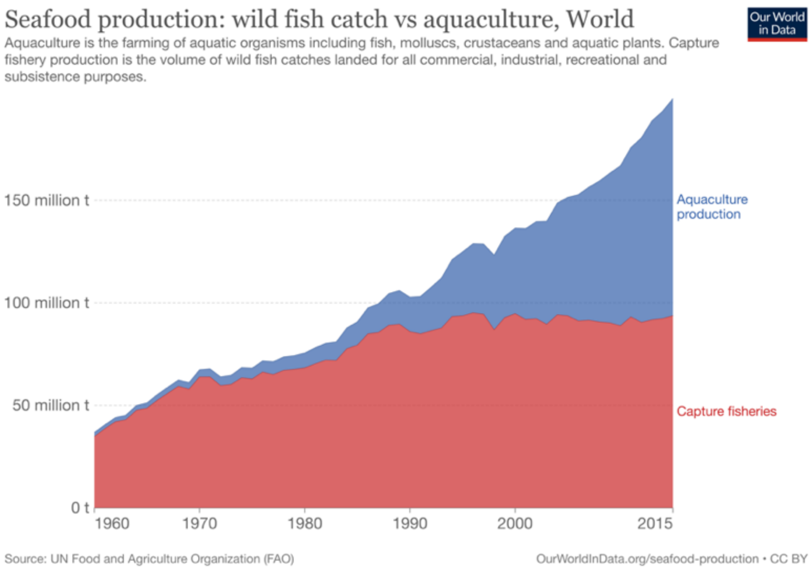


Figure 1. Global Fish Production 1960-2015

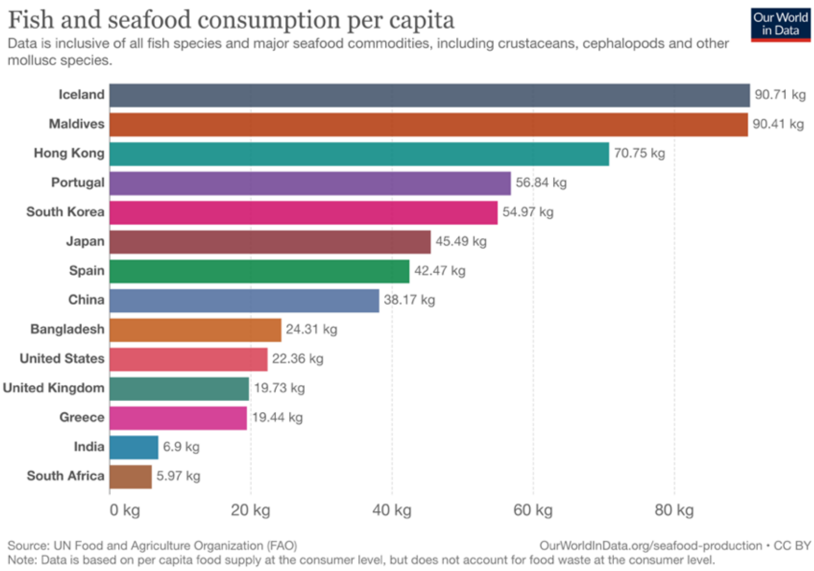


Figure 2. Fish and Seafood consumption per capita

2.2 Maritime Plastic Waste

2.2.1 Waste generation and disposal in the Fishing Industry

Polymers have become the ubiquitous working resource of the modern economy, combining unsurpassed functional properties with low cost, especially in plastic packaging. Their use has increased twenty-fold in the last half-century and is expected to double again in the following 20 years (Lebreton & Andrady, 2019). Today, almost everyone, everywhere, everyday encounters plastics. While the current plastics economy offers many advantages, it also has drawbacks becoming more apparent by the day. After a short first-use cycle, 95% of the value of plastic packaging, or $80-120 billion, is lost to the economy each year. An incredible 32%

of plastic packaging escapes collection systems and imposes high economic costs by reducing the productivity of crucial natural systems such as the oceans and clogging urban infrastructure (*WEF_The_New_Plastics_Economy*, n.d.). Hence, highlighting a shift from linear consumption to a circular model could generate a $706 billion economic opportunity (Ellen MacArthur & McKinsey & Company, 2013). By 2040, mismanaged plastic waste will accumulate to almost triple to 239 million metric tonnes (*Global Plastic Waste Management Projections 2016-2040*, n.d.)

Plastic debris is probably the most significant and most harmful component of marine litter. Abandoned, lost, or otherwise discarded fishing gear (ALDFG), also called "ghost gear" (Figure 3), constitutes a significant part of marine plastic pollution in the world's oceans and seas and is an inevitable by-product of global fisheries. It is the most lethal form of marine plastic debris (FAO - United Nations, 2018; Lebreton et al., 2018; *WWFintl_ghost_gear_report*, n.d.).

Figure 3. Ghost Gear – Entangled turtle in ALDFG and intertwined with the seabed (Greenpeace, 2019; WWFintl_ghost_gear_report, *n.d.).*

A comprehensive overview of the different capture fishing methods with the corresponding nets used and a loss-risk analysis can be found in the Appendix 3.

2.2.2 Key Figures & Dimensions

Today, an estimated 150 million metric tonnes of plastic are circulating in our oceans (Fitterling, 2019), with an additional 6 to 12 million being added annually (Greenpeace, 2019). Due to ultraviolet radiation and environmental conditions, degrading processes occur over a long period of time turning plastics into micro (<5mm) and macroparticles. These particles float in so-called patches. The biggest is the Great Pacific Garbage Patch (GPGP). It is 1.6 Million SQ KM wide, a figure four to sixteen times higher than previously reported (Lebreton et al., 2018). This data emerged from 3 research expeditions since 2015 conducted by the Non-profit Foundation “The Ocean Cleanup” (The Ocean Cleanup, 2021). The project began with a Multi-Level-Trawl Expedition allowing measurements of 11 water layers simultaneously. Next was the so-called Mega Expedition, which extracted over 1.2 million plastic samples from a fleet of ships. Two Aerial expeditions eventually uncovered that at least 46% of the total waste mass was comprised of fishing nets, shown by Figure 4 (Lebreton et al., 2018). Similar observations can be made on the seafloor of the Gulf of Alicante, where 68% of the plastic identified as being fishing-related (García-Rivera et al., 2017).

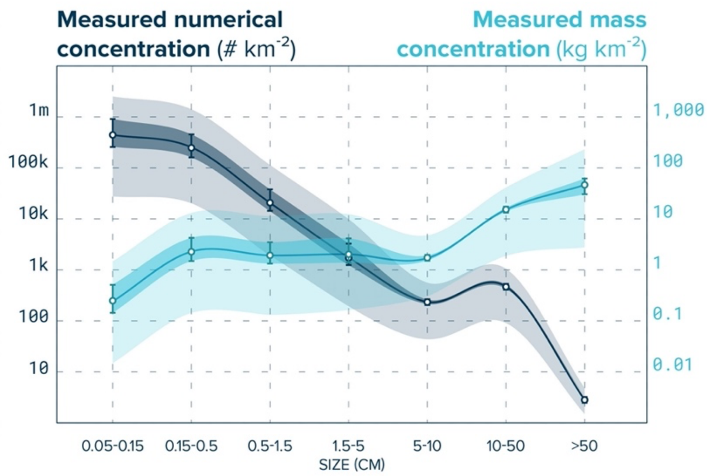


Figure 4. Distribution of ocean plastic particles (Henderson & Green, 2020)

The current consumption paradigm whereby humans produce, use, and dispose of products, and most notably, plastics, has significant drawbacks: Every year, $ 80 - 120 billion worth of plastic packaging is discarded. Apart from the financial costs, the oceans are expected to contain more plastics than fish (by weight) by 2050 if the current level is maintained. (*WEF_The_New_Plastics_Economy*, n.d.)

At present, plastic pollution is ubiquitous in the environment - from remote mountain lakes (Free et al., 2014) to the deep trenches of the oceans (Jamieson et al., 2019) to the very air we breathe (Brahney et al., 2020). It is evident that plastic pollution has become one of the most critical environmental issues of our time. Without an immediate paradigm shift, the future does not look bright, and the accumulation of ocean plastics will grow exponentially, see Figure 5.

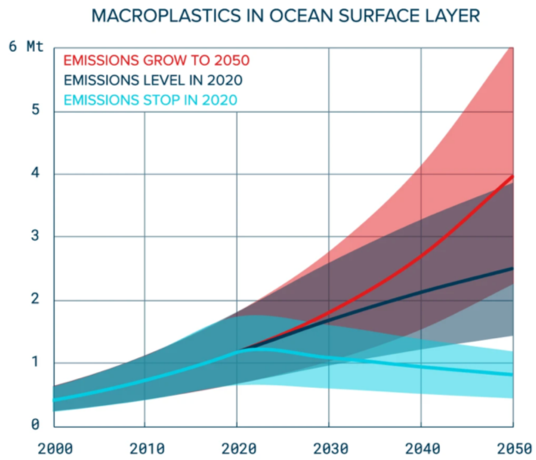


Figure 5. Outlook of Macroplastics (Lebreton et al., 2019)

2.2.3 Impact on Maritime Life, Humans and Society

So-called ghost nets are a particular menace to marine life. As stated above, these are nets that have been torn off and lost during fishing or are damaged old nets that have been deliberately thrown overboard. These nets can float in the sea for years to come. In addition, other nets, fishing lines, and marine litter are caught in the floating tangle so that over time the ghost nets expand into patches of waste reaching several hundred meters in diameter (Peng et al., 2020).

This threatens marine life – 46 percent of the species on the IUCN Red List of Threatened Species (*IUCN Red List*, n.d.), at least 344 animal species worldwide are affected by marine plastic. Mammals, turtles, and seabirds account for 161 species that are also affected (Kühn et al., 2015). All these have been impacted by ALDFG, mainly through entanglement or ingestion, which impacts biodiversity. Crucially ALDFG's continue to ensnare fish after being lost or abandoned, which paradoxically results in the waste of essential fisheries resources and lost value. In addition, it damages sensitive marine habitats (e.g. coral reefs) when on the seafloor or washed ashore and poses hazards to navigation and safety at sea when floating on the surface. Animals can die after ingesting disintegrated pieces of ALDFG, and microplastics from ALDFG enter the food chain with potential health issues for humans (FAO, 2020; *WWFintl_ghost_gear_report*, n.d.). Through a process called bioaccumulation, chemicals in plastics enter the body of the animal that eats the plastic, and through the food chain, chemicals make their way through the food chain, which includes humans (Gall & Thompson, 2015).

2.3 Upcycling and Recycling of Maritime Litter

2.3.1 Present Methods and eco-innovative use cases

Plastic materials have a central role in the context of recycling processes but also are gaining attention due to policy and business debates surrounding the sustainable development of industrial production (Europe, 2020; Geissdoerfer et al., 2017). It is possible to distinguish four main recycling processes: primary, secondary, tertiary, and quaternary recycling (Bocken et al., 2016a). The primary (also known as closed-loop) recycling corresponds to the recycling of decontaminated and single-type plastics to obtain recycled material with characteristics similar to virgin plastic. Secondary recycling refers to the recycling of contaminated plastics in order to get recycled plastics with lower performance characteristics than the original materials. Tertiary recycling refers to the recovery of monomers through the depolymerization of plastic waste, generally by chemical or thermal recycling. This recycling process is used when it is impossible to perform primary or secondary recycling due to difficulties identifying and sorting the material into plastic waste. Finally, quaternary recycling is carried out if none of the previous processes can be carried out due to the number of cycles and the deterioration of the plastic's properties. Quaternary recycling corresponds to energy recovery by incineration (Singh et al., 2017).

Waste treatment of collected marine debris includes all available treatment options: re-use, recycling, landfilling, and energy recovery. Different present and future EU measures and funds, and strategic investments accelerate various efforts (*European Commission, Plastics in a Circular Economy*, n.d.). Specifically targeting nets, the North Fundy Fisherman association has collected derelict fishing gear from the ocean, cleaned them, and subsequently re-used nets for their former function, but with only minimal success (*Ghost Gear | Fundy North Fishermen's Association*, n.d.).

Apart from material recycling, marine litter has also been upcycled into art (*Olive Ridley Project*, n.d.) and furniture out of derelict Greek fishing gear, Figure 7 (*BlueCycle - Products*, 2021),. In collaboration with the environmental organization Parley for the Ocean, the sports brand Adidas created a running shoe made partially from marine litter (*Adidas_x_parley*, n.d.). The latest achievement is the new Patagonia product with their partner Bureo. They collect polluted nets from local fishermen off the coast of South America and process them into NetPlus® material, which helps protect wildlife and supports local fishing communities through financial incentives. The nets are sorted, washed, shredded, and prepared for upcycling. Next, the prepared nets are melted and processed into yarn, and finally woven into jackets (*NetPlus® - Patagonia*, n.d.). Many more start-up companies have emerged with the capability of collecting and re-/upcycling old fishing gear. The product ranges include sunglasses, surfing fins, garden accessories, and carpets (Charter et al., 2021).

Another conglomerate of initiatives implicates the following parties: The Healthy Seas initiatives oversees the different projects and brings together all stakeholders. One of the founding partners is AquaFil (oldest Recycler in EU, 1965), a chemical processer specialized in the recycling of nylon. Their process uses re-/depolymerization to generate the so-called Econyl yarn, which is used for textiles, carpets, and 3d-printed furniture. The other big recycler is the Norwegian company Nofir (founded in 2008), a master in collecting and recycling discarded equipment. In cooperation with the NGO Ghost Diving, they use volunteer divers to retrieve ghost nets, transport, clean, sort, and recycle them for end products like Bracenets. The Hamburg-based company is well known for donating 5€ on each sold item to support the Healthy Seas ambitions. Nofir's Line of Recycling can be seen in Figure 6. They also are closely tied to AquaFil and supply them with material for chemical recycling. Additionally, another recycler at scale is Plastix based in Denmark.

Figure 6: Nofir's Line of Recycling (Nofir, 2021)

All these projects demonstrate how ALDFG can be repurposed into new high-value products. They push unconventionally beyond upcycling by showing how innovative paradigms such as alternative production and cooperation can be introduced to create more sustainable products. But, since the introduction of waste into the ocean occurs much earlier in the life cycle of marine litter than when it gets to be treated after collection, prevention must start much earlier at the root of plastic production. So, we need both a drastic input reduction and an increase in collection and recycling efforts to achieve Sustainable Development Goal 14.1, which requires input prevention and a significant stock decline by 2025 (United Nations, SDG, n.d.).

Figure 7. BlueCycle - Furniture from upcycled fishing gear

In addition, various international agreements, regulations, and recommendations have emerged. The Global Ghost Gear Initiative (GGGI) is a cross-sectoral alliance dedicated to shaping future sustainable fisheries. In 2017, GGGI developed the Best Practice Framework for the Management of Fishing Gear (BPF) and later partnered with the FAO to develop 17 different solution projects worldwide, which are overseen by the help of the WWF International (*GGGI2020AnnualReport*, n.d.; *GGGI-WWF*, n.d.). The latest C-BPF recently published by the GGGI forms the basis for all ongoing standardization and certification processes of governmental authorities worldwide (Global Ghost Gear Initiative, 2021).

2.3.2 Additive Manufacturing, Distributed Manufacturing, and Recycling Concepts

Three-dimensional printing (3DP), also known as Additive Manufacturing (AM), has been around for decades. The printing process works in an identical way to the standard inkjet printer. However, instead of printing layers of ink on paper, a 3D printer uses a material flow to build three-dimensional objects from digital models (Berman, 2012). The additive process deposits successive thin layers of material upon each other, producing a final three-dimensional product. There are almost no boundaries to the design. The typical AM layer-by-layer technique can be utilized in a variety of processes. In Fused Deposition Modelling (FDM), the material is heated and selectively dispensed through a nozzle. Stereolithography (SLA) uses a bath of light-curing photopolymer resin. The liquid polymer is exposed to UV light and again forms a model layer by layer. Selective Laser Sintering (SLS) prints an object by fusing successive layers of powder with a laser. The process particularly facilitates the creation of complex and interlocking shapes. Other manufacturing processes are available, such as Binder jetting (BJ). Depending on the companies' manufacturing parameters and product requirements, selecting the proper printing process is often the biggest hurdle (Niaki et al., 2019). Simultaneously, a wide variety of materials can be utilized, namely: plastics, resins, rubbers, ceramics, glass, concretes, and metals (Attaran, 2017; Gebler et al., 2014).

In the last couple of years, many companies have adopted AM technologies and are beginning to enjoy real business benefits from the investment. The main growth drivers are cost savings, agility, personalization, supply chain improvements, and especially business transformation with new revenue streams. AM provides a cost-effective and time-efficient way to fabricate products with complicated geometries and advanced material properties and functionality (Rejeski et al., 2018; Savolainen & Collan, 2020). This can be seen in the Gartner AM Hype Cycle 2019, reference Figure 8, showing many different use cases developed. This thesis will mainly focus on Material Extrusion and -Jetting, which are already on the Plateau of Productivity now, and the integration of electronics within the printing process. In general, the technology is maturing quickly and has worked its way into several markets (Wohler's Associates, 2019). In 2019, the global Additive Manufacturing Market was estimated at $12 billion and expected to reach $35 billion by 2024, growing at an average of 24% CAGR (*EY, 2019*, n.d.; Wohler's Associates, 2019).

