Aquatic Debris from European Aquaculture - Advice to the Aquaculture Advisory Council

Final Report

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Photo credit: Fiona Nimmo, Poseidon. Salmon farming in the Western Isles of Scotland, UK

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Acronyms used

AAC	Aquaculture Advisory Group
A-BPF	GGGI Best Practice Framework for Aquaculture Gear
AIP	Aquaculture Improvement Project
ALDFG	Abandoned, lost or discarded fishing gear
ASC	Aquaculture Stewardship Council
BPF	Best Practice Framework
EPR	extended producer responsibility
EPS	Expanded polystyrene
EU	European Union
FAO	Food and Agriculture Organisation
FRP	Fibre Reinforced Plastics
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
JACUMAR	Junta Nacional Asesora de Cultivos Marinos
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
MSC	Marine Stewardship Council
MSFD	Marine Strategy Framework Directive
Mt	Metric tonne
PA	Polyamide
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
SOP	Standard Operating Procedure
SSPO	Scottish Salmon Producers Organisation
SUP	Single Use Plastics
UHMwPE	Ultra-high molecular weight polyethylene
USD	United States Dollar
WFD	Water Framework Directive

1. Background and Purpose

1.1 Background

Marine litter is defined as 'any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment as a result of human activity', and is also commonly referred to as 'marine debris' (Galgani *et al*. 2013). Marine litter has been recognized as a threat to ocean health since our understanding of the environmental aspects of human actions in the world's oceans started to expand in the 1970s, prompting international regulations to prevent inputs of marine litter, most notably the London Convention (LC), London Protocol (LP) and the International Convention for the Prevention of Pollution from Ships (MARPOL), and serving as the focus of several international scientific conferences held since the mid-1980s (GESAMP, 2020). The United Nations 2030 Agenda for Sustainable Development includes Sustainable Development Goal 14.1 to significantly reduce marine pollution of all kinds, including marine debris, by 2025 (UNSDG, 2030).

Until recently the focus of marine litter production has been from the perspective of capture fisheries, and the contribution of abandoned, lost or discarded fishing gear (ALDFG). 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 pen rings and nets themselves, as well as in feeding systems) in coastal fishponds (e.g. in pond liners) and in shellfish farming (e.g. mussel socks, oyster spat collectors, mussel pegs). These plastics are susceptible to loss through mismanagement, deliberate discharge or from extreme weather events. Whilst 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).

In the European Union (EU) this issue has recently received close attention from a Horizon 2020 project to prevent aquatic debris from aquaculture, 'AQUA-LIT'. AQUA-LIT developed a 'toolkit' that provides more than 400 ideas and solutions to tackle aquatic litter in the aquaculture sector from prevention to recycling. These solutions were co-developed with aquaculture stakeholders in Europe based on the barriers they found in having a good aquatic litter management plan. The toolbox also includes information on which ports have the facilities to receive waste, a database of funding opportunities for aquatic litter projects, an aquatic litter inventory that provides an overview of the available knowledge on aquatic litter originating from the aquaculture sector, a set of policy recommendations for the EU Member States and lastly, specific action plans for outermost regions.

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 the 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 that the aquaculture sector might face by 2025 regarding non-organic aquatic litter (Vidal *et al*, 2020).

1.2 Purpose

The purpose of this report is to build upon the results of the AQUA-LIT project and other relevant sources in order to produce a succinct report on the issue of marine debris in relation to EU aquaculture and how this is managed and is intended to provide recommendations for future action.

This report was requested by the Aquaculture Advisory Council (AAC) Horizontal Matters Working Group (WG3) and will support AAC's Work programme 2020 – 2021.

1.3 Scope

Although the report is formally tasked with looking at 'marine litter', it covers both debris and litter. Debris refers to "*broken or torn pieces of something larger*", often resulting from something that has been destroyed or damaged, whilst 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 whilst *litter* occurs from human carelessness and lack of environmental awareness.

