GLOBAL GHOST GEAR INITIATIVE®

BEST PRACTICE FRAMEWORK

FOR THE MANAGEMENT OF AQUACULTURE GEAR

Ocean Conservancy®

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REPORT INFORMATION

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Oyster and shellfish farm, Ireland

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Aerial view of prawn farm with aerator pump in front of Khao Sam Roi Yot National Park, Thailand.

ACRONYMS USED

A-BPF	GGGI Best Practice Framework for the Management of Aquaculture Gear
AIP	Aquaculture Improvement Project
ALDFG	Abandoned, lost or otherwise discarded fishing gear
ASC	Aquaculture Stewardship Council
C-BPF	GGGI Best Practice Framework for the Management of Fishing Gear
EPS	Expanded polystyrene
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FRP	Fiber-reinforced plastics
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
GGGI	Global Ghost Gear Initiative®
GRP	Glass-reinforced plastic
HDPE	High-density polyethylene
LCA	Life cycle analysis
LDPE	Low-density polyethylene
LLDPE	Linear low-density polyethylene
MERRAC	Marine Environmental Emergency Preparedness and Response Regional Activity Centre
MSC	Marine Stewardship Council
Mt	Metric ton
NOWPAP	Northwest Pacific Action Plan
PA	Polyamide (nylon)
PC	Polycarbonate
PE	Polyethylene
PET	Polyethylene terephthalate (polyester)
PMMA	Polymethyl methacrylate (acrylic)
PP	Polypropylene
PRF	Port reception facilities
PS	Polystyrene
PVC	Polyvinyl chloride
RAS	Recirculated aquaculture system
ROV	Remotely operated vehicle
SOP	Standard operating procedure
SSPO	Scottish Salmon Producers Organisation
SUP	Single use plastics
UAV	Unmanned aerial vehicle (drone)
UHMwPE	Ultra-high molecular weight polyethylene
USD	United States Dollar

1 BACKGROUND AND PURPOSE

1.1 BACKGROUND

The Global Ghost Gear Initiative® (GGGI) is the foremost global alliance dedicated to tackling the problem of abandoned, lost and otherwise discarded fishing gear (ALDFG or "ghost gear") by building evidence about the extent of the problem; defining, informing and implementing practices and policies that prevent gear from getting lost; and catalyzing and replicating scalable solutions to recover gear around the world. Founded by World Animal Protection in 2015 and now hosted by Ocean Conservancy since 2019, the GGGI's strength lies in the diversity of its participants, including the fishing industry, the private sector, academia, governments, and intergovernmental and nongovernmental organizations.

Over the last decade, there has been considerable attention focused on the scale of ALDFG and the impacts on the aquatic environment by ALDFG through ghost fishing, entanglement and habitat damage (Macfadyen *et al.* 2009). This attention has been revitalized in recent years by the growing realization of the scale and potentially catastrophic impact of plastic pollution and its accumulation in aquatic ecosystems, and the contribution of ALDFG to this global problem. In 2017, the GGGI took a major step forward by producing its Best Practice Framework for the Management of Fishing Gear for wild capture fisheries (C-BPF)[1].

With the increasing awareness of the impact of plastics on aquatic environments, attention is also being focused on aquaculture. Plastics are used extensively in marine fish farming; for example, in cages (e.g., in the collars and nets themselves, as well as in feeding systems), in coastal fishponds (e.g., in pond liners), and in shellfish farming (e.g., in mussel socks, oyster spat collectors and mussel pegs). These plastics are susceptible to loss through extreme weather events, mismanagement of waste or deliberate discharge. Although global losses of plastics from aquaculture to the aquatic environment are probably lower in volume than from fishing (Huntington, 2019), aquaculture continues to grow worldwide, being the fastest growing food producing sector with an expected growth of 37% by 2030 over 2016 rates (FAO, 2020).

The GGGI therefore decided in 2020 to produce a Best Practice Framework for the Management of Aquaculture Gear (A-BPF), commissioning Tim Huntington of Poseidon Aquatic Resource Management Ltd. (Poseidon)—who drafted the original C-BPF—to lead its development.

1 See https://www.ghostgear.org/resources

1.2 STRUCTURE AND PURPOSE OF THIS BEST PRACTICE FRAMEWORK

This Best Practice Framework consists of two main parts:

1. **Overview and current status (Sections 1–4)** provides a description of how aquaculture can contribute to aquatic debris and describes "best practice" approaches to address this.

2. **The Best Practice Framework (Sections 5–7)** provides a structured, stakeholder-based framework for reducing aquaculture gear loss and aquatic debris, reusing and recycling aquaculture equipment and recovering lost aquaculture equipment or debris (broken down as prevention, mitigation and remediation).

The purpose of the A-BPF is to develop a framework for best practices for reducing the entry of debris and litter into the aquatic environment from aquaculture. The A-BPF is global in nature and covers a wide range of aquaculture operations and sector participants.

1.3 METHODOLOGY

In late 2019, Poseidon produced a short scoping report in preparation for the A-BPF. The scoping report was explicitly based on a recent white paper produced for the Aquaculture Stewardship Council (ASC)[2] that, for the first time, attempted to identify what plastics are used in different forms of aquaculture, the main causes for the loss of these plastics into the aquatic environment and the pathways by which the plastics arrive there. The purpose of the scoping report was to provide the GGGI with an understanding of how plastic and other materials leak into the aquatic environment from aquaculture, and then to propose an approach to, and scope of, the A-BPF.

Following confirmation of the scope (see next section) and overall structure, a draft A-BPF was prepared. Although the original intent was to develop this draft through an iterative process of drafting, stakeholder validation and refinements with involvement by stakeholders in different parts of the world, that approach was stymied by the onset of the

2 See https://www.asc-aqua.org/wp-content/uploads/2019/11/ASC_Marine-Litter-and-Aquaculture-Gear-November-2019.pdf

COVID-19 pandemic in 2020. As a result, a draft was prepared based on extensive literature reviews and one-to-one discussions with relevant stakeholders.

The draft A-BPF then underwent a rigorous stakeholder review and validation process by Ocean Outcomes (O2). This stakeholder consultation, finalized on 31 March 2021, included:

- Development of a targeted stakeholder outreach matrix with nearly 150 priority aquaculture stakeholders to provide input on aquaculture aquatic debris and sustainability issues.
- Development and implementation of a three-pronged engagement strategy consisting of a detailed document review, interview discussions and group webinars.
- Outreach to nearly 100 of those priority stakeholders across 20 countries to solicit participation in A-BPF consultation.
- Creation of 'personalized' versions of the A-BPF draft for roughly 50 stakeholders, 31 of whom provided feedback in written form.
- Interviews with 18 experts, individually or in small groups, to gather feedback on the A-BPF.
- Three group webinars with a total combined participation of 71 individuals.
- Collation of 33 review drafts into a single master A-BPF review document that included all substantive written feedback and comments from each consulted stakeholder.
- Higher level synthesis and recommendations based on feedback and comments from consulted stakeholders.

1.4 SCOPE OF THE BEST PRACTICE FRAMEWORK

The A-BPF is intended to be generic and wide ranging. While its initial use is likely to be from larger and well-established aquaculture businesses, the framework is also aimed at smaller aquaculture operations across a wide spectrum of production methods, scales and intensities around the world.

More details on the scope of the A-BPF are in Section 3.1.

Photo credit: Credit Eleanor Church—Lark Rise Pictures

2 OVERVIEW OF AQUACULTURE SYSTEMS

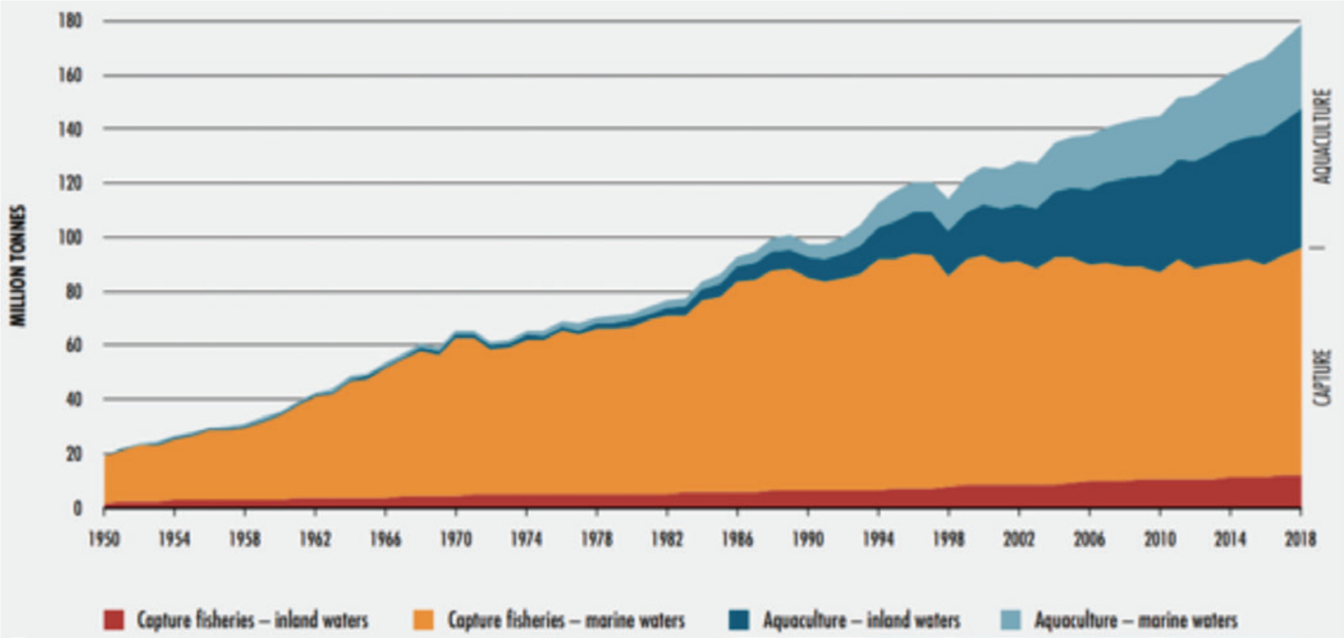
2.1 GLOBAL AQUACULTURE PRODUCTION

According to the United Nations Food and Agriculture Organization (FAO), aquaculture "is understood to mean the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated."[3] The term "mariculture" is sometimes used for aquaculture in aquatic environments.

Global fish production peaked at about 179 million tonnes in 2018, with aquaculture representing 46% of the total and 52% if non-food uses (including reduction to fishmeal and fish oil) are excluded (see **Figure 1** below).

[3] http://www.fao.org/fishery/statistics/global-aquaculture-production/en

FIGURE 1: WORLD CAPTURE FISHERIES AND AQUACULTURE PRODUCTION



Source: FAO, 2020. This figure excludes aquatic mammals, crocodiles, alligators and caimans, seaweeds and other aquatic plants.

Global aquaculture production (including aquatic plants) in 2018 was 114.5 million tonnes, with the first-sale value estimated at USD 263.6 billion (FAO, 2020). The total production included 82.1 million tonnes of food fish, 32.4 million tonnes of aquatic plants and 26 thousand tonnes of non-food products. Farmed food fish production included 54.3 million tonnes of finfish, 17.7 million tonnes of mollusks and 9.4 million tonnes of crustaceans. Farmed aquatic plants included mostly seaweeds and a much smaller production volume of microalgae.

Since 2000, world aquaculture no longer enjoys the high annual growth rates of the 1980s and 1990s (10.8% and 9.5%, respectively). Nevertheless, aquaculture continues to grow faster than other major food production sectors. Annual growth declined to a moderate 5.3% from 2008 to 2018, although double-digit growth still occurred in a small number of individual countries, particularly in Africa from 2006 to 2010.

2.2 CLASSIFICATION OF AQUACULTURE SYSTEMS

2.2.1 INFRASTRUCTURE TYPE

Given that aquaculture involves the farming of a wide range of species types (e.g., finfish, crustaceans, bivalves and seaweeds) in cold, temperate and warm waters, both in saltwater and freshwater, it is not surprising that multiple production systems are involved. Although there are established classification systems for different types of fishing gear, this is less clear cut for aquaculture. Classification systems for aquaculture have been approached in different ways, with most authorities classifying by the level of intensity (e.g., production biomass per cubic meter of water), from very extensive (<2 kg/m^3) to hyper-intensive (>20 kg/m^3) systems.

In 2006, an alternative classification approach was advocated based upon both the connectivity of the aquaculture system with the natural environment and the productivity intensity in order to help determine the impact of aquaculture on the environment. This alternative classification approach included open aquaculture systems (e.g., most shellfish aquaculture), partially-open aquaculture systems (e.g., pens/cages, ponds and flow-through tanks) and closed aquaculture systems (e.g., recirculated aquaculture systems (RAS)) (Huntington *et al.* 2006).

FAO currently uses a more system type-based approach for its statistics (FAO, 2017), aggregating aquaculture production systems into five different groups:

- Ponds.
- Cages, raceways, tanks, enclosures and pens.
- Lakes, reservoirs, dams, barrages, flood plains and irrigation systems.
- Rice-fish paddies (rice fields used for aquaculture).
- Suspended/hanging systems, on-bottom systems and off-bottom systems.

For the purpose of the A-BPF, we have classified aquaculture production into system types. See Table 1.

2.2.2 STAGES IN AQUACULTURE PRODUCTION

The majority of the world's aquaculture is now closed cycle (i.e., all life stages are contained and managed, although wild-caught juveniles are still used in some situations). Typically, there are the following stages:

- **Hatcheries:** Hatcheries are usually dedicated units for the reproduction and initial rearing of eggs and larvae. They will sometimes contain broodstock units where the parents are held and prepared for reproduction, as well as facilities for producing live feeds that form the diet of many early stage finfish and shellfish. Given that the biomass involved is small—millions of marine larvae can be reared in a relatively small area—hatcheries are usually compact in nature with high levels of monitoring and husbandry. Water quality is highly controlled, and most systems are highly contained to minimize the risks of disease and other sources of mortality.

TABLE 1: CLASSIFICATION OF AQUACULTURE SYSTEMS FOR THE A-BPF

System	Location	Description
Open water pens	Subtidal areas (>10 m depth) out to the offshore[1]. Also in lakes and reservoirs.	Plastic, metal or wooden pens with (i) floating collars suspending net enclosures and (ii) deep-water submersible cages, both flexible and rigid. Used for grow-out worldwide for a variety of species (e.g., salmon and yellowtail). Conducted in the open environment.
On and off-bottom culture	Mainly intertidal or shallow subtidal areas of coasts, estuaries and lagoons.	On bottom (e.g., sown into or laid upon the substrate) and off bottom (e.g., on trestles/poles) culture using mesh bag containment. Mainly used for shellfish but also used for seaweeds.
Suspended ropes/ longlines	Subtidal areas. Can be close to the shore, but often placed in deeper waters.	Longlines suspended from buoys, or rafts with rope droppers, both of which are anchored to the seabed. Used worldwide for grow-out of shellfish (e.g., mussels, oysters and scallops often in suspended lantern nets). Includes off-bottom seaweed farming on longlines. Conducted in the open environment.
Coastal and inland ponds	Coastal ponds are either tidal-fed or use pumped seawater (up to 20 m above sea level). Inland ponds are mainly adjacent to rivers, irrigation canals or groundwater.	Mainly used for grow-out of shrimp/nurseries and grow-out of finfish in tropical areas, as well as carp, trout and other freshwater fish in temperate areas. Some are flow through, others are static. Waste/harvest water drains into the open environment. Ponds are either unlined earth, or lined with clay, plastic and other materials.
Tanks (including recirculated aquaculture systems (RAS))	In largely flood-free terrestrial areas, often enclosed, with access to adequate water supplies.	Usually higher density farming of a wide range of species in many different conditions. Usually in an enclosed area with increasing levels of water reuse, including hatcheries, nurseries and increasingly, grow-out. Full or partial wastewater drainage into the open environment, depending on the level of recirculation/reuse[2].
Other systems		Variety of different systems including farming in lagoons, etc. generally conducted in the open environment.

1 Offshore aquaculture can be defined as > 3 km from the coast, often with water > 50 m depth.
2 Reuse is often used in other agricultural systems, such as hydroponics.

- **Nurseries:** As the larvae metamorphose into juveniles (e.g., 2–5 mm shellfish spat or 1–2 cm fry and fingerlings), the required space and water flow expands rapidly. At this stage, juveniles will go into a larger facility—the nursery—where they can be fully weaned onto formulated diets in preparation for grow-out. Nurseries are often tank-based, but they may also be smaller ponds or cages within ponds where the water quality and food presentation can be carefully monitored. Nurseries are often adjacent to hatcheries, but they may also be located near final grow-out facilities.
- **Grow-out facilities:** Once the cultured organisms are ready, they will be stocked into final grow-out facilities. These facilities are large in scale, as they need to have sufficient space to allow the animals to grow and achieve their final market weight. The facilities are less intensively managed than are the facilities for the earlier stages, but they will still require regular husbandry activities such as stock monitoring, feeding and occasional grading.

There are exceptions to the above process. In some circumstances, there is still a dependence on wild juveniles for stocking purposes. For instance, many bivalve farms depend on the use of relayed juveniles or those collected from natural spatfalls (natural accumulations of larvae on the seabed). For some species, the reproduction cycle has not been commercially replicated, so they are caught and then reared in captivity (e.g., tuna ranching in large, offshore cages).

2.2.3 TRENDS IN AQUACULTURE PRODUCTION

There are no global figures on the proportion of production by these different systems. Open water cages are favored by those farming in colder and temperate water (e.g., Norway, Chile and Canada), while pond systems tend to be used in warmer waters where there is higher natural productivity. In general, there is a trend towards intensification of production, driven by a combination of a finite number of suitable aquaculture sites and improved technology for managing wastewater and maintaining water quality within the systems. There is also a shift from lower trophic species such as carp to more carnivorous species such as sea bass, especially among the middle classes in rapidly developing countries.

A more recent trend has been recirculated aquaculture systems (RAS), which are highly enclosed systems with only a limited potential as a source of aquatic debris or other connections/pathways to the natural environment. RAS can be placed almost anywhere and are attracting a lot of attention from potential investors in intensive aquaculture. In time, RAS likely will be the future of global fish production, but issues in scaling up production and competing with more traditional forms of aquaculture make this is a long-term aspiration.

In countries where marine aquaculture is well-established, there tends to be pressure to move aquaculture operations offshore where there is less competition for sea space and where there are often better growing conditions. However, offshore locations are exposed to extreme weather, have extended logistical supply chains and pose the potential for catastrophic containment or mooring failures. The development of multiuse offshore platforms that combine offshore aquaculture and energy production is likely (Abhinav *et al.* 2020), and it would contribute to the United Nations' Sustainable Development Goal (SDG) 7 on achieving "affordable and clean energy" and SDG Goal 14 on "life below water".

In the last decade, Integrated Multi-Trophic Aquaculture (IMTA) systems also have become more important in aquaculture facilities. IMTA systems provide an opportunity to reduce environmental impacts through direct uptake of dissolved nutrients (Vidal *et al.* 2020). Also, with these systems relying on incorporating various species from different trophic levels, cost-efficiencies will increase due the higher number of marketable products. These systems will, however, introduce further potential for plastic and other material losses into the aquatic environment.

Lastly, the European Union (EU) is exploring how to increase the sustainable production, safe consumption and innovative use of algae and algae-based products to help achieve the objectives of the European Green Deal, which calls for the transition to a green, circular and carbon-neutral EU (Camia *et al.* 2018; EC, 2020). An increase in algae production could be expected because algae represent a largely untapped resource, have limited carbon and environmental footprints, and can be used to produce food, feed, pharmaceuticals, bioplastics, fertilizers and biofuels. In the EU, microalgae are cultivated in open (e.g., raceway ponds) or closed (photobioreactors) systems (Dos Santos *et al.* 2019), while macroalgae operations use pole culture, suspended rope culture and bottom culture techniques (Sandra *et al.* 2020). With the expansion of algae production, these techniques could be used in other parts of Europe where seaweed and microalgae aquaculture might not be developed yet.