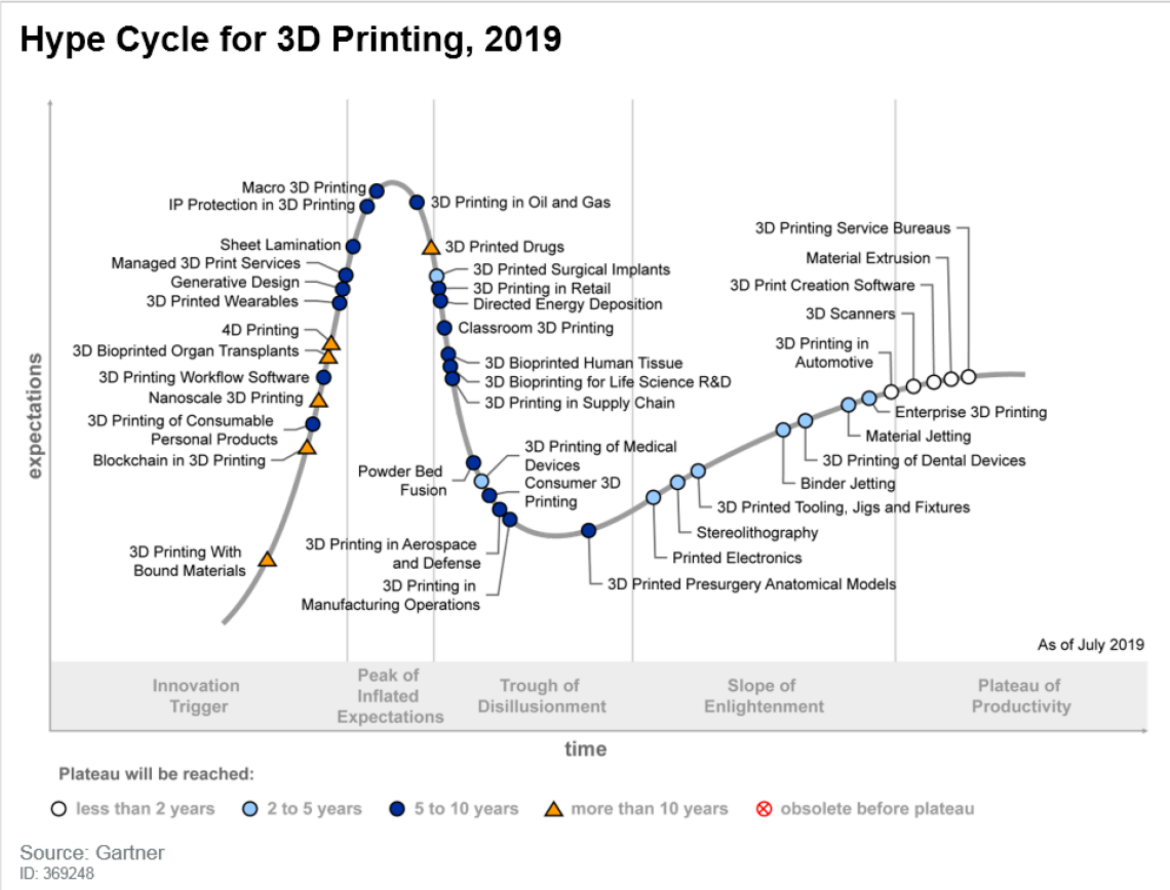


Figure 8. Hype Cycle of Additive Manufacturing - Gartner 2019

3DP has demonstrated high potential to enable product life extension through product redesign, repair, remanufacturing, and upgradability (Matsumoto et al., 2016). The process provides a new life for marine plastic waste with a certified procedure for converting it into pellets, which will be reintroduced back to the plastic industry, and into recycled 3D printing filament (Ford & Despeisse, 2016; Woern et al., 2018) introduces new life from discarded products. Fishy Filaments is a success story of recycling local materials into 3D printing filaments for FDM. Located in Cornwall, UK, Fishy Filaments repurposes Cornish nylon fishing nets into a high-quality, engineering-grade 3D printing filament (*Fishy Filaments*, 2021).

> *„Distributed manufacturing can be defined as the ability to personalize product manufacturing at multiple scales and locations, be it at the point of consumption, sale or within production sites that exploit local resources, exemplified by enhanced user participation across product design, fabrication and supply, and typically enabled by digitalization and new production technologies (Srai et al., 2016)."*

This statement clearly shows that Distributed 3D Printing Systems enable a transition to an environmentally sustainable circular economy (Bogers et al., 2016; Zhong & Pearce, 2018).

2.4 Academic, Strategic & Managerial relevance

2.4.1 What is Circular Economy (CE)?

„The circular economy focuses on eliminating the traditional linear processes of "take, make and waste" by implementing a closed-loop system that continuously rere-uses materials within a closed-loop system (Ellen MacArthur, 2021)."

A "circular economy" is an economic system in which the value of products, materials, and other assets in the economy are preserved for as long as possible by improving their efficient reusability in production and consumption.. This reduces the environmental impact of their usage and the emission of waste and hazardous substances to a minimum at all stages of their life cycle. The origins of CE are rooted primarily in ecology, environmental economics, industrial ecology, and as a central social issue, forgetting the passive "throwaway" culture of the linear economy. (Ghisellini et al., 2016; van Buren et al., 2016). To create a transition from an "end-of-life" concept to Cradle-to-Cradle™, with the circular economy shaping a new vision for resource management, renewable energy, value creation and entrepreneurship are needed (McDonough & Braungart, 2010; Bocken et al., 2016b; Joustra et al., 2013). Recently, the European Commission estimated that the transition to a circular economy could bring annual economic benefits of €600 billion to the EU manufacturing sector alone (Ellen MacArthur & McKinsey & Company, 2013; Korhonen et al., 2018).

Plastics and ALDFG's that accumulate after use can - in terms of the circular economy - be converted into valuable raw materials. Applying these circular principles could trigger a significant wave of innovation with benefits for the entire supply chain (*WEF_The_New_Plastics_Economy*, n.d.).

2.4.2 The Biosphere Rules – a Management Framework for Circular Economies

Studies about CE have indicated that sustainable, economic, and environmental benefits can generate hundreds of billions of dollars (Ellen MacArthur & McKinsey & Company, 2013). However, despite its considerable economic potential, adoption of CE practices faces numerous technological, financial, and institutional barriers at both the macro and micro levels. Often new entrepreneurial entrants not incumbents drive market change (Hockerts & Wüstenhagen, 2010). The following set of guidelines, termed the Biosphere Rules, guide 3D printing towards a closed-loop circular design model (G. C. Unruh, 2008) and support overcoming barriers.

Additionally, after conducting several industry case studies with various first-mover companies, a framework was developed (G. Unruh, 2010), which incorporated the following characteristics:

- *Materials Parsimony* - Minimize the types of materials used in products, focusing on life-friendly and economically recyclable materials.
- *Value Cycle* - Recover and recycle materials from end-of-use goods into new value-added products.
- *Power Autonomy* - Maximize power autonomy of products and processes to function on *renewable energy.*
- *Sustainable Product Platforms* - Leverage value cycles for profitable scale, scope, and knowledge economies as product platforms.
- *Function over Form* - Fulfill customers' functional needs in ways that sustain the value cycle.

2.4.3 Disruptive Innovation and Digitalization fostering Industry Transformation

On one hand, the term disruption refers to processes of destroying certainties and turning away from habits, but also to ways of embarking on something new, such as the creation of new structures or processes of change. This potentially implicates a multitude of different actors within an ecosystem. The concept of disruptive technologies challenges the traditional business of incumbents with innovations that create paradigm shifts (C. M. Christensen & Overdorf, 2000). Christensen coined the term disruptive innovation and distinguished it from sustaining innovation which is merely about improving existing products or services (C. M. Christensen, 1997). The term disruptive has come to be applied not only to technologies but also to services and business models (C. M. Christensen, 2006; C. Christensen & Raynor, 2003). Examples include discount department stores, low-cost airlines with point-to-point connections, ride-hailing platforms like Uber, initially online businesses for bookstores, and Camera-Film makers transitioning to the camera business like Kodak (Markides, 2006). Christensen identified two distinctive types of disruptive innovations: new market innovations and low-end innovations (C. Christensen et al., 2013). The impact of these two types of disruptive innovations on markets is different and very dependent on its value chain and contextuality. But also new business models innovations like Subscriptions models can disrupt a new market or low-end innovation (*McKinsey Report_Disruptive-Forces-in-the-Industrial-Sectors*, n.d., 2018). The main enterprise-level factors influencing disruptive innovation include four aspects: Strategy, organization, marketing, and resources (C. M. Christensen et al., 2018).

If this all leads to lasting fundamental changes, for example in institutions' ways of thinking or technological possibilities, the expression "transformation" is often used. The terminology of digital transformation or digitalization entails networking, transparency, interactivity, personalization. Information, products, and services have become interconnectable in real-time and alter existing business processes (Pagani & Pardo, 2017; Verhoef et al., 2021). Digital transformation has affected industries like Spotify, substantially changing the music industry, Booking.com and Airbnb fundamentally altering the hotel industry, and Netflix disrupting the TV broadcasting and film industry. New digital growth strategies can be developed with the classic Ansoff Matrix (Ansoff, 1957) and are essentially a function of organizational structures, digital resources (Verhoef et al., 2021).

Innovation across industry boundaries is becoming a strategic imperative: The creative combination of complementary competencies is the ticket to the innovation in the future. The future scenarios that emerge from system transformations are cross-sector synergies with various interests at play. Collaboration in the "coupled" process occurs through alliances, cooperation, and joint projects in which give-and-take is crucial. Different stakeholders no longer oppose each other but cooperate as they operate within a common business model (Gassmann & Enkel, 2004).

3 Methodology

The following section outlines the methodology of this study. First, the problem statement with its research questions is examined. The solution approach based on the model which was developed is then described. Finally, in this context, the chosen validation process through the research methods is elucidated, which forms the basis for analysis of the results is presented in section 4.

Within the scope of capture fishing industries that directly contribute to global ocean plastic pollution, the **problem statement** is defined as follows: How do we ecologically transform the current fishing industry through innovative business models, thereby addressing the global plastics waste problem in the oceans through reconceptualizing recycling schemes and use of material resources?

The literature review and specifically the developed closed-loop circular designed business model serve as a foundation for the **research questions**, which are as follows:

RQ1: Is a circular business model for nets employing recycled ocean plastics and additive manufacturing viable for the fishing industry?

RQ2: What is the prognosis for ecological transformation with measurable impact for sustainable fishing?

To address the situation outlined in the problem statement and literature review, the following business model innovation in section 3.1 was developed. The Model was later tested within the scope of the subsequent expert interviews. It is clear that this model involves a variety of actors with different incentives and normative notions of what the industries should entail. The interactions between these different actors and phenomena can lead to significant unintended consequences. Under these conditions, various factors have relative weights for outcomes (Stake, 1995), and hence research needs to be cognizant of this.

As a common and accepted qualitative research data collection technique, interviews were conducted to gain insights and knowledge from domain specialists (Patton, 2014). Semi-structured interviews allow for adaption to individual circumstances with additional follow-up questions if necessary (Kvale, 1994). A pre-designed interview questionnaire facilitated consistency across all interviewees (Patton, 2014).

3.1 The paradigm shift – A Closed-Loop Circular Design Subscription Model for Fishing Nets

The previously described problem statement and the proposed business model innovation will be discussed and validated with the industry experts.

The holistic vision for fishing nets presented in Figure 9 highlights industry issues described in the previous section pertaining to global marine plastic debris. We adopted a Problem-Solution approach. This helped develop the closed-loop circular design subscription model displayed in Figure 10. The model is anchored in a recurring process and entails a holistic vision of the industry and its stakeholders. A decisive side benefit is that there is up to 82% (Plastix, 2021) less CO_2 emissions with recycling of nets as opposed to the conventional production methods with virgin oil plastics.

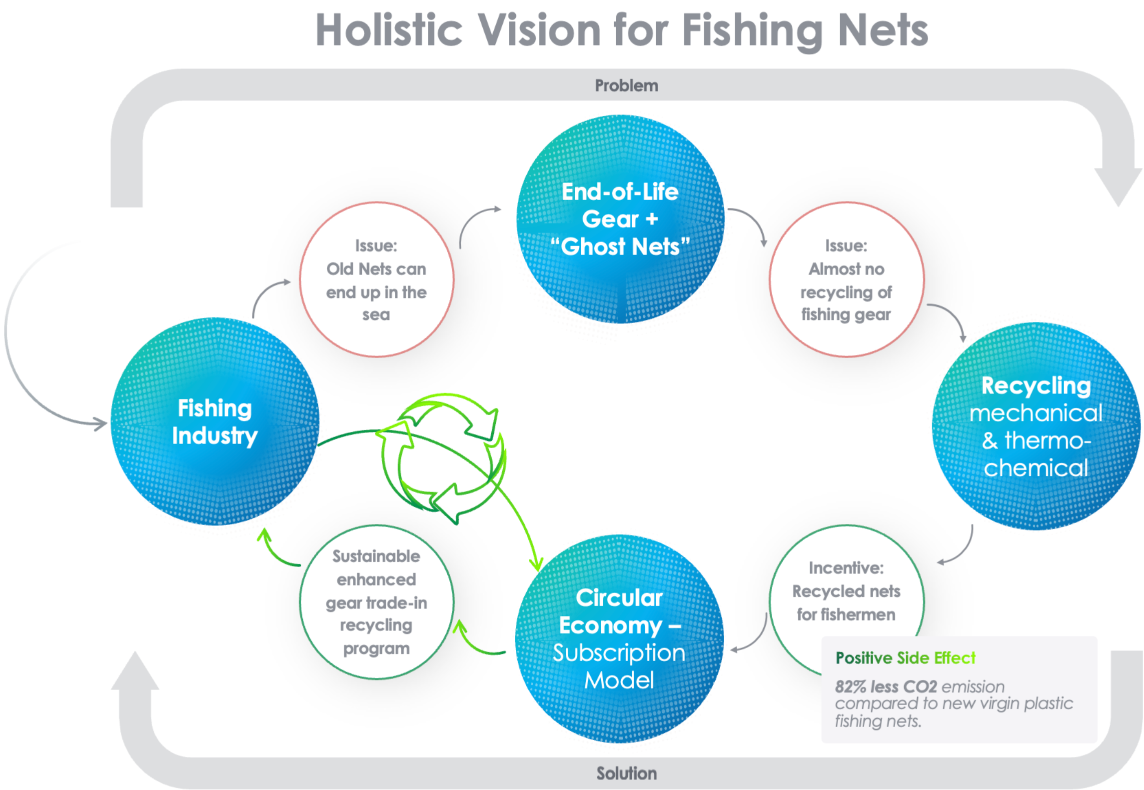


Figure 9: Holistic Vision for Fishing Nets

This circular business model draws upon the notions of disruptive technologies and business model innovation:

> *The cradle-to-cradle approach promotes non-toxicity and material purity to achieve a safer and more restorative use of resources, enable high-value recycling, and retain the value embedded in materials. It also encourages upcycling, where material waste can be re-used for higher-value applications. Again, this circularity principle aligns with 3DP (Baumers et al., 2017).*

The major causal factor for such a model is self-accountability and how to incentivize fishermen. With the start of the subscription contract, each fisherman can choose between different sizes, mesh widths, lengths of the agreement, number of trade-in options, and variety of traceability technologies, thus gaining full customization. The initial nets are ideally a mixture of retrieved nets – ghost gear – and end-of-life gear. They're built in a modular way and thereby are quickly interchangeable.

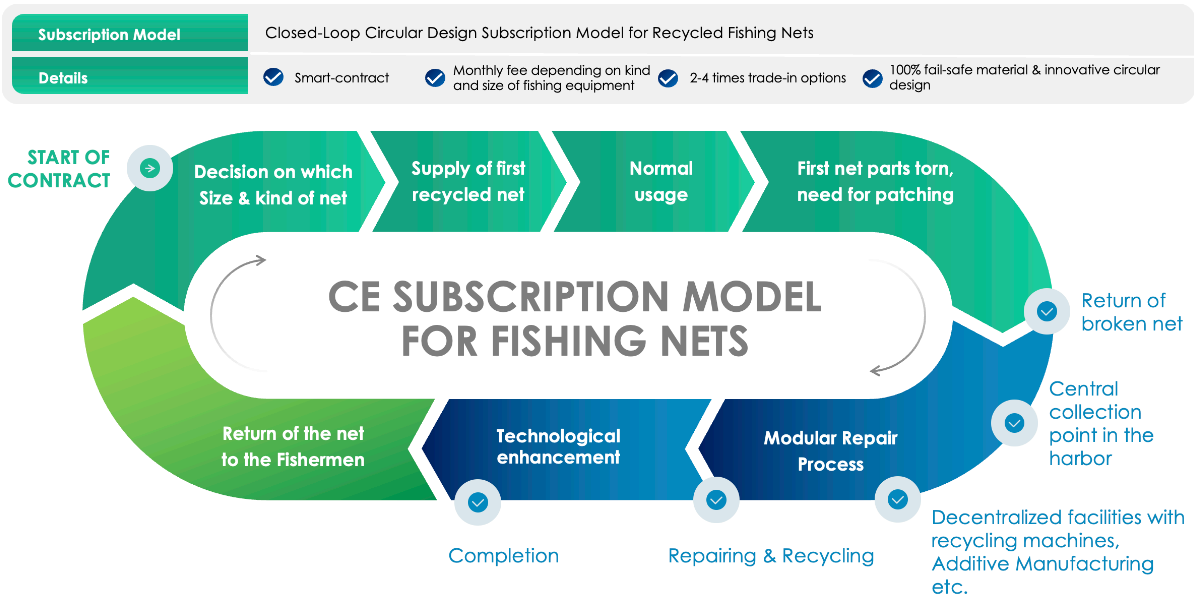


Figure 10: Closed-Loop Circular Design Subscription Model for Recycled Fishing Nets

Whenever needed, the repair process can be carried out at the central collection point available in the ports. From there, nets will be transported to decentralized facilities, so-called maker hubs. Here they will run through several stages of the recycling and repair process. In this process, the additive manufacturing[1] advantages facilitate different options depending on the required fishing activities. Possibilities like environmentally friendly non-lead material for gillnets and its sinking lines can be implemented in the printing process. Innovative sensor technologies such as RFID or GPS can be integrated, and even targeted node material reinforcement for high strains can be adjusted. The final process consists of a quality check and sensor functionality test. Lastly, the net is returned to the fishermen. The process is fully transparent and less labor-intensive. Also, a fast process with quick turnarounds is ideal as no catch losses or downtime for fishing occur.

3.2 Qualitative Analysis: Semi-Structured Expert Interviews

At the core of the expert interview method is identifying and conceptualizing selected content-related aspects of the research material and it's systematic description. A semi-structured approach was utilized to permit flexibility (Kvale, 1994). Therefore, an interview questionnaire was set up, containing three topic blocks with another three open questions: referring to the industry expertise or research focus; ocean plastic debris and its environmental impact; innovations, and disruptions of the respective industry. Follow-up and sub-questions were

[1] *In general, we assume that based on my successful feasibility study of my Bachelor thesis in cooperation with the well-known Fraunhofer Research Institute, additive manufacturing processes with any kind of recycled fishing nets are possible but strongly dependent on material purity, usage intentions, and processing technologies*

prepared to assure several alternatives if an interviewee's response did not provide sufficient information to answer the research question. In the last part of the interview, an open dialogue was anticipated to get differentiated individual opinions on the developed circular design model.