The focus of the report is on marine debris and litter. However we recognise that aquaculture in the interior of the EU can also produce debris e.g. from riverine or lacustrine operations and that this can also contribute to marine litter. We have therefore entitled this report 'Aquatic Debris from European Aquaculture - Advice to the Aquaculture Advisory Council' in order to reflect this fact.

Finally the geographical scope of this report is mainly the European Union, although examples and good practice may be taken from relevant sources outside of the EU.

1.4 Sources of information

The primary source of information is the AQUA-LIT project[1], in particular the various Work Package (WP) report deliverables produced by this Horizon 2020 project, in particular:

- WP2. State of Play
    - D2.2 Knowledge Wave on Marine Litter from Aquaculture Sources (Sandra *et al*, 2019)
    - D2.3 Available Tools and Measures (Devriese *et al*, 2019)
    - D2.4 Potential Future Impacts (Vidal *et al*, 2020a).
- WP4. Toolbox for Integrated Approaches
    - D4.1 From prevention to recycling toolbox (Vidal *et al*, 2020b)
- WP5. Scaling up the Tide
    - D5.1 Policy recommendations (Hipólito *et al*, 2020)
    - D5.3 Transferability mechanisms
    - D5.4 Exploitation plan

[1] See https://aqua-lit.eu/

We have also accessed other information, including:

- Global Ghost Gear Initiative (2021). **Best Practice Framework for the Management of Aquaculture Gear**. Prepared by Huntington, T. of Poseidon Aquatic Resources Management Ltd. for GGGI. 81 pp. plus appendices. https://www.ghostgear.org/s/GGGI-Best-Practice-Framework-for-the-Management-of-Aquaculture-Gear-A-BPF.pdf
- Sustainable Business Network SBN (2020). **Tackling plastic waste in New Zealand aquaculture**. 43 pp + appendices https://www.mpi.govt.nz/dmsdocument/41121/direct
- Lusher, A.L.; Hollman, P.C.H.; Mendoza-Hill, J.J. (2017). **Microplastics in fisheries and aquaculture: status of knowledge on their occurrence and implications for aquatic organisms and food safety**. FAO Fisheries and Aquaculture Technical Paper. No. 615. Rome, Italy. http://www.fao.org/3/a-i7677e.pdf
- Sundt, P., P-E Schulze, F. Syversen (2014). **Sources of microplastic-pollution to the marine environment**. Report no: M-321|2015 to the Norwegian Environment Agency (Miljødirektoratet). 86 pp.,

For a full list of literature cited in this document, see **Appendix A**.

2. Aquatic debris from aquaculture

2.1 Overview of EU aquaculture

In 2018 the EU aquaculture sector generated some 74,000 jobs (c. 40,000 FTE) and 1.2 million metric tonnes (mt) of seafood with a sales value of around EUR 4.1 billion in 2018 (STECF, 2020). EU aquaculture production is mainly concentrated in four countries: Spain (27%), France (18%), Italy (12%), and Greece (11%). It is estimated that there are circa 15,000 aquaculture enterprises in the EU-27.

The EU aquaculture sector essentially consists of three major subsectors, with different history and characteristics: (i) marine finfish (22% by volume); (ii) marine shellfish (54% by volume); and (iii) freshwater finfish farming (24% by volume). Crustaceans and seaweed are also farmed in the EU, but these activities have been developed on a smaller scale.

Unlike fishing gear, there is no internationally agreed classification of aquaculture gear. Compared to aquaculture in the tropics, the temperate aquaculture carried out in the EU takes place in relatively few culture system types. An analysis of aquaculture production data reported through the DCF (see table below) suggests that the majority of EU aquaculture is produced in seven main systems.

Table 1: EU aquaculture by production system type (% of production volume, 2012 – 2016)

Gear type	2012	2013	2014	2015	2016	Average
Cages	26%	29%	34%	34%	38%	32%
On-bottom culture	27%	26%	25%	22%	23%	24%
Rafts	15%	15%	14%	15%	16%	15%
Tanks and raceways	15%	12%	10%	9%	10%	11%
Long line	7%	9%	7%	8%	10%	8%
Ponds	4%	5%	6%	6%	1%	4%
Hatcheries & nurseries	2%	1%	1%	1%	1%	1%
Other	4%	4%	4%	5%	2%	4%
Grand Total	100%	100%	100%	100%	100%	100%

Source: DCF

Cages (also called pens) produce around a third (32%) of EU aquaculture production, mainly in marine waters. Now mainly made of plastic (mainly HDPE), these facilities are by far the biggest user of plastic in terms of volume in the aquaculture sector.