2.3 STAKEHOLDERS

In line with the GGGI BPF for wild capture fisheries (C-BPF), the A-BPF is also focused on different stakeholder groups. Therefore, we have conducted a brief analysis of typical stakeholder groups involved in aquaculture around the world:

TABLE 2: STAKEHOLDER TYPES IN AQUACULTURE

Stakeholder group	Description
Equipment designers, manufacturers, distributors and installers	Businesses involved in the design, production, presale distribution, sale and installation of aquaculture equipment
Aquaculture operators	Individuals or organizations managing and operating aquaculture sites and the supporting facilities.
Aquaculture producer associations	Non-statutory organizations representing aquaculture businesses. Most producer associations are organized around a region (e.g., transboundary, national or local) and/or a theme (e.g., species or system-based).
Harbor and port operators	Bodies operating and managing ports that service aquaculture operations.
Aquaculture sector managers and regulators	Statutory management bodies that set policy, plans and regulations for aquaculture activities.
Fisheries, environmental protection and waste management agencies	Bodies or agencies responsible for enforcing aquaculture and associated environmental regulations, including waste management.
Aquaculture and aquatic environment research	Government or private sector organizations that conduct research and development.
Seafood ecolabel and certification programs	Organizations that set and maintain third-party audited standards for responsible sourcing of seafood.
Seafood companies in the aquaculture value chain	Processors, wholesalers and retailers that use seafood products from aquaculture.
Nongovernmental organizations	Nongovernmental advocates for sustainability and good practices.
Other rights holders and stakeholders potentially impacted by aquaculture operations	Other stakeholders with an interest in the A-BPF might include wild capture fishers, local and indigenous communities, local and regional planners, etc.

3 AQUACULTURE SYSTEMS AND THEIR CONTRIBUTION TO AQUATIC DEBRIS

3.1 MATERIALS EMANATING FROM AQUACULTURE OPERATIONS

The Honolulu Strategy[4] (NOAA/UNEP, 2011) defines aquatic debris as including "any anthropogenic, manufactured, or processed solid material (regardless of size) discarded, disposed of, or abandoned in the environment, including all materials discarded into the sea, on the shore, or brought indirectly to the sea by rivers, sewage, stormwater, waves, or winds." Aquatic debris may result from activities on land or at sea and is considered synonymous with marine litter. The United Nations Environment Programme (UNEP) and the European Commission (EC) define marine litter as "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment" (UNEP, 2005; Galgani *et al.* 2010).

Aquatic debris originating from aquaculture can take a number of forms:

1. **Large debris composed of sections of aquaculture equipment,** such as cage collars, rafts, boats, tanks, piping, buoys, nets, moorings and ropes.
2. **Smaller litter originating from aquaculture operations,** such as feed sacks, sand bags, discarded gloves and clothing, food and drink containers, plastic bags and other packaging, feeding trays, cable ties, containers, fish boxes, etc.
3. **Abraded material originating from the wear and tear of equipment,** including ropes, expanded polystyrene (EPS) blocks and fillings and ultraviolet (UV) light damaged plastics.

It should be noted that, unlike the Honolulu Strategy, we use the terms "debris" and "litter" advisedly. Debris refers to "broken or torn pieces of something larger," often resulting from something that has been destroyed or damaged, while litter refers to "items that have been deliberately discarded, unintentionally lost or abandoned, or transported by winds and rivers, into the environment" (Vidal *et al.* 2020). This suggests that debris is more likely to result from an accident or a catastrophic event while litter occurs from human carelessness and lack of environmental awareness.

To date, there has been limited analysis of the composition of aquaculture-derived aquatic litter. It is likely that the vast majority of persistent and mobile litter from aquaculture will be plastics (Sandra *et al.* 2019). The average proportion of plastics varies between 60% to 80% of total marine debris and can reach as much as 90% to 95% of the total amount of marine litter (Derraik, 2002; Galgani *et al.* 2015). An estimated 19–23 million metric tons of plastics entered the world's ocean from land-based sources in 2016 alone (11% of global plastic waste) and, left

[4] The Honolulu Strategy: A Global Framework for Prevention and Management of Marine Debris

unabated, could reach over 90 million tonnes per year by 2030 (Borelle *et al.* 2020). The vast majority of these plastics are expected to persist in the environment in some form over long time scales (Andrady, 2015) and over time these plastics will likely fragment into microplastics. Although removing some marine plastics is possible, it is time-intensive, expensive and inefficient (Beaumont *et al.* 2019).

A preliminary approach for evaluating the potential impacts that the aquaculture sector might face by 2025 regarding nonorganic litter was published in 2020 (Vidal *et al.* 2020). Based on external drivers (such as climate, policies and legislation, and patterns in seafood consumption), twelve different factors were assessed to forecast the potential future increase or decrease of marine litter by 2025 by aquaculture type and by sea basin.

Other aquatic debris derived from aquaculture is composed of either wood (used to construct fish cages and pens, as well as pallets), steel (fish cages, anchors, corner plates, mooring chains and fittings), other metals (thimble for rope attachments, floats and buoys, mussel cone laser marking, racks and padlocks), natural textiles (burlap bags for seafood collection, mussel socks), rubber (clothing such as safety boots, floats and buoys) and concrete (sinkers). Wood tends to float and decay (a process accelerated by wood-boring species) and eventually sink when waterlogged (Charles *et al.* 2016). It is a relatively benign material that has constituted much of the non-anthropogenic aquatic debris load in nature (e.g., fallen timber washed out from a watershed). Steel, either as a homogenous unit (e.g., a steel structure) or as a composite material (e.g., metal components within a water pump) is also fairly benign, although it can pose a navigation hazard if large enough. Most metal will sink and corrode over time through a combination of galvanic corrosion, oxidization and physical abrasion.

Given the current global focus on the contribution of plastics to aquatic debris and litter, particular focus will be paid to plastics in the A-BPF.

3.2 PLASTICS AND THEIR USE IN AQUACULTURE

Like any other industry, aquaculture makes extensive use of plastics in equipment and in packaging for various items used during the course of normal operations. Indeed, most plastics are an excellent material for use in a hostile aquatic environment, where the durability of plastic, including its resistance to abrasion and rust, improves the longevity and reliability of equipment. Also, the lightweight nature of plastics reduces handling and associated costs. In addition, the ability to mold plastics into specific shapes means it is ubiquitous in a fish farm, such as in the form of high-density polyethylene (HDPE), polystyrene foam-filled sea cage collars, polymer-coated cage nets and plastic harvest bins. This section attempts to classify the ways in which plastics are used by different forms of aquaculture.

Plastics are widely used in aquaculture system components because they are light, reasonably strong and cheap, largely unaffected by seawater corrosion over their working life, and can be formed to different shapes, including solid blocks, fibers and films. As will be demonstrated in the following section, there are different types of plastics to suit different environments, applications and budgets.

The tabular analysis includes two steps:

1. **Overview of different plastic types and their characteristics.** Table 3 examines how different plastics are used in aquaculture and looks at their key characteristics in terms of their strengths and weaknesses.

2. **Plastics use in different aquaculture systems.** Table 4 looks at the various constituent components of each of the five aquaculture systems described previously and examines how plastics are used in each of these systems.

BOX 1: PLASTICS: UBIQUITOUS MATERIAL OR ENVIRONMENTAL CURSE?

Plastics, which are typically organic polymers of high molecular mass, are materials that are malleable and that can be molded into solid objects. There are two broad categories of synthetic plastics: (i) thermoplastics (e.g., polyethylene, polypropylene and polyvinyl chloride) that can be reheated and reshaped and (ii) thermosets (e.g., polyurethane) that after initial heating cannot be remelted and reformed. Fully synthetic plastics have been around for over a century and—due to their low cost, ease of manufacture, versatility, and imperviousness to water—are used in a multitude of products since they became mass produced in the 1940s and 1950s.

However, one of the greatest strengths of fully synthetic plastics—their durability, with their chemical structure rendering them resistant to many natural processes of degradation—means that they are extremely persistent once their useful life has come to an end. Plastic debris has now become one of the most serious problems affecting the aquatic environment worldwide, not only for coastal areas of developing countries that lack appropriate waste management infrastructure, but also for the world's ocean as a whole. This is because slowly degrading large plastic items generate microplastic (<5 mm) particles that spread over long distances by wind-driven ocean surface layer circulation (Thevenon et al. 2014) and are ingested by small marine life at the base of the food web. Plastics—including fishing gear—also have a significant impact on freshwater systems, beyond the freshwater systems being a vector for the introduction of plastics into the marine environment (Nelms *et. al.*, 2021)

Awareness of this problem has been growing in recent years, with increasing public pressure for action to reduce the flow of plastics into the aquatic environment through less single use plastic consumption, increase recycling and cleaning up beaches and the ocean of existing material.

3.3 AQUATIC DEBRIS AND LITTER FROM AQUACULTURE: PATHWAYS, RISKS AND IMPACTS

3.3.1 BASIC CAUSES

There are a number of general causes for the loss of plastics and other materials from aquaculture operations into the environment. So far as we know, these causes have not been formally classified, but they fall into the following categories:

1. **Low-level losses through routine farming operations:** Even with the best run operations, there will be the inevitable low-level loss of materials through wear and tear, environmental abrasion and attrition from predators.

2. **Extreme weather:** Extreme weather in the form of large storms and extreme temperatures is a major cause of lost debris from aquaculture operations. Large storms are usually accompanied by high winds, large waves and heavy rainfall, all of which can cause equipment failure. In coastal areas, storm surges can overwhelm pond farm areas and wash everything out to sea. Freezing temperatures can also be a major hazard by coating structures with ice, which can cause them to sink or break apart. Climate change has been implicated in an increase in the frequency and severity of extreme weather events (Dabbadie *et al.* 2018).

3. **Inadequate planning and management:** The loss of aquaculture equipment through insufficient planning and management can take a number of forms, including:

   a. <u>Poor siting, modelling, layout, installation and maintenance:</u> As can be seen from the

TABLE 3: OVERVIEW OF DIFFERENT PLASTIC TYPES AND THEIR CHARACTERISTICS

<table>
<tr><th rowspan="2">Material</th><th colspan="3">Characteristics</th></tr>
<tr><th>In use</th><th>Recyclability</th><th>When lost</th></tr>
<tr><td>Acrylic (PMMA)</td><td>Lightweight, shatterproof thermoplastic alternative to glass. Primarily used in office and lab fixtures.</td><td>Commonly recycled.</td><td>Slow levels of abrasion.</td></tr>
<tr><td>Expanded polystyrene (EPS)</td><td>Extremely light and can be formed into specific shapes. Mainly used to fill floatation devices (including net collars), either by extrusion (within a plastic or metal shell) or as blocks. Has high insulation properties.</td><td>Commonly recycled (see NOWPAP MERRAC, 2015)[1].</td><td>Very buoyant. Accumulates on beaches. Easily abrades and breaks into smaller and smaller pieces that become economically unrecoverable.</td></tr>
<tr><td>Fiber-reinforced plastic (FRP)</td><td>Includes glass-reinforced plastic (GRP). Used in piping systems and holding tanks.</td><td>Difficult to recycle.</td><td>Will splinter in time.</td></tr>
<tr><td>High-density polyethylene (HDPE)</td><td>Tough, chemically resistant rigid thermoplastic. Used in a wide variety of equipment.</td><td>Commonly recycled.</td><td rowspan="6">Will fragment, abrade and weather, leading to secondary microplastic formation. Likely to sink as it is heavier than water.</td></tr>
<tr><td>Linear low-density polyethylene (LLDPE)</td><td>Very flexible and strong plastic. Used in pond liners 0.5–40mm.</td><td>Commonly recycled.</td></tr>
<tr><td>Low-density polyethylene (LDPE)</td><td>The most common type of plastic sheeting. It is a flexible sheeting form (0.5–40 mm). Due to its flexibility, LDPE conforms well to a variety of surfaces but is not as strong or dense as some other types of plastic sheeting.</td><td>Increasingly recycled.</td></tr>
<tr><td>Nylon (polyamide, PA)</td><td>Strong, elastic and abrasion resistant. Used primarily in nets and ropes.</td><td>Specialist recycling required.</td></tr>
<tr><td>Polyethylene (PE)</td><td>Cheap rope and net material.</td><td>Commonly recycled.</td></tr>
<tr><td>Polyethylene terephthalate/ polyester (PET)</td><td>More expensive, strong but inelastic water-resistant rope material. Also used to make plastic bottles.</td><td>Commonly recycled.</td></tr>
</table>

1 https://www.thebalancesmb.com/expanded-polystyrene-foam-recycling-eps-facts-and-figures-2877914

Material	Characteristics		
	In use	Recyclability	When lost
Polypropylene (PP)	Used as a reasonably cheap floating rope and woven into sacks and tarpaulins.	Increasingly recycled.	Abrades easily.
Polyvinyl chloride (PVC)	Commonly used in piping. Tough and weathers well.	Rarely recycled.	
Ultra-high molecular weight polyethylene (UHMwPE)	Expensive, low friction, very light and strong. Used mainly in pen netting and for mooring structures.	Specialist recycling required.	Unknown, but stronger than most materials.

Source: Various, including CIFA, 2011

previous section, plastics are used extensively in many aquaculture infrastructure components, including cage collars, nets and mooring equipment. These will all be subject to wear and tear, especially in a dynamic offshore environment. Thus, the adequacy of the equipment for the environment into which it is placed (see GESAMP, 2001), and the subsequent installation, maintenance and replacement will all have an influence on (i) how much plastics will abrade (e.g., leading to secondary microplastic formation) and (ii) the risk of equipment failure and the loss of plastics and other components into the aquatic environment.

b. Poor waste management: Considerable amounts of plastic and other waste might be generated by aquaculture, including from feed sacks, plastic-wrapped consumables and disposable equipment (e.g., plastic gloves, cable ties, etc.). These different waste streams need to be disposed of responsibly, requiring safe and secure waste collection (e.g., not vulnerable to informal waste pickers or being blown away by high winds). This can be a challenge, especially when operations are taking place at sea (e.g., on cage sites) or on large and often exposed coastal pond sites.

c. Limited recycling: Many aquaculture components have a finite life (e.g., nets). At present, recycling opportunities for plastics from aquaculture gear are limited, and this is often complicated by the number of different plastics used and by other factors such as antifoulant coatings used on nets and mooring gear.

d. Farm decommissioning: Farming operations and sites might be closed down for a wide variety of reasons, such as poor financial performance or external factors. There are thousands of hectares of abandoned shrimp and finfish ponds sites around the world[5], with differing levels of decommissioning and cleanup. Abandoned farms—of which there are many—are subject to vandalism, natural degradation and decay, all of which may result in plastics and other materials being lost into the aquatic environment.

[5] https://thefishsite.com/articles/250000-hectares-of-abandoned-shrimp-ponds-worldwide

TABLE 4: PLASTIC USE IN DIFFERENT AQUACULTURE SYSTEMS

System	Key plastic components	PMMA	EPS	FRP
Open water pens	Floating collars (including handrails)			
	Collar floatation		●	
	Buoys (in mooring systems)			
	Ropes (in mooring systems)			
	Net enclosures			
	Predator and other nets			
	Feeding systems (pipes and hoppers)			●
On and off-bottom shellfish cultures	Mesh bags/cages/boxes and fasteners			
	Spacers			
	Cable and other straps/ties			
Suspended ropes/ longlines	Buoys (in mooring systems), including plastic bottles in some systems			
	Ropes (in longlines & moorings)			
	Raft floatation		●	
	Stock containment (nets/meshes/cages)			
Coastal and inland ponds	Pond liners			
	Sampling /harvest nets			
	Plastic green/poly housing			
	Aerators/pumps			
	Feeding systems (pipes, feeders and trays)			●
Tanks (including recirculated aquaculture systems RAS)	Spawning, incubation and stock holding tanks			●
	Pipework (including connectors and valves)			●
	Office/laboratory fixtures and fittings	●	●	

HDPE	LLDPE	LDPE	Nylon	PE	PET	PP	PVC	UHMwPE
●							●	
●		●		●				
			●	●	●	●		
●			●			●		●
●			●	●				
●							●	
●								
●			●	●			●	
			●					
●		●		●	●			
●			●	●	●	●		
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●			●			●		●
●	●	●						
●			●			●		●
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●							●	
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●							●	
		●	●				●	

e. Lack of awareness and training: The understanding and capacity of managers and staff to minimize the risk of plastics loss is key. This implies the need for appropriate policy frameworks, supported by awareness-building and, where necessary, manager and staff training.

4. **Deliberate discharge:** In some cases, equipment and consumables may be deliberately discarded or abandoned, especially if the costs of removal or collection are deemed too high, or if access to sufficient waste management facilities is limited or nonexistent. This suggests that poor waste management in general is likely to be a higher risk in less profitable aquaculture operations (e.g., through the lack of easily accessible waste facilities and through poor waste management supervision). Vandalism is also a possible cause of equipment failure (for instance, recreational fishers cutting floating cage nets to release fish into the wild).

3.3.2 PATHWAYS AND RISK

Having examined the major causes of equipment and consumable losses from aquaculture, we now look at the main pathways for debris and litter from aquaculture into the aquatic environment, with a view of the risk involved.

The pathway element of this review examines the ways in which (i) equipment and consumables transition from performing an effective role in the farm to becoming an uncontrolled waste or debris, and (ii) how this waste or debris is transported into the aquatic environment.

The risk element examines the likelihood of this happening. Although risk analysis in aquaculture is a specialist subject that has been extensively studied (see Bondad-Reantaso *et al.* 2008), these studies have rarely covered risks associated with plastics loss and the subsequent impacts. This review is conducted for the various aquaculture systems identified earlier in this document. The risks are summarized in Table 5 on page 26.

OPEN WATER PENS

The majority of salmon farming globally is by open water farming in sea pens (often called cages), a method also used for tropical species such as groupers, yellowtail and cobia. The advantage of cage farming is that farmers can use coastal waters with good water exchange to farm fish in their natural environment. However, although open water farms are often sited in sheltered areas, they are often exposed to harsh wind and wave conditions that can lead to equipment failure and loss. This loss is usually directly into the sea, where the strong currents, chosen to maximize water exchange, will rapidly abrade, break and disperse debris (and fish) into the aquatic environment.

The most likely causes of cage and cage component losses are extreme weather, poor waste management and installation wear and failure (due to poor siting, installation and/or maintenance). Extreme weather, mostly from large storm events, can cause moorings to fail and result in cages (e.g., collars and nets) being damaged or destroyed. Some elements (e.g., intact elements of cage collars) can be recovered, but net segments, feeding systems, ropes and buoys may be lost. In addition, any EPS used to increase cage/raft buoyancy may also be lost, often in a fragmented and unrecoverable form. Hinojosa and Thiel (2009) and Hinojosa *et al.* (2011) determined that the majority of floating marine debris in southern Chile was produced by salmon and bivalve aquaculture, mostly consisting of EPS, plastic bags and plastic fragments[6]. Some microplastic fragments were attributed to the use of EPS in buoys for aquaculture

[6] Expanded polystyrene (EPS), which is intensively used as a floatation device by mussel farms, was very abundant in the northern region but was rarely used in the southern region of the study area (southern Chile). Food sacks from salmon farms were also most common in the northern region, where ~85% of the total Chilean mussel and salmon harvest is produced.

facilities in Korea (Heo *et al.* 2013; GESAMP, 2015). Microplastics can also be generated from net washing operations where fibers and other materials may be washed out in the process, and microplastics could even be generated over time by abrasion from pelleted feeds being pumped through plastic piping at high speeds.

Nimmo and Cappell (2009) reported that marine litter (mainly plastic feed bags) from salmon cage farms in Scotland was mainly attributed to "bad practice by certain operators." Poor waste management, such as personal litter and feed bags, may result from either a lack of collection/reception facilities or poor awareness on the part of staff. Cages can also be damaged or vandalized, most often by poachers or recreational fishers wanting to release caged stock. In addition, marine cages may be vulnerable to damage from nonfarm vessels, especially if the cages are sited in or adjacent to a busy navigational route.

SUSPENDED ROPE/LONGLINE AQUACULTURE OF BIVALVES

Bivalves are often farmed on ropes suspended from floating rafts or from buoyed longlines. Depending upon the species and aquaculture system used, bivalve farms are usually placed in bays or channels where there is sufficient spat/feed availability, water exchange to remove organic matter and water depth (typically 15–30 meters). As with finfish cages, these bivalve farm sites are vulnerable to extreme weather and possible conflict with other water users in coastal bay areas. The causes and pathways of plastics and other materials lost from rope/longline aquaculture are very similar to those from finfish cages, in that many plastic components are included in the floating rafts or other suspension methods. The main difference is that bivalve aquaculture systems lack nets, although they do include long lengths of mainly plastic rope and pegs or stoppers, which are vulnerable to abrasion (thus generating microplastics) and loss. The suspension methods are usually buoyed longlines or wooden (or, increasingly, plastic) floating rafts, both of which can be subject to partial or complete loss. As with any other remotely sited aquaculture facility, responsible decommissioning is also important. For example, in the Spanish autonomous community of Galicia, floating mussel rafts known as "bateas" are mainly wooden structures that are towed into large-item waste management collection points (with consequent fees to be paid by the farmer) or disassembled before being transferred for recycling or incineration (Vidal *et al.* 2020).