After an initial approach and confirmation for the interview, every interviewee received a calendar invitation with a quick briefing of the topic and a video conferencing link. Due to Covid-19 and the different locations of every participant, all interview sessions were conducted remotely via the online conferencing tool Microsoft Teams. The interviews ranged from 55-80 minutes in length. At the beginning of each session, we asked consent to record the session and assured interviewees of confidentiality of the results.

In Total, there were seven interviews, whereas one was with a focus group, so overall there were eight respondents. These participants represented various sectors of the fisheries economy relevant to the research question while also being some of the best experts in their respective fields. A tabular summary of the interviews and given answers can be found in Appendix 1. All interviewees granted permission to be named and quoted in the following sections.

Each interview recording was transcribed for the data to be analyzed and structured. This was done with the use of the software application called trint. The transcripts partially had to be translated and revised afterwards. The subsequent coding has been performed utilizing the software tool called MAXQDA allowing the interviews to be grouped into categories with sub-codes derived from inductive and deductive processing (Rädiker & Kuckartz, 2020). This approach permits better comparability and statistical evaluation capabilities (Bryman, 2016).

3.3 Quantitative Analysis: Survey

This research method was chosen and designed to obtain a fundamental understanding of capture fishing activities and the related causes of ghost gear, end-of-life nets, and other plastic pollution. The data was gathered through an online survey, specifically targeting fishermen only.

The survey was split into two parts. The first part was about gathering relatively high-level information about the fishing industry, particularly the primary fishing techniques used amongst various fish species with different net settings. Additionally, costs, fishing days, workers on one vessel, and recycling capabilities were queried. The second part was about introducing a closed-loop circular design subscription model for fishing gear. Under this scheme, fishermen could obtain a fully functional net with the option of several repair cycles included in the subscription, . In particular, this was done to identify whether the model would be generally accepted. It also sought to determine the price range, meaning the willingness to pay, for such a system. The questions were mainly multiple-choice, with a few input questions pertaining to home country, fishing area, and utilized fishing gear dimensions. Two filter questions were implemented to improve the sample representability: one question inquired whether the participant had distinctive fishing knowledge. And the other query asked about the number of years in the industry.

The distribution of the poll occurred in multiple ways: via network connections to big tuna producers in Portugal and small fishermen along the Portuguese coast. Some experts from the interviews assisted for this thesis, by distributing the poll across their networks. This was meant that there was reach to fishermen in parts of Scotland, the UK, and the northern part of Germany. Additionally, with the help of the Thünen research institute for fishing and WWF Germany, the survey was distributed in their networks as well.

3.4 Subsidiary conclusion

A combination of quantitative and qualitative research is applicable for this case study because this approach utilizes methods and established measurement techniques to quantify phenomena and test hypotheses (Bryman, 1988) while providing tangible outcomes typically related to qualitative research (ibid.). The conclusions drawn from both allow statistically significant results and contextualized real-world findings (Brannen & Coram, 1992). Ideally, the triangulation method is to create inferences from convergence or complementarity between research approaches (Fetters & Molina-Azorin, 2017) and thus increase the credibility of results (Morgan, 2019).

4 Analysis & Findings

The theory-based implications on the link between pervasive marine pollution and the fishing industry (see 2.2.1, 2.2.2), as well as the various current recycling strategies (see 2.3) and innovations, are largely reflected in the results of this study. Nevertheless, the data obtained from the interviews led to new insights. It was also possible to gain more clarity into the various aspects of fishing net recycling, especially since the experts had different views, opinions, experiences, and knowledge. This analysis is discussed in the following chapter. Additionally, the last section concludes by evaluating results from the discussion and validation process of the developed model presented in 3.1.

4.1 Survey Results

Unfortunately, it was not possible to obtain statistically significant results from the survey. Further details and the cause of this can be found in the Limitation chapter 7.

4.2 Semi-Structured Interview Results

Every semi-structured interview had three topic blocks: it began with general questions about the respondent's industry and their relevant expertise, as they are directly connected to the research topic. All participants had fascinating stories to tell and provided interesting insights, particularly on their current efforts, e.g., scaling and repositioning their companies or research endeavors, and more. The enablers, accelerators, and hurdles they had to overcome were discussed. Furthermore, the matter of worldwide marine plastic pollution was addressed, and the ongoing recycling schemes known to the expert were considered. Finally, the conversation turned to the last topic block of innovators and disruptors, in which different digital transformative technologies and possible applications were explored. All interviewees presented their future outlook on their respective fields combined with views about industry transformation. The sessions were rounded off with an open discussion and validation of the developed subscription model. This enabled the researcher to identify meaningful findings relevant for possible real-life implementation.

The following is an analysis of the interviews.

4.2.1 Capture Fishing Industry and Nets

The decision on which net design or material to use depends on many factors, including cost, material characteristics and properties (e.g., strength, flexibility, durability, weight, buoyancy), plus previous experience using particular designs or materials and existing regulations of common fisheries policy have to be factored in as well. Cost-effectiveness is also an essential component in the choice of fishing gear. Environmentally friendly design is not always considered in selecting materials and design, as it is often more expensive. This fact was confirmed in unison by all interviewees.

Shallow or coastal water fishing nets

Many different net designs and practices are used for fishing. An extensive overview can be found in Appendix 3.

Gillnets are among the most commonly used fishing gear. A single gillnet typically consists of the four most frequently manufactured types of plastic:

- ◊ Main Body - Polyamide (PA6 or PA6.6, Nylon) – strong material but absorbs water, thus heavy and moist. (PA6 and PA6.6 have different melting points)
- ◊ Sink lines - Polystyrene (PET) is used for coating the lead weights – high-density fiber material
- ◊ Float lines – either polyethylene (PE) or polypropylene (PP) with a lower density than water, sometimes with additional polystyrene floats for better buoyancy

(Dr. Andrea Stolte, Ben Kneppers, Prof. Martin Charter, Uwe Lichtenstein, Joel Baziuk)

Note: the lead used in the sink lines is problematic for recycling gillnets as it is a toxic substance. Lead can be recycled in a metal recycling process but it is challenging to separate from its polyester sheathing. If lead weights in sink lines can be replaced by less hazardous materials, this will allow the sink lines to be recycled when re-use is not possible. (Dr. Andrea Stolte, Uwe Lichtenstein).

Deepwater fishing nets

The plastic used for the different **trawling techniques** and long lines are mainly monofilaments of PE, nylon, and PET. A recent trend has been to use material made from a combination of nylon and polyethylene in some mesh sections (usually when a specific combination of strength, energy absorption, and wear resistance is required) (Dr. Andrea Stolte, Ben Kneppers, Uwe Lichtenstein). Mixed fiber materials such as polysteel are also used but are not recyclable (Ben Kneppers). Of concern is that trawl netting and aquaculture nets are coated with potentially toxic copper to decrease biofouling (Prof. Martin Charter).

4.2.2 Fishing practices and material loss

Regarding fishing practices and material loss, interviewees stated that: *"Overall, no fishman ever wants to lose their gear, right? I mean, it's a thing that happens. But nobody, no fisherman wants to lose their gear, cost them money. It's the means by which they harvest seafood to feed the world. So there are global food security ties to that as well."* (Joel Baziuk), (Dr. Andrea

Stolte, Uwe Lichtenstein, Ben Kneppers). So, nets can be costly, and no fisherman loses their net voluntarily, but it still happens due to various circumstances. This poses the question of alternative gear design, and in terms of a long-term vision, maybe an exploration of novel approaches for fishing. As Joel Baziuk states: *"You know, technology has changed over time. I mean, the involvement or the evolution of gillnets as monofilament materials like it's changed. Although you know the myth, the methodologies of fishing the materials might have changed a little bit, but the methodologies of fishing haven't really changed in a century or more. Is it time to look at different ways to fish?"*. Furthermore, product life extension is not yet widely factored in from the design phase. Eco-design and circular design are not currently practiced in the fishing gear industry.

Finally, fish is an excellent protein resource if fishing is done correctly and sustainably. So, it continues to make sense to build the industry. The catch swims freely until the end, thus being happily caught everything is in the spirit of animal welfare. (Uwe Lichtenstein)

4.2.3 Ocean Plastic Pollution: Opinions and Recycling Efforts

> *"The biggest problem is turning off the tap as it were. The proverbial tap needs to be turned off. And until you do that, the removal work is - you know, that the analogy gets overused all the time, but it's applicable - is that you're mopping the floor before you're turning off the tap, and you're not really." (Joel Baziuk)*

Some interviewees described how lost fishing nets pose a threat to marine habitats. So, as the trawling nets have sink- and swim-lines, they keep going up and down in the water column and continue to fish meaninglessly. It's different with "green nets" as they are lighter than water. They will float until too many animals get entangled in them. Then the whole net collapses and sinks to the seabed. It is a trap for sharks, turtles, dolphins, whales, and others. Once at the seabed and after a while, when the biologic decomposition process is complete, the nets drift back to the surface and the cycle starts again (Dr. Andrea Stolte, Uwe Lichtenstein, Ben Kneppers, Joel Baziuk).

A further problem is dolly ropes which is the name given to orange or blue plastic threads often attached to the underside of bottom-trawling nets to protect them against wear and tear. Due to abrasion and poor waste management, they end up in the sea during fishing operations, making them one of the most prevalent litter items on beaches. Dolly ropes are also a massive recycling obstacle and have to be managed separately in PE recycling most of the time (Uwe Lichtenstein, Dr. Andrea Stolte).

On huge trawlers on the high seas, the situation is quite different. Here it's common to patch small holes in nets on the ship's deck using small off-cuts. Larger sections of the net removed during repairs are flushed off the deck when the catch is hauled-in. Most trawling gear found on beaches bordering the North Sea, North-Atlantic, and Arctic Sea are discarded parts from on-ship repairs, almost 70-90 percent (Dr. Andrea Stolte, Joel Baziuk).

In addition, under European law, fishermen are required to report lost nets if they cannot recover them. But reports are rare because it is unclear who is responsible for recovery unless it represents an obstacle for waterways. In this case, expensive salvage operations are carried out by respective authorities with national fisheries and environmental agencies taking responsibility and securing funding for a quick recovery.

4.2.4 Recycling Efforts

It is necessary to carefully distinguish between the three most common recycling methods for fishing nets, also stated in the European Waste Framework (2008/98/EC): Mechanical recycling, chemical recycling, and thermal processing (incineration/energy recovery). Mechanical recycling consists of mechanically shredding and melting plastic fibers into pellets. Chemical recycling encompasses all processes for the depolymerization of plastics, meaning technologies where plastic waste is broken down into chemical building blocks. In the case of polyamide used in fishing gear, depolymerization results in monomers, which are then used to produce new plastic (Dr. Andrea Stolte, Prof. Martin Charter).

All Interviewees agreed that capture fishing gear is a complex material to recycle, as they use different forms of plastics and metals. Customization of nets due to variation and particular circumstances boosts material variation and presents recycling challenges. For recycling to be successful certain material purity and quality are required. For this reason, ghost gear or ALDFG will only be recyclable in rare cases, as they are most often heavily contaminated with salt, sediments, and other residues. But through a mechanical cleaning process, a certain level mixed with end-of-life gear will be definitely viable through a repurposing process.

This challenges present recycling operators who run operations close to at cost due to complicated logistics, dissembling, sorting, and cleaning of nets. Currently, nylon (PA6) netting and PP/PE floats and lines are recycled by Aquafil in Slovenia and Plastix A/S. These must be separated into individual polymer components before being shipped to recycling facility. (Dr. Andrea Stolte, Joel Baziuk, Uwe Lichtenstein, Prof. Martin Charter) Bureo even stated: "*A process where we can basically get the material back to the same quality as virgin Nylon. And so that's where we can get it back to the filament and replace the virgin from oil-based virgin resources. Instead, we can have it replaced entirely from 100 percent end-of-life fishing nets*." (Ben Kneppers) However, the mixed fibers such as poly steel must be cut out manually (ibid) as is the case for other hazardous materials such as dolly ropes, lead in sink lines, or copper coating (Prof. Martin Charter, Dr. Andrea Stolte, Uwe Lichtenstein).

Current collection points for the disposal of fishing nets are very limited, but that's not the main problem. The issue is more about how it's done. Collection points generally do not offer different material sorting options. Most mix the discarded nets with industrial/commercial waste, there is no recycling but only incineration of the material. Under the EU Port Reception Facilities (PRF) Directive (EU/2019/883) there is an obligation for ports to provide adequate facilities for the reception of waste from ships. Ports must ensure separate collection and waste receptacles for fishing gear. This should be further developed towards a central solution with net producers and waste collectors working together. Most waste management enterprises do not see themselves accepting nets at the moment. Moreover, collection or drop-off points are limited to mainly big ports, and logistics are complex. This needs to be extended (Dr. Andrea Stolte, Uwe Lichtenstein, Joel Baziuk).

The available recycling methods of fishing nets do not fully present circular design solutions so far, but rather upcycling. One Exemption is Bureo in cooperation with Patagonia. In their case, they managed to upcycle nylon from fishing nets into winter jackets, which can then be returned and eventually reintroduced into the closed-loop circular design recycling process to produce new material for jackets (Ben Kneppers, Joel Baziuk, Prof. Martin Charter, Dr. Andrea Stolte).

Another significant issue is the labeling and certification of products that contain recycled marine plastic. So far, there is no technical definition or ISO standard in place. For example, the Adidas shoe described in section 2.3.1 is allegedly made of recycled fishing gear polymers.

But to what percentage? Is it 0.5 percent or 1 percent? The French Advertising Authority now called them out for this inappropriate use of circularity terms of their products. Also, you're seeing the European Commission and other national governments, even including the US, starting to clamp down on claims around circular products. This takes the discussion about greenwashing to a whole new level (Prof. Martin Charter, Dr. Andrea Stolte).

4.2.5 Hurdles and Challenges in the Industry

Interviewees were asked to identify what they believe were the biggest **hurdles and challenges to addressing fishing net pollution and expanding recycling efforts**. All participants, so 100%, identified Scaling of Solution, Material supply, Policy (e.g. EPR, standardization, and certification), Politics/Regulations, and Funding as the main obstacles. But also, Cross-industry connections, capacity, further R&D efforts, Industry competition, and Education were also believed to be challenges.

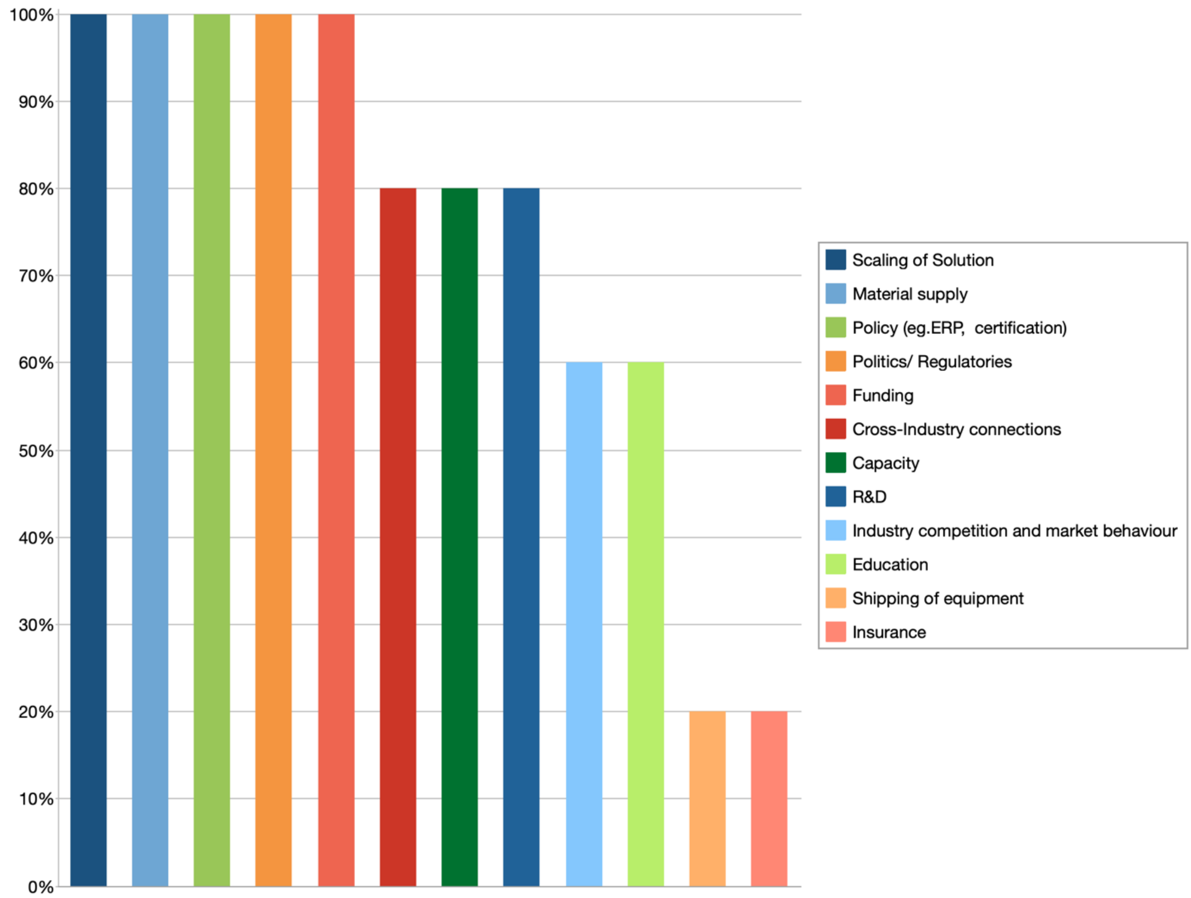


Figure 11: Distribution of Interview answers on Hurdles and Challenges in the fishing industry. (100% represents concordant answers by all interviewees)

The main challenges and Hurdles are:

Scaling of Solutions across the industry:

- Solutions like Bureo with an entirely new supply chain can be complex to scale across fishing communities, ports, and countries. It is difficult to make viable for every fisherman in need.
- Retrieval actions of ghost gear as WWF, Healthy Sea – Ghost Diving, and GGGI need to be more distributed, connected, and centrally planned to reach more communities.
- It is essential to understand the local context, geographies, regulatory framework, and from there to scale solutions. Lasting solutions are needed.
- Recycling possibilities are currently only available with high transportation costs available. Collection networks need to be expanded.
- There is no high economic benefit from recycling fishing gear today, and costs for regular collection, transport, and sorting are high.
- There is lack of coordination across the value chain, from net manufacturers to end-user. Stakeholder involvement and cost-sharing are required.
- There are information asymmetries.