The bottom culture of shellfish is the second largest form of aquaculture (24%) and can be sub-divided into two main forms, off-bottom culture where the shellfish is elevated away from the bottom substrate by either plastic bags on steel trestle or on wooden 'bouchot' pole or is directly laid on the bottom substrate and is essentially grown without any *in situ* infrastructure and is harvested using traditional fishing gear (e.g. dredges).

Shellfish are also reared on suspended ropes hanging below rafts and floating longlines. Rafts and floating longlines are two important shellfish production types, both depending upon suspending plastic-based ropes that collect and grow-on bivalves in coastal waters. Like cages / pens, they also rely on an extensive network of mooring ropes and buoys that use high levels of plastics.

Most land-based aquaculture uses tanks and raceways at some point in their production cycle, especially during the hatchery / nursery stages, but also for grow-out. Most tanks are plastic or fibreglass, as is the extensive supporting supply / effluent pipe network. Tanks and raceways are developed in a land-based controlled environment with chances of losing anything in the marine environment being very low.

A more traditional approach to land-based farming takes place in earthen ponds. These have relatively little plastic components, although farms in sandier soils may have plastic or synthetic rubber liners to reduced seepage, as well as using predator nets to protect against piscivorous birds and animals. There are few examples of artificial earthen ponds used to rear marine species in the EU. However, marine plastic pollution from ponds has been reported by Finland.

2.2 Causes of debris and litter from EU aquaculture

The AQUA-LIT project, whilst acknowledging the exposed nature of much of EU marine aquaculture, does not investigate the causes of debris and litter being abandoned, lost or discarded by aquaculture. This issue has been examined in more depth by Huntington (2019) developed further for the GGGI (GGGI, 2021) who categorise this in general as follows:

1. Low-level losses through routine farming operations
2. Extreme weather
3. Inadequate planning and management, including:
    a. Poor siting, modelling, layout, installation and maintenance:
    b. Poor waste management:
    c. Limited recycling:
    d. Farm decommissioning:
    e. Lack of awareness and training
4. Deliberate discharge

These drivers for plastic loss from aquaculture can be linked in terms of risk to different aquaculture systems. This suggests that open water aquaculture systems such as finfish pens and shellfish rope systems are particularly vulnerable to both extreme weather, as well as routine loss (see **Table 2** overleaf). Coastal ponds and to some extent inland ponds, are less vulnerable, but are still at risk of inundation through flooding. In contrast, entirely terrestrial farms using tanks and recirculating aquaculture systems (RAS) are less vulnerable to the risks listed above.

Table 2: Causal risk analysis for equipment and / or consumable loss from different aquaculture systems