ON AND OFF-BOTTOM CULTURE OF SHELLFISH AND SEAWEED

The extensive farming of bivalves and other shellfish, as well as macroalgae, takes place either directly on the intertidal zone/seabed or suspended above on fixed structures or floating lines. On-bottom farming usually involves the seeding of juveniles into the substrate (e.g., clams) or laying them directly on the seabed (e.g., mussels) for on-growing and harvesting. This involves very little or no infrastructure or husbandry equipment, and thus the potential for significant debris loss is very low. The off-bottom culture of bivalves (e.g., oysters) is usually conducted on fixed trestles in the intertidal zone where the stock is contained in mesh bags or containers that are often secured onto the trestle with cable ties or elastic strapping. In Ireland, it was estimated that the smallest oyster grower has about 30,000 HDPE bags in use while others have 200,000 bags or more, with at least two million bags in use at any one time in what is a relatively small industry (Thornberry, 2019). These bags can be readily recycled, but they need to be cleaned, stripped of extraneous components and stockpiled in order to be accepted by recyclers. Many tropical seaweed farmers use PET or HDPE plastic bottles as line floats, which are frequently lost and cheaply replaced.

COASTAL AND INLAND PONDS

Aquaculture pond systems are situated in flat coastal or inland areas and use an adjacent water

Large shrimp farm in Saudi Arabia (National Aquaculture Group, Al Lith)

Photo credit: Google Map

supply to fill earthen or lined ponds. The rate of water exchange depends upon the species being farmed and the scale and intensity of production. Most intensive coastal shrimp ponds exchange up to 25% of their water per day. Inland ponds that rear active species such as trout tend to be small with a constant exchange of water, while lower trophic carp require less water exchange and intermittent water top-ups. In both cases, the ponds are occasionally drained (e.g., during harvest or for desilting when effluent water discharge will peak).

Coastal pond aquaculture usually takes place in ponds constructed just above the high tide mark. In some countries, water is captured from high spring tides, thus negating the need for pumps, and is mainly for small-scale, extensive systems in developing countries. Most coastal pond aquaculture employs some form of a pumping system to raise water from the sea into a header channel or tank whereby it drains through gravity into the ponds and then back out to the sea via various control points. Coastal pond aquaculture can be done on a very large scale, with hundreds of hectares under cultivation. Where there is insufficient clay content in the soil, plastic liners are used (see photo of National Aquaculture Group's farm in Al Lith, Saudi Arabia, above).

A major cause of plastics loss in coastal pond sites is through extreme weather. To reduce pumping costs, most coastal pond farms are built close to the sea and just above the high-water mark, and they are thus vulnerable to storm surges and flooding from upstream water courses. For example, the coasts of India, Bangladesh and Myanmar within the Bay of Bengal are frequently exposed to cyclones, which cause storm surges of over 3 meters and whose effects are exacerbated by heavy rain and inland flooding (Katare *et al.* undated). In China, over 55,000 hectares of coastal fishponds were damaged by typhoons[7] between 1949 and 2000 (Xu *et al.* 2005). Such events will wash unsecured equipment into the sea, often near sensitive habitats such as coral reefs, mangroves and coastal wetland areas. Many coastal pond systems are found in developing countries, and the infrastructure for waste collection and recycling is often lacking. Also lacking in many instances is awareness of the impacts of lost plastics and the need to ensure that they are stored and disposed of responsibly. Another issue is inappropriate farm decommissioning, with large areas of coastal pond farms abandoned for various reasons (e.g., financial, pond siltation, storm damage) and left to deteriorate, allowing big items such as pond liners to disintegrate and disperse into the environment.

Inland aquaculture ponds tend to have fewer waste issues. They are less vulnerable to storm events, although they can be overwhelmed by flooding,

[7] Also known as a cyclone (Indian and South Pacific oceans) or hurricane (Atlantic and NE Pacific oceans).

especially if they are poorly situated in or adjacent to a floodplain. Most inland pond systems tend to be smaller in scale than their coastal counterparts, which may mean that formal waste management systems are lacking. Inland ponds may, however, have better access to waste collection and disposal services if they are sited near larger population centers. They also tend to be in better soils with higher clay content, and thus they do not normally need the pond liners that are required on sandy coastal soils.

TANKS (INCLUDING RAS)

Most hatcheries and nurseries and an increasing number of intensive grow-out farms are now utilizing tanks that are normally made of GRP (see photo below), HDPE, concrete and steel.

In addition to the tanks, there are extensive water supply and drainage pipes and control valves, also made of HDPE or PVC, together with supporting components such as filtration and water treatment equipment, pumps and office fittings.

Despite the extensive use of plastics in tank-based aquaculture, the risk of plastic loss into the aquatic environment is low (see Table 5). In most cases, operations are situated in a building or a secure area to prevent theft and to protect them from the elements. As they tend to be intensive systems, often with a degree of recirculation, water demand is relatively low, and thus they can be sited well away from flood risk areas. Due to the high investment cost, they are usually well-managed with good waste management and with good linkages to external waste disposal facilities. They are also reasonably easy to decommission and are usually located in sites with a high demand for alternative uses. (For instance, a barramundi RAS farm in Lymington, UK, was built on the site of a former pizza factory, and when the farm ceased operation, the site was converted to a brewery.) There may be some risk of low-level loss of plastic biomedia through poorly filtered effluent waters giving rise to operational sources of micro/mesoplastic pollution.

In summary, aquaculture systems in coastal or marine locations are most vulnerable to chronic, low-level plastic loss through poor equipment installation/maintenance and inadequate waste management, as well as to possible larger-scale loss from catastrophic,

Glass-reinforced plastic tanks used in a UK hatchery

Source: Purewell Fish Farming Equipment Ltd

TABLE 5: CAUSAL RISK ANALYSIS FOR EQUIPMENT AND/OR CONSUMABLE LOSS FROM DIFFERENT AQUACULTURE SYSTEMS

<table>
<tr><th rowspan="2">Aquaculture system</th><th rowspan="2">Routine farming operation</th><th colspan="2">Inadequate planning and management</th></tr>
<tr><th>Waste management</th><th>Siting, installation and maintenance</th></tr>
<tr><td>Open water cages and pens</td><td rowspan="2">HIGH
Site-dependent, complex mooring and dynamic multiuser environment.</td><td rowspan="2">HIGH
Exposed to elements and challenging to collect waste.</td><td rowspan="2">HIGH
Site-dependent, complex mooring and dynamic multiuser environment.</td></tr>
<tr><td>Suspended ropes/cages</td></tr>
<tr><td>On- and off-bottom shellfish culture</td><td>LOW TO MEDIUM
No major structures.
High predator interactions.</td><td>MEDIUM TO HIGH
Small sites with often insufficient waste collection.</td><td>LOW TO MEDIUM
No major structures. Often in well-charted inshore areas.</td></tr>
<tr><td>Coastal ponds</td><td rowspan="2">LOW
Stable environment with embedded (nonmoving) components.
Medium level predator interactions.</td><td>MEDIUM TO HIGH
Large sites, often in developing countries.</td><td>LOW TO MEDIUM
Few large, fixed plastic structures (except pond liners).</td></tr>
<tr><td>Inland ponds</td><td>LOW TO MEDIUM
Smaller sites, usually with access to waste collection.</td><td>LOW TO MEDIUM
Few large, fixed plastic structures (except pond liners).</td></tr>
<tr><td>Tanks (including RAS)</td><td>LOW
Stable, complex infrastructure.
Low predator interactions.</td><td>LOW
Small sites with good waste management.</td><td>LOW
High-tech sites usually with strong infrastructure support.</td></tr>
</table>

Color codes:	Low	Low to Medium	Medium	Medium to High	High

Recycling levels	Farm decommission-ing	Awareness and training	Deliberate discharge	Extreme weather
LOW TO MEDIUM Collars mostly single material and recyclable. Nets less easy, but possible, to recycle.	LOW Relatively easy to decommission and reuse components on other sites.	LOW TO MEDIUM Mainly operated by larger companies with good human resources management.	MEDIUM Often in remote locations and deep water, providing opportunity for undetected deliberate discharge. Vulnerable to vandalism.	HIGH Often in exposed sites and vulnerable to strong winds and high waves.
LOW TO MEDIUM Few large, fixed plastic structures. Considerable use of SUPs.	LOW Light, easily moved fixtures and fittings.	MEDIUM Mostly small-scale operations.	LOW TO MEDIUM Low level discard (e.g., cable ties).	MEDIUM In shallow or intertidal waters exposed to extreme weather.
LOW TO MEDIUM Few large, fixed plastic structures (except pond liners).	MEDIUM TO HIGH High cost to restore land (e.g., fill in ponds).	MEDIUM Often in developing countries.	LOW TO MEDIUM Low level discard (e.g., fry stocking bags).	HIGH Vulnerable to storm surges, inland flooding and storm landfalls.
LOW TO MEDIUM Few large, fixed plastic structures (except pond liners).	LOW Usually redeveloped for alternative use.	MEDIUM Usually smaller operators with limited human resources management.	LOW Smaller sites, usually with access to waste collection.	MEDIUM Can be subject to watershed flooding.
LOW Large, single plastic tanks and pipework easily recycled.	LOW Usually redeveloped for alternative use.	LOW High-tech installations require skilled, trained staff.	LOW Smaller sites, usually with access to waste collection.	LOW Mostly enclosed and away for high-risk environments.

weather-related events. It is also important to consider the issue of scale and cumulative effect. Large-scale operations may be more formally managed, but they may pose a higher risk due to the level of activity and the materials being used. Small-scale operations may not have formal management systems but they may have higher levels of oversight on the ground. However, even if there are only low levels of plastic leakage, cumulatively that leakage may be significant, especially in sensitive coastal or wetland environments.

3.3.3 IMPACTS

The impacts of debris and litter from aquaculture have not been studied to the same extent as they have from capture fisheries. The main impacts are likely to be as follows.

GHOST FISHING

The scope of ghost fishing from lost aquaculture equipment is significantly less than from capture fisheries, as most aquaculture debris will not contribute directly to ghost fishing (e.g., most finfish nets are not rigged to catch fish and are usually small mesh (e.g., up to 2.5 cm/1”), although some predator nets may be larger mesh (e.g., 2.5 cm/1” or more, up to around 20 cm/8”) and thus capable of entangling fish and other aquatic animals in some circumstances). That said, macroalgae farming systems are using moorings, lines and floats as a growing substrate that is at risk of being lost (Campbell *et al.* 2019).

INJURY AND MORTALITY OF VULNERABLE AQUATIC ANIMALS AND BIRDS

In addition to ghost fishing, lost predator nets and ropes can result in both (i) entanglement, whereby they entangle or entrap animals, including fish, marine turtles and aquatic mammals; and (ii) ingestion, whereby fragments of nets or lines are intentionally or accidentally ingested. Entanglement is far more likely to cause mortality than ingestion (Laist, 1987). Fishing-related gear, balloons and plastic bags have been estimated to pose the greatest entanglement risk to aquatic fauna (Wilcox *et al.* 2016).

HABITAT AND BENTHIC COMMUNITY DAMAGE

Lost nets can impact benthic environments through smothering, abrasion, and ”plucking” of organisms, meshes closing around organisms, and the translocation of seabed features. Lost nets may eventually become incorporated into the seabed. Other heavy aquaculture debris may also sink to the bottom and cause localized benthic damage, especially in vulnerable marine ecosystems (VMEs) such as coral reefs. Eventually, large objects may become more stable and integrated into the substrate, but this depends on local oceanographic conditions.

SOCIAL IMPACT OF AQUATIC LITTER

Large pieces of debris as well as extensive litter (e.g., cable ties and other fastenings, plastic bottles used as floats, and pieces of rope) are unsightly and can have considerable social costs in relation to the recreational value of coastal waters, beaches and other land-water interfaces (Brouwer *et al.* 2017). This can impact the perceived social licenses afforded to aquaculture in coastal and rural communities. There are also economic costs associated with beach cleanups.

AQUATIC DEBRIS AS A VECTOR FOR ALIEN INVASIVE SPECIES (AIS)

The global spread of nonindigenous species (species that have been transported inadvertently or intentionally across ecological barriers and that have established themselves in areas outside their natural range) is one of the greatest drivers of biodiversity loss, second only to habitat loss and fragmentation, posing a threat to the integrity and functions of ecosystems.

The transport of nonindigenous species through natural or anthropogenic litter is occurring passively, without control on species, materials and transportation schemes other than hydrodynamics and environmental factors. The transport of biota on litter items is potentially a new problem because of the recent proliferation of floating particles, which are mostly plastics and which have been implicated in dispersing harmful algal bloom (HAB) species (Masó, 2003). Aquatic plastic litter is characterized by its longevity at sea and by its surface properties, which favor attachment by biota and thus the possibility of transporting mobile and sessile species to new areas. Consequently, species transported by rafting can alter the composition of ecosystems (Nava and Leoni, 2021) and alter genetic diversity through breeding with local varieties or species.

AQUACULTURE-DERIVED DEBRIS AS AN OPERATIONAL OR NAVIGATION HAZARD

The presence of aquaculture-derived aquatic debris such as ropes and netting can interfere with maritime operations such as fishing and subsea engineering as well as navigational safety in a number of ways (Johnson, 2000).

- Aquatic debris that gets caught in bottom trawls or snagged and enmeshed in gillnets and other fishing gear can damage fishing gear and pose a health and safety risk when recovering the gear and removing the debris.
- Fouling or entanglement of a vessel's propeller, propeller shaft, rudder, jet drives or water intakes can potentially affect a vessel's stability in the water and/or restrict its ability to maneuver. If a vessel is disabled with reduced visibility, it may be endangered by a larger vessel or poor weather.
- Benthic or subsurface debris has the potential for fouling vessel anchors and equipment deployed from research vessels, putting a vessel and its crew at risk.

Incidents may create the need to send divers underwater to attempt to clear debris. Depending on sea state, work in close proximity to a vessel's hull can be dangerous. The Marine Debris Program of the National Oceanic and Atmospheric Administration (NOAA) demonstrates a wide range of impacts from aquatic debris in general[8].

[8] See https://marinedebris.noaa.gov/discover-issue/impacts

Salmon farm in Norway

CONTRIBUTION TO, AND IMPACT OF, AQUATIC MICROPLASTICS

Global estimates of plastic litter in the aquatic environment are around 27–66.7 million metric tons (Eunomia, 2016). Borelle *et al.* (2020) estimated that 19–23 million metric tons of plastics entered the world's ocean from land-based sources in 2016 alone (11% of global plastic waste) and, left unabated, could reach over 90 million tonnes per annum by 2030. Similarly, Eunomia (2016) estimated that 12.2 million tonnes of plastic waste enter the aquatic environment annually, primarily from land-based sources (74%), fishing litter (9.4%), primary microplastics (7.8%) and shipping litter (4.9%). Of this, they estimated:

- 94% ends up on the seafloor (approximately 70 kg/km^2).
- 5% ends up on the shoreline (approximately 2,000 kg/km^2).
- 1% remains on the ocean surface (18 kg/km^2).

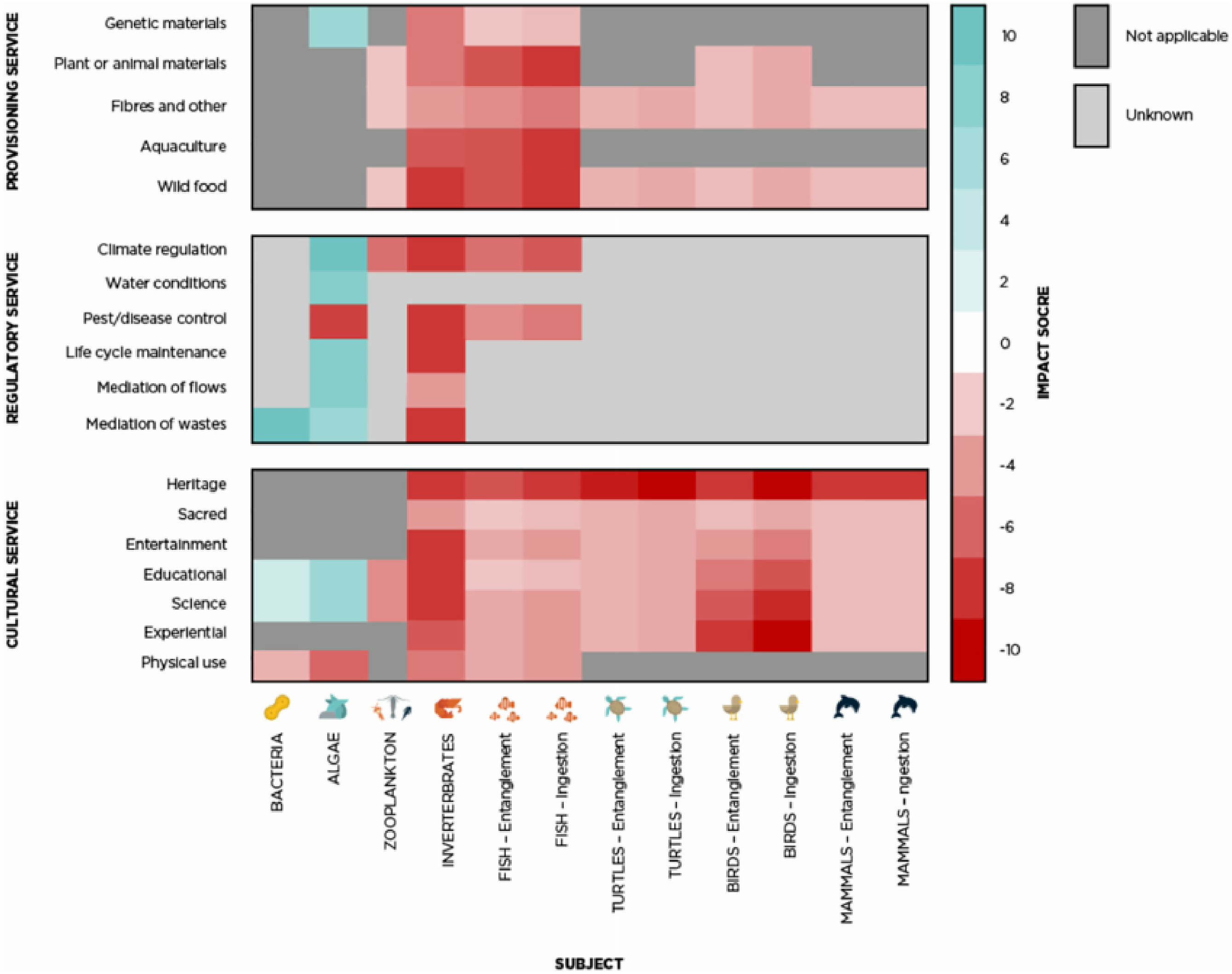
Beaumont *et al.* (2019) examined the global ecological, social and economic impacts of aquatic plastic, and they calculated that the economic costs of aquatic plastic, as related to aquatic natural capital, are conservatively estimated at between USD 3,300 and USD 33,000 per tonne of aquatic plastic per year, based on 2011 ecosystem service values and aquatic plastics stocks. Given that this value includes only aquatic natural capital impacts, the full economic cost is likely to be far greater. They examined the impact of aquatic plastic on different types of biota (see horizontal axis in Figure 4 and how this might relate to provisioning, regulatory and cultural services (vertical axis). Their examination suggests that the main impacts are on birds (via ingestion), fish (via entanglement and ingestion) and invertebrates (via entanglement ingestion and rafting). In terms of impact on services, plant, wild food and aquaculture production are all negatively affected, as are a wide variety of regulatory and cultural services, mainly via invertebrate ingestion of plastics.

In the context of aquaculture, microplastics (particles < 5mm) are generated from the wear and tear/abrasion of moving couplings, ropes and other dynamic components, as well as through abrasion and environmental degradation of plastic components. Microplastics might also be generated through the breakdown of EPS blocks or fillings, or the loss of biomedia from RAS systems. Lusher *et al.* (2017) looked specifically at the contribution and impact of microplastics to fisheries and aquaculture. They noted that at present there is no evidence that microplastics ingestion has negative effects on populations of wild and farmed aquatic organisms, though this is being contested by other more recent authors (e.g., Li *et al.* 2020, Zhang *et al.* 2020). For people, the risk of microplastic ingestion is reduced by the removal of the gastrointestinal tract in most species of seafood that are consumed. However, most species of bivalves and several species of small fish are consumed whole, which may lead to microplastic exposure.