Material supply:

- A supply chain is needed that can consistently and efficiently deliver the material that you're collecting from fishermen and turning into high-quality raw material.
- Demand is increasing, but the supply cycle of end-of-life gear is not sufficient yet.
- The problem of material purity and pre-processing issues need to be resolved.

Policy (e.g., EPR, certification and standardization, fisheries policies):

- Extended producer responsibility (EPR) has a huge role, and increased regulation around the responsible management of end-of-life materials is essential, but further development is needed. There has been no universal approach until now.
- EPR imposes the risk of amplifying the unauthorized import of nets from different countries.
- There is risk that EPR fees will be transferred into higher costs for end consumers.
- European Maritime, Fisheries and Aquaculture Fund (EMFAF): The goal is to ensure that fishing is rebuilt quickly, modernized, climate-neutral, that aquaculture facilities are built ecologically but are also competitive, and that fisheries can be maintained in Europe.

- A more enhanced certification committee at EU Level for ISO standards and labeling is required.

Politics and Regulations:

- The bureaucratic hurdles for applying for funding are too onerous.
- Exemption permits for research and testing of fishing nets are not beneficial.
- There is no control of what happens on the high seas. No adequate regulations or frameworks are in place.

Costs and Funding:

- Fishermen cannot be expected to carry out pre-processing of nets with extensive sorting and dismantling work for free, in addition to the heavy-duty work involved in work at sea. Costs of logistics are still too high as well.
- Processes for applying for funding must be faster and easier.
- Unless there are private-public partnerships, there won't be sufficiently mature recycling infrastructure for fishing gear.
- More funding schemes are needed.

Additional main obstacles:

- Design for better traceability and interchangeability of nets. New sustainable design to reduce environmental impact in the marine environment if lost. Reducing the number of different polymers used in gillnets and simplifying their dismantling after use could increase the amount of fishing gear entering the recycling process.
- R&D of lead lines and less hazardous materials for them.
- More standardization of fishing gear design across borders.
- Technological innovation needs to be supported by governments
- Lack of solid data for GhostGhost gear and microplastics.
- Uniform waste classification scheme forfor fishing gear in Europe
- Enhancement of cross-industry interaction with fishermen, NGOs, academics, governments, seafood industry members, and retailers.

Some other problems were identified and addressed, but they were of no benefit to the objectives of this paper and were therefore disregarded. All of the above-discussed topics aim towards more universal and innovative approaches in general, and point to a need for transformation in the industry.

4.2.6 Innovations and Disruptions in the Industry

The innovations and disruptions shown in Figure 12 were presented and explained by the interview partners. Various examples of applications are pointed out in this following context.

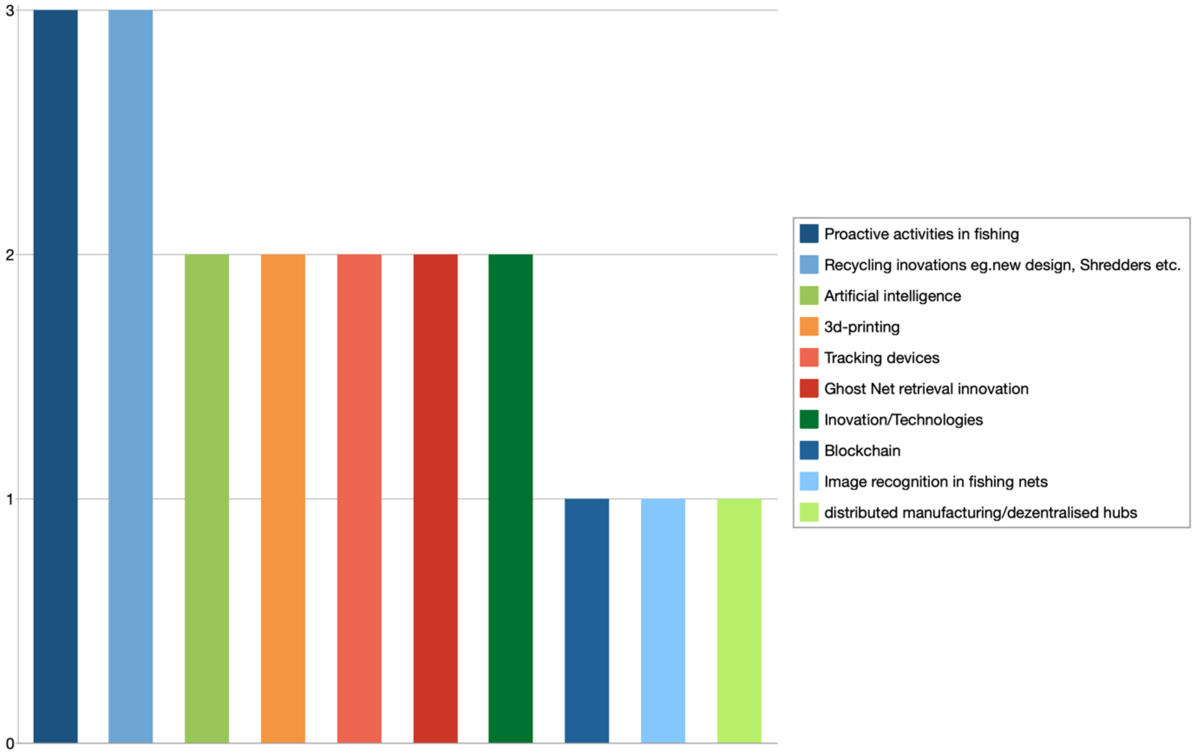


Figure 12: Innovations and Disruptions of the Fishing Industry - Nr. of interviewees mentioning the topic

For proactive activities in fishing, the following examples were given:

Iceland already has a material return scheme in place and is testing a rental system for nets. They report that 80 % of returned nets can be re-used or recycled by the net producer (Dr. Andrea Stolte);

A design in Norway called emergency buoy, which is basically a balloon used in trap fishing. Once a trap is lost, the buoy will pop up and the trap is effectively disabled (Joel Baziuk);

Research projects of new trawling nets with short cycle catching and image recognition can significantly increase the amount of catch and fish quality (Uwe Lichtenstein);

Several recycling ideas were presented, such as new ways of shredding and dry-cleaning nets and testing new net designs for interchangeability. Other examples were: a new research tracking device in the Baltic Sea, and a project by Portugal and Galicia (Spain) called NetTag;

Dr. Andrea Stolte proudly presented how WWF Germany Ghost Gear uses new technology for ghost net retrieval. They use sonar to detect nets on the seabed effectively and very accurately;

Dr. Felix Wunner and Tobias Nickl showcased how additive manufacturing, combined with decentralized hubs and distributive manufacturing, can be a key enabler for drastically reducing costs, storage, and labor.

4.2.7 Environmental impact

A fishing net can last up to 500 years in the marine environment and kill hundreds of aquatic habitats, yet it is not entirely clear what it does in terms of carbon emission. However, the most tangible CO_2 emission saving is by switching virgin plastic from oil to recycled plastic (Ben Kneppers, Dr. Andrea Stolte):

> *It was estimated that* ***plastics production and the incineration of plastic waste give rise globally to approximately 400 million tonnes of CO_2 a year.*** *Using more recycled plastics can reduce dependence on the extraction of fossil fuels for plastics production and curb CO_2 emissions. According to estimates, the potential annual energy savings that could be achieved from recycling all global plastic waste is equivalent to 3.5 billion barrels of oil per year. (European Commission, Plastics in a Circular Economy, n.d.)*

A new study claims that catching fish using heavy trawl nets releases about the same amount of carbon dioxide (CO_2) worldwide as the aviation industry, as they drag across the seabed. Trawling stirs up the sediments of the seabed, which act as massive carbon sinks which, in turn, leads to the emitting of CO_2 emissions. (Sala et al., 2021) However, this needs to be further verified by future research.

Another point is the social-environmental impact, which can occur by providing satisfactory solutions for fishermen and incentives to return nets.

4.2.8 Towards a Circular Economy Model in the Capture Fishing Industry

Interviewees agreed that in general, fishermen care about the future of their habitats, which could be seen as stewardship for the ocean for many in the industry. But most are rather reactive than proactive and wait for policies to be implemented. A cause for this lack of execution might be the previously mentioned hurdles of costs, funding, regulations, and other missing incentives (Dr. Andrea Stolte, Prof. Martin Charter, Joel Baziuk, Uwe Lichtenstein).

However, some motivated fishermen have obtained diving licenses, funded from their own money, to retrieve ghost gear. This is because they have faced problems associated with equipment getting tangled up in old gear and they have thus sought to solve the problem themselves. The next challenge for them was the disposal of the gear, because of the lack of drop-off points, as explained earlier. And this is why they contacted the WWF Germany Ghost Gear initiative to ask for help (Dr. Andrea Stolte). This unsatisfactory situation calls for an innovative use and return business model.

To successfully shift toward a circular design model, the following five crucial points need to be tackled and overcome:

- **Minor polymer variation** – the number of materials needs to be reduced. Ideally, large sections of uniform material. This makes the pre-processing, sorting, and recycling a lot easier.
- **High purity of material** - makes recycling more profitable and attractive.
- **Modularity** – net design should employ a circular design approach allowing easy assembling and disassembling of parts and for maintenance and repair
- **Eco-design** – easy recycling. Thus, minimizing labor time and processing costs.
- **Traceability and transparency** – allowing tracking of material in the supply and value chain to enhance recycling efficiency and reduce gear loss.

These arguments are in line with the Biosphere Framework for circular design, introduced in 2.4.2. Additionally, this requires the involvement of all stakeholders across the value chain for the best possible integration into a circular economy model. Furthermore, this can be facilitated through the following approach. The European EPR scheme, which will be introduced on December 31st, 2024, will accelerate further goals as to be seen in the following statement:

> *Requirement for Member States to implement Extended Producer Responsibility (EPR) for fishing gear and components of fishing gear containing plastic. Under the EPR schemes, producers of fishing gear containing plastic should cover the cost for the separate collection of waste fishing gear containing plastic and its subsequent transport and treatment. The producers shall also cover the costs of the awareness-raising measures regarding fishing gear containing plastic. EU Member States are required to set up the EPR Schemes for fishing gear by 31st December 2024. The Directive also envisages the European Commission to request European standardization organization to develop harmonized standards for circular design of fishing gear. (The Single Use Plastics Directive (EU/2019/904))*

Further details are not available because of a lack of data for exact pricing models, etc.

Also, a good example of a recently implemented EPR scheme that has been successful is Chile. The program is already being applied by producers in cooperation with Bureo and other stakeholders (Ben Kneppers).

4.2.9 Responses & Opinions on the developed Subscription Model

All interviewees were introduced to the closed-loop circular design subscription model developed for this thesis and were requested to provide feedback. A rough division of the responses is shown in Figure 13. In general, all respondents found the model to be a good approach and were positively interested. Most respondents reflected that it touches on most of the key issues. Further, positive responses such as *“(..) and if you find breakthroughs that could solve the issues, that's absolutely groundbreaking on an actual real-life industry opportunity. I think that's very worthwhile what you're working on.”* were also received.

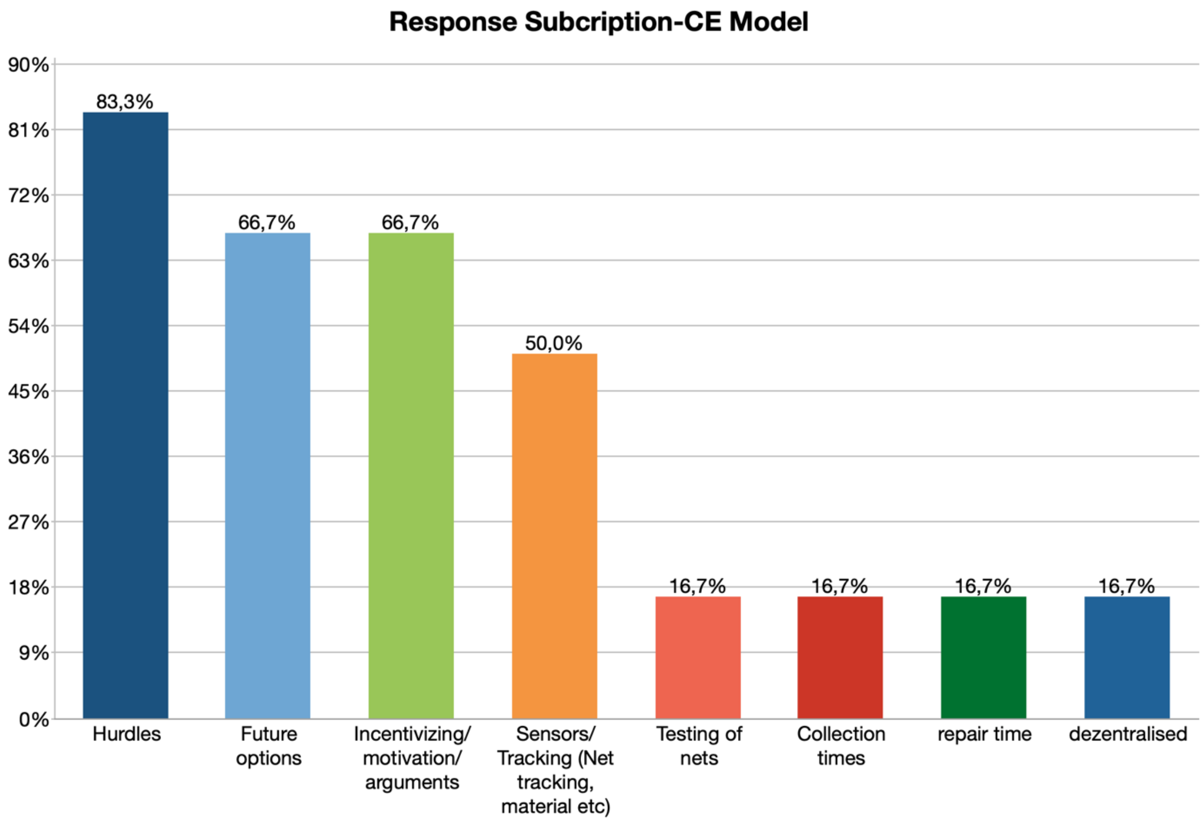


Figure 13: Response and Opinion areas on the developed subscription model. (100% represents all interviewees who commented on this topic)

Furthermore, all interviewees expressed a certain hesitancy concerning the technical implementation. This can be clearly seen at the 83,3 percent of “Hurdles” given as an answer. The main hurdles and challenges identified are:

- The **culture of fishing** – will be the biggest challenge to overcome the almost non-existent innovation openness of the fishing communities, very conservative sector (all respondents have said that).
- **Cost-competitiveness** - to the current methods in place.
- **Net producers** - how to connect the model with the current production of nets.
- **Material separation** as pre-processing of recycling – how and by whom is it done?
- The **chemical behavior** of recycling – possible agglomeration needed.
- **Additive manufacturing** – development and costs to design specialized 3d-printing process.
- **Location of hubs** – intelligent distribution and costs. How many hubs are feasible and make sense, depending on geographical location.
- **Quality assurance** – nets need to be as good as previously owned nets.

For **future options or recommendations**, the following comments were made: It is possible to include additives, but high costs are a barrier to better connectivity of monomers (Ben Kneppers, as Bureo has done research in this regard). The modularity approach is an excellent way for fast repair processing and customization. Still, it was recommended to conduct further research on how to implement and make technically feasible connection points techniques. The possible technological implementation of a 3D scanner for pre-processing to analyze material was advised (Dr. Felix Wunner). And as a potentially beneficial option for states and regulators, the trackability solution offers data for overfishing countermeasures and new EPR pricing schemes.
A recommendation was first to use the model in coastal fishing, as most nets break there. Furthermore, the costs for these nets are not as high as large trawl nets, so the highest possible turnover is achievable (Dr. Andrea Stolte).

Another highly discussed response was **incentivizing and motivating fishermen** for the model. Here the remark was: *"But they will only engage if there is zero cost or there is some benefit to them. An example we have in Canada, they get paid to disassemble the nets. So there's an additional net income.".*" (Prof. Martin Charter).). This approach was also confirmed by Joel Baziuk and is also already in place at Bureo (Ben Kneppers). Once fishermen see the value of the subscription model and its benefits, they will be highly motivated to sign up for a sustainable return system. And as they are "*'pack rats', they again get motivated by success stories of the implementation, meaning if they see how successful it is in the neighbor port, they will want to have it as well."* (Joel Baziuk)

Another point frequently raised was the need for **extended tracking technologies**, in which the subscription model contains several options depending on areas of operation. Thus, firstly the supply chain is transparent, beginning with the original manufacturer, on to the owner and finally into the repair cycles. Secondly, the fish catch is traceable (Prof. Martin Charter, Joel Baziuk). More frequent, small markings - such as passive RFID tags - on net sections would provide information on where and in which fisheries areas most net parts are lost. Countermeasures could be developed together with the fishermen concerned (Dr. Andrea Stolte).

Other points that were positively commented upon were: "*The advantages of **distributed manufacturing**, that you don't need these extreme production capacities, you need less space, less electricity, smaller shop floors and can build something there and don't need large production facilities.*" (Tobias Nickl), this in line with the advantages discussed in section 2.3.2. Also, it can be combined with the **collection point availabilities** and **fast repair** processes, optimizing the **transitioning downtime of fishermen**.

Finally, the model developed received compliments, *"It simply proves that you can act more sustainably through modularity, customization, and by enabling digital business models to make life better in the end for traditional industries like fishing."* (Dr. Felix Wunner).

5 Key Findings & Final Discussion

In the context of this paper, assessing and gaining approbation for the circular economy model to sustainably transform the capture fishing industry was achieved. To conclude, findings and key takeaways will be summarized in the following section. Moreover, the research statement and questions will be linked and answered through the final discussion of the developed circular-design model.

Key Findings:

- ◊ The ubiquitous matter of ocean plastic pollution is partly due to lost fishing gear and imposes high risks of microplastics from decomposing nets. This threatens marine species, the marine biosphere, and plastics entering the food chain eventually end up being consumed by humans.
- ◊ Due to financial dependence on fishing quotas and the associated livelihood risks, the conservative fisheries sector and its culture are currently reactive rather than proactive.