Aquaculture system	Routine farming operation	Inadequate planning & management					Deliberate discharge	Extreme weather
		Waste management	Siting, installation & maintenance	Recycling levels	Farm decommission-ing	Awareness & training		
Open-water cages & pens **Suspended ropes / cages**	**High** Site-dependent, complex mooring and dynamic multi-user environment.	**High** Exposed to elements and challenging to collect waste	**High** Site-dependent, complex mooring and dynamic multi-user environment.	**Low to Medium** Collars mostly single material and recyclable. Nets less easy, but possible, to recycle.	**Low** Relatively easy to decommission and re-use components on other sites.	**Low to Medium** Mainly operated by larger companies with HR management resources.	**Medium** Often in remote locations and deep water, providing opportunity. Vulnerable to vandalism.	**High** Often in exposed sites and vulnerable to strong winds / high waves.
On & off-bottom shellfish culture	**Low to Medium** No major structures. High predator interactions.	**Medium to High** Small sites with often insufficient waste collection	**Low to Medium** No major structures, often in well-known inshore areas.	**Low to Medium** Few large, fixed plastic structures. Considerable use of SUPs.	**Low** Light, easily moved fixtures & fittings.	**Medium** Mostly small-scale operations.	**Low to medium** Low level discard e.g. cable ties.	**Medium** In shallow or inter-tidal, so exposed.
Coastal ponds	**Low** Stable environment with embedded (non-moving) components. Medium level predator interactions.	**Medium to High** Large sites, often in developing countries.	**Low to Medium** Few large, fixed plastic structures (except pond liners)	**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.
Inland ponds		**Low to Medium** Smaller sites, usually with access to waste collection.	**Low to Medium** Few large, fixed plastic structures (except pond liners)	**Low to Medium** Few large, fixed plastic structures (except pond liners)	**Low** Usually redeveloped for alternative use.	**Medium** Usually smaller operators with limited HR management.	**Low** Smaller sites, usually with access to waste collection.	**Medium** Can be subject to watershed flooding.
Tanks (inc. RAS)	**Low** Stable, complex infrastructure. Low predators.	**Low** Small sites with good waste management.	**Low** High tech sites usually with strong infrastructure support.	**Low** Large, single plastic tanks & 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.

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

Source: GGGI (in preparation)

2.3 Key characteristics of aquatic debris and litter from EU aquaculture

2.3.1 Sources

AQUA-LIT reviewed a number of data sources to characterise the nature of marine litter stemming from aquaculture, including the OSPAR, HELCOM and Marine Litter Watch beach litter databases. Whilst lamenting the lack of data they noted that (Sandra *et al*, 2019):

- In the **North Sea**, aquaculture debris is mainly originating from finfish and shellfish aquaculture activities.
- In the **Mediterranean and Baltic Sea**, primarily shellfish aquaculture-related debris was collected. In many countries only shellfish aquaculture related debris was monitored and recorded, and therefore impossible to compare with other aquaculture activities.
- The **North-western Adriatic** Sea and the **region of Corfu island** show the highest proportion of aquaculture related debris in relation to the total amount of debris.
- The **highest percentages of the mariculture related debris** were found on the seafloor (14.75%), followed by the sea surface (11.25%) and the beach (4.08%).

Sandra *et al* also included an 'litter inventory' on marine litter from aquaculture activities which is divided into general (A), specific (B) and other potential (C) items. The general items include materials such as ropes, nets, floats, containers and strapping materials, whilst specific items included animal tags, oyster nets & bags, anti-predator netting, plastic mesh and bags, lantern nets, trays, longlines, pen floatation and pontoon debris.

2.3.2 Amounts

What data and assessments do exist are regionally specific. The AQUA-LIT project estimated the proportion of marine litter (primarily plastic) in the North, Baltic and Mediterranean Seas that is attributable to finfish and shellfish aquaculture (Sandra *et al*. 2019). They found that the "*highest percentages of the mariculture related debris were found on the seafloor (14.75%), followed by the sea surface (11.25%) and the beach (4.08%)*", with hotspots in the northwest Adriatic and around Corfu Island. They concluded that the highest average proportion of aquaculture-related litter in relation to the total amount of litter was to be found on the seafloor rather than in beaches or in the water column, suggesting that much is hidden from plain view.

In the wider European Economic Area, aquaculture-associated gear and debris losses are grossly estimated at 3,000 to 41,000 tonnes annually (GESAMP, 2020), and aquaculture debris already in the ocean may be 95,000 – 655, 000 tonnes of litter (Sherrington *et al*. 2016; GESAMP, 2020)). Sherrington *et al*. also extrapolated work by Sundt *et al* in 2014 to estimate that 11 kg of plastic waste is generated for every ton of aquaculture product output in Norway. More recently, Sundt (2018) estimates that in Norway 25,000 tonnes of plastic from aquaculture is discarded at sea annually (e.g. net pen collars, pipes, nets, feed hoses and ropes).