Of potentially greater concern are the smallest microplastics (1–100 nm, referred to as "nanoplastics"), some of which can be absorbed across cell membranes, including gut epithelia. Nanoplastic particles can cross cell membranes and bioaccumulate following their transfer across trophic levels (Lusher *et al.* 2017). Furthermore, plastics often contain potentially toxic additives that impart certain desirable qualities to plastic polymers. Nanoplastics are also hydrophobic and will adsorb persistent bioaccumulative toxins, among other compounds, from water. There are large knowledge gaps and uncertainties about the human health risks from plastics in general, and from nanoplastics in particular.

There are two ways in which it has been suggested that plastics might act as a vector facilitating the transport of chemicals to organisms upon ingestion. Some plastics contain potentially harmful chemicals that were incorporated during manufacture. These additives include plasticizers, antimicrobials and flame retardant chemicals that could be released to

FIGURE 4: ECOSYSTEM IMPACTS OF MARINE PLASTIC ON BIOTA (HORIZONTAL AXIS) AND SERVICES (VERTICAL AXIS)



Source: Beaumont *et al.,* (2019). A score of −10 (dark red) denotes significant risk to this service at the global level with high potential social and/or economic costs; a score of +10 (dark blue) denotes significant potential benefit from this service at the global level, with high potential social and/or economic benefits. Dark grey shading indicates that the supply of ecosystem service from the associated subject is negligible. Light grey shading indicates that the relationship between ecosystem service and subject is unknown.

organisms upon ingestion (Rochman and Browne, 2013; Oehlmann *et al.* 2009). In addition to the release of additive chemicals, plastics are known to absorb persistent organic pollutants from water, and in a matter of days concentrations on the surface of the plastic can become orders of magnitude greater than in the surrounding water (Mato *et al.* 2001). If these absorbed chemicals desorb upon ingestion, this could provide a route for facilitating the transfer of chemicals to biota (Teuten *et al.* 2007). A key challenge is to establish the relative importance of plastics in the transfer of chemicals to organisms compared to other pathways such as via food uptake or directly from seawater (Bakir *et al.* 2016). In addition to the potential for transfer of chemical additives, plastics adsorb chemicals from seawater, and if the plastic is ingested these chemicals may also become available to organisms (Teuten *et al.* 2009).

3.4 SYNTHESIS

As stated earlier in this report, there is very little specific information currently available on the relative quantitative contribution of aquaculture to debris in the aquatic environment. The focus has been mainly on land-based sources and from capture fisheries (see Macfadyen *et al.* 2009 and Richardson *et al.* 2019) and other sea-based sources. Given that aquaculture production is currently increasing at around 5.3% per annum (FAO, 2020), it is evident that this situation needs to be addressed.

Plastic—which now forms the main material in aquaculture equipment and consumables—is an extremely versatile and useful substance, and it will no doubt continue to be used in aquaculture for many years to come. However, with the growing awareness of the impact and persistent nature of plastics in the aquatic ecosystem, there is a need to identify the drivers and pathways for aquaculture-related plastic loss and to put in place measures to reduce this plastic loss to the absolute minimum possible.

Plastic is used widely in aquaculture and in a diverse number of applications. It is used as a flotant (for cages, rafts and mooring systems), in filament form (in ropes and nets), as structural or containment components (in cage collars, buoys, tanks and pipework) and as a film (in pond liners, barrier membranes and packaging). These diverse materials all have different properties, which means they will behave differently when in the water. Some will abrade slowly (e.g., PE, PET and PP ropes), leading to sinking microplastic formation; some will fragment (e.g., EPS in floatation structures), also leading to floating microplastics; and others are stronger and will persist in the aquatic environment for generations.

The causes of plastic and other material loss from aquaculture are also varied. Low level ”leakage” can occur from intertidal and subtidal installations just through the working of components in a highly dynamic environment, leading to the abrasion of ropes, EPS floatation and other structures. To a certain extent, this is unavoidable but can be exacerbated by poor site selection, underspecification and a lack of maintenance. There is also an unquantified but likely low level of plastic loss through poor waste management (e.g., plastic feed bags and personal litter), which is itself a function of awareness and managerial capacity.

Probably the main reason for aquatic litter from aquaculture is extreme weather and its potential catastrophic impact on facilities. In the case of intertidal or subtidal facilities, this means entire components (e.g., cages, nets, rafts and plastic containers) being lost directly into the sea. While some major components are likely to be recovered, smaller items are likely to be permanently lost. Similarly, coastal pond farms are vulnerable to large storms and their associated tidal surges/flooding which may lead to the loss of large amounts of plastic, very little of which is likely to be recovered. Given the continued growth in coastal aquaculture, particularly in Asia, as well as the likely increase in the frequency and severity of tropical storms, this will likely remain the main cause of aquatic-related litter from aquaculture.

Extreme weather is not the only vector for plastic loss in aquaculture. In many circumstances, poor management, allied to business fragility, associated pressure on resources and often business failure may all contribute to poor maintenance, retention of substandard equipment and, in the case of whole business failure, abandonment of entire sites and associated infrastructure (Alex Adrian, Crown Estate Scotland, pers. comm., 2021). These situations are more likely to render installations more vulnerable to extreme weather.

Tank-based and seaweed aquaculture is unlikely to contribute significantly to plastic pollution. Most are secured against extreme weather and human interference (theft and vandalism) and are usually isolated from the physical pathways that lead to the sea.

It is quite clear that while plastic and other debris lost from aquaculture and capture fisheries are often considered together, the drivers and pathways are different, even if the eventual impacts are similar. In capture fisheries, fishing gear is either abandoned (e.g., deliberately not retrieved), lost (e.g., through gear conflict—unintended interaction with other gear—or extreme weather) or discarded (deliberately disposed of at sea because there is not enough space to store it on board, the gear is damaged, or gear disposal facilities back at port are insufficient). In aquaculture, the primary drivers are extreme weather, insufficient facility or waste management, and in some cases deliberate discard, particularly where access to waste management options is limited or nonexistent.

Finally, while it is currently impossible to even accurately estimate the contribution of aquaculture to aquatic litter and the aquatic plastic stock, it is evident that it is probably localized and relatively low compared to capture fisheries. By their nature, capture fisheries are often more active and widespread activities and are therefore at a larger risk for gear loss. In particular, mobile fishing gear (e.g., trawls and dredges) are at risk of snagging the bottom, while static gear (e.g., gillnets and traps) are often left unaccompanied, and so are vulnerable to other human activities and to a dynamic natural environment (see GGGI's Best Practice Framework for the Management of Fishing Gear (C-BPF) for more information).

This inability to accurately estimate aquaculture's contribution to aquatic litter and the aquatic plastic stock is a major gap in our knowledge. Given the likely continued growth of aquaculture, its contribution will increase unless more measures are made to reduce single use plastic usage, reuse and recycle end-of-life plastic components, and prevent and recover lost plastics and other aquaculture-derived debris where practical.

Prawn farm, Yen island, Phu Yen, Vietnam

4 POTENTIAL MANAGEMENT OPTIONS TO REDUCE DEBRIS AND LITTER FROM AQUACULTURE

4.1 MANAGEMENT OPTIONS

Following GGGI's BPF for the Management of Fishing Gear (C-BPF), we have organized management options under three different headings as follows:

- **Prevention:** avoiding the occurrence of aquaculture-derived aquatic debris in the environment.
- **Mitigation:** reducing the impact of aquaculture-derived aquatic debris in the environment.
- **Remediation:** removing aquaculture-derived aquatic debris from the environment.

4.1.1 PREVENTION

The major emphasis of this A-BPF is on prevention, e.g., avoiding the loss of aquaculture equipment, components and litter into the aquatic environment in the first place. There are various approaches to this, which are described below.

POLICY AND PLANNING APPROACHES

- Develop a formal solid waste policy that sets out how aquaculture businesses will manage their nonbiological waste[9], including debris and litter production. This will include all materials but is likely to focus primarily on persistent materials such as plastics. The policy should reduce and where possible eliminate (i) the use of single use plastics, (ii) plastics with low levels of recyclability, (iii) equipment that mixes different types of plastic, thus complicating/increasing the cost of recycling, and (iv) methods that hinder recyclability (e.g., coating of nets with substances that impede recycling). Further, policies should include (v) gear tagging requirements to assist with recovery.
- Reduce the risk of aquaculture operations contributing to the aquatic debris load by preparing a formal risk assessment examining low-level risks (e.g., plastic packaging being blown into the water) as well as high-level risks (e.g., facility vulnerability to extreme weather), and develop management and mitigation measures to reduce these risks. An example of developing such measures is the '"Storm and Hurricane Preparedness" planning for off-bottom oyster aquaculture in the Gulf of Mexico[10].
- Ensure that environmental and social impact assessments (ESIAs) recognize the potential risks of using plastics in aquaculture, especially in exposed coastal sites. As part of the environmental impact assessment (EIA) process, early engagement with relevant communities can help with better anticipating issues (siting, hazards, etc.) and provide engagement opportunities for the public if concerns are raised.

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9 This therefore excludes biological issues such as metabolic and fecal waste, pathogens and genetic materials, which are expected to be covered in separate policies.

10 https://shellfish.ifas.ufl.edu/hurricane-resources/

- Introduce deposit schemes to collect gear separately, recycling rebates to motivate farmers, and extended producer responsibility (EPR) schemes to motivate systematic collection of end-of-life gear/equipment. Support the development of local or regional recycling/reuse schemes to incentivize producers to use less mixed-plastic material to facilitate the recycling process and help with the upgrading of waste handling facilities as well as create incentives to invest in more durable materials and alternative solutions.

SITE DESIGN, INSTALLATION, OPERATION AND MAINTENANCE APPROACHES

- Reduce equipment wear and tear levels through the following measures:
  - Ensure that physical infrastructure components (e.g., anchors, mooring systems, cage collars, and longline systems) are appropriate for the physical and chemical environment.
  - Ensure that any plastic or other waste materials generated by routine maintenance (e.g., net washing) are captured before they can reach the natural environment.
  - Use alternative materials or higher specification plastics, e.g., PET or UHMwPE that are resistant to abrasion and are stronger and lighter than materials such as PE. It should be noted that these may be more difficult to recycle than lower grade alternatives.
  - Develop and use aquaculture equipment manufacturing standards such as those in Scotland[11] and Norway[12].
- Reduce the risk of equipment loss or failure through the following measures:
  - Ensure that maintenance regimes are in place and followed and that equipment and fittings are replaced within their expected lifetime and immediately following any noticeable damage.
  - Develop or expand contingency plans for expected extreme weather conditions to include the potential for gear loss (e.g., removal of vulnerable equipment).
  - Monitor weather forecasts and implement contingency plans when necessary.
  - Integrate monitoring schemes into farm management plans and evaluate the plans on a regular basis. Offer incentives to farmers who comply with monitoring efforts.
  - Report accidental losses of aquaculture equipment and infrastructure to the relevant authority and record events in a logbook with all information about the loss.
  - Have in place a tracking and labelling system (e.g., serial numbers on gear) to facilitate monitoring, identification and retrieval of lost gear.
  - Introduce annual maintenance contracts (AMC) between aquaculture farmers, equipment manufacturers and other service providers to carry out regular checkups of entire aquaculture farming infrastructure to maintain gear and other equipment, and to repair and recover any damaged gear and other equipment after a storm (even if the damaged items are located in another country bordering the same sea basin).
  - Create a communication channel that connects all involved stakeholders with the aim to recover items that have been lost, broken or abandoned by farmers.
  - Clearly mark and light aquaculture facilities and ensure the facilities are located on navigation charts.

[11] https://www.gov.scot/publications/technical-standard-scottish-finfish-aquaculture/
[12] https://www.regjeringen.no/globalassets/upload/kilde/fkd/bro/2005/0013/ddd/pdfv/255320-technical_requirements.pdf

RECYCLING AND RESPONSIBLE DISPOSAL APPROACHES

- Plastics used in aquaculture should be designed, manufactured and sold with an environmentally acceptable, affordable and accessible solution available to the user once the equipment has reached its end of life.
- Maximize the reuse of plastics. This may mean buying high specification items rather than cheap single use alternatives[13], and possibly investing in recovery, cleaning and redistribution. Engage with equipment suppliers to maximize the use of recyclable plastics in aquaculture equipment. Obtain information on what plastics are used and in what components, to assist with sorting and recycling.
- Practice preventative maintenance where plastic and other components are replaced (i) before the risk of failure starts to increase and (ii) before the component is so damaged by environmental conditions (e.g., UV light, salt, etc.) that recycling is no longer technically or economically possible.
- Ensure that there are systems in place to facilitate the reuse of plastics and other materials. This could include a sorting system, waste collection points, wash plants, and storage and inventory systems. Set up collaborations between farmers, port authorities and gear producers to locate and establish collection points for the disposal of aquaculture equipment in port reception facilities.
- Encourage deposit schemes, e.g.:
  - Grant a discount on subsequent purchases: This would allow for a farmer to bring back items used to the seller/manufacturer and get a discount on the price of the following purchase depending on the weight/volume/quantity returned.
  - Return a deposit: This would call for the farmer to leave a deposit when purchasing equipment, and to get that deposit back from the seller/manufacturer once the farmer returns the used items.

[13] An example might be buying reusable gloves rather than commonly used single use latex versions.

- Foster joint responsibility: Ensure that the responsibility of recycling is extended to the producers and do not leave it as the sole responsibility of the farmer.
- Cooperate in handling waste with other industries/neighbor states.
- Develop a recycling policy and associated management systems, e.g.:
  - Develop a plastics inventory to track recyclable plastics and their status on site.
  - Establish facilities and standard operating procedures (SOPs) for decommissioning equipment and recovering plastic (and other) components for recycling.
- Have larger companies consider working with aquaculture small-medium enterprises (SMEs) to collect recyclable waste and add that waste to their own managed waste streams.
- Develop decommissioning plans for farm sites that are closing down, to ensure that all plastic elements are disposed of responsibly (e.g., sold to other businesses, recycled, etc.).
- Encourage the inclusion of decommissioning plans, liabilities and responsibilities in operating permits. Some U.S. states require new aquaculture lease holders to establish a bond when beginning their operations. If the farm shuts down, the bond helps to cover removal costs.

TRAINING AND AWARENESS-RAISING APPROACHES

- Develop and implement staff environmental awareness training to motivate better practices. Develop and implement SOPs for maintenance, contingency and other regimes to promote good practices.
- Develop management and staff awareness about the need to reuse (rather than replace with new) equipment and fittings, even if this requires additional training.
- Support campaigns organized by the public sector to increase customer awareness that higher prices (derived from new EPR systems in place, alternative materials, certification by an independent body such as ASC, etc.) are related to better environmental quality of the aquaculture product.
- Develop branding or labelling to raise awareness about gear loss among consumers.
- Introduce a community reporting system to identify and address gear loss and littering from aquaculture facilities.

4.1.2 MITIGATION

Compared to capture fisheries equipment (which is specifically designed and rigged to catch fish in the wild), there are relatively few options for mitigating the potential for aquaculture-derived debris or litter to ghost fish once lost. There are, however, useful lessons to be learned from the capture fisheries sector on mitigation approaches (see GGGI, 2021).

One possible approach is the introduction of biodegradable materials for single use plastics used in aquaculture, such as cable ties, shellfish bag fasteners and feed sacking. However, there are challenges associated with this, especially if such items are expected to last a long time (e.g., cable ties fixing shellfish bags to trestles).

There is also the opportunity to replace large-mesh (e.g., predator) plastic nets with biodegradable materials. While there has been some research into biodegradable netting in the fishing industry (Kim *et al.* 2015), there are still considerable challenges around affordability, performance and durability. A success story, though, regards the mussel socks used for mussel suspension cultures and mussel larvae collector installations, made from biodegradable materials and in use in the

Netherlands. Continuous longline mussel culture using cotton socking has significantly reduced the use of plastic socks and dropper lines that used PE rope tied to header lines. These small pieces of rope are cut at harvesting and are often lost overboard. Another success story is that In Ireland, spat are increasingly being collected on reusable "hairy" rope and encased in biodegradable cotton mesh, replacing single use plastic mesh. Oyster growers can reuse bags for up to 10 years, often repairing tears (Gráinne Devine, BIM, pers. comm., March 2021).

There are now a number of initiatives looking to develop fishing gear and aquaculture equipment that have biodegradable components and are more easily recyclable. One such initiative is the EU-funded INdIGO (Innovative Fishing Gear for Ocean) project, which commenced in late 2020. This cross-border France–England project has four key components: (i) a situational analysis, (ii) new gear development, (iii) a study of marine aging of plastics and the environmental impact of new materials and (iv) a "psycho-ergonomic approach" to integrate end users at each stage of the development of the new gear. This four-year project aims to reduce the amount of plastic in the Channel area of the UK and France by 3% through the development of biodegradable fishing equipment.

One issue is that currently there is no agreed standard for "biodegradability" in the aquatic environment, and questions remain about whether biodegradable materials truly degrade in these conditions and, if they do, whether they simply break down into harmful microplastics. Until this is resolved, many operators will avoid such materials.

4.1.3 RECOVERY AND REMEDIATION

- The reporting of the loss or abandonment of aquaculture equipment is needed. This is not trivial, will need minimum quantity thresholds set, and has considerable challenges involved (e.g., to whom reports are made, how information is compiled, how this reporting can be made global). However, given the advantages (e.g., alerting other marine users to the possible presence of large floating objects) and the contribution it could make to quantifying and analyzing aquaculture-derived debris, the impacts of this reporting could be significant.
- Develop SOPs for locating and recovering lost or abandoned aquaculture equipment, including:
  - Accurate inventory of the material used, and material exiting operations, so that the identification of items that get more easily lost, and the consequent development of a mitigation plan, can be put in place.
  - Recurrent litter collection within and outside the site to clear and responsibly dispose of any items lost during routine operations.
  - Integrated and standardized monitoring schemes with guidelines and recurrent fixed timeframes to get standardized results. This could be done internally, in collaboration with other sectors or facilities, or outsourced. The techniques used could vary among diving operations, ROVs, drones, and other techniques when applicable, such as using the correlation between biomass and material losses.
  - Emergency recovery of lost equipment/debris after accidents, severe weather events and other unexpected events.
  - Clear labelling to allow for the easy identification and origin of any recovered aquaculture equipment and components, and to facilitate the return of these components to their owners.
  - For key equipment that is at risk of loss, embedding GPS transmitters, RFID technology, and/or other tracking devices.

4.2 IMPLEMENTATION MECHANISMS FOR AQUACULTURE FACILITY MANAGEMENT

Having looked at the different management approaches and measures for preventing, mitigating and remediating lost aquaculture-derived debris and litter, this section examines how these approaches and measures have been applied in practice. The purpose is to help identify how best practice might best be applied, e.g., through (i) legislation and other regulatory approaches, (ii) voluntary actions, possibly via a code of conduct, (iii) third-party aquaculture certification and/or (iv) improved awareness and information.

4.2.1 LEGISLATION AND OTHER REGULATORY APPROACHES

One main implementation approach to the management of aquaculture installations is mandatory legislation. This option is the primary means for authorities to influence sectoral behavior. The advantage of legislative measures is that they can be required of all businesses and individuals and compliance can be reinforced through punitive measures. However, it is often challenging to develop broad legislative mandates that have sufficient detail to provide effective requirements, and implementation and enforcement depends on funding.

One example of legislation contributing to reduced installation failure in aquaculture is the Norwegian Standard NS 9415 (Standard Norge, 2009) and the subsequent Norwegian Ministry of Fisheries and Coastal Affairs' NYTEK[14] (2012) Regulations. The NS 9415 standard guides the site surveys, risk analysis, design, dimensioning, production, installation and operation of an aquaculture facility. It provides a proven framework that an organization can follow. In addition, NS 9415 defines the requirements for the components of a fish farm including: net pens, floating collars, rafts and mooring equipment and connections (see Berstad and Heimstad, 2017).

[14] Regulations on technical standards requirements for floating aquaculture facilities (NYTEK regulations). See https://lovdata.no/dokument/SF/forskrift/2011-08-16-849

Interior of a closed-system shrimp farm

In the EU, two recent directives have implications for the use of plastics and other persistent materials in aquaculture. They are the (i) directive on the reduction of the impact of certain plastic products on the environment (the Single Use Plastics Directive, also referred to as the SUP Directive) and (ii) the revised Directive on Port Reception Facilities (PRF) for the delivery of waste from ships (the PRF Directive), both of which entered into force in 2019. The SUP Directive targets the 10 single use plastic products most often found on Europe's beaches and seas, including from aquaculture and fishing. The SUP and PRF directives complement each other, in particular through the application of extended producer responsibility (EPR) schemes for the financing of waste collection from fishing and aquaculture. Under the EPR schemes, manufacturers and producers of aquaculture equipment and their assembling elements (ropes, twines) will be responsible for the organization and costs of the separate collection of waste gear from ports and for their subsequent transport and appropriate treatment. These measures are coupled with the obligation to conduct awareness raising measures about farm components at particularly high-risk of loss.