◊ Fishing methodologies have not changed in centuries. This calls for action with a future-oriented vision for fishing practices.
◊ Product life extension of the design of fishing nets is not yet widely factored in. Eco-design and circular design are not currently practiced in the fishing gear industry.
◊ A reasonable return system with a cross-border solution is needed. Collection points of fishing nets in ports are very limited, and, if available, it is unclear who is responsible for what post-processing.
◊ Fishing gear is a complex material to recycle, but if pre-processing and material purity is done correctly, recycling is feasible and has great potential value.
◊ New disruptive technologies such as 3D printing and distributive manufacturing can be the key enabler for a business model innovation.
◊ Lack of data or asymmetries of information – Introduction of new nets into the fishing industry does not get tracked and correlated with returned end-of-life end points. Thus, we can conclude that nets end up in the oceans.

Overall, all interviewees were unequivocal in expressing a definite need for change, but successful transformation can only be achieved by carefully considering the above points. Also, they predicted slow transformation if the model were to be implemented.

Discussion about the closed-loop circular design subscription model for capture fishing nets

In order to illuminate the research questions and test the proposed subscription model, the industry experts were extensively interrogated.

In summary, easy access to drop-off points and easier sorting of materials, as well as a design that focuses not only on functionality and durability at sea but also on recyclability, are prerequisites for increasing the quantity and probability of recycled fishing gear. This can be facilitated through the developed subscription scheme. The priority is to keep fishing gear products in circulation for as long as possible, promoting re-use and remanufacturing, which can be seen as a closed-loop circular design approach. This is possible due to the modular eco-design of nets, enhancing customization, ramping up disassembling processes, raising material purity, and improving cost-competitiveness. The model offers several pricing schemes to optimize incentives for fishermen and individualize them to specific fishing practices. Additional revenue streams for fishermen can be integrated into the model as they could be paid for manual pre-processing, similar to the process carried out in the example of Bureo

(Source: Ben Kneppers). Fundamentally, we can speak of a shift towards a service model with different functions available for used nets.

In addition, the innovative manufacturing process of additive manufacturing allows extra customization possibilities, the automation of sensor installation, plus even higher durability and strain resistance of nets with the material reinforcement of critical parts and nodes.

Furthermore, the so-called decentralized maker hubs will decrease costs and increase production lead times, thus reducing the downtime of fishermen. The collection and logistics for net transports can be solved through the intelligent placement of hubs close to fish distribution centers, so shared transportation costs can be leveraged.

These arguments confirm viability of the model for the capture fishing industry. Still, the hurdles stated in section 4.2.9 need to be bridged, and further research and development must occur. For example, fitted gear tracking options can reduce the impact of fishing gear on the environment by, acting as a deterrent to intentional or improper disposal of fishing gear. This would provide material identification across the value chain and transparency respecting the origin of producers to further support recycling possibilities. Tracking of location further enables the subsequent retrieval of lost gear and could help to prevent illegal, unreported, and unregulated (IUU) fishing. The traceability option further allows regulators to gather more data and conquer the overfishing issue.

Finally, if such a model is realized, the recommended way to disseminate it around the industry is to use a constellation of major ports, which would enable other fisheries centers and ports to see that successful environmentally friendly implementation is possible. There would also be creation of new job opportunities in the local collection and additive manufacturing sites. So, the key is to create scalable industry through developing infrastructure in major ports, leading to adaption in the sector. This can be seen as a targeted implementation aiming to overcome fishing culture resistance and recommended by Joel Baziuk.

Having established the transformational approach of the industry now, an ecological prognosis with a measurable impact can be formulated. Implementing an EPR and other directives in the near future and a confirmed reduction of lost gear in the marine environment will directly impact the industry towards more sustainable fishing. This impact will be measurable with the help of production and net return numbers. Also, increasing ESG pressure on corporations will have measurable impact. Hence the circular design subscription paradigm contributes to supporting the UN Sustainable Development Goals (SDGs) (*Size of the image reflects the impact), further details of the targets can be seen in Appendix 1:

6 Conclusion

There are two pivotal management practices that have recently attracted a lot of interest: Business Model Innovation and Circular Economy. This paper focuses on both areas. Thus, the aim of this thesis has been to examine the viability of a closed-loop circular design subscription business model for the capture fishing net industry, as there has not been an approach similar to this thus far. Globally, only a few closed-loop systems are currently in place. The proposed solution would be progressive and ready for future adaptability in accordance with shifting industry requirements.

As fishing methodologies have not changed for centuries, a call-to-action with a future-oriented vision for fishing practices clearly is needed. This is further stimulated by policies and directives, such as the new Extended Producer Responsibility initiative, which will accelerate industry transformation. However, success can only be achieved if thoughtfully developed and with a comprehensive value chain integration. Otherwise, the smallest and weakest link in the chain will be affected by additional costs and lead to inefficiencies. The developed model offers countermeasures and fosters incentives for fishermen, hence endorsing the deep-rooted cultural imperative for security.

In fact, when both the subscription model and the EPR solution are combined and integrated at the EU- level, it has a positive outcome for both sides. Because the EU context will be so revealing, other countries following suit and implementing something similar within the same methods and timeframe would be likely.

Moreover, the increasing environmental consciousness, in most parts of the world, will make further greening of the fishing industry easier to achieve in the future. Most likely, people will be very willing to pay more for fish if they know its origin and that it's caught in a sustainable manner. Documentaries, such as Netflix's "Seaspiracy" (*SEASPIRACY DOCUMENTARY*, 2021) are useful, although some claims are partly exaggerated and out of context. However, fishermen can clearly help reduce carbon emissions by increasing the efficiency of catching fish, but the precise environmental impact of changes is still hard to quantify.

Disruptive innovation is generally seen as progress and beneficial development. But there can be significant negative externalities that arise from disruption if not all parties cross-industry are equally incorporated. Therefore, industry transformation needs to be carefully assessed and precisely planned across multi-stakeholders to ensure a successful transition from a linear to a circular business model. Nevertheless, if this change pathway in the capture fishing industry is effected, then this paper has served as a conceptual framework for possible real-world implementation.

7 Limitation

As several industry experts confirmed and warned, it is practically impossible to generate survey responses from fishermen. Even the Associate Director of the GGGI, Joel Baziuk, with more than 20 years of experience in the fishing industry and an extensive network in harbors and with fisherman and fisheries authorities, stated in the expert interview: that he had *"dismal responses to a survey trying to ascertain the amounts of fishing gear that are out there"* when he conducted a survey. Unless, as he says, *"if you can meet with them in person and you can actually put a face to a name and have that sort of a conversation with them, then things become far easier to do."* Dr. Andrea Stolte also confirmed the same in our interview. Nevertheless, due to Covid-19 (SARS-CoV-2), this was nearly impossible to be carried out in a personal form in current times.

Sadly, Covid-19 also limited the number of industry-expert interviews, as two of the confirmed interviews had to be canceled on short notice due to related health conditions of the interviewees. This somewhat limited the empirical significance of the data, as a bigger sample size - in other words, more interviewees – would have increased accuracy of evaluating the hypotheses.

Lastly, there was no response to the interview invitation from the company Fishy Filaments™. Fishy Filaments' recycling of fishing nets produces an engineering grade and dimensionally accurate raw material filament used in Fused Deposition Modelling (FDM) 3D printing. It would have been of great interest to gain insights on their process for future research purposes and for model development.

8 Future Research & Collaboration Recommendations

To further the scope of the model, it is crucial to create a business plan as well as to detail the financial projections from different subscription options. These should be subject to a cost-benefit analysis and considered in the context of a full life cycle analysis, taking CO_2 emissions into account during the manufacturing and operational phases along with during transport of the fishing gear for recycling at the end of its life.

Furthermore, quantitative analysis would be a valuable contribution to the literature and would add a further iteration to the present study. Also, as of now, no up-to-date data is available on the actual numbers of fishing nets polluting the oceans. With more quantitative research, it would be interesting toto test the model further and gather insights into how fisheries stakeholders would accept, adapt, and be willing to take on such a subscription model.

Additionally, technical research needs to be continued through a potential feasibility study for the specialized 3D printing process with a floating printing bed. This could achieve the highest flexibility and endurance standards. Moreover, the recycling methods need to be investigated, e.g., whether mechanical recycling or chemical processing represents a better solution for additive manufacturing of fishing nets. Having established the benefits of tracking equipment for nets, it would be interesting to technically evaluate the different integration possibilities.

The initial assessment and analysis of geographical best-fit locations also need to be explored. All solutions should be tailored to the specific location where they are to be implemented, for example, taking into account the different harbors, port authorities, fishing areas, and distributed manufacturing possibilities.

Additionally, future cooperation is advised with the Working Group on Fishing Technology and Fish Behaviour (WGFTFB), jointly supported by the International Council for the

Exploration of the Sea (ICES) and the Food and Agriculture Organization of the United Nations (FAO). This cooperation could be facilitated in a cross-sectoral network of internationally established experts to share best practices and serve as a facilitation platform for addressing relevant research needs and challenges. Other collaborations with potential significant cross-industry partnerships represent enablers for the transition to a circular economy. Joint ventures could be a very good approach, for example, to integrate the existing solution of Fishy Filaments™ into the circular design additive manufacturing.

The possible implementation of the model into the EU EPR return fee scheme should be evaluated, as it will support higher recycling rates for fishing gear. This needs thorough consideration from a costs and benefits point of view.

Finally, the model developed could also be implemented in aquaculture fisheries. Here, implementation is more straightforward since nets are designed and utilized more universally. Also, a possible adaptation of the 3D printing solution for buoys and other fishing equipment to bridge machine downtime can be investigated.

Peter Drucker once said that *"The greatest danger in times of turbulence is not turbulence itself, but to act with yesterday's logic."* In every aspect, we live in an era of transformational change triggered by digitalization, industry convergence, overlapping ecosystems, ubiquitous connectivity and an increasing environmental crisis. Our era requires new procedures of companies, regulators, market players, and the society at large to deal with ongoing disruptions and accompanying environmental changes.

References / Bibliography

Adidas_x_parley. (n.d.). Retrieved 15 April 2019, from https://www.adidas-group.com/media/filer_public/a7/93/a793905f-7ef0-4d84-9b6a-f0d89e4ba424/adidas_x_parley_qa_website_de.pdf

Ansoff, H. I. (1957). Strategies for diversification. *Harvard Business Review*, *35*(5), 113–124.

Attaran, M. (2017). The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing. *Business Horizons*, *60*(5), 677–688. https://doi.org/10.1016/j.bushor.2017.05.011

Baumers, M., Tuck, C., Wildman, R., Ashcroft, I., & Hague, R. (2017). Shape Complexity and Process Energy Consumption in Electron Beam Melting: A Case of Something for Nothing in Additive Manufacturing?: Shape Complexity and Energy Usage in 3D Printing. *Journal of Industrial Ecology*, *21*(S1), S157–S167. https://doi.org/10.1111/jiec.12397

Berman, B. (2012). 3-D printing: The new industrial revolution. *Business Horizons*, *55*(2), 155–162. https://doi.org/10.1016/j.bushor.2011.11.003

BlueCycle—Products. (2021). Blue Cycle. https://bluecycle.com/en/the-products/

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016a). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016b). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Bogers, M., Hadar, R., & Bilberg, A. (2016). Additive manufacturing for consumer-centric business models: Implications for supply chains in consumer goods manufacturing. *Technological Forecasting and Social Change*, *102*, 225–239.

Brahney, J., Hallerud, M., Heim, E., Hahnenberger, M., & Sukumaran, S. (2020). Plastic rain in protected areas of the United States. *Science*, *368*(6496), 1257–1260.

Brannen, J., & Coram, T. (1992). *Mixing methods: Qualitative and quantitative research* (Vol. 5). Avebury Aldershot.

Bryman, A. (1988). *Quantity and Quality in Social Research* (0 ed.). Routledge. https://doi.org/10.4324/9780203410028

Bryman, A. (2016). *Social research methods*. Oxford university press.

Charter, M., Carruthers, R., & Jensen, S. F. (2021). *Products from Waste Fishing Nets*. 31.

Christensen, C. M. (1997). *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*.

Christensen, C. M. (2006). The ongoing process of building a theory of disruption. *Journal of Product Innovation Management*, *23*(1), 39–55.

Christensen, C. M., McDonald, R., Altman, E. J., & Palmer, J. E. (2018). Disruptive Innovation: An Intellectual History and Directions for Future Research. *Journal of Management Studies*, *55*(7), 1043–1078. https://doi.org/10.1111/joms.12349

Christensen, C. M., & Overdorf, M. (2000). Meeting the challenge of disruptive change. *Harvard Business Review*, *78*(2), 66–77.

Christensen, C., & Raynor, M. (2003). *The innovator's solution: Creating and sustaining successful growth*. Harvard Business Review Press.

Christensen, C., Raynor, M. E., & McDonald, R. (2013). *Disruptive innovation*. Harvard Business Review.

Ellen MacArthur. (2021). *Circular economy—Overview*. https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

Ellen MacArthur & McKinsey & Company,. (2013). Towards the circular economy. *Journal of Industrial Ecology*, *2*, 23–44.

Europe, P. (2020). Plastics—The Facts 2020. *PlasticEurope*, *1*, 1–64.

European Commission, Plastics in a circular economy. (n.d.). Retrieved 19 October 2021, from https://www.europarc.org/wp-content/uploads/2018/01/Eu-plastics-strategy-brochure.pdf

EY, 2019. (n.d.). Retrieved 20 October 2021, from https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/advisory/ey-3d-printing-game-changer.pdf

FAO. (2020). *The State of World Fisheries and Aquaculture 2020*. FAO. https://doi.org/10.4060/ca9229en

FAO - United Nations. (2018). *Achieving blue growth: Building vibrant fisheries and aquaculture communities.* http://www.fao.org/3/CA0268EN/ca0268en.pdf

Fetters, M. D., & Molina-Azorin, J. F. (2017). The journal of mixed methods research starts a new decade: Perspectives of past editors on the current state of the field and future directions. *Journal of Mixed Methods Research*, *11*(4), 423–432.

Fisher Projects. (2020). *The Global Fishing Industry*. https://fisherproject.org/the-global-fishing-industry

Fishy Filaments. (2021). Fishy Filaments. https://fishyfilaments.com/

Fitterling. (2019). *We must stop choking the ocean with plastic waste. Here's how*. World Economic Forum. https://www.weforum.org/agenda/2019/01/we-can-stop-choking-our-oceans-with-plastic-waste-heres-how/

Ford, S., & Despeisse, M. (2016). Additive manufacturing and sustainability: An exploratory study of the advantages and challenges. *Journal of Cleaner Production*, *137*, 1573–1587. https://doi.org/10.1016/j.jclepro.2016.04.150

Free, C. M., Jensen, O. P., Mason, S. A., Eriksen, M., Williamson, N. J., & Boldgiv, B. (2014). High-levels of microplastic pollution in a large, remote, mountain lake. *Marine Pollution Bulletin*, *85*(1), 156–163.

Gall, S. C., & Thompson, R. C. (2015). The impact of debris on marine life. *Marine Pollution Bulletin*, *92*(1–2), 170–179. https://doi.org/10.1016/j.marpolbul.2014.12.041

Gassmann, O., & Enkel, E. (2004). *Towards a theory of open innovation: Three core process archetypes*.

Gebler, M., Schoot Uiterkamp, A. J. M., & Visser, C. (2014). A global sustainability perspective on 3D printing technologies. *Energy Policy*, *74*, 158–167. https://doi.org/10.1016/j.enpol.2014.08.033

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

GGGI2020AnnualReport. (n.d.). Retrieved 14 October 2021, from https://static1.squarespace.com/static/5b987b8689c172e29293593f/t/609d412de5470f6f6b1927ea/1620918589468/032021_GGGI2020AnnualReport_v2+Final.pdf

GGGI-WWF. (n.d.). Retrieved 14 October 2021, from https://static1.squarespace.com/static/5b987b8689c172e29293593f/t/60e34e4af5f9156374d51507/1625509457644/GGGI-OC-WWF-O2-+LEGISLATION+ANALYSIS+REPORT.pdf

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, *114*, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007

Ghost Gear | Fundy North Fishermen's Association. (n.d.). Fundy North Fisherme. Retrieved 18 October 2021, from https://www.fundynorth.org/ghost-gear

Global Ghost Gear Initiative. (2021). *Best Practice Framework for the Management of Fishing Gear: June 2021 Update.* [94pp. & appendices]. Poseidon Aquatic Resources Management Ltd. for GGGI. https://doi.org/10.25607/OBP-1650

Global plastic waste management projections 2016-2040. (n.d.). Statista. Retrieved 19 October 2021, from https://www.statista.com/statistics/1270110/plastic-waste-management-projections-worldwide/

Greenpeace. (2019, November 6). Greenpeace report reveals how ghost gear from the fishing industry forms majority of ocean plastic pollution. *Oceanographic*. https://www.oceanographicmagazine.com/news/ghost-gear-greenpeace/

Hartley, B. L., Pahl, S., Veiga, J., Vlachogianni, T., Vasconcelos, L., Maes, T., Doyle, T., d'Arcy Metcalfe, R., Öztürk, A. A., Di Berardo, M., & Thompson, R. C. (2018). Exploring public views on marine litter in Europe: Perceived causes, consequences and pathways to change. *Marine Pollution Bulletin*, *133*, 945–955. https://doi.org/10.1016/j.marpolbul.2018.05.061

Henderson, L., & Green, C. (2020). Making sense of microplastics? Public understandings of plastic pollution. *Marine Pollution Bulletin*, *152*, 110908. https://doi.org/10.1016/j.marpolbul.2020.110908

Hockerts, K., & Wüstenhagen, R. (2010). Greening Goliaths versus emerging Davids—Theorizing about the role of incumbents and new entrants in sustainable entrepreneurship. *Journal of Business Venturing*, *25*(5), 481–492. https://doi.org/10.1016/j.jbusvent.2009.07.005

Huysveld, S., Hubo, S., Ragaert, K., & Dewulf, J. (2019). Advancing circular economy benefit indicators and application on open-loop recycling of mixed and contaminated plastic waste fractions. *Journal of Cleaner Production*, *211*, 1–13. https://doi.org/10.1016/j.jclepro.2018.11.110

Issifu, I., & Sumaila, U. R. (2020). A Review of the Production, Recycling and Management of Marine Plastic Pollution. *Journal of Marine Science and Engineering*, *8*(11), 945. https://doi.org/10.3390/jmse8110945

IUCN Red List. (n.d.). Retrieved 20 October 2021, from https://www.iucn.org/downloads/status_of_the_world_s_marine_species_factsheet_en.pdf

Jamieson, A. J., Brooks, L., Reid, W. D., Piertney, S., Narayanaswamy, B. E., & Linley, T. (2019). Microplastics and synthetic particles ingested by deep-sea amphipods in six of the deepest marine ecosystems on Earth. *Royal Society Open Science*, *6*(2), 180667.