3. Impacts of aquatic debris from aquaculture

3.1 'Ghost fishing' and entanglement

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), although some predator nets maybe larger mesh (e.g. 2.5 cm or more, up to around 20 cm) and thus capable of entangling aquatic animals and ghost fishing in some circumstances). That said, the growing production of macroalgae farming systems are using large areas of moorings, lines and floats as a growing substrate which are at risk of being lost (Campbell *et al*, 2019).

In addition to 'ghost fishing', lost predator nets and ropes can result in both (i) entanglement, whereby these 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 were estimated to pose the greatest entanglement risk to aquatic fauna (Wilcox *et al*, 2016).

3.2 Habitat damage

Lost nets (e.g. pen containment or predator) can impact benthic environments through smothering, abrasion, 'plucking' of organisms, meshes closing around them, 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 biogenic reefs. Eventually large objects may become more stable and integrated into the substrate, but this depends upon local oceanographic conditions.

3.3 Aquatic debris as a vector for alien invasive species (AIS)

The global spread of non-indigenous species (species that have been transported inadvertently or intentionally across ecological barriers and 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 ecosystems integrity and functions. Transportation through natural or anthropogenic litter is occurring passively, without control on species, materials and transportation scheme other than hydrodynamics or 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 have been implicated in dispersing harmful algal bloom (HAB) species (Masó, 2003). Aquatic plastic litter is characterized its longevity at sea and its surface properties which favour attachment and thus the possibility of transport to new areas of both mobile and sessile species. Consequently, species transported by rafting can alter the composition of ecosystems (Nava & Leoni, 2021) and alter the genetic diversity through breeding with local varieties or species.

3.4 Impacts on other maritime users and communities

Both large pieces of debris as well as extensive litter e.g. cable ties and other fastenings, plastic bottles used as floats, 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 social license afforded to aquaculture in coastal and rural communities. There are also economic costs associated with beach clean-ups.

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

- Becoming caught in bottom trawls or snagged and enmeshed in gillnets and other fishing gear. This can both damage the fishing gear as well as 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 the vessel's stability in the water and/or restrict its ability to manoeuvre. If disabled with reduced visibility, such a vessel may be endangered by a larger vessel or poor weather.
- Benthic or subsurface debris has the potential for fouling vessel anchors as well as 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 the debris. Depending on sea state, work in close proximity to a vessel's hull can be dangerous.

3.5 Contribution to micro and nanoplastics

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. They might also be generated through the breakdown of EPS blocks or fillings, or the loss of bio-media from RAS systems. Lusher *et al* (2017) looked specifically at the contribution of - and impact to - fisheries and aquaculture of microplastics. In terms of the latter, they note that at present there is no evidence that microplastics ingestion has negative effects on populations of wild and farmed aquatic organisms, but this is being contested by other more recent authors (e.g. Li *et al*. 2018, Zhang *et al.* 2020). In humans the risk of microplastic ingestion is reduced by the removal of the gastrointestinal tract in most species of seafood 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 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 of plastics in general, and in particular nanoplastics.

There are two ways in which it has been suggested 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 organisms upon ingestion (Rochman & 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).

3.6 Impacts on aquaculture operations

Van der Meulen *et al*. (2014) considered aquaculture of mussels and oysters as a case study to assess the potential risks of microplastics on the economic value of the shellfish industry. The authors conclude that there is a hazard of microplastics to the aquaculture sector due to overlap in the areas in which microplastics occur and where aquaculture is conducted. They projected a yearly loss of 0.7% of annual income every year for the sector arising from shellfish ingestion and associated biological affects and loss of sales revenue. Under high concentrations of microplastics, effects can be observed in mussels and oysters that could affect revenue. Despite there being little or no evidence of direct impacts on seafood production in terms of economic value or on human health, the presence of plastic in seafood may influence the acceptance of these products and potentially lead to economic losses as a result of a perceived risk by consumers (Van der Meulen *et al*., 2014; GESAMP, 2015).