From a search through FAOLEX database[15] of the United Nations Food and Agriculture Organization, there appear to be few examples elsewhere of legislation relating to the pathways and risk of debris loss from aquaculture. In India, the "Guidelines for Regulating Coastal Aquaculture" (Coastal Aquaculture Authority, 2005) state, "Good site selection and incorporation of mitigatory features in the farm design are the best ways to avoid problems related to flood levels, storms, erosion, seepage, water intake and discharge points." In New Zealand, the Rock Oyster Farming Regulations (1964)[16] state, "No person shall erect any structure in any leased area unless the structure is designed and constructed with due regard to such circumstances as might reasonably be expected to arise from tidal action, stress of either, storm, flood, or like occurrences which may constitute a hazard to navigation in the event of the structure or any part thereof breaking adrift."

In general, specific requirements for governing the loss of aquaculture equipment are unlikely to be in regulations themselves, but they may be required through planning controls, EIAs, licensing approvals, and development rights[17]. In many countries, there is not much more than general EIA and aquaculture licensing controls (e.g., applicants must demonstrate what environmental risks are present, including those from storms/floods, and how they will be mitigated). In these cases, EIA and/or aquaculture guidelines (if they exist at all) could potentially refer to risks of equipment damage from natural events. In countries where there are more comprehensive controls, these are more likely to be found in standards or specific requirements in guidelines. In the Norwegian exampled covered above, the technical requirements for cage design are specific in NS 9415 and are legally required in order to obtain a license.

The International Maritime Organization (IMO) and its Marine Environment Protection Committee (MEPC) has established Annex V of the International Convention for the Prevention of Pollution from Ships (MARPOL). The latest version of MARPOL Annex V (IMO, 2017) does not specifically mention aquaculture as a source of ship-based pollution, but it does cover a number of generic waste items that might be generated by aquaculture activities, such as nets, rope and some fish harvest gear (e.g., brailers).

15 http://www.fao.org/faolex/en/
16 http://faolex.fao.org/docs/texts/nze84984.doc
17 Development rights, whether through regulatory processes or separately via the granting of access rights to require a security to cover decommissioning and disposal of an installation in the event of business default. While this is intended to prevent major dereliction and hazards, it is also burdensome on business as an upfront cost. There is the potential to link the requirement for a security to plastics management and site maintenance where noncompliance will trigger the requirements for said security.

4.2.2 VOLUNTARY ACTIONS AND GUIDANCE

The majority of measures investigated in Section 4.1 can be implemented through voluntary means. This rather broad category can include the following approaches:

Codes of Practice: Codes of Practice (CoP) are sets of rules, usually established by a representative or umbrella body, to harmonize and improve the conduct of its members. CoP are widely used in the fishing industry to develop and formalize a collective best practice approach, sometimes as support to a third-party certification initiative. For instance, the "Code of Good Practice for Scottish Finfish Aquaculture" (CoGP) includes specific guidance on how waste materials should be collected and responsibly disposed of (SSPO, undated).

Voluntary agreements: Another voluntary approach is the establishment of agreements between different parties to improve coordination and reduce the potential for misunderstanding and conflict. These are well established in capture fisheries (e.g., the South Devon Inshore Potting Agreement (IPA) in England), but they are less well-established in aquaculture circles.

Good and responsible design: A third approach, and one rather different from those preceding, is encouraging good and responsible design. This covers a number of different areas, including the design of pens/cages, nets, mooring systems and feeding systems.

4.2.3 THIRD-PARTY AQUACULTURE CERTIFICATION

The last two decades have seen a rise of seafood-related ecolabels, mainly Type I[18] voluntary, multiple criteria-based schemes such as the ASC, GLOBALG.A.P. and Best Aquaculture Practices (BAP). Ecolabelling in fisheries and aquaculture has emerged in response to a public and industry perception that public mechanisms alone (i.e., policy and regulation) have failed to adequately manage the sustainability of aquatic resources. Ecolabelling is seen as providing incentives that

18 ISO, 2012, Environmental labels and declarations: how ISO standards help. Available at: http://www.iso.org/iso/environmental-labelling.pdf


Salmon farm and support buildings, Norway

drive improvements in fisheries and aquaculture management by rewarding best practices. These rewards are said to include market access, price premiums and consumer satisfaction. As such, co-labelling is seen as a tool with which to encourage industry to address shortfalls in fisheries and aquaculture policy, regulation and management (MRAG *et al.* 2015). MRAG *et al.* (2015) mapped over 100 seafood ecolabelling schemes, mapping 73 in detail. Of these, only 16 covered capture fisheries and a further 27 covered capture fisheries as well as aquaculture. While we have not done a definitive appraisal of all of these aquaculture-related ecolabelling schemes, there are currently limited explicit references assessing and including the potential for ghost fishing in assessments.

To date, most aquaculture certification schemes have focused on biological waste issues (e.g., the release of metabolic and fecal waste, pathogens and genetic material into the wider environment), but have yet to focus on nonbiological waste. The ASC has developed a number of standards that allow for third-party certification of aquaculture systems around seven principles and criteria to minimize environmental and social impacts. At present, these standards do not include a common criterion that covers debris from aquaculture, although some standards do include some relevant considerations such as the "handling and disposal of hazardous materials and wastes" (Shrimp, Criterion 7.7) and "managing non-biological waste from production" (Salmon, Criterion 4.5). The ASC is currently considering how to further incorporate waste management considerations in its species-based standards. A recent ASC White Paper (Huntington, 2019) is based on ASC's "5 Rs" approach—Reduce, Reuse, Recycle, Recover, Refuse—to help address negative impacts of aquaculture equipment and plastic waste from aquaculture.

4.2.4 IMPROVED AWARENESS, INFORMATION AND OTHER INITIATIVES

The final set of implementation approaches mainly revolves around greater stakeholder awareness of the issue and how it can be provided, the provision of more information to assess and combat aquaculture-derived aquatic debris loss and its consequences, and possible manufacturer-related initiatives to limit gear loss and its impacts.

One such approach has been the development of the AQUA-LIT[19] "toolbox" an EU-funded project to prevent aquatic debris from aquaculture. The toolbox provides more than 400 ideas and solutions–from prevention to recycling–to tackle aquatic litter in the aquaculture sector. These solutions were co-developed with aquaculture stakeholders in Europe based on the barriers they encountered in trying to devise a good aquatic litter management plan. The toolbox also includes information about which ports have facilities to receive waste, a database of funding opportunities for aquatic litter projects, an aquatic litter inventory that provides an overview of available knowledge on aquatic litter originating from the aquaculture sector, a set of policy recommendations for EU member states and specific action plans for outermost regions.

Although aimed mainly at European stakeholders, many of the AQUA-LIT solutions are applicable to other regions and contexts. The project has also produced a number of useful reports, including one on policy recommendations to reduce aquaculture litter (Hipólito *et al.* 2020); a selection of best practices applied to different sea basins (AQUA-LIT publication, 2020); an overview of global, regional, European, and national action plans and documents that contain measures to reduce or avoid aquatic litter from the aquaculture sector (Devriese *et al.* 2019); and an evaluation of the potential impacts of the aquaculture sector by 2025 regarding nonorganic aquatic litter (Vidal *et al.* 2020).

19 See https://aqua-lit.eu/

5 BASIC PRINCIPLES FOR THE BEST PRACTICE FRAMEWORK FOR THE MANAGEMENT OF AQUACULTURE GEAR

5.1 SCOPE

The scope of the Best Practice Framework (A-BPF) is as follows:

- **Geographical:** Worldwide.
- **Environments:** Marine, transitional and freshwaters.
- **Production systems:** This covers all aquaculture production systems (see Section 2.2). However, the risk analysis (see Table 5) indicates that open water cage, coastal and inland pond systems are those with the highest risk, so they are the primary focus of the A-BPF, although lower risk systems are also covered. Likewise, the focus is mainly on grow-out systems, which operate at a larger scale and often in less controlled situations than hatcheries (and, to a lesser extent, nurseries).

  While most of the A-BPF is focused on aquaculture installations themselves, it is also recognized that there is a need to include fabrication/assembly within the scope of the A-BPF, since many production systems are put together either in situ or more commonly on adjacent foreshore where plastic wastes can arise from processes such as fusion welding, drilling for access platform attachments, etc. These processes may not be undertaken by aquaculture operators themselves who may not be aware of this impact.
- **Material composition:** While it is recognized that aquaculture can produce metal, rubber, steel, natural fibers and wood-based debris and litter (Sandra *et al.* 2020), plastics are likely to form the majority of material emanating from aquaculture. Given their persistence and negative effects in the aquatic environment, combined with their ability to break down into micro- and nanosize particles, plastic-based debris and litter (see Section 3.1 for definitions) are prioritized in the A-BPF. However, the A-BPF also covers other materials commonly used in aquaculture, such as steel and wood.
- **Size and nature of material:** The A-BPF covers both debris (e.g., broken parts of containment or other aquaculture infrastructure, usually fairly large in nature) and litter (e.g., lost or discarded materials, usually fairly small in nature and often made up of single use plastics (SUPs)[20]. The A-BPF also includes measures to reduce the level of abrasion in aquaculture, a significant source of primary microplastics[21].

[20] Single use plastics, often also referred to as disposable plastics, are commonly used for plastic packaging and include items intended to be used only once before they are thrown away or recycled. In the aquaculture context, these might include feed bags, spare part packaging, non-reusable cable ties, etc. See UNEP (2018).

[21] Primary microplastics are plastics directly released into the environment in the form of small particulates.

5.2 PURPOSE AND PRINCIPLES

The **purpose** of the Best Practice Framework is to provide clear guidance to a range of relevant stakeholders—including but not limited to seafood businesses, the aquaculture industry, certification programs and local and national authorities/governments—on how to effectively address the issue of aquaculture-derived plastics in the aquatic environment.

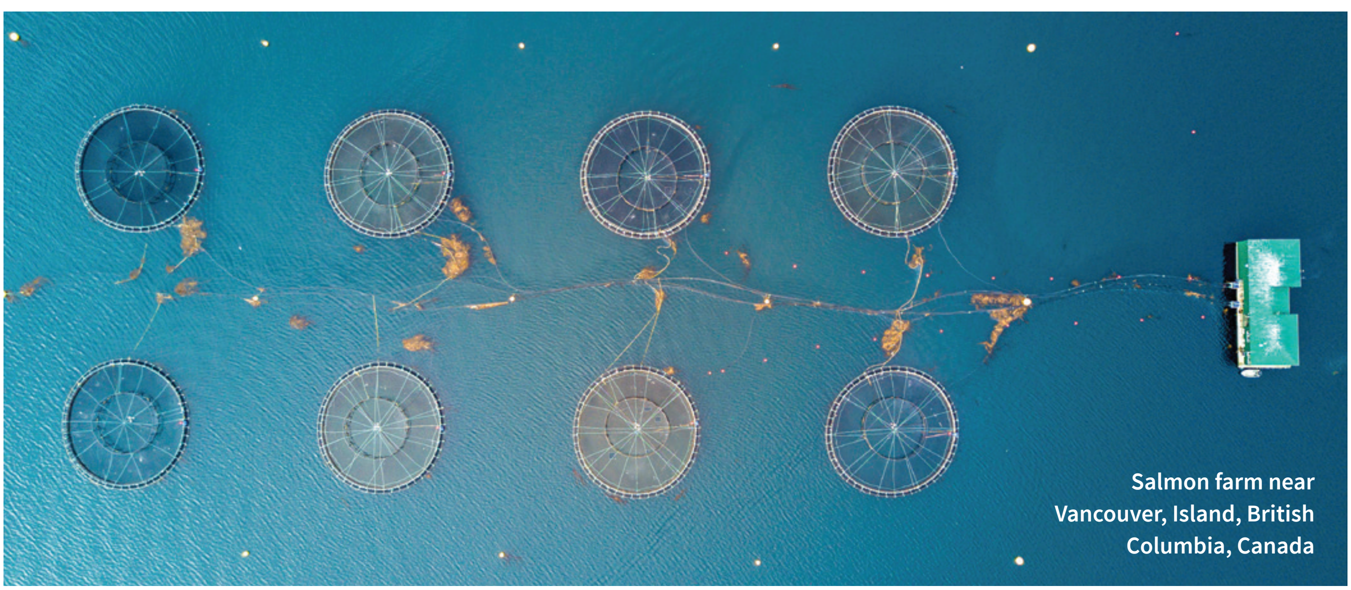
The basic principles of the A-BPF are as follows:

- Management responses to preventing the accumulation of aquatic debris from aquaculture will vary, depending on the type and scale of aquaculture involved. In any case, prevention is preferred over mitigation and remediation for reasons discussed in section 4.1 above. Therefore, the A-BPF focuses on preemptive prevention in particular.
- Likewise, the focus of the A-BPF is on large plastic debris originating from aquaculture grow-out operations, but it also covers other materials, large and small, from all aquaculture operations, both terrestrial and in the water.
- Although, as noted above, appropriate management responses will likely be specific to different aquaculture types and scales, the A-BPF is generic in approach to ensure maximum applicability.
- The framework is aimed at a wide range of stakeholders, both private and public, nongovernmental and governmental.
- The A-BPF allows aquaculture stakeholders to engage in an informed and structured fashion, allowing for the development of strategies for facilitating change in the operation and management of aquaculture facilities so that the impact of aquaculture-derived aquatic debris is minimized in the future.

In recognition of the diverse roles and responsibilities different stakeholders (see section 5.3 for more details) have in aquaculture, the framework attempts to identify best practice approaches for individual stakeholder types.

In each case, the same structure is used:

- **Principles of best practice:** includes a brief statement about the role of the stakeholder in aquaculture and its governance and provides a brief set of basic principles of ”best practice”.
- **Key best practice actions and approaches:** advocates a set of ”best practices” and principles addressed to the stakeholders in each section.



Salmon farm near Vancouver, Island, British Columbia, Canada

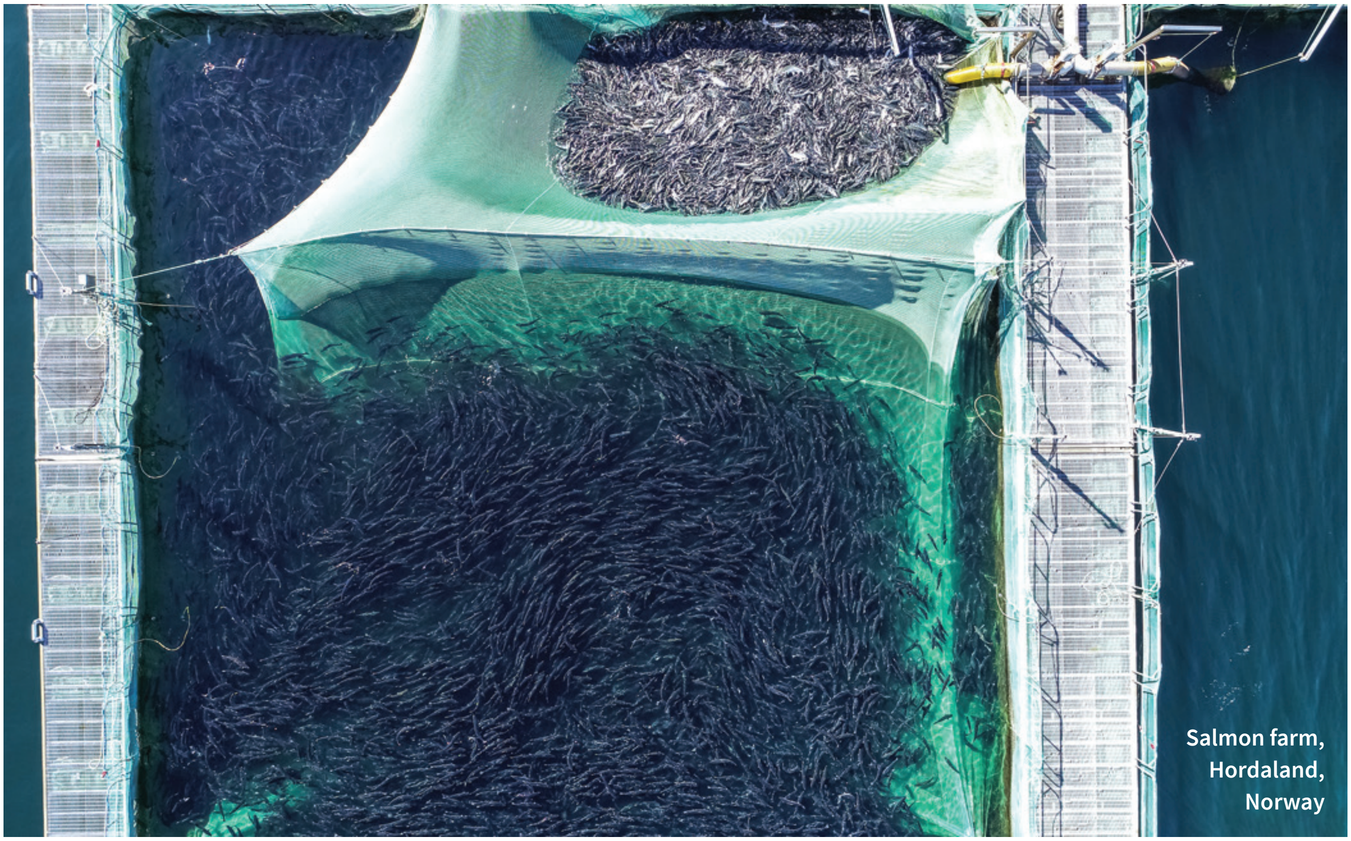
5.3 STAKEHOLDERS ADDRESSED BY THESE GUIDELINES

Stakeholder Group	Role	Best Practice Areas
1. Equipment designers, manufacturers, distributors and installers	Businesses involved in the design, production, presale distribution, sale and installation of aquaculture equipment.	Embedded traceability; research into and use/integration of natural or biodegradable materials; commitment and innovation around circular economy principles. Should include manufacturers of fish cages, nets, tanks, feeding systems and ancillary equipment (e.g., aerators, etc.).
2. Aquaculture operators	The individuals or organizations managing and operating aquaculture sites and supporting facilities.	Conducting risk assessments for losing gear; in/out inventories for key farm components, especially if deployed offshore; keeping a logbook and registering all gear losses; ensuring that moorings and other critical infrastructure are maintained and can withstand extreme conditions; training of staff to reduce littering rates; SOPs for high-risk events and, if necessary, for post-event recovery; responsible decommissioning of reduced/fallowed farming operations.
3. Aquaculture producer associations	Nonstatutory organizations representing aquaculture businesses. Most producer associations are organized around a region (e.g., transboundary, national or local) and/or a theme (e.g., species or system-based).	Codes of Practice specific to aquaculture; spatiotemporal agreements with other marine space users; scheduled maintenance and monitoring of facility and gear losses; communication protocols; feasible EPR schemes based on circular economy and 5Rs approach.
4. Harbor and port operators	Bodies operating and managing ports servicing aquaculture operations.	Accessible, low-cost gear and litter disposal and sorting facilities; implementation of deposit schemes; integration into recycling initiatives; better awareness of responsible disposal opportunities.

Stakeholder Group	Role	Best Practice Areas
5. Aquaculture sector managers and regulators	Statutory management bodies setting policy, plans and regulations for aquaculture activities.	Designation of spatiotemporal restrictions in high-risk areas; development of appropriate farm marking and identification regulations; conducting impact assessments to gauge unintended consequences of management actions on equipment and gear loss; asking for monitoring schemes and decommission plans as part of the criteria for the licensing process; use of lodged bonds or securities to fund recovery in the event of business default.
6. Fisheries, environmental protection and waste management agencies	Bodies or agencies responsible for enforcing aquaculture and associated environmental regulations, including waste management.	Establishing registries and databases of lost/abandoned aquaculture facilities; registries and databases for encountered aquaculture-related debris; enforcement of farm lighting, marking and identification regulations.
7. Aquaculture and marine environment researchers	Government or private sector organizations conducting research and development.	Development of improved containment systems that minimize the risk of both catastrophic loss and low-level littering; improvement of monitoring technologies to reduce costs and increase efficiency; optimization of aquaculture equipment material and life-cycle steps; alternative materials research; innovation on automated seafloor waste collection systems; a knowledge sharing platform; more efforts on modelling of floating aquatic litter; cooperation with gear producers.
8. Seafood ecolabel and certification programs	Organizations setting and maintaining third-party audited standards for responsible sourcing of seafood.	Aquaculture facility and gear loss needs to be included in all seafood sustainability standards, with supporting guidance provided where necessary; label on good aquatic litter management.
9. Seafood companies in the aquaculture value chain	Processors, wholesalers and retailers utilizing seafood products from aquaculture.	Ensure seafood sourcing avoids high-risk aquaculture operations and that they participate in relevant initiatives (e.g., equipment recycling) where possible.