Joustra, D. J., de Jong, E., & Engelaer, F. (2013). *Guided Choices: Towards a Circular Business Model*. C2C BIZZ.

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular Economy: The Concept and its Limitations. *Ecological Economics*, *143*, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Kühn, S., Bravo Rebolledo, E. L., & van Franeker, J. A. (2015). Deleterious Effects of Litter on Marine Life. In M. Bergmann, L. Gutow, & M. Klages (Eds.), *Marine Anthropogenic Litter* (pp. 75–116). Springer International Publishing. https://doi.org/10.1007/978-3-319-16510-3_4

Kvale, S. (1994). *Interviews: An introduction to qualitative research interviewing.* Sage Publications, Inc.

Lebreton, L., & Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. *Palgrave Communications*, *5*(1), 6. https://doi.org/10.1057/s41599-018-0212-7

Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., Hajbane, S., Cunsolo, S., Schwarz, A., Levivier, A., Noble, K., Debeljak, P., Maral, H., Schoeneich-Argent, R., Brambini, R., & Reisser, J. (2018). Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. *Scientific Reports*, *8*(1), 4666. https://doi.org/10.1038/s41598-018-22939-w

Markides, C. (2006). Disruptive innovation: In need of better theory. *Journal of Product Innovation Management*, *23*(1), 19–25.

Matsumoto, M., Yang, S., Martinsen, K., & Kainuma, Y. (2016). Trends and research challenges in remanufacturing. *International Journal of Precision Engineering and Manufacturing-Green Technology*, *3*(1), 129–142. https://doi.org/10.1007/s40684-016-0016-4

McDonough, W., & Braungart, M. (2010). *Cradle to cradle: Remaking the way we make things*. North point press.

McKinsey Report_Disruptive-forces-in-the-industrial-sectors. (n.d.). Retrieved 15 December 2021, from https://www.mckinsey.com/~/media/mckinsey/industries/automotive%20and%20assembly/our%20insights/how%20industrial%20companies%20can%20respond%20to%20disruptive%20forces/disruptive-forces-in-the-industrial-sectors.ashx

Morgan, D. L. (2019). Commentary—After Triangulation, What Next? *Journal of Mixed Methods Research*, *13*(1), 6–11. https://doi.org/10.1177/1558689818780596

NetPlus®—Patagonia. (n.d.). Retrieved 19 October 2021, from https://eu.patagonia.com/pt/en/netplus/

Niaki, M. K., Torabi, S. A., & Nonino, F. (2019). Why manufacturers adopt additive manufacturing technologies: The role of sustainability. *Journal of Cleaner Production*, *222*, 381–392. https://doi.org/10.1016/j.jclepro.2019.03.019

Nofir. (2021). *Our process*. Nofir. https://nofir.no/en/our-process/

Olive Ridley Project. (n.d.). Retrieved 18 October 2021, from https://oliveridleyproject.org/wp-content/uploads/2017/03/ORP-News_March-2017_3.pdf

Pagani, M., & Pardo, C. (2017). The impact of digital technology on relationships in a business network. *Industrial Marketing Management*, *67*, 185–192. https://doi.org/10.1016/j.indmarman.2017.08.009

Patton, M. Q. (2014). *Qualitative research & evaluation methods: Integrating theory and practice*. Sage publications.

Peng, L., Fu, D., Qi, H., Lan, C. Q., Yu, H., & Ge, C. (2020). Micro- and nano-plastics in marine environment: Source, distribution and threats — A review. *Science of The Total Environment*, *698*, 134254. https://doi.org/10.1016/j.scitotenv.2019.134254

Petrossian, G. A. (2019). *The last fish swimming: The global crime of illegal fishing*. ABC-CLIO.

Plastix. (2021). How we do it. *Plastix*. https://plastixglobal.com/howwedoit/

Rädiker, S., & Kuckartz, U. (2020). *Focused Analysis of Qualitative Interviews with MAXQDA* (1st ed.). MAXQDA Press. https://doi.org/10.36192/978-3-948768072

Rejeski, D., Zhao, F., & Huang, Y. (2018). Research needs and recommendations on environmental implications of additive manufacturing. *Additive Manufacturing*, *19*, 21–28. https://doi.org/10.1016/j.addma.2017.10.019

Ritchie, H., & Roser, M. (2021). Biodiversity. *Our World in Data*. https://ourworldindata.org/fish-and-overfishing

Sala, E., Mayorga, J., Bradley, D., Cabral, R. B., Atwood, T. B., Auber, A., Cheung, W., Costello, C., Ferretti, F., Friedlander, A. M., Gaines, S. D., Garilao, C., Goodell, W., Halpern, B. S., Hinson, A., Kaschner, K., Kesner-Reyes, K., Leprieur, F., McGowan, J., … Lubchenco, J. (2021). Protecting the global ocean for biodiversity, food and climate. *Nature*, *592*(7854), 397–402. https://doi.org/10.1038/s41586-021-03371-z

Savolainen, J., & Collan, M. (2020). How Additive Manufacturing Technology Changes Business Models? – Review of Literature. *Additive Manufacturing*, *32*, 101070. https://doi.org/10.1016/j.addma.2020.101070

SEASPIRACY DOCUMENTARY. (2021). SEASPIRACY. https://www.seaspiracy.org

Singh, N., Hui, D., Singh, R., Ahuja, I. P. S., Feo, L., & Fraternali, F. (2017). Recycling of plastic solid waste: A state of art review and future applications. *Composites Part B: Engineering*, *115*, 409–422. https://doi.org/10.1016/j.compositesb.2016.09.013

Srai, J. S., Kumar, M., Graham, G., Phillips, W., Tooze, J., Ford, S., Beecher, P., Raj, B., Gregory, M., Tiwari, M. K., Ravi, B., Neely, A., Shankar, R., Charnley, F., & Tiwari, A. (2016). Distributed manufacturing: Scope, challenges and opportunities. *International Journal of Production Research*, *54*(23), 6917–6935. https://doi.org/10.1080/00207543.2016.1192302

Stake, R. E. (1995). *The art of case study research*. sage.

The Ocean Cleanup. (2021). *About Us*. The Ocean Cleanup. https://theoceancleanup.com/about/

UNEP, P. J. K. (Main. (2016). *Marine plastic debris and microplastics—Global lessons and research to inspire action and guide policy change*. https://doi.org/10.13140/RG.2.2.30493.51687

United Nations, SDG. (n.d.). *Goal 14 | Department of Economic and Social Affairs*. Retrieved 15 September 2021, from https://sdgs.un.org/goals/goal14

Unruh, G. (2010). *Earth, Inc.: Using nature's rules to build sustainable profits*. Harvard Business Press.

Unruh, G. C. (2008). The biosphere rules. *Harvard Business Review*, *86*(2), 111–117.

van Buren, N., Demmers, M., van der Heijden, R., & Witlox, F. (2016). Towards a Circular Economy: The Role of Dutch Logistics Industries and Governments. *Sustainability*, *8*(7), 647. https://doi.org/10.3390/su8070647

Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Qi Dong, J., Fabian, N., & Haenlein, M. (2021). Digital transformation: A multidisciplinary reflection and research agenda. *Journal of Business Research*, *122*, 889–901. https://doi.org/10.1016/j.jbusres.2019.09.022

WEF_The_New_Plastics_Economy. (n.d.). Retrieved 13 October 2021, from https://www3.weforum.org/docs/WEF_The_New_Plastics_Economy.pdf

Woern, A. L., McCaslin, J. R., Pringle, A. M., & Pearce, J. M. (2018). RepRapable Recyclebot: Open source 3-D printable extruder for converting plastic to 3-D printing filament. *HardwareX*, *4*, e00026. https://doi.org/10.1016/j.ohx.2018.e00026

Wohler's Associates. (2019). *Wohlers Associates Publishes 23rd Edition of Its 3D Printing and Additive Manufacturing Industry Report | Wohlers Associates*. http://wohlersassociates.com/press77.html

WWFintl_ghost_gear_report. (n.d.). Retrieved 13 October 2021, from https://wwfint.awsassets.panda.org/downloads/wwfintl_ghost_gear_report_1.pdf

Zhong, S., & Pearce, J. M. (2018). Tightening the loop on the circular economy: Coupled distributed recycling and manufacturing with recyclebot and RepRap 3-D printing. *Resources, Conservation and Recycling*, *128*, 48–58. https://doi.org/10.1016/j.resconrec.2017.09.023

Appendices

Appendix 1

Sustainable Development Goals targets related to marine litter. (adapted from Source (UNEP, 2016; Issifu & Sumaila, 2020))

SDGs Target Index	SDG Targets Linked to Marine Debris
6.3	By 2030, the quantity of untreated wastewater should be halved.
11.6. 1	By 2030, minimize the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.
12.1	Implement the 10-year framework of programme on sustainable production and consumption of all countries acting, with advanced economies taking the lead, considering the development and capabilities of developing economies.
12.2	By 2030, achieve the sustainable management and efficient use of natural resources.
12.4	By 2020, achieve the environmentally sound management of chemicals and wastes throughout their life cycle. In accordance with agreed international frameworks and significantly reduce their release to air, water and soil in order to reduce their adverse impacts on human health and the environment.
12.5	By 2030, substantially minimize waste generation through prevention, reduction, recycling and reuse.
12.b	Develop and implement tools to monitor sustainable development impacts for sustainable tourism that create jobs and promote local culture and products.
14.1	By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based sources, including marine debris and nutrient pollution.
14.2	By 2020, sustainably managed and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience and act for their restoration in order to achieve healthy and productive oceans.
14.7	By 2030, increase the economic benefits to Small Island Developing States and least developed economies from the sustainable use of marine resource, including through sustainable management of fisheries, aquaculture and tourism.
14.a	Increase scientific knowledge, develop research capacity and transfer marine technology, considering the intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine technology, in order to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing economies, in particular Small Island Developing States and least developed economies.
14.c	Enhance the conservation and sustainable use of oceans and their resources by implementing international law as reflected in UNCLOS, which provides the legal framework for the conservation and sustainable use of oceans and their resources, as recalled in paragraph 158 of The Future We Want.
15.5	Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species.

Appendix 2

The most significant quantifiable responses collected during the interviews are summarized here, specifying each respondent's role. Topics beyond these five main variables were also raised in each interview, but because they were not widely discussed, they are not displayed in this presentation. However, these findings are used within the thesis when appropriate. The same accounts for the given feedback and input about the circular designed subscription model.

Full transcript or audio can be provided upon request.

The table has a color scheme that facilitates an intuitive visual representation of the trend and tendency for each response (green – positive, orange – neutral, red – negative)

		Block A - Industry of Expertise		Block B - Ocean Plastic		
Name	Role	Current efforts impacting/contributing to industry?	Biggest Hurdles/Accelerators in the Industry	How to tackle or improve the Ocean Plastic debris	To what extend, or how is recycling of ocean plastic done?	Ocean plastic contributing to global warming?
Uwe Liechtenstein	Scientist at the Thünen Institute, Researcher and Engineer for fishing technology	Simulation of dynamic flow of nets, circular design certification and standardization studies, image recognition project, dolly rope suspension project, research on trawling and aquaculture	Policy, Regulations, Funding, Capacity, Material supply, Education / R&D, Scaling of Solution, Cross-industry connections, industry competition	Big problem dolly ropes - research efforts to suspension of those. New net design. Less material mix (crucial), consumer awareness	The Ocean CleanUp, Plastix, Nofir, Aquafill, WWF, Ghost divers	Consumer awareness, more data and education needed on CO2 emissions, plastic damaging environment as CO2 storage
Prof. Martin Charter	Director, The Centre for Sustainable Design®, University for the Creative Arts (UCA) Advisory board GGGI	Research focused on product sustainability and sustainable innovation, Member of BSI Circular Economy steering board and was past chairman of ISO 14006 (eco-design management systems) and previous UK expert to both ISO and BSI groups on ISO TR 14062 (eco-design).	Capacity, Scaling of Solution, Cross-Industry connections, Material supply, Politics, / Policy (EPR), Funding, / Education, Industry competition	New eco-net design, more circular approach needed, tracking and general measurement of ocean plastic, EPR scheme, Circular design and material supplier Bureo, GGGI	G20 is aware, but not general approach, EPR scheme, standardization and certification needed, a lot of pilot projects - Plastix, Nofir, Aquafill (Econyl - 20m investment just recently), Circular design and material supplier Bureo,	Gear manufacturers no environmental considerations
Dr. Andrea Stolte	Lead WWF Germany Ghost gear initiative (NGO)	WWF Germany Ghost gear initiative projects for salvage and searching for the nets, and collect old discarded nets	Policy (EPR), Regulations, Capacity, Material supply, Education, Insurance, R&D, Scaling of Solution / Funding / Cross-industry connections, industry competition, hazardous lead in sink lines	WWF Ghost Gear initiative, many divers for salvage and search of Ghost gear, sonar technology, tracking could help, innovative net design, EPR if done right,	The Ocean CleanUp, Plastix, Nofir, Aquafill, WWF, Ghost divers, Bracenet, Fishy Filaments, EcoAlf, very important to differentiate between different recycling processes	Microplastics everywhere, but not sure how that impacts CO2, they distribute different species worldwide, from microorganisms to bacteria to pathogenic germs
Ben Kneppers	Co-founders and CEO of Bureo Advisory board GGGI	Focus on running a supply chain across South America to collect and recycle end-of-life fishing nets with the company Bureo	Policy, Regulations, Capacity, Material supply, Education, Scaling of Solution / R&D / Cross-industry connections, industry competition	Collect, recycle , educating and giving the right incentives for fishers, plus infrastructure, direct partnerships, premium payment for end-of-life gear, full trackability and transparency	Bureo + Patagonia partnership,	recycled material has lower carbon footprints than virgin plastics sourced directly from oil, 100 percent end-of-life fishing nets with quality of virgin plastic.
Joel Baziuk	Associate Director of the Global Ghost Gear Initiative	Alliance dedicated to tackling the objectives of the problem of lost, abandoned fishing gear around the world. focus across prevention, mitigation and remediation strategies and look to build evidence to find best practices in foreign policy and then catalysing replicate solutions	industry competition, Regulations (removal permits), Capacity, Material supply, Education, Insurance, Scaling of Solution, shipping of equipment / Funding (slowly starting to increase), Policy (ERP, G7 acknowledged pollution issue) / Cross-industry connections, R&D	prevention, mitigation and remediation strategies and look to build evidence to find best practices in foreign policy and then catalysing replicate solutions, Education of fishers, return infrastructure, logistics needed	GGGI projects in Indonesia, in the Pacific Northwest of the United States, in the Gulf of Maine, in. Vanuatu in the Caribbean and in a few other places around and around the world, best practice framework, Pescara Azul out of Norway	entangle marine megafauna like whales impacting plankton and CO2 etc., production of virgin plastics major source of carbon in the atmosphere, burning fossil fuels
Dr. Felix Wunner, Focus Group	Manager at Accenture, lead for additive manufacturing in the ASGR	We focus on additive manufacturing, we are trying everything that Accenture can do in the area of digital, from digital strategy, digital transformation, to digital twin, digital threat, value chain, shop floor. From Accenture leadership to scaling and then distributive manufacturing	R&D, Education, strong industry competition, Funding Capacity, Scaling of Solution / / Cross-industry connections	recycling and stop or reduce at leas input of pollution	Bureo + Patagonia partnership, own company called FiveOcean	Catalysis of oil based plastic production a lot of CO2 emissions, less fish and plankton less CO2 bonding, Not sure about seabed as CO2 storage
Tobias Nickl	Additive manufacturing, distributive manufacturing @Accenture	ibid	Funding / / Capacity, Scaling of Solution			
Handan Özgöcen	Analyst @Accenture, M.Sc. Mechanical Eng. - Carbon Capture@Climeworks	ibid	Policy, Regulations / Funding / Cross-industry connections, R&D (in regards to CO2 emissions)	Malaysia, Indonesia, etc. will be much higher after China will keep producing unless forced		So in the long term, no matter how efficient the whole cycle is, it has a lot of CO2, virgin plastic production

	Block C - Innovations/Disruptors			Opinion on CE recycling model		
Name	Circular Economy Examples	What innovative technology could disrupt your industry	Your industry in 5 years	Opinion on CE recycling model	Technological implementation	other comments
Uwe Liechtenstein	deposit bottle system in Germany, so if you really have a bottle reuse glass bottles,	Tracking & Labelling, AM, AI for fish predictions, Image recognition	Innovative fishing gear for less CO2 emission and higher efficiency	positive - the trend is going in the direction of a deposit system or return system, argument of financial incentive	*hesitant*	*tracking of net is really good and relevant, material purity important*
Prof. Martin Charter	Bureo + Patagonia, fishing gear in Sweden. They are starting a project looking at the circular design of fishing gear, but it's very early stages, ISO TC323, blue circular economy project	AM, 3D scanner for better design, modular design, CAD software ecological simulations and circular design options	Regulations will extend, entrepreneurs moving in, more innovations in terms of circular design and sustainability efforts	positive - that's good what you're doing, problematic with fishers, community rather conservative	*hesitant*	you're making good progress and you sound like you've highlighted a number of key issues already with your concept, but fishers are resistant to changes!!
Dr. Andrea Stolte	Plastix recycling of nets, EcoAlf in Spain, and Aquafill, but only upcycling into clothes or furniture so far, PET bottles recycling.	The sensor technologies for monitoring, innovative net design, new recycling methods	Hopefully better ways for salvages, no or almost no lost gear, better return infrastructure and design of nets, ideally less fish consumption even maybe	positive - interesting, but important to have well designed collection point system, fishing culture can be a problem,	*hesitant*	*Recycling needs further research, technical feasibility studies with research institutes advised.*
Ben Kneppers	Bureo + Patagonia	Potentially Additive Manufacturing but more research needed, not really interested in innovation such as AI or robotics in terms of labour, but for tracking and transparency yes	Scaling our solution to offer a solution to every fisher in need	positive - will take time to implement and difficult to convince fishers	*hesitant*	*be careful with the recycling process, material purity is key*
Joel Baziuk	Ocean Legacy is working on that	Predicative modelling with AI to find out where nets could be located, software and systems for tracking etc., innovations like "rope less gear", vessel and fishing techniques e.g. rescue buoy unit for traps in Norway,	Mindshift towards sustainable thinking will hopefully happen globally	positive - makes sense to tackle with such an approach, but depends on location etc. Collection costs/benefits	*hesitant*	*very good idea, dezentralised hubs is great if done correctly, AM good*
Dr. Felix Wunner, Focus Group	circular economy is great in principle and unfortunately they still work far too little, Bureo		Engineering towards generic design. individualize IoT-based user data, set up the entire shop floor so that your MES or MRP systems	positive - question of AM implementation - more arguments needed, and how to convince fishing culture	*hesitant*	*Costs of R&D of AM can be high, start collecting funding early*
Tobias Nickl		distributive manufacturing: extreme production capacities. You need less space, less electricity, smaller shop floors and can build something there and don't need large		positive - good, but AM will need further research	*hesitant*	
Handan Özgöcen				positive - good approach	*hesitant*	

Appendix 3

(Global Ghost Gear Initiative, 2021) - BEST PRACTICE FRAMEWORK FOR THE MANAGEMENT OF FISHING GEAR

(Graphics with an overview of fishing gear and risk analysis)

Based on the above, the following gear classes are included in the Framework:

Gear class	Examples of gear types
Gillnets	Includes fixed, drifting and other tangling nets, including trammel nets
Fish aggregating devices	Anchored and drifting FADs
Traps and pots	All traps, pots and other static fish traps
Longlines	Includes drifting, bottom and pelagic set longlines
Bottom trawls	Single, pair, twin and beam trawls for finfish and shrimp; also includes Danish, Scottish and other fly seines
Hooks and lines	Includes hand lines, pole and line, trolling and jigging (both mechanized and by hand)
Mid-water trawls	Single or pair mid-water trawls, mainly targeting small pelagic species
Seine nets	Includes purse seines, ring nets and beach seines

It should be noted that we have also included fish aggregating devices (FADs) in this analysis. FADs are gear used to aggregate fishes and increase catch per unit effort. They are always used in conjunction with another gear type (e.g., seine nets or hooks and lines) and are often lost or abandoned at sea (more details on this can be found in the FAD section starting on page 13 of this document). Excluded are dredges and other large mechanical devices, as these are not easily lost, are readily recovered and not considered to be involved in ghost fishing. The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) Working Group on sea-based sources of marine litter (WG 43) is building an understanding of sea-based sources of marine litter, in particular from the shipping and fishing sectors, including the relative contribution of different sources, analysis of plastic use and management within both industries and the range and extent of impacts from sea-based sources of marine litter. In developing the C-BPF, the risk analysis evaluated dominant fishing gears based on (i) the likelihood of being abandoned, lost or discarded and (ii) the impact on aquatic life and habitats if lost.

2.2 RISK ANALYSIS OF ALDFG BY GEAR TYPE

To develop best practices, it's important to understand which types of gear are most likely to become ALDFG, and what their potential impacts are in the environment. We evaluated all the main gear types and assigned subjective risk scores based on the best available information currently available. The two attributes are:

1. **Likelihood of loss:** Considers the likelihood of each gear type being abandoned, lost or discarded in the first place.
2. **Impact once lost:** Considers the impact of abandoned, lost or discarded gear on aquatic life and the environment more generally. This includes likelihood of ghost fishing, the risk of entanglement with aquatic mammals, reptiles and birds as well as possible habitat damage. It also considers where the disintegration and abrasion of plastic elements of the gear might lead to microplastic production.

VERY LOW	LOW	MEDIUM	HIGH	VERY HIGH
1	2	3	4	5

The risk element is scored out of 5, and both likelihood and impact are color-coded as shown above.

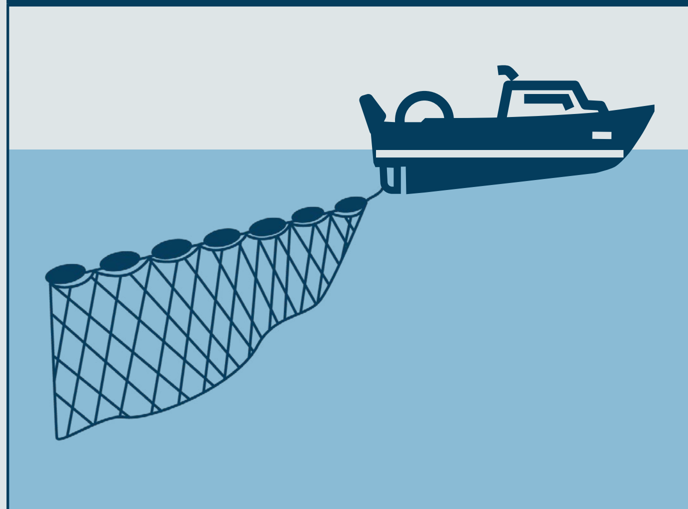
The ranking applied to each gear type indicates a sense of the relative risk (likelihood and impact) from these different gear types. The process by which these risks are assigned are empirical, based on an extensive literature review (see Appendix A for full bibliography), as well as expert knowledge. However, it is fully appreciated that both the likelihood of ALDFG—and the impacts these may have—are highly context specific, potentially varying significantly by fishery, fisheries management practices, geography, etc. This guide is intended as a starting point for establishing best practices to deal with the relative risks of each gear type based on the analysis of each below.

For more information on assessing the risk and impact of ALDFG, and in particular its contribution to marine plastics and microplastics, see GESAMP (2020)[7] and Gilman *et al,* 2021.

[7] Proceedings of the GESAMP International Workshop on Assessing the Risks associated with Plastics and Microplastics in the Marine Environment (see Appendix A for full citation and link).

Photo credit: Eleanor Church—Lark Rise Pictures

2.2.1 GILLNETS



DESCRIPTION

Gillnets are single walls of netting which can either be fixed or allowed to drift (pictured). They catch fish by enmeshing or entangling them usually around their gill covers. *Trammel nets* are a variant of gillnets that consist of three parallel panels of nets with different mesh sizes which can be used to catch a much wider variety of species. *Entangling nets* are usually set on the seabed and have large meshes to capture shellfish and large whitefish such as monk, ray and turbot (also known as ray nets).

TYPICAL FISHERIES IN WHICH GEAR IS USED

Gillnets are widely used in both artisanal and small-scale commercial fisheries worldwide. It is an effective fishing method, suited to a wide range of waters, and gillnets are generally cheap and easy to buy and repair. Gillnets mainly target demersal and epipelagic finfish but are also used for small pelagic species and tuna. They can be set on the surface, midwater or on the bottom.

GEOGRAPHIC DISTRIBUTION OF USE

Gillnets are widely used in both temperate and tropical waters. They are particularly popular in NE European waters, much of Africa and the Middle East and south-east Asia. They are also a common gear for use in estuarine, river or lake fisheries worldwide.

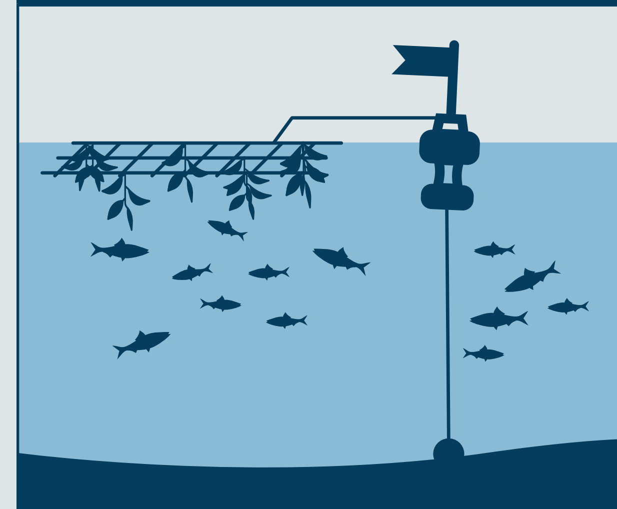
CONTRIBUTION TO ALDFG AND GHOST FISHING

Susceptibility to loss: Gillnets can have high rates of loss, particularly in mixed fisheries areas where gear conflicts (especially with mobile gear) are more likely. In Northern Australia's EEZ, Indonesian and Australian fishers identified the snagging of nets (78%) and gear conflicts (19%) as the main causes of gear loss (Richardson *et al,* 2018). Many gillnets are set in areas with strong tidal or other currents and are thus susceptible to accidental loss. As gillnet panels are relatively cheap, there is less incentive to recover lost or abandoned gear, and their deliberate discarding at sea (either due to lack of storage space or heavy damage) is not infrequent.

Impact of ALDFG: Abandoned, lost or discarded gillnets can continue to fish before the net breaks down and buoyancy is lost. As they are often made of light material, e.g., monofilament netting, they are not easily seen by fish and other aquatic animals and will often re-suspend in different current conditions. With a wide range of mesh sizes and structures, the risk of entanglement with aquatic animals and seabirds is high. Gillnets will eventually accrete to the substrate. While this may reduce entanglement and subsequent mortality of aquatic life, it does not eliminate species impacts. Nets on the seafloor can continue to ghost fish for the life of the material's structural viability; however, the species that are impacted may be different than those that were impacted when the net was buoyant and suspended in the water column (i.e., a shift from impacts on pelagic to benthic species).

LIKELIHOOD (OF 5): 5	IMPACT (OF 5): 5

2.2.2 FISH AGGREGATING DEVICES (FADS)



DESCRIPTION

A fish aggregating device (FAD) is a man-made object used to attract fish. They are then fished using purse seines or, in coastal waters, hand lines. They are either anchored to a fixed location (aFADs) or drifting (dFADs) and are tracked by locator beacons. FADs use a combination of natural, e.g., palm fronds, and artificial, e.g., netting materials, to extend their presence. aFADs are anchored to a fixed location and have an underwater structure of a mooring line and "streamers" typically made from rope or shade cloth that attract fish. The surface end of the mooring line is attached to buoys of various configurations to provide buoyancy.

TYPICAL FISHERIES IN WHICH GEAR IS USED

The main users of dFADs are the tropical tuna fisheries targeting pelagic tuna such as yellowfin, bigeye and skipjack tuna. Coastal aFADs are often used to encourage smaller-scale fishers to move outside the reefs, and will mostly target neritic tunas, jacks and mahi mahi.

GEOGRAPHIC DISTRIBUTION OF USE

FADs are mainly found in tropical regions. dFADs are used extensively in the Atlantic, Indian and Pacific Ocean pelagic tuna fisheries. Coastal aFADs are used by many small island and archipelagic states in particular, but are also used in other tropical coastal waters, usually in a depth between 50 to 1,000 meters, although some may be deeper.

CONTRIBUTION TO ALDFG AND GHOST FISHING

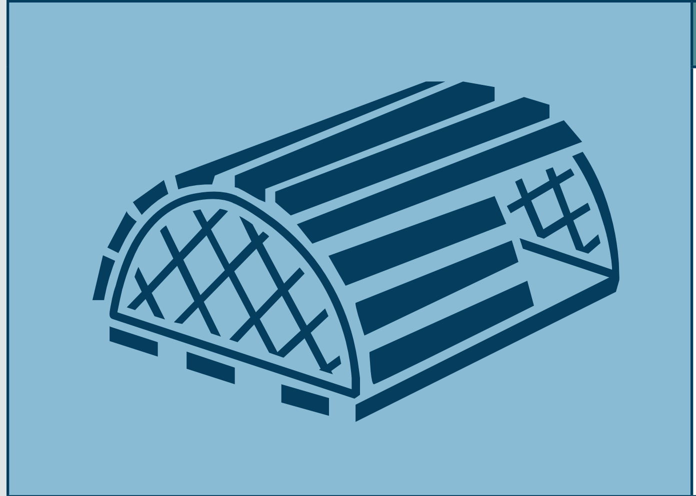
Susceptibility to loss: FAD loss has become an increasingly important issue. While drifting FADs represent a considerable investment, losses can occur due to dFADs sinking, locator beacon failure or deliberate abandonment when they drift beyond a cost-effective distance from main fishing areas (Richardson *et al,* 2017). Anchored FADs are also prone to loss, mainly due to mooring failure, and are less easy to recover as they are not generally equipped with location equipment.

Impact of ALDFG: The main impact for abandoned, lost or discarded FADs (and indeed some FADs still under the control of fishers) is from entanglement with FAD netting, with sharks and, to a lesser extent, aquatic turtles which are particularly vulnerable (Filmalter *et al,* 2013). Non-entangling netting under dFADs has been proposed as a solution, but this netting can become entangling when it is damaged during beaching or colliding with a reef. Until 100% biodegradable and non-entangling designs are available (ISSF, 2019) and broadly applied by purse seine fisheries, abandoned, lost or discarded FADs will continue to pose a large ghost fishing risk, significantly contribute to aquatic pollution, and continue to cause significant damage to sensitive aquatic environments such as coral reefs when they drift ashore. It should be noted that many tuna purse seine fleets are now being required by RFMOs to switch to non-entangling FADs.

aFADs typically pose a reduced risk of entanglement and pollution than dFADs. This is largely because the lengths of purse seine netting that are typically attached to dFADs would cause too much drag in currents and strain the mooring lines used by aFADs. As a result, aFADs typically use "streamers" made of rope and strips or relatively small panels of small mesh shade cloth as aggregators.

LIKELIHOOD (OF 5): 5	IMPACT (OF 5): 4

2.2.3 TRAPS AND POTS



DESCRIPTION

Traps and pots[1] are a collective term for structures into which fish or shellfish are guided or enticed through funnels that encourage entry but limit escape. These include pots, creels, cuttlefish pots, fish traps, etc. For the purpose of this report, they also include fixed gears such as fyke and stake nets. Pots can be made of natural materials like bamboo, as well as plastic and metal.

Traps are normally laid in strings connected by ropes and marked with buoys at each end of the string.

TYPICAL FISHERIES IN WHICH GEAR IS USED

Traps and pots are used in a wide variety of crustacean and finfish fisheries. For crustacean fisheries, traps or parlour type pots are particularly popular to catch lobster, crab and nephrops. Traps can also be used to catch finfish, e.g., the Seychelles *cordonnier* (rabbitfish) fishery. Most pots are baited.

GEOGRAPHIC DISTRIBUTION OF USE

Traps and pots are usually used in shallow coastal waters, as well as in the margins of rivers and lakes. The use of pots in temperate waters is mainly targeted at crustacean fisheries, while warmer waters tend to have a more mixed crustacean (e.g., spiny lobster/swimming crab) or finfish use.

CONTRIBUTION TO ALDFG AND GHOST FISHING

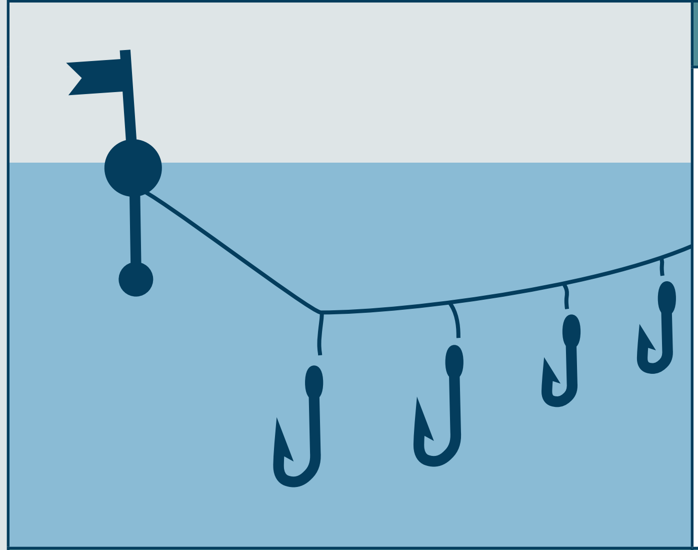
Susceptibility to loss: Like gillnets, the loss of traps and pots is often linked to conflict with towed gears, as well as with other inshore water vessels and even large aquatic mammals. They are also particularly susceptible to theft and accidental loss through storms and other events. The increased use of GPS and other navigational devices, even by smaller vessels, has reduced the incidence of accidental trap loss. Longer pot strings may be easier to recover, while individual pots may be less so.

Impact of ALDFG: Pots and traps also tend to pass through a progressive process of ghost fishing. As they are usually baited when they are set, if the pot is lost, over time the bait or lost catch attracts scavengers. These scavengers may become entrapped and subsequently die, forming new bait for other scavengers. Entrapped animals may escape over time. Animals captured in abandoned, lost or discarded traps die from starvation, cannibalism, infection, disease, or prolonged exposure to poor water quality (i.e., low dissolved oxygen). A key point is that catching efficiency depends on gear design, species behavior and seasonality. A second key risk of this gear is entanglement of large aquatic mammals with connecting ropes and lines, which can occur both when the gear is under control or is abandoned, lost or discarded.

LIKELIHOOD (OF 5): 4	IMPACT (OF 5): 4

[1] There does not seem to be any definitive difference between "pots" and "traps" and the two terms are used interchangeably in most literature.

2.2.4 LONGLINES



DESCRIPTION

Longlining can be used to target both pelagic and demersal fish with the lines being rigged and set at a position in the water column to suit the particular species. A basic longline consists of a long length of line made of light rope or, more commonly, heavy nylon monofilament; this "main line" can be many miles in length depending on the fishery. To this main line, multiple branch lines with baited hooks (snoods) are attached at regular intervals. This rig is set either on the seabed (demersal) or in midwater (pelagic) with a buoy at either end and allowed to fish for a set period.

TYPICAL FISHERIES IN WHICH GEAR IS USED

Longlines are used extensively, both on the surface (usually targeting large pelagic species such as tunas and billfish) and on the bottom, targeting high value demersal species.

GEOGRAPHIC DISTRIBUTION OF USE

Longlines are used in a wide variety of locations. Their use in temperate waters tends to be focused on demersal fish such as cod but can also be used in the water column for species such as halibut. In tropical waters longlines are commonly used to catch tuna, as well as bottom species like snappers and groupers.

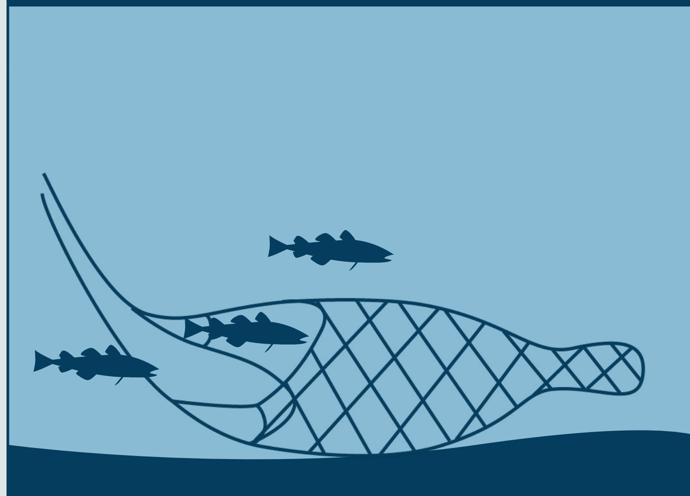
CONTRIBUTION TO ALDFG AND GHOST FISHING

Susceptibility to loss: One of the main problems with longlines is how easily they can snag on the seabed and break away from the vessel. The extensive use of longlines, their often extremely long-set configuration, and relatively low cost means that the overall quantity of longlines lost is likely to be high. But figures to substantiate this are few and far between. There could be some deliberate gear discarding when tangled or damaged, particularly if there is not adequate space on the vessel to return the damaged gear for disposal.

Impact of ALDFG: The mortality rate from lost demersal longlines is usually low, as is associated habitat damage (Pham *et al,* 2014). Such lost gear may persist in the environment, however, when it is constructed of monofilament. Ghost fishing mortality is a function of the gear type, the operation and the location in regard to active ocean features and elements. Lost longline gear may continue to catch fish as long as bait exists on the hooks. Fish caught on the hooks may themselves become a form of bait for subsequent fish, both target and non-target, and longlines will not stop fishing until all of the hooks are bare. Baited hooks may also pose an ingestion risk to aquatic mammals, birds, turtles and other animals and the lines themselves pose an entanglement risk.

LIKELIHOOD (OF 5): 3	IMPACT (OF 5): 3

2.2.5 BOTTOM TRAWLS



DESCRIPTION

A bottom (or demersal) trawl with a wide tapering net ending with a cod-end where trapped fish collect. The net is predominately made from HDPE netting in various thicknesses. During construction the netting is lashed to the frame ropes (headline, footrope and wing lines) usually with a nylon (PA) twine.

Towed by a powered vessel using trawl warps, they often use doors or a heavy beam to maintain the net opening. Mainly used to capture demersal finfish or shrimp.

TYPICAL FISHERIES IN WHICH GEAR IS USED

Widely used by commercial whitefish, shrimp and nephrops fisheries in temperate waters. More associated with shrimp fisheries in tropical waters. Due to the need for powerful vessels, is generally conducted by commercial fisheries operating on the continental shelf.

GEOGRAPHIC DISTRIBUTION OF USE

Mainly the eastern seaboard of North America, shallow coastal waters of NE Europe, the NE and SE coasts of South America, West Africa, most coastal waters of SE Asia and Australia.

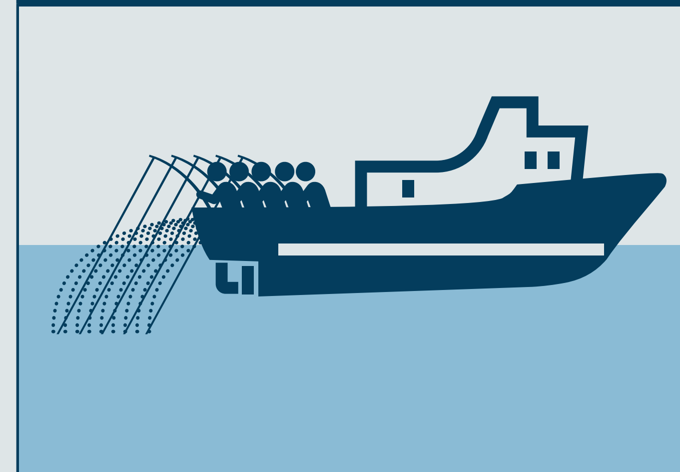
CONTRIBUTION TO ALDFG AND GHOST FISHING

Susceptibility to loss: Apart from the Norwegian, FANTARED and some Irish and United Kingdom surveys, there is little other reference in literature to the levels of loss of trawl nets and other mobile gear. Anecdotal information suggests that considerable effort is put into the immediate recovery of lost gears due to their high value, combined with improvements in navigation and gear marking technologies. However, it is apparent that some trawl nets are lost, possibly even in considerable volume. For example, three-quarters of fishing debris found on beaches on Cape York, Australia consists of trawl nets, and the majority (around 79%) of fishing debris is of southeast Asian manufacture. It is also likely that trawl warps are sometimes discarded at sea (Macfadyen *et al,* 2009).

Impact of ALDFG: The larger diameter synthetic multifilament twine common to trawl nets is the key factor that reduces ghost fishing mortality in lost trawl gear as it tends to weigh the net down, speeding the substrate aggregation process. However, this can increase the likelihood of entanglement with aquatic mammals, reptiles or birds. In dynamic areas such as tidal streams or even oceanic current gyres, abandoned, lost or discarded trawl nets may not accrete to the seabed and may cause more damage as they move around. In this case they may represent a potential navigation hazard or cause physical abrasion to the benthic substrate.

LIKELIHOOD (OF 5): 2	IMPACT (OF 5): 3

2.2.6 HOOKS AND LINES



DESCRIPTION

Handlines may be used with or without a pole or rod. For fishing in deep waters, the lines are usually operated using reels or frames on which to store the long length of line. The bait may be artificial or natural. ***Pole and line*** fishing (pictured) involves a number of crew equipped with a bamboo or fiberglass pole with a short, unbaited hook. This gear type includes ***jigging*** with lines, operated by hand and used in small boats. Trolling is a method of towing artificial lures to attract fish.

TYPICAL FISHERIES IN WHICH GEAR IS USED

Handlines are used to catch tunas as well as demersal species and are a common recreational fishing gear. Pole and line fishing (pictured) is commonly used for skipjack and other tunas. Jigging is used to catch both finfish and cephalopods, often in combination with lights.

GEOGRAPHIC DISTRIBUTION OF USE

Hooks and lines are used in a wide variety of locations. Their use in temperate waters tends to be focused on demersal fish such as cod but can also be used in the water column for species such as halibut. In tropical waters hand lines are commonly used to catch tuna, as well as bottom species like snappers and groupers.

CONTRIBUTION TO ALDFG AND GHOST FISHING

Susceptibility to loss: Hooks and sections of line can be lost through snagging with the bottom, the age-related brittleness of monofilament line, and when they are broken by large fish or other animals. Although abandoned, lost or discarded hooks and lines are generally small in size, their extensive use by both commercial and recreational fishers in often rocky and complex benthic environments means that the cumulative volume is likely to be considerable. A recent analysis found that 29%[1] of fishing lines used globally are lost (Richardson *et al,* 2019).

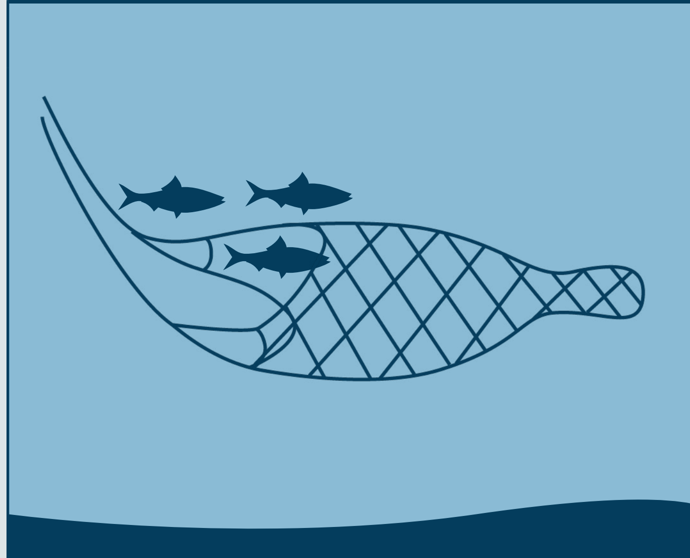
Impact of ALDFG: Hooks can become embedded in fish or other animal jaws, inhibiting feeding and causing local trauma that can lead to eventual mortality. Lines can become wrapped around both aquatic flora and fauna with subsequent entanglement. Both baited and unbaited hooks may also pose an ingestion risk to aquatic mammals, birds, turtles and other animals. Foraging birds—both seabirds and water birds such as swans—are at particular risk from both engorging hooks and becoming entangled in line.

This said, the potential for ghost fishing from lost hooks and lines is usually low. Such lost gear may persist in the environment as it usually consists of a monofilament line that will gradually break up and contribute to the microplastic load (Lusher *et al,* 2017).

LIKELIHOOD (OF 5): 3	IMPACT (OF 5): 2

[1] The overall loss was 29%. The predicted percentages of gear loss across the subcategories were 23% for handlines, 65% for pole-lines, and 20% for longlines. However the authors acknowledge that the available data and studies geographically over-represent North America and Europe from commercial fisheries.

2.2.7 MID-WATER TRAWLS



DESCRIPTION

A mid-water (or pelagic) trawl towed by one or two vessels using a set of midwater doors to open the net horizontally. The position within the water column is controlled by the speed of the vessel and the amount of weight on the wing ends.

TYPICAL FISHERIES IN WHICH GEAR IS USED

Mid-water trawls are usually used to target large schools of mainly small pelagic species such as anchovy, sardines, herring, mackerel, capelin, rock fish and Antarctic krill. Like bottom trawls they usually require powerful vessels and the large catch volumes require considerable on-board handling and storage space. As such they are mainly restricted to larger commercial operations.

GEOGRAPHIC DISTRIBUTION OF USE

Used extensively to target large volumes of small pelagic fish, either for direct human consumption or for reduction into fishmeal. They are used extensively around the world in polar, temperate and tropical waters.

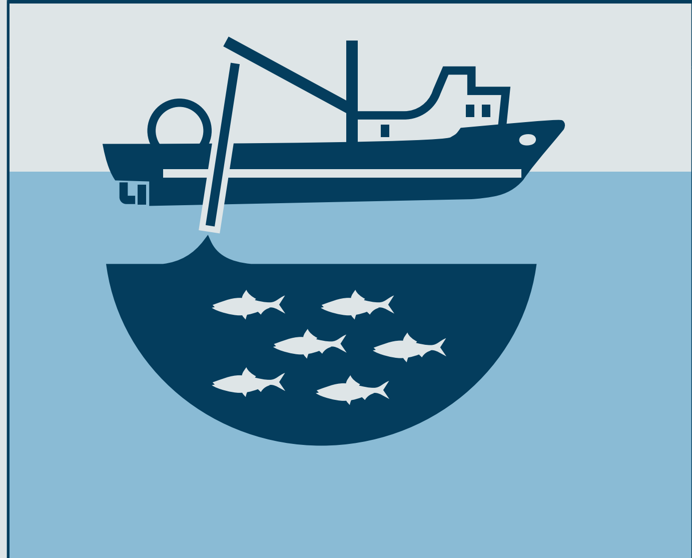
CONTRIBUTION TO ALDFG AND GHOST FISHING

Susceptibility to loss: As they are fished mid-water they seldom have contact with the bottom and thus gear loss is relatively infrequent. Usually being large and expensive sets of equipment, if lost, attempts will be made to recover the gear. Given the size of the gear, and the sophistication of the vessels involved, this is usually successful.

Impact of ALDFG: With a smaller mesh size than bottom trawls, these small pelagic fish targeting nets may capture fish, but being large and heavy are more likely to quickly accrete to the seabed. With a small mesh they are less likely to entangle aquatic animals, although other elements of the gear such as the warps and head/foot ropes may be problematic. They may cause damage to sensitive habitats if moved by currents, although will tend to be lost in deeper, possibly less biodiverse seabed areas.

LIKELIHOOD (OF 5): 1	IMPACT (OF 5): 2

2.2.8 SEINE NETS



DESCRIPTION

A ***purse seine*** (pictured) is large, surface-set net used to surround a shoal of pelagic fish, the bottom of which is then drawn together to enclose them. A ***ring net*** works in a similar manner and is usually operated by surrounding a shoal of pelagic fish with a wall of netting, often operated by two boats. ***Beach seines*** are used to encircle fish in shallow water, with the net being drawn together by fishers on a beach.

TYPICAL FISHERIES IN WHICH GEAR IS USED

Purse seines are used to capture both large and small pelagic fish. They are an important gear for fishing tuna (around 65% of tuna is caught this way[1]), often in association with FADs. These gears are also used for capturing small pelagic species such as anchovy and mackerel. Ring nets are typically used in shallower waters than purse seine nets, and they tend to capture smaller fish such as anchovy and chub mackerel.

GEOGRAPHIC DISTRIBUTION OF USE

Purse seines are commonly used for tuna fisheries in the Atlantic, Indian and Pacific Oceans. They are also an important gear for the large forage fisheries in the Pacific Ocean off South America. Ring nets are a common gear in coastal and archipelagic tropical waters, especially for neritic tunas and small pelagic species.

CONTRIBUTION TO ALDFG AND GHOST FISHING

Susceptibility to loss: As they are fished on the surface, purse seines and ring nets seldom have impact with the bottom and thus complete gear loss is highly unusual. Usually being large and expensive sets of equipment, if lost, attempts will be made to recover the gear. Given the size of the gear, the fact that it is floating, and the sophistication of the vessels involved, this is usually successful. There is potential for the loss of floats from purse seines, and while these are normally retrieved or washed up, their breakup may contribute to the microplastic load. For FADs, see page 13.

Impact of ALDFG: With a smaller mesh size than bottom trawls, those purses seines targeting small pelagic fish may capture fish but being large and heavy are more likely to quickly accrete to the seabed. With a small mesh they are less likely to entangle aquatic animals. They may cause damage to sensitive habitats if moved by currents, although will tend to be lost in deeper, possibly less biodiverse seabed areas. However, as mentioned above, abandoned, lost or discarded purse seines are very rare.

LIKELIHOOD (OF 5): 1	IMPACT (OF 5): 2

[1] Unpublished Poseidon analysis of tuna RFMO data in 2018

BACKGROUND AND SCOPE

2.2.9 SYNOPSIS

The analysis of fishing gear usage has examined two key elements: (i) the *extent of their global use;* and (ii) the *overall risk they pose* in terms of ghost fishing and other ALDFG impacts.

The review of global fishing gear use indicates that midwater and bottom trawls and seine nets account for the majority of fish catches by volume. When calculated by effort, the results are similar: trawls (both bottom and mid-water) are ranked highest, but hook and line (including longlines) and gillnets also rank highly. Traps and pots are relatively less used, but still globally significant, especially—but not exclusively—in small-scale fisheries. When considering the risk of ghost fishing, gillnets pose the highest risk, with FADs second, and traps and pots third.

The conclusion of this combined analysis is that it is worth considering all these gear types in the Best Practice Framework. Although seine nets and trawls have the lower risk of ghost fishing, the fact that they account for the highest volume of global catches means they need to be considered, especially as losses can be concentrated in relatively small areas. Conversely, while traps and pots and FADs account for lower volumes of fish capture, they have a relatively higher risk of ghost fishing, and therefore must also be considered.

The above analysis also shows that gear loss and consequential ghost fishing is a global phenomenon, and this must be reflected in the framework. Both gillnets and traps and pots—the two main fishing gears with a high risk of ghost fishing—are used both in temperate and tropical waters, although there will be an emphasis on shallower coastal waters where they are mainly deployed. Mid-water trawls and purse/ring seines are more often deployed in deeper pelagic waters, mainly by larger-scale fisheries, and this again needs consideration.

Using the likelihood and impact scoring multiplied together to produce a rudimentary risk assessment, gillnets pose the most risk of ghost fishing, FADs second, and traps and pots third. Hooks and lines, longlines, bottom and mid-water trawls and seine nets pose a relatively lower risk for ghost fishing, despite their extensive use worldwide.

GEAR CLASS	LIKELIHOOD	IMPACT	TOTAL RISK
Gillnets	5	5	25
Fish aggregating devices	5	4	20
Traps and pots	4	4	16
Longlines	3	3	9
Bottom trawls	2	3	6
Hooks and lines	3	2	6
Mid-water trawls	1	2	2
Seine nets	1	2	2

3 MANAGEMENT OPTIONS AND MECHANISMS FOR RESPONSIBLE FISHING GEAR USE

3.1 OPTIONS FOR PREVENTING, MITIGATING AND REMEDIATING ALDFG

3.1.1 PREVENTATIVE MEASURES

Preventative measures are the default preferred approach, in that they prevent ALDFG from getting into the aquatic environment in the first place.

SPATIAL AND/OR TEMPORAL MEASURES

The use of spatial and or temporal restrictions on fishing have considerable potential to reduce gear conflicts and to ensure that fishers reduce the risk of their gear interacting with vulnerable aquatic habitats or species. With the widespread use of GPS mapping, this is a practical and targeted approach. However, like most forms of management, the involvement of fishing practitioners and other stakeholders is critical in designating areas and identifying gear/time restrictions to both ensure that their professional and expert knowledge is included, and that the resulting measures are acceptable and that implementation is possible.

Marine spatial management is not a new concept but is gathering increasing acceptance worldwide. Maritime Spatial Planning (MSP) is an important component of the revised EU Common Fisheries Policy (CFP), as it enables a more strategic approach to fisheries management by providing opportunities to manage fishing effort and increase capture efficiency and the eventual value of seafood products. Spatial management provides the following benefits related to the use of fishing gear:

- Reduces the potential for gear conflict, especially between mobile and static fishing gear, and thus maximizing the economic potential of individual fisheries;
- Can provide protection of vulnerable aquatic habitats, where appropriate, with the designation of core and buffer areas;
- With a temporal element, can protect vulnerable seabirds and aquatic animals at periods when the potential for interaction is particularly high, e.g., parent seabirds foraging during the nesting season, spawning aggregations, and juvenile fish nursing periods; and,
- Provides opportunities for, and reduces the potential for conflict with, other sea uses, including recreational fishing, sailing and other marine-related activities.

As discussed above, local maritime spatial planning is necessarily a participatory process to improve both effectiveness and compliance levels. It can also be used to reduce gear conflicts and improve operational tenure, especially between commercial and small-scale fishing operations in coastal areas. While such approaches are generally part of a wider fisheries management regime, voluntary designations of spatial-temporal zoning measures are not uncommon.