As reported by Werner *et al* (2016), valuable insights on the socio-economic implications of marine litter on aquaculture, among other targeted sectors (tourism, fishing, navigation) in the Adriatic-Ionian region are provided by a study carried out within the framework of the IPA-Adriatic funded DeFishGear project (Vlachogianni, 2016). The results from the survey-based study carried out in six countries (Albania, Croatia, Italy, Greece, Montenegro and Slovenia) showed that the average annual direct and indirect marine litter related costs for the aquaculture sector were assessed to be some € 3,228 per aquaculture farm unit. In comparison to the average cost of marine litter to aquaculture producers recorded at 580 € per year in Scotland (Mouat *et al*, 2010), the costs assessed in the Adriatic-Ionian macro-region were considerably higher. The total costs for the aquaculture sector in the region were difficult to be estimated, however given the large-scale operations of this sector the overall costs seem to be of substantial magnitude. In general, the majority of costs were incurred because of: (i) loss of time due to clearing litter from the farm facilities (989 €/year); (ii) costs for divers to clean facilities or to un-foul boat propellers (803 €/year); (iii) cost of new equipment and facilities (663 €/year); (iv) loss of revenue due to spoiled livestock (541 €/year); (v) costs of repairs due to marine litter (200 €/year); and (vi) cost of injuries due to marine litter (32 €/year).

4. Current management approaches

4.1 Legislation and other regional / national planning mechanisms

Recognition that aquaculture is a potentially a significant contributor to the marine plastic load is relatively recent and as a result there is very little specific legislation available to control or mitigate this. There is wider legislation at a variety of levels that is designed to reduce both sea-based sources as well as terrestrial leakage of plastic into the sea. Those relevant to aquaculture are briefly examined below.

4.1.1 EU Regional level

The *Marine Strategy Framework Directive* (MSFD) is the first EU legal instrument to address explicitly marine litter. Assessment of the status, target setting, monitoring, reporting and implementation of measures related to marine litter are carried out in accordance with relevant MSFD provisions and have been further specified within a Commission Decision (2017/848/EU). The first adopted threshold value refers to marine litter on coastlines.

The EU waste legislation was amended in 2018 aiming, *inter alia*, to halt the generation of marine litter and to strengthen the link between waste management and marine litter prevention. The amended *Waste Framework Directive* (WFD) acknowledges that, since marine litter, in particular plastic, stems to a large extent from land-based activities, specific measures should be laid down in waste prevention programmes and waste management plans (see in particular Article 28 paragraph 3 (iii)(f) and Article 28 paragraph 5) . Those measures need to be coordinated with the measures required under MSFD and the EU Water Framework Directive (Directive 2000/60/EC).

Two more recent EU Directives have implications for the use of plastics and other persistent materials in aquaculture, these being the (i) *Directive on the reduction of the impact of certain plastic products on the environment* (the ‘Single Use Plastics’ or ‘SUP Directive’) and (ii) the revised *Directive on Port Reception Facilities* (PRF Directive) for the delivery of waste from ships, both of which entered into force in 2019. The SUP Directive targets the ten 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 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 organisation 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 on the high-risk components. Article 8(7) of the PRF Directive states that ‘Member States shall ensure that monitoring data on the volume and quantity of passively fished waste are collected and shall report such monitoring data to the Commission’.

It is noted that the new Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030 (European Commission, 2021) include (i) “applying a circular-economy approach, including the use of waste”, (ii) “ensuring environmental monitoring of aquaculture sites, including water quality, discharges and emissions (of organic matter, nutrients, plastics, veterinary medicines, other pollutants, or any form of waste and litter)” and (iii) “limiting the contribution of aquaculture activities to marine litter”.

4.1.2 EU Member State and third country level

From a search through the AQUA-LIT outputs and the FAOLEX database, t[2]here appear to be few examples of legislation relating to the pathways and risk of debris loss from aquaculture elsewhere:

- In Belgium the Flemish Integral Action Plan on Marine Litter will map aquaculture litter in Flanders and develop "sustainable water management" by 2022.
- In France, legislation to implement the MSFD plans to limit the degradation of the impacted habitats by limiting access to the relevant marine culture plots in tidal areas, and by collecting and recycling litter generated by them.
- In Spain, the 2008 Junta Nacional Asesora de Cultivos Marinos (JACUMAR) report resulted in a 'Guide for the minimisation of aquaculture waste' being published. An update in 2017 includes guidance on recycling plastic materials, reducing loss of equipment and staff training and awareness.
- The German Programme of Measures (PoM) for the Marine Protection of the German Parts of the North Sea and the Baltic Sea provides fact sheets that include SEA-specific information on the environmental impacts and assessed alternatives for each measure, including those for reducing marine litter coming from aquaculture
- In Scotland, the Technical Standard for Scottish Finfish Aquaculture (Marine Scotland, 2015) states that "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 end of life".
- In Norway there are minimum standards and associated guidance (e.g. such as the Norwegian NS 9415 standard) for installing, operating and decommissioning aquaculture installations, especially in open water sites. According to a review by Bermstad and Heimstad (2017) this has led to a significant reduction in stock escapes.
- In India, the 'Guidelines for Regulating Coastal Aquaculture (Coastal Aquaculture Authority, 2005) state that "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) state that "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".

For a list of global actions and measures on aquaculture-related debris, see Annex 1 in the AQUA-LIT Deliverable D2.3 (Devriese *et al*, 2019).

[2] See www.fao.org/legal/databases/faolex/en/

4.2 Sector management approaches

Guidance on good management in reducing the loss of plastic from aquaculture facilities has only just emerged over the last few years. There are two main sources, (i) the AQUA-LIT project and (ii) the GGGI Best Practice Framework for Aquaculture Gear (A-BPF).

4.2.1 Management approaches from the AQUA-LIT Project

The AQUA-LIT project has produced a series of deliverables since 2019, culminating in the development of their online 'Tide Against Marine Litter Toolbox'[3]. This toolbox, which is also available as a smart phone app), is structured around a series of themes with associated measures (see figure below).

Figure 1: Structure and contents of the AQUA-LIT 'Tide against marine litter' Toolbox

Main components	Measures

1. Solutions and measures (see next column)
• By stage
  ○ Prevention and reduction
  ○ Monitoring and quantification
  ○ Removal and recycling
• By measure
  ○ Knowledge
  ○ Legislation
  ○ Responsibility
  ○ Support
• By sea basin
  ○ Mediterranean
  ○ North
  ○ Baltic
• By type of aquaculture
  ○ Fish
  ○ Shellfish
  ○ Seaweed
2. Port facilities
3. Funding opportunities
• European programmes
• National programmes
• Transnational; Programmes
• Grants & Investors
4. Submit Info
5. Marine Litter Inventory
6. Action Plans and Policy Recommendations
• Action Plans
• Policy Recommendations
Source: https://aqua-lit.eu/toolbox
	Knowledge
	• Data quantification on marine debris
	• Materials and design
	• Research and innovation
	• Marine debris management
	• Research and awareness
	Legislation
	• Pre-conditions for licensing
	• Regulations
	• Policy
	• Harmonisation
	• Certification
	Responsibility
	• Share responsibility
	• Producer responsibility
	• Farmer/User responsibility
	• Corporate social responsibility
	Support
	• Financial support
	• Technical support
	• Support for monitoring
	• Support for education, communication and awareness-raising

[3] See https://aqua-lit.eu/toolbox

4.2.2 Management approaches from the GGGI A-BPF

The recently published GGGI Best Practice Framework for Aquaculture Gear (A-BPF, see GGGI, 2021) takes a more stakeholder-focused approach, recognising that different sector participant types will have very different roles and responsibilities for managing aquaculture facilities and reducing the risk of plastic debris loss into the marine environment. These are described in the table below.

Table 3: Main aquaculture sector stakeholders, roles and best practice areas

Stakeholder group	Role	Best practice areas
1. Equipment designers, manufacturers, distributors and installers	Businesses involved in the design, production, pre-sale distribution, sale and installation of aquaculture equipment	Embedded traceability; research into and use of / integration of natural or biodegradable materials; commitment and innovation around circular economy principles.
2. Aquaculture operators	This individuals or organizations managing and operating aquaculture sites and supporting facilities.	Conducting risk assessments for losing gear, in / out inventories for key farm components; keeping a logbook and registering all gear losses, ensuring moorings and