Stakeholder Group	Role	Best Practice Areas
10. Nongovernmental organizations	Nongovernmental advocates for sustainability and good practices.	Coordination of advocacy, actions and information gathering; contributing to a centralized aquatic debris/ghost fishing information hub/forums (such as the GGGI global data portal[1]); organizing aquaculture debris and litter recovery in vulnerable areas; pressure for producers to implement good aquatic litter management practices.
11. Other rights holders and stakeholders potentially impacted by aquaculture operations	Other stakeholders with an interest in the A-BPF might include wild capture fishers, local and indigenous communities, local and regional planners, etc.	Recording and reporting both critical and chronic loss of debris and litter from aquaculture.

1 https://globalghostgearportal.net/login.html



Salmon farm, Hordaland, Norway

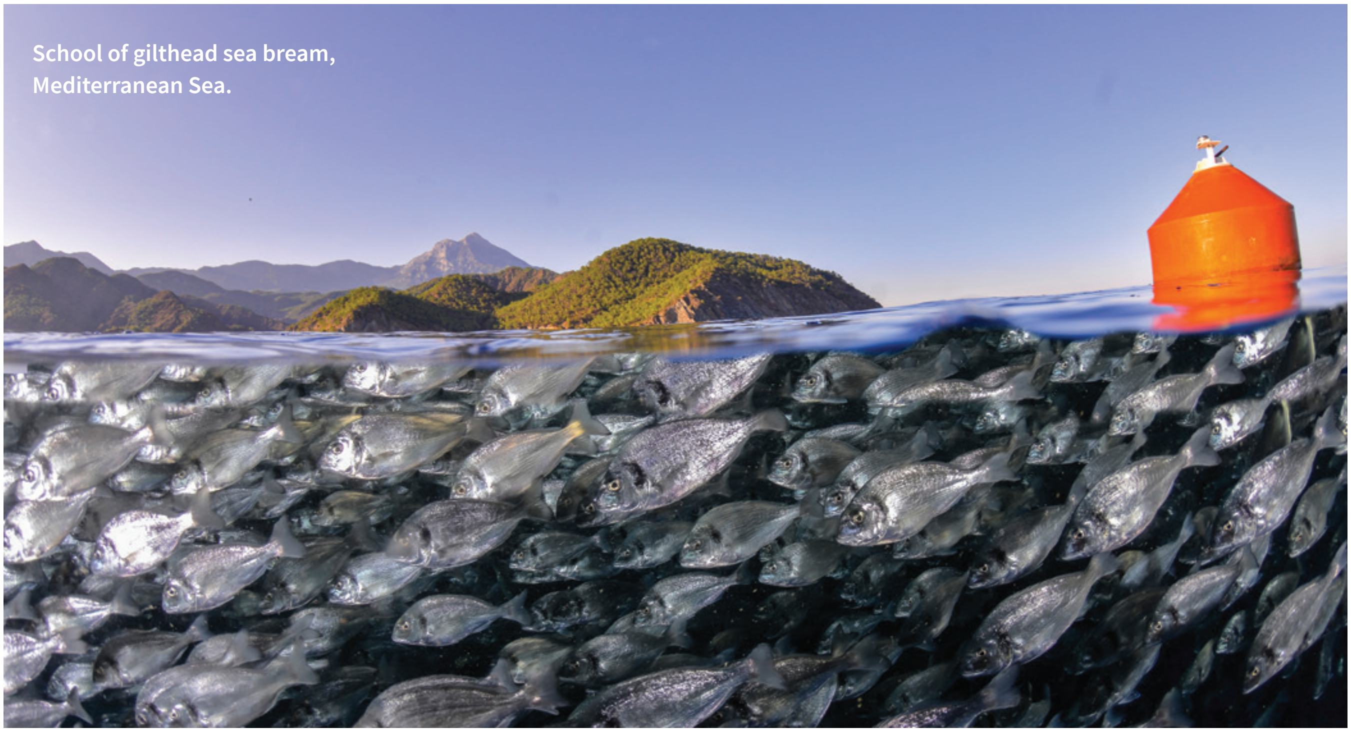
6 THE BEST PRACTICE FRAMEWORK FOR THE MANAGEMENT OF AQUACULTURE GEAR

6.1 AQUACULTURE EQUIPMENT DESIGNERS, MANUFACTURERS, DISTRIBUTORS AND INSTALLERS

6.1.1 PRINCIPLES OF BEST PRACTICE

Aquaculture equipment covers a wide array of equipment from net pens and tanks to nets, ropes, buoys and ancillary materials. As increasingly recognized by aquaculture equipment manufacturers, they have an important role to ensure that their products are designed, used and subsequently disposed of in a responsible manner. In particular, adopting circular design principles of reducing the complexity of materials used (to aid recovery and reprocessing) and ensuring any adoption of new materials avoids unintended consequences.

This may include (i) improving the opportunities for embedding traceability into major gear components, (ii) the buyback of old equipment for reconditioning or recycling into new products (possibly allied to deposit schemes for returned gear), and (iii) sponsorship and/or implementation of responsible gear disposal schemes.


School of gilthead sea bream, Mediterranean Sea.

6.1.2 KEY BEST PRACTICE ACTIONS AND APPROACHES: AQUACULTURE EQUIPMENT DESIGNERS, MANUFACTURERS AND INSTALLERS

	Approach and Principle	Best Practice	Other Participants
Prevention	Design gear to reduce and ease maintenance needs and improve equipment reliability within clearly stated specifications.	• Ensure equipment has clearly stated specifications, tolerances and limitations. • Where possible, ensure that these stated product specifications, etc. are certified by an accredited certification body. • Ensure that gear/equipment development proposals include measures to demonstrate decreased use of plastics, use of recycled materials and ongoing management to avoid pollution as part of environmental impact assessment plans. • Consider the use of securities to fund recovery in the event of business default or serious mismanagement.	• Aquaculture operators • Aquaculture regulators
	Develop and introduce new materials that are simple to reuse and recycle.	• Develop materials to have a high value at their end of life to increase demand for recycling. • Avoid mixing of different materials in gear/equipment design that inhibits their recyclability. • Ensure components are easy to disassemble into different recycling streams. • Ensure materials resist fouling to reduce pre-recycling preparation. • Use materials that discourage predator interactions.	• Research and development bodies

	Approach and Principle	Best Practice	Other Participants
Prevention *(continued)*	Build in traceability for equipment and components where practical, based on an industry-wide Code of Practice (see Section 6.3.2). These gear traceability systems should be linked to standard record-keeping practices of commercial transactions. Retailers of aquaculture equipment, if different from the manufacturer, should include batch numbers in their record keeping.	• Implement a traceability system that allows for the recording of ownership transfer at the main transaction points in the supply chain from manufacture to end of life. • Develop and maintain inventories of plastics and plastic products used on installations, with records of procurement and disposal. • Work with regulators to embed licensing and other identification information into traceability data.	• Aquaculture equipment manufacturers and sale agents • Aquaculture operators • Regulators
	Design effective, integrated and cost-efficient equipment marking and lighting systems for aquaculture gear.	• Design equipment so that clear marking and lighting systems can be added to all main components to ensure their visibility under a variety of different operating conditions.	• Marine lighting engineers
	Facilitate and promote aquaculture equipment recycling and responsible disposal.	• Ensure that equipment uses recyclable plastics where possible, with components made of different plastic types easily separable for disassembly and recycling. • Support the implementation of responsible end-of-life equipment disposal schemes, including free “turn it in” depots in key fishing and aquaculture areas.	• Port operators • Recycling companies
	Move to EPR to add the environmental costs associated with a product throughout the product life cycle to the value chain.	• Build in the responsibility and costs for the recovery, recycling or otherwise responsible disposal of end-of-life aquaculture equipment. EPR may take the form of a reuse, buyback or recycling program. • Investigate financing/end-of-life equipment takeback schemes for smaller operators aspiring to be responsible.	• Regulators

Approach and Principle		Best Practice	Other Participants
Mitigation	Collaborate with aquaculture operators, industry organizations and researchers to test and improve equipment design and materials.	• Reduce the use of potentially damaging material in aquaculture equipment (e.g., the use of expanded polystyrene (EPS) or other similar materials that break up and abrade when released into the environment). • If EPS or other friable materials are to be used, implement restrictions such as their being fully encased in a rigid, durable, non-toxic shell such as thick HDPE. • Ensure major equipment components are easily visible (e.g., to reduce their navigation risk to other marine users) if lost or abandoned.	• Research and development bodies • Aquaculture operators
Remediation	Research and develop materials and equipment designed to facilitate its recovery if lost or abandoned.	• Ensure major equipment components are easily located (e.g., through markings, radar reflectors, RFID tracking, passive acoustic transponder tags, lighting and GPS tracking devices).	• Research and development bodies
	Collaborate with management authorities to assist in tracing the origin and ownership of recovered aquaculture equipment.	• Encourage and facilitate industry-wide agreement of data embedding, coding and other practices. • Encourage recording of aquaculture equipment/component production and transaction points to be made available to management authorities upon request.	• Aquaculture regulators • Aquaculture operators

6.2 AQUACULTURE OPERATORS

6.2.1 PRINCIPLES OF BEST PRACTICE

Businesses or individuals owning and operating aquaculture facilities are key stakeholders in these guidelines. The partial or even complete loss of aquaculture equipment and farming units is an ever-present risk, especially in exposed or otherwise vulnerable locations.

Aquaculture operations therefore need to identify the key risks to the safety and security of their infrastructure and plan for possible loss. This can then be mitigated through careful site selection, monitoring schemes, robust and preemptive maintenance regimes and farsighted risk assessment and contingency planning.

6.2.2 KEY BEST PRACTICE ACTIONS AND APPROACHES: AQUACULTURE OPERATORS

Approach and Principle		Best Practice	Other Participants
Prevention	Ensure that farm operations are risk-assessed to allow for proportionate, targeted and effective approaches to aquaculture facility management.	• Conduct formal risk assessments to ensure that potential vulnerabilities that might result in infrastructure failure or loss are identified, that the likelihood and potential of impacts are estimated, and that appropriate contingency plans are developed (see more below). • Ensure that such risk assessments are included in aquaculture site selection, and that decision-making and mitigation approaches are developed as appropriate. • Ensure that such risk assessments are included in environmental and, where appropriate, social impact assessments where the downstream impacts of facility (and associated stock) losses are considered. • Create, use and maintain plastics inventories and records of use and disposal.	• Aquaculture sector managers and regulators • Fisheries and environmental protection agencies
Prevention	Ensure that a circular approach is taken from farm design and construction to operation and end-of-life decommissioning.	• Ensure that farm design acknowledges the extreme conditions to which the equipment might be exposed and sets sufficient specifications to mitigate these conditions. • Perform preemptive maintenance to ensure that the risk of equipment failure is minimized. • Plan for the responsible disposal of redundant or end-of-life equipment.	• Equipment designers and manufacturers

	Approach and Principle	Best Practice	Other Participants
Prevention *(continued)*	Ensure that facilities are well-managed so that equipment loss from accidents and negligent third-party actions or force majeure are minimized.	• Ensure that management and staff are provided adequate training so that (i) they are aware of the potential and impact of plastic loss into the aquatic environment and (ii) they are able to undertake the necessary protocols (e.g., SOPs) to prevent equipment failure or aquatic debris and litter loss. • Introduce annual maintenance contracts to ensure regular checks and necessary repairs/replacement.	• Aquaculture producer associations (to prepare Codes of Practice) • Equipment suppliers
	Develop corporate policies for the use and disposal of solid, nonbiological waste.	• Develop corporate policies for (i) the management of solid, nonbiological waste, with a particular focus on plastics and other persistent materials; (ii) the minimization of the use of SUPs in farming operations; and (iii) the monitoring of waste management effectiveness at farm/organizational levels. • Avoid the use of small, light plastic items that are prone to be lost in windy or other challenging environments. • Consider certification to environmental management systems such as under the ISO 14001 standards.	• Port operators • Aquaculture Regulators
	Participate in research programs to test novel approaches under commercial conditions.	• Be open to pilot-testing new materials, procedures and traceability systems to assist them to become cost-effective alternatives to traditional approaches.	• Research organizations
Mitigation	Use natural or biodegradable synthetic materials where possible, especially for short-term or single use plastic applications.	• Use biodegradable materials where possible. While biodegradable materials are not typically suitable for long-term applications, they may be useful for short-term fixes. For instance, the use of biodegradable cable ties might be considered for shellfish bags that are intermittently opened and closed within their working life. However, the impacts of biodegradable materials on the local environment need to be considered (i.e., potential rapid degradation into microplastics).	• Equipment designers and manufacturers • Aquaculture and aquatic environment researchers

	Approach and Principle	Best Practice	Other Participants
Mitigation *(continued)*	Establish contingency plans to minimize infrastructure loss due to extreme weather or other events threatening farm infrastructure.	• Design contingency plans and SOPs in advance of known risk events. These plans and procedures might include: – Reinforcing moorings, moving or (in the case of submersible cages) sinking cages and moving staff and unnecessary equipment to safety. – Putting extra/specialist staff on standby. – Caching or stockpiling emergency equipment and supplies at strategic locations.	• Equipment designers and manufacturers • Other stakeholders potentially impacted by aquaculture operations
Remediation	Maintain an inventory system to manage major plastic components on site.	• Establish an appropriate in/out inventory system for all key plastic components. Provide information on plastic types (polymers and products/components), approximate volumes/weights, installation date, expected lifetime and anticipated replacement date, location on farm and decommissioning plans. Connect this inventory system to an equipment labelling/tagging program.	• Equipment designers and manufacturers
	Participate in debris reporting schemes to ensure that damage to the environment and risks to safe navigation are minimized.	• Provide officially required[22] and/or voluntary data on any major infrastructure failure or loss of equipment into the aquatic environment, detailing the date and circumstances of loss, the nature of the equipment or debris and the risk it might present to other sea users or the environment. • Organize and fund local aquatic debris cleanup programs as part of a corporate social responsibility (CSR) strategy.	• Fisheries and environmental protection agencies
	Participate in equipment/farm decommission plan/bond programs.	• Voluntarily engage in decommissioning plan/bond/insurance programs when establishing new farms, to mitigate the risk of losing equipment and incurring expensive recovery costs.	• Equipment designers and manufacturers

[22] 'Officially required' refers to situations where the loss of aquatic debris must be reported by laws (see Sections 4.2.1 and 6.5).

	Approach and Principle	Best Practice	Other Participants
Remediation *(continued)*	Prepare and develop SOPs for locating, tracking and recovering lost equipment and other debris from farming operations.	• Develop preemptive SOPs for staff and others who respond to possible scenarios as identified in risk assessments, to maximize the efficiency and effectiveness of recovery operations. These SOPs could cover: – Locating, mapping and characterizing aquatic debris originating from farming operations. – Tracking the movement of, and the hazard presented by, aquatic debris originating from farming operations. – Planning and undertaking aquatic debris recovery operations (either after a specific event or on a periodic basis).	• Aquaculture producer associations
	Build corporate social responsibility and introduce a community reporting system to identify and address gear loss and littering from aquaculture facilities.	• Work with local communities to demonstrate that every effort is made to reduce the incidence of aquatic debris loss and to recover lost material at appropriate intervals. Allied to this would be a community reporting system to allow local communities to report lost, discarded or abandoned debris from aquaculture, with the expectation that the debris would be removed from the aquatic or coastal environment in due course.	• Other stakeholders potentially impacted by aquaculture operations

6.3 AQUACULTURE PRODUCER ASSOCIATIONS

6.3.1 PRINCIPLES OF BEST PRACTICE

While many actions can be effectively taken at the individual business level, collective associations or producer associations that represent certain species groups, production system types and geographical areas have the potential to address common issues among their members and to leverage cooperation and assistance from other parts of the aquaculture sector.

In particular, aquaculture producer associations and supply chain business associations can work on behalf of their members to ensure that their knowledge and concerns are incorporated into voluntary and mandatory management measures.

6.3.2 KEY BEST PRACTICE ACTIONS AND APPROACHES: AQUACULTURE PRODUCER ASSOCIATIONS

Approach and Principle		Best Practice	Other Participants
Prevention	Develop Codes of Practice on behalf of members to facilitate and encourage responsible farming operation, cooperation among members and end-of-life equipment/solid waste management.	• Identify common issues and management needs across the membership (and with other similar organizations where appropriate) to determine whether a Code of Practice might provide a set of standards and best practices to address these issues and needs at various spatial scales, including at bay or watershed levels. • Develop of a Code of Practice, identifying minimum, good and best practice levels. • Agree how a Code of Practice might be implemented, e.g., voluntary, self-certification by the fisheries organization, etc.	• Aquaculture operators
	As the use of offshore facilities and vessel-based aquaculture increases, develop means and mechanisms to comply with MARPOL's Annex V, in conjunction with regulatory bodies where appropriate.	• Encourage members to comply with MARPOL Annex V regulations on waste management at sea. If necessary (and as recognized by Article 6.4.1 in Annex V), governmental assistance might be sought in "developing resolutions, bylaws and other internal mechanisms" (IMO, 2012).	• Aquaculture operators • Aquaculture sector managers and regulators

	Approach and Principle	Best Practice	Other Participants
Prevention *(continued)*	Work on behalf of members to liaise with other aquatic economic activities and conservation initiatives, together with the competent authorities, in establishing marine spatial and temporal planning tools to minimize the potential for unwanted interactions with other sea users.	• Work with members to review the advantages, disadvantages and mitigatory options of marine spatial planning approaches (e.g., creation of formal aquaculture areas). • Work with statutory authorities involved in spatial planning to develop and encourage optimal working solutions that minimize the potential for interactions between aquaculture and other sea users. This should include navigation, capture fisheries and recreational interests.	• Aquaculture operators • Aquaculture sector managers and regulators • Other stakeholders potentially impacted by aquaculture operations
	Provide guidance to members on options for reducing aquatic debris from aquaculture.	• Provide guidance relevant to members on options for reducing the risk of aquatic debris production, including equipment and material options, projected equipment life spans, joint end-of-life equipment collection and recycling, etc.	• Equipment designers and manufacturers • Aquaculture operators
	Where aquaculture producer associations procure goods or services on behalf of their members, require suppliers to conform to best practice where applicable (e.g., Codes of Practice).	• Develop a responsible procurement strategy that requires suppliers to conform to certain standards in terms of design, quality and traceability. This strategy could be aimed at fulfilling measures in the A-BPF, but it could also be expanded to include other considerations, such as social and ethical procurement.	• Equipment designers and manufacturers • Aquaculture operators
	Liaise with third-party seafood certification bodies to address management and information requirements for reducing the impacts of debris from aquaculture on aquatic fauna, flora and habitats.	• Related to the other preventative measures mentioned above, work with aquaculture improvement projects (AIPs) and 3rd party certification bodies to ensure that members adhere to benchmarks and standards to which they are party. • A key focus will be the operational management and information requirements for best practice in waste management, in particular (i) to reduce the contribution of aquaculture to the aquatic plastic stock and (ii) to encourage the responsible use of plastics in aquaculture.	• Seafood ecolabel standard and certificate holders • Aquaculture operators

Approach and Principle		Best Practice	Other Participants
Mitigation	Develop reporting protocols for reporting the loss or abandonment of aquaculture facilities and/or their components, and develop recovery procedures on behalf of members.	• Liaise with the relevant aquaculture regulatory authorities to develop protocols and procedures for reporting the loss or abandonment of aquaculture facilities and/or their components. The nature and scope of this reporting system should reflect the scale of farming operations involved and the specific circumstances in which the loss or abandonment took place (e.g., through severe weather, accidents or equipment failure).	• Aquaculture sector managers and regulators • Fisheries and environmental protection agencies
Remediation	Identify, map and clear aquaculture-derived aquatic debris "hotspots" that represent either an operational or navigational hazard to members and others, or that represent a significant risk to the aquatic environment, including the entangling of aquatic species occupying the region.	• Periodically consult members to understand whether aquaculture-derived debris represents either an operational or safety hazard to members and others, or that might be affecting the aquatic environment and its flora and fauna. • For aquaculture subsectors where there is the low-level but persistent loss of equipment, contribute to a GIS-based reporting and mapping system (such as the GGGI global data portal) to monitor the distribution and accumulation of aquaculture-derived debris in order to support the timing and nature of clean-up operations. • Engage with the public, private and NGO sectors to investigate cost-effective methods of recovering aquatic debris from aquaculture on a routine or as needed basis. • Encourage large and small companies to cooperate in recovering aquatic debris and litter.	• Aquaculture operators • Fisheries and environmental protection agencies • Aquaculture and aquatic environment researchers

6.4 HARBOR AND PORT OPERATORS

6.4.1 PRINCIPLES OF BEST PRACTICE

Many coastal or offshore aquaculture operators use nearby ports or harbors to service their facilities. This use can cover equipment deployment and recovery, personnel transfer, the disembarking of supplies such as feed, and the landing of harvested products.

It is important that it is convenient, safe and relatively inexpensive to dispose of smaller end-of-life equipment and litter in port. Ports, and in particular port reception facilities (PRFs), should work with aquaculture operators and organizations to ensure that adequate facilities are provided. For larger pieces of equipment (e.g., pen collars and whole nets), the responsibility for their disposal will likely lie with the aquaculture operators, but port authorities should assist in facilitating the landing and transfer of those pieces of equipment through the port area. Given the relationships ports have with local government, businesses and other local interests, ports also have a potential role in catalyzing the development of the downstream recycling and disposal of received material in a responsible and cost-effective fashion.

6.4.2 KEY BEST PRACTICE ACTIONS AND APPROACHES: PORT OPERATORS

	Approach and Principle	Best Practice	Other Participants
Prevention	For ports servicing offshore aquaculture operations, provide affordable facilities for the landing and, where appropriate, temporary storage of redundant, end-of-life or recovered aquaculture equipment. This may require public funding to ensure affordability.	• Consider the likely needs of the fast-growing coastal and offshore aquaculture sector in vessel traffic forecasts and landside needs analyses as part of recurrent planning and development processes. This should cover, but not be limited to: – The transfer and possible temporary storage needs of large aquaculture infrastructure components, bulk feed and other supplies through port facilities. – The landing, temporary storage (including space for sorting and disassembly) and responsible disposal of end-of-life aquaculture equipment. – Inclusion of end-of-life aquaculture equipment into port waste management plans where appropriate.	• Aquaculture producer associations • Aquaculture sector managers and regulators • Fisheries and environmental protection agencies
	Where necessary, develop agreements between aquaculture operators and fishing-orientated ports to address common waste disposal problems.	• Some traditional fishing harbors may focus on capture fisheries interests rather than on aquaculture operators. Common ground may need to be found, including regarding cost-sharing, to build on synergies and shared end-of-life gear/waste disposal issues.	• Aquaculture associations

	Approach and Principle	Best Practice	Other Participants
Prevention *(continued)*	Provide waste sorting, cleaning and disposal facilities for aquaculture-derived debris and litter recovered by third parties, such as fishers and those involved with aquatic litter retrieval initiatives.	• As required by IMO's MARPOL Annex V, signatory states must provide "adequate facilities at ports and terminals for the reception of garbage without causing undue delay to ships, and according to the needs of the ships using them" (IMO, 2012). • Offer sorting systems for different materials, e.g., between light plastics (e.g., PE, PP, etc.) and high-density polymers (e.g., PA, PET, etc.).	• Fisheries and environmental protection agencies • Waste disposal businesses • Other stakeholders potentially impacted by aquaculture operations
	Develop agreements with aquaculture equipment manufacturers and recycling businesses to maximize opportunities for cost-effective and environmentally responsible disposal of landed waste.	• Assist aquaculture facility operators, companies and organizations to "work with national and local government officials, regional administrators, commercial interests, and local waste disposal infrastructure managers to develop landside waste disposal strategies, including waste segregation, that encourage reduction, reuse, and recycling of ship-generated wastes landed ashore at PRFs" (IMO, 2009).	• Fisheries and environmental protection agencies • Aquaculture operators • Aquaculture producer associations
	Exchange information with IMO's Port Reception Facility (PRF) database to ensure that specialist reception facilities are easily located.	• Communicate to country focal points accurate and up-to-date information about fishing gear and other waste reception facilities available at port. This information can then be communicated to the fishing industry via the IMO's PRF database, accessible through the IMO Global Integrated Ship Information System (GISIS) website (https://gisis.imo.org/Public/Default.aspx).	• Fisheries and environmental protection agencies • Aquaculture sector managers and regulators
Remediation	Provide a common forum (e.g., notice boards, web fora, other communication) for port users on (i) prevention and mitigation approaches and (ii) relaying reports of aquatic debris (including from aquaculture) to other mariners.	• Display and promote information at the port on the management and responsible disposal of plastic waste and retrieved debris from aquaculture and other sources. • Develop a system to compile and exchange information on lost fishing gear and other potential navigation hazards with all maritime traffic.	• Aquaculture operators • Aquaculture producer associations • Other stakeholders potentially impacted by aquaculture operations

6.5 AQUACULTURE SECTOR MANAGERS AND REGULATORS

6.5.1 PRINCIPLES OF BEST PRACTICE

The emphasis of these best practice guidelines is on voluntary mechanisms, possibly allied with third-party certification initiatives.

This said, aquaculture sector management authorities and other statutory regulators have a clear role to play in the permitting and management of aquaculture operations at regional, national and local levels. This may be through establishing minimum standards and requirements via legislative means, or in assisting aquaculture producer organizations, associations and other business groups in maintaining voluntary best practice.

6.5.2 KEY BEST PRACTICE ACTIONS AND APPROACHES: AQUACULTURE SECTOR MANAGERS AND REGULATORS

	Approach and Principle	Best Practice	Other Participants
Prevention	Develop national/regional standards for aquaculture site surveys, risk analyses, design, dimensioning, production, installation and operation.	• Develop minimum standards for key stages of sustainable aquaculture sector development, through consultation with aquaculture sector participants. These standards might not be focused specifically on the reduction of aquatic debris, but that should be taken into account over the course of site scoping and development. An example of one such standard is the 2009 Norwegian Standard NS 9415 and the subsequent 2012 NYTEK Regulation. The NS 9415 standard guides the site surveys, risk analysis, design, dimensioning, production, installation and operation of an aquaculture facility.	• Equipment designers and manufacturers • Aquaculture producer associations • Aquaculture operators • Third-party auditors
	Introduce an EPR scheme for aquaculture equipment producers and supply chain components.	• Implement an EPR scheme to transfer to manufacturers some of the responsibility (financial and/or physical) for the appropriate disposal of their post-consumer equipment. Assigning such responsibility could provide incentives to prevent waste at source and can promote better product design. However, different approaches and their costs/benefits would need to be carefully considered. The involvement of producer and supply chain associations would be essential in the design of such schemes.	• Equipment designers and manufacturers • Aquaculture producer associations • Aquaculture operators

	Approach and Principle	Best Practice	Other Participants
Prevention *(continued)*	Include aquaculture facility decommissioning responsibilities into site and operator licensing conditions. Incorporate decommissioning plans at the beginning of the licensing process.	• Consider implementing decommissioning plans as part of a wider EPR scheme. This scheme should be supported by a sanction program that would include revoking licenses and imposing penalties for noncompliance. • Consider the use of financial bonds and/or withholding of taxes to ensure that the costs of responsible disposal (either through repurposing, recycling or approved disposal methods) are built into the cost of operation, either through licensing or through equipment purchases.	• Equipment designers and manufacturers • Aquaculture producer associations • Aquaculture operators
	Provide public sector financial support to address common issues through research and development (R&D), infrastructure development, lost equipment reporting and monitoring, etc.	• Identify and address common issues across different aquaculture producers and supply chains to minimize the production of aquatic debris and supporting its recovery when necessary. This could be through (i) targeted R&D (e.g., into equipment design), (ii) the provision of common infrastructure (e.g. landing facilities, and storage and sorting areas) and (iii) supporting the costs for debris tracking and recovery.	• Equipment designers and manufacturers • Aquaculture producer associations • Aquaculture operators

	Approach and Principle	Best Practice	Other Participants
Mitigation	Establish appropriate reporting regimes, such as those stipulated by MARPOL, the London Convention and others. These will need to cover all aquatic debris, whether from aquaculture, fishing or other aquatic and even terrestrial sources.	• Ensure that policy, management and regulatory authorities implement a practical and robust aquatic debris reporting system that is consistent with the context of different aquaculture operations under their jurisdiction. • Develop and implement reporting protocols and pathways in cooperation with aquaculture equipment manufacturers, farm operators, and producer and supply chain associations, as well as with maritime and other relevant administrations. • Maintain a record/register of aquaculture-derived aquatic debris reported as being found, lost, abandoned or disposed of. This record/register should include details of: – Size, nature and characteristics of the debris. – Any identification marks or other indicators of origin. – Date, time and position of loss or retrieval, depth of water, etc. – Reason for loss (if known). – Weather conditions. – Any other relevant information. • Harmonize and connect with other registers where possible at regional, national and other levels. Over time, such registers could be merged where appropriate and/or submitted to the GGGI global data portal.	• Fisheries and environmental protection agencies • Aquaculture producer associations • Aquaculture operators

	Approach and Principle	Best Practice	Other Participants
Remediation	Partner or collaborate with appropriate organizations, NGOs, commercial entities and/or other national governments to fully recognize the potential threat of aquaculture-derived debris to the aquatic environment and its users.	• Develop regional and/or national communication frameworks to enable the recording and sharing of information on aquaculture-derived debris. • Develop frameworks to assist aquaculture operations in reporting the partial or total loss of aquaculture facilities and their components to the coastal state in whose jurisdiction the loss occurred. Such frameworks should take into consideration implementation challenges in small-scale and widely dispersed aquaculture operations. • Encourage farming operations to have adequate equipment and training available to facilitate the recovery of aquatic debris in a cost-effective and timely fashion. Where possible, the owner and the relevant authority should collaborate to enhance recovery efforts. Owners (national or foreign) should be informed of the debris recovered (when appropriately marked) so that they can organize collection for reuse or safe disposal. • Impose a potential damage bond where appropriate to ensure that cleanups can be covered if an operator is noncompliant with regulations and/or has significant/consistent debris issues that are not adequately addressed. • Extend the scope of the EPR provisions under national legislation/directives relating to single use plastics (e.g., the SUP Directive in the EU) for cleanups of aquaculture gear.	• Aquaculture sector managers and regulators • Fisheries and environmental protection agencies • Aquaculture producer associations • NGOs • Other stakeholders potentially impacted by aquaculture operations

6.6 FISHERIES, ENVIRONMENTAL PROTECTION AND WASTE MANAGEMENT AGENCIES

6.6.1 PRINCIPLES OF BEST PRACTICE

Aquaculture operations—which tend to take place in fixed, permitted locations—do not come under the same scrutiny as wild fisheries operations in open access waters. However, the location and scale of aquaculture operations are often controlled through zoning and permitting regimes, and the environmental impact of their operations is often monitored within their anticipated zone of impact.

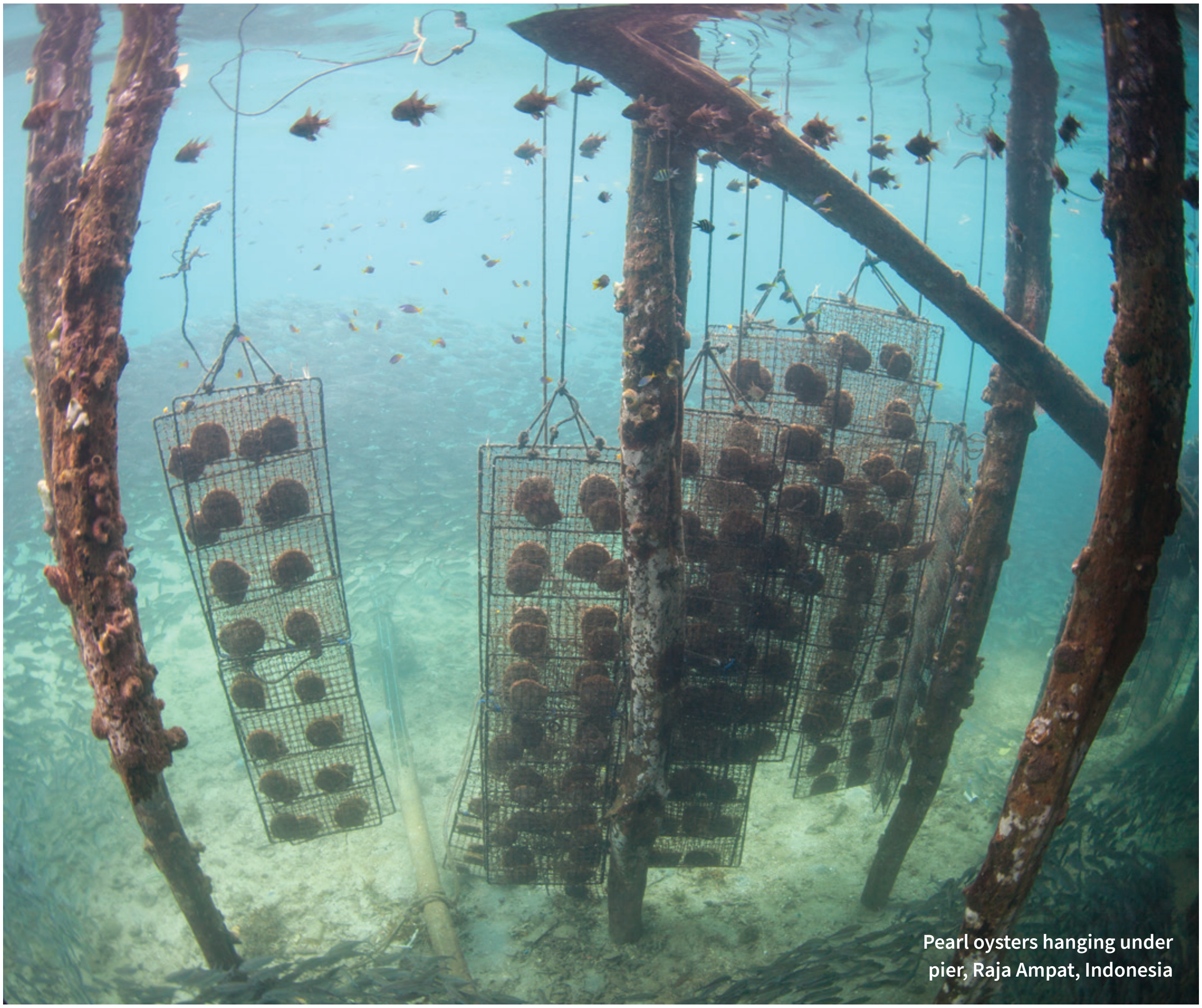
Aquaculture regulators (often operating within a wider fisheries administration) and environmental protection and waste management agencies can reduce the risk of environmental damage from aquaculture debris through a combination of (i) aquaculture development planning, (ii) monitoring farm construction, operation and decommissioning and (iii) providing public sector support for waste management.

6.6.2 KEY BEST PRACTICE ACTIONS AND APPROACHES: FISHERIES, ENVIRONMENTAL PROTECTION AND WASTE MANAGEMENT AGENCIES

Approach and Principle		Best Practice	Other Participants
Prevention	Use spatiotemporal zoning and planning within a multisectoral framework to prioritize and, where appropriate, restrict permitted economic activities (including aquaculture) to maximize the sustainable use of sea areas and reduce the potential for spatial conflicts.	• Use maritime planning mechanisms to identify aquatic areas suitable for different forms of aquaculture, and work within a multisectoral framework to agree on the spatial, temporal and scale boundaries. Based on this, work with other maritime economic activities to maximize operational synergies and minimize possible sea area use conflicts. This will help reduce structural and operational risks for aquaculture operators.	• Aquaculture sector managers and regulators • Aquaculture producer associations
	Design, monitor and enforce aquaculture and other maritime economic activities to ensure that they adhere to zoning and permitted activity rules and regulations.	• Conduct monitoring, control and surveillance activities to ensure that different sea users are adhering to their permitted development limits and are following good navigation and other operational practices.	• Aquaculture sector managers and regulators • Aquaculture producer associations
	Ensure that large scale/ high-risk aquaculture activities put in place environmental and waste management plans as part of the permitting process.	• Introduce, where appropriate, the need for environmental risk/waste management plans to be submitted and approved as part of the operational permitting process.	• Aquaculture sector managers and regulators • NGOs

	Approach and Principle	Best Practice	Other Participants
Prevention *(continued)*	Set standards for the marking, identification and electro-optical position signaling (e.g., radar reflectors, lighting, AIS/GPS beacons, etc.) for sea-borne aquaculture facilities and components.	• Ensure that all facilities are detectable, well-marked and lit so that they do not present a navigation risk. Authorities should also consider minimum standards that facilities need to be following, including the use of radio or satellite beacons showing the locations of key components and displaying ownership information in accordance with local regulations. For large installations, these markings, lighting and beacons might be distributed around different components (e.g., feed barges, cages, etc.).	• Aquaculture sector managers and regulators • Aquaculture producer associations
	Conduct impact assessments to gauge unintended consequences of management actions on equipment and gear loss.	• Assist permitting agencies to model and assess the consequences of large-scale aquaculture development on public goods and services (e.g., common sea space).	• Aquaculture sector managers and regulators • Aquaculture producer associations
Mitigation	Provide information and technical and logistical support to aquaculture operations in the event of a catastrophic or major event that results in damage, unit fragmentation and debris production at aquaculture facilities.	• Provide information on the location and nature of vulnerable maritime assets (including natural assets, such as coral reefs) that might be useful to aquaculture operations trying to attend to and mitigate the impact of lost farm units and aquatic debris resulting from major events. • Integrate data collection, compilation, information dissemination and management responses with other relevant initiatives such as farmed stock escapes and recapture.	• Aquaculture sector managers and regulators • Aquaculture producer associations • Other stakeholders potentially impacted by aquaculture operations

Approach and Principle		Best Practice	Other Participants
Remediation	Provide information and technical and logistical support to the aquaculture sector where appropriate to support locating and recovering aquaculture debris.	• Provide information on the location and nature of vulnerable maritime assets (including natural assets, such as coral reefs) that might be useful for the planning and implementation of aquaculture debris recovery programs.	• Aquaculture sector managers and regulators • Aquaculture producer associations • Other stakeholders potentially impacted by aquaculture operations



Pearl oysters hanging under pier, Raja Ampat, Indonesia

6.7 AQUACULTURE AND AQUATIC ENVIRONMENT RESEARCHERS

6.7.1 PRINCIPLES OF BEST PRACTICE

Concerns about the contribution of aquacultural debris to aquatic pollution in general, and to aquatic plastics in particular, are relatively new. With aquaculture continuing to expand relative to capture fisheries efforts, it is important that the issue is better understood, and that prevention, mitigation and remediation approaches are improved as a result.

Research can be focused in a number of directions. The development of stock containment systems—especially when they are in offshore or exposed areas—could be made more robust and resilient to extreme weather conditions. The aquaculture industry can also work with other offshore engineering disciplines to improve remote monitoring and reduce conflict risks (e.g., collisions with other maritime activities in increasingly crowded seas). Research can also be directed at the use of alternative materials to reduce the impact of aquaculture-derived debris and to improve the cost-effectiveness of component recovery, reuse and recycling. Additionally, there is a need for research to develop our understanding of the impact of aquatic debris, especially microplastics, on the aquatic ecosystem and its trophic structures so that the findings can be used to prioritize waste management or minimize impacts in the case of gear/equipment loss.

Net pens in the Aegean Sea, Greece

6.7.2 KEY BEST PRACTICE ACTIONS AND APPROACHES: AQUACULTURE AND AQUATIC ENVIRONMENT RESEARCHERS

	Approach and Principle	Best Practice	Other Participants
Prevention	Develop improved containment systems that minimize the risk of (i) catastrophic loss and debris production and (ii) low-level littering.	• Direct research at improving material and component strength, reliability and stress monitoring specifically for containment systems and mooring methods to ensure that they are robust and appropriate for any extreme conditions they may periodically encounter. In addition, research could assist with the development of new methods for reducing vulnerability under occasional extreme conditions (e.g., submerging or moving facilities to relative safety).	• Equipment designers and manufacturers • Aquaculture operators
	Examine the opportunities for remote sensing, ROVs, UAVs, artificial intelligence and other emerging technologies in maritime surveillance and environmental monitoring.	• Research remote site surveillance and environmental monitoring that reduces the risk of damage to aquaculture facilities and the consequent production of aquatic debris. This is particularly relevant with sea areas becoming increasingly crowded and controlled. It is essential that aquaculture operation managers are enabled to monitor site and facility conditions and potential threats in real time and increasingly autonomously.	• Aquaculture sector managers and regulators • Aquaculture operators
	Develop interdisciplinary and cross-border collaborations with and between academic and commercial research into robust offshore engineering solutions and aquatic debris management.	• Develop common technological solutions to overcome the challenges of operating in a hostile and crowded maritime environment as offshore aquaculture is likely to become more integrated with other offshore maritime economic activities such as renewable energy production.	• Aquaculture sector managers and regulators • Aquaculture operators • Other stakeholders potentially impacted by aquaculture operations
	Develop approaches that maximize knowledge transfer across the aquaculture sector, both nationally and internationally.	• Conduct research and development that results in better and safer aquaculture facilities and operations, and share these developments with other stakeholders, both at home and abroad. This could include publishing results in peer-reviewed journals as well as promoting advances in the industry press and conference circuits.	• Aquaculture producer associations

Approach and Principle		Best Practice	Other Participants
Mitigation	Examine opportunities for the use of new or rebalanced materials that are stronger and less damaging to the environment if lost.	• Conduct research in supporting key areas. Due to its relative durability, versatility and cost, plastic has become the dominant material in many aquaculture systems (e.g., pens, nets, shellfish bags, ropes). Research is needed into three main areas. – Develop plastic components that are strong, easily maintained, and can be easily recovered, disassembled and recycled. – Develop replacements for materials that easily abrade or break up into smaller pieces (e.g., EPS, which is commonly used for floatation). – Research/consider nonplastic alternatives where appropriate.	• Equipment designers and manufacturers • Aquaculture operators
	Examine the possibility of developing natural or synthetic biodegradable materials that have a long active life and that can be deactivated (to reduce ghost fishing or other forms of entanglement and habitat smothering) if lost.	• Conduct research into alternatives to use instead of aquaculture equipment or consumables that are more likely to ghost fish, entangle aquatic animals or smother habitats (e.g., predator nets, containment netting panels) or persist in the aquatic environment (e.g., plastic gloves, fixings, packaging, etc.). Research should focus on cost-effective alternatives that deactivate upon loss.	• Equipment designers and manufacturers • Aquaculture operators • NGOs
	Conduct research to better understand the potential impacts of plastics and other materials on the aquatic environment in order to develop approaches to minimize these impacts before gear/equipment loss.	• Conduct further research into the impact of aquatic debris, especially microplastics, on the aquatic ecosystem and its trophic structures. Use the findings to prioritize waste management or minimize impacts in the case of loss.	• Equipment designers and manufacturers • Aquaculture operators • NGOs • Fisheries and environmental protection agencies

Approach and Principle		Best Practice	Other Participants
Remediation	Develop practical and effective technology for maritime surveillance to better detect and quantify lost or derelict aquaculture equipment in the water column or on the seabed.	• Conduct research into cost-effective technology/modelling to assist with locating likely areas of high gear accumulation and to help with recovery programs. One of the major factors in the cost of recovering aquaculture debris is locating its position. Much of this debris might be floating or barely submerged, and so is likely to be highly mobile. Other debris may sink and thus may only be detectable by side-scan sonar or ROVs, which are costly to deploy.	• Fisheries and environmental protection agencies
	Provide protocols for equipment/component monitoring programs based on Life Cycle Analysis (LCA)/circular economy approaches.	• Develop protocols/good practices/ SOPs for aquaculture businesses through the supply chain to adopt the LCA/circular economy approach to gear design and management.	• Equipment designers and manufacturers • Aquaculture operators

Rainbow trout fingerlings in incubator, Khabarovsk Krai, Russia

6.8 SEAFOOD ECOLABEL AND CERTIFICATION PROGRAMS

6.8.1 PRINCIPLES OF BEST PRACTICE

The ecolabelling of seafood, mainly though the third-party certification and assessments of individual aquaculture sites and businesses, is an important market driver for responsible aquaculture.

In comparison to wild capture fisheries, aquaculture standards have not yet fully recognized the role of aquaculture in generating debris and the consequences this debris might have on the aquatic environment. While ghost fishing is possibly less of an issue from most aquaculture-derived debris than it is from lost gear from wild capture fisheries, there are still potential impacts in terms of engagement, habitat damage and ingestion of plastic particles. There is also a role for aquaculture improvement projects (AIPs) to help identify problems and drive better practice.

6.8.2 KEY BEST PRACTICE ACTIONS AND APPROACHES: SEAFOOD ECOLABEL AND CERTIFICATION PROGRAMS

Approach and Principle		Best Practice	Other Participants
Prevention	Identify key risks to aquaculture operations (and their supply chains) that might result in damage to their infrastructure and the consequent generation of aquaculture debris and associated impacts on aquatic ecosystems and their components.	• Conduct research into the main drivers for the generation of aquaculture-derived debris, the risks and impacts, in order to include these elements in their certification standards for different species groups and production system types. These will need to recognize the influence of scale and intensity, as well as the different farming stage involved. • Introduce third-party auditing procedures for fish farm design standards such as Norway's NS 9415.	• Aquaculture and aquatic environment research • NGOs
	Develop certification criteria and scoring guideposts that encourage aquaculture businesses to follow best practices in reducing their risk to the aquatic environment throughout the lifetime of a farming operation.	• Establish certification criteria related to the outcome, management and information associated with aquatic debris loss, together with the associated scoring guideposts, to (i) set minimum performance standards and (ii) encourage best practices (see Section 6.2.2) from aquaculture operators. This should reflect the entire life cycle of farming units (e.g., from design and site selection through to construction, operation and decommissioning). It should also reflect the scale and capability of different aquaculture operations and operators.	• Aquaculture and aquatic environment research • Aquaculture operators

Approach and Principle		Best Practice	Other Participants
Prevention *(continued)*	Work both with (i) aspiring aquaculture operations that are entering into AIPs as well as (ii) more advanced operations that have undergone, or are undergoing, the certification process to reduce the risk of generating aquatic debris.	• Encourage and support less advanced and well-managed aquaculture businesses alike through technical assistance programs associated with AIPs or other such mechanisms.	• Aquaculture producer associations • NGOs
	Encourage larger companies to work with their individual aquaculture production units to reduce the generation of aquatic debris through group certification.	• Encourage group certification that will enable larger, umbrella companies to guide and mentor those under them (e.g., subsidiaries, informally contracted growers, etc.) in the reduction of aquatic debris and responsible decommissioning of end-of-life aquaculture equipment.	• Aquaculture producer associations • NGOs
Mitigation	Recognize and provide guidance on managing the consequences of aquaculture-derived aquatic debris on the aquatic environment.	• Assist aquaculture businesses, their supply chains and the wider community to understand the consequences and need for managing aquatic debris derived from aquaculture, both through certification standards and supplementary support programs.	• Aquaculture producer associations • NGOs
Remediation	Include certification criteria and audit scoring guideposts that encourage the safe, cost-effecient and effective cleanup of aquatic debris from aquaculture operations.	• Include benchmarks, scoring guidelines and/or scoring guidance that recognize and acknowledge best practices in aquaculture operations to recover aquatic debris and litter that is lost or abandoned by the operation under assessment. This could include specific measures, strategies or other means. • Include benchmarks, scoring guidelines and/or scoring guidance that recognize and acknowledge best practices in aquaculture operations that participate in programs that recover debris and other aquatic litter.	• Aquaculture producer associations • NGOs

6.9 SEAFOOD COMPANIES IN THE AQUACULTURE VALUE CHAIN

6.9.1 PRINCIPLES OF BEST PRACTICE

Seafood businesses (e.g., those companies involved in the purchase, processing and value adding, distribution and sale of seafood) have a considerable role in ensuring that their raw material is procured from responsible and well-managed aquaculture operations that minimize the potential for—and consequences of—the loss of debris and litter from aquaculture into the aquatic environment.

While the predominant sustainability strategy of seafood businesses is to source from aquaculture operations that have been certified as responsibly farmed, seafood companies are increasingly involved in encouraging aquaculture businesses to enter aquaculture improvement projects, funding and participating in research, and providing consumer information and awareness-building.

6.9.2 KEY BEST PRACTICE ACTIONS AND APPROACHES: SEAFOOD COMPANIES IN THE AQUACULTURE VALUE CHAIN

Approach and Principle		Best Practice	Other Participants
Prevention	Ensure that seafood sourcing avoids high-risk aquaculture operations and participates in relevant initiatives (e.g., equipment recycling where possible, reduced use of SUPs and generally embracing circular economy principles).	• Ensure that sourcing policies recognize the risks of damage of aquaculture infrastructure and the production of aquatic debris, and ensure that they are managed effectively, either through sourcing raw material from certified aquaculture operations (see best practice guidelines for third-party certification in Section 6.8) or through developing specific procurement guidelines and audit/verification systems. • In the case of retailers in particular, consider measures to reduce sourcing from high-risk aquaculture operations that, directly or indirectly, may lead to the production of aquatic debris and litter.	• Seafood ecolabel standard and certification programs • NGOs
	Require suppliers to conform with best practice as promoted through the guidance in the GGGI A-BPF and other relevant guidelines (e.g., AQUA-LIT).	• Work with AIPs and third-party certification bodies to ensure that their raw material supply chain avoids fisheries with unacceptable levels of aquatic debris production.	• Seafood ecolabel standard and certification programs • NGOs

	Approach and Principle	Best Practice	Other Participants
Prevention *(continued)*	Ensure that supply chain components also minimize the risk of contributing to terrestrial and aquatic debris production.	• Ensure that circular economy policies and waste management systems are aligned to the same high level as expected from aquaculture suppliers. This might cover equipment and materials such as fish boxes, packaging and SUPs.	• Equipment suppliers and distributors
Mitigation	Ensure that any third-party sourcing strategies/policies recognize the impacts of aquaculture-derived debris on the aquatic environment and ensure that these are managed effectively (see best practice guidelines for third-party certification in Section 6.8).	• Many seafood companies and multiple retailers depend upon third-party certification of their supply chain to ensure responsible environmental and social standards are being maintained. However they will need to check to ensure that the relatively newly recognized contribution of aquatic debris to the marine plastic stock is appropriately covered in these assessments. (see best practice guidelines for third-party certification in Section 6.8).	• Seafood ecolabel standard and certification programs • NGOs
Remediation	Ensure that third-party sourcing strategies/policies recognize the efforts of aquaculture operators to recover their equipment if lost or abandoned. Where companies have their own sustainable sourcing guidelines, they should favor those aquaculture operations that participate in recovery programs for aquatic debris (see best practice guidelines for third-party certification in Section 6.8).	• In addition to ensuring the prevention and mitigation of aquaculture-derived debris in the marine environment (see above), seafood businesses should encourage their suppliers to engage in debris and litter recovery, both from their own operations as well as through wider CSR and community-based recovery programs (see best practice guidelines for aquaculture operators in Section 6.2.2).	• Seafood ecolabel standard and certification programs • NGOs

6.10 NONGOVERNMENTAL ORGANIZATIONS

6.10.1 PRINCIPLES OF BEST PRACTICE

Nongovernmental organizations (NGOs) have proved to be key advocates of good practice and responsible aquaculture, and they participate in a wide variety of activities, ranging from research and managing AIPs to providing seafood consumers and other stakeholders with valuable information.

With regard to fishing gear management and addressing the consequences of ALDFG, NGOs have a particular role in capacity-building, research, developing Codes of Practice and awareness-raising.

6.10.2 KEY BEST PRACTICE ACTIONS AND APPROACHES: NONGOVERNMENTAL ORGANIZATIONS

Approach and Principle		Best Practice	Other Participants
Prevention	Advocate for positive change while focusing on a wide range of actors, including policymakers, seafood businesses and aquaculture operators.	• Identify opportunities for reducing levels of aquaculture-derived debris and mitigating its impacts through objective, evidence-based analysis to inform the development of carefully defined advocacy campaigns targeted at the relevant actors throughout the supply chain and governance framework.	• Aquaculture operators • Aquaculture producer associations • Other stakeholders potentially impacted by aquaculture operations
	Act as catalytic partners, with a particular focus on small-scale aquaculture operations; develop and facilitate local stakeholder involvement; and assist with consensus-building and program planning.	• Provide a pivotal role in developing local interests and building consensus over common issues of concern where small-scale aquaculture operators lack the ability to mobilize their resources or gain sufficient consensus to join forces. NGOs can assist the united grouping to develop a coordinated approach to addressing common problems, whether through a unified Code of Practice or a memorandum of understanding, and/or other approaches as appropriate.	• Aquaculture producer associations • Seafood ecolabel standard and certification programs
	Provide direct capacity-building and training, mainly (though not exclusively) to small-scale aquaculture operations, to improve practical skills and ensure environmental and financially sustainable businesses.	• Contribute to skills development through a combination of direct training, group training workshops, mentoring or e-learning to address skill gaps in aquaculture or related business management, especially when related to reducing the vulnerability of aquaculture operations to extreme weather and other causes of aquatic debris loss.	• Aquaculture producer associations

Approach and Principle		Best Practice	Other Participants
Prevention *(continued)*	Raise public awareness about emerging or underreported issues related to the loss of aquaculture equipment and the subsequent impact on the aquatic environment.	• Identify issues relevant to aquaculture-derived debris and its impacts that could benefit from increased public (and other stakeholder) awareness. • Develop targeted awareness-building resources and prepare and distribute supporting information.	• Aquaculture producer associations
	Act as an independent intermediary and auditor where appropriate.	• Provide independent risk assessments to small-scale or other aquaculture businesses that wish to better understand the vulnerability of aquaculture operations to extreme weather and other causes of aquatic debris loss.	• Aquaculture producer associations • Aquaculture and aquatic environment research • AIP providers
Mitigation	Provide research and survey support for mitigatory actions that either reduce the ability of aquaculture-derived debris to continue to fish, or that directly address the impacts of that debris on aquatic animals and birds, habitats and other key components of the aquatic ecosystem.	• Support research and other actions to reduce the impact of aquaculture-derived debris in the aquatic environment. This can include developing survey methodologies to identify debris accumulation hotspots, especially in coastal waters and strand lines, and conducting research to estimate the socioeconomic benefits resulting from debris removal/reduction.	• Aquaculture and aquatic environment researchers • Aquaculture producer associations
Remediation	Identify, catalyze funding for and, where appropriate, manage and implement remediation projects for abandoned aquaculture facilities and aquaculture-related aquatic litter recycling. Support and supervise volunteer cleanup programs.	• Coordinate practical responses to aquatic environmental issues where appropriate, such as removing aquatic debris and litter from the water and associated shoreline. • Assist local stakeholders in identifying debris accumulation hotspots, develop and assess debris removal options, raise funding and organize debris removal and responsible disposal.	• Aquaculture producer associations • Other stakeholders potentially impacted by aquaculture operations

6.11 OTHER STAKEHOLDERS POTENTIALLY IMPACTED BY AQUACULTURE OPERATIONS

6.11.1 PRINCIPLES OF BEST PRACTICE

While a lot of fishing takes place out to sea or away from populated areas, most aquaculture is closer to shore where it benefits from sheltered conditions and easy access from the land. As a result, aquaculture operations are often visible to coastal residents and visitors alike, bringing benefits and sometimes challenges to the local environment and its population. One of the key complaints of communities and visitors living adjacent to aquaculture operations is the generation of debris and litter from everyday operations as well as from severe weather or other natural events.

6.11.2 KEY BEST PRACTICE ACTIONS AND APPROACHES: OTHER STAKEHOLDERS POTENTIALLY IMPACTED BY AQUACULTURE OPERATIONS

Approach and Principle		Best Practice	Other Participants
Prevention	Establish linkages between community/local businesses and aquaculture operators (and, where appropriate, producer associations) to build mutual awareness and trust over joint local aquatic environment stewardship.	• Institute a co-management approach between local stakeholders and aquaculture operations with their stewardship area to monitor, manage and, where appropriate, recover debris and litter from aquaculture. • Implement a community reporting system that allows local communities to report lost, discarded or abandoned debris from aquaculture (see Section 6.2.2).	• Aquaculture operators
Mitigation (no best practice areas yet identified)			

	Approach and Principle	Best Practice	Other Participants
Remediation	Record and report critical and chronic loss of debris and litter from aquaculture.	• Record and, where appropriate, report bad practices as well as major or chronic debris and litter events suspected to be from aquaculture. This could apply to individuals, communities and non-aquaculture businesses living and operating in areas around aquaculture facilities. • Report such instances directly to the aquaculture businesses concerned and potentially to the GGGI global data portal. Where the source of the debris/litter is in doubt (or the contacted aquaculture business is nonresponsive), such instances could be reported either to the responsible aquaculture producer organization involved or, in absence of that, to the local environmental management authority. • Develop relationships with other local marine users, particularly capture fisheries, to recover equipment and other litter and provide a collection center for onward disposal. • Work collaboratively with other local stakeholders, NGOs, etc. that have experience in aquatic debris/litter removal to ensure a more cohesive approach and response framework. • Participate in local/regional cleanup activities and help identify the origin of debris by reporting it to the GGGI global data portal and by following specific guidelines such as the AQUA-LIT Marine Litter Inventory from Aquaculture Activities[23].	• Aquaculture operators • Aquaculture producer associations • NGOs

[23] https://aqua-lit.eu/assets/content/MARINE%20LITTER%20INVENTORY.pdf

7 IMPLEMENTATION OF THIS BEST PRACTICE FRAMEWORK

Like the GGGI's BPF for wild capture fisheries (C-BPF), this A-BPF to reduce aquatic gear loss and debris from aquaculture is centered around the different stakeholders involved in the aquaculture supply chain. As the key practitioners, is up to these stakeholders to review and, where appropriate, adopt the recommendations provided in the document.

That said, there are various means by which implementation of the A-BPF can be initiated and supported by various stakeholder groups. This includes:

- **Investigating how EPR schemes might work in practice,** balancing voluntary versus regulatory mechanisms involved and determining how this can be rolled out in an effective way without adding unnecessary regulatory or financial burdens to the private and public sector bodies involved.
- **Encouraging the development of standards for equipment marking and component (e.g., ropes and nets) traceability.**
- **Developing model documents/templates for risk assessments, equipment and plastic inventories, etc.** These might also be integrated into existing systems/certification program requirements.
- **Working with aquaculture producer associations to produce Codes of Practice to reduce aquatic debris production from aquaculture.** These can be developed for certain aquaculture systems and further expanded to encompass different production systems, scales and circumstances.
- **Developing minimum standards and associated guidance** (e.g., such as Norway's NS 9415 standard) for installing, operating and decommissioning aquaculture installations, especially in open water sites.
- **Integrating aquatic debris monitoring from aquaculture with other aquatic debris monitoring and tracking services from ALDFG and other sources.** Many components in aquaculture are also used by capture fisheries operations and other maritime activities (e.g., ropes and buoys).
- **Incorporating elements of the A-BPF into voluntary, third-party certified responsible aquaculture standards.** Many retailers—and an increasing numbers of consumers—put their faith in seafood produced by businesses independently certified as being responsibly produced under standards developed by ASC, GLOBAL.GAP and BAP, amongst others. Therefore, although certification bodies represent a stakeholder group in their own right (see Section 6.8), the incorporation of even some of the basic principles and best practices in this framework could have a large multiplier effect.
- **Driving better practices through AIPs.** AIPs are being increasingly used to support aspiring aquaculture producers and businesses to meet

best practices, either to move into a certification program or simply to support their own CSR ambitions. This could include incorporating various elements of the best practice framework into the AIP action plans and providing technical assistance where appropriate.

- **Developing local (e.g., bay/estuary) level co-management with neighboring communities** to monitor, manage and where appropriate, recover debris and litter from aquaculture.

Finally it is acknowledged that, even after incorporating the considerable level of feedback to the A-BPF, this is the first edition. As with the C-BPF for wild capture fisheries, this is intended to be part of an iterative process, with the A-BPF undergoing periodic review and update to reflect changing circumstances, technologies and methodologies as well as experiences of stakeholders as they start adopting some of the guidance provided. GGGI welcomes constructive feedback. This will help us ensure that this A-BPF remains relevant, practical and effective over time.

School of European sea bass, Mediterranean Sea

APPENDIX A: REFERENCES AND BIBLIOGRAPHY

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The Global Ghost Gear Initiative is the world's only cross-sectoral alliance dedicated to driving solutions to abandoned, lost and discarded fishing gear globally.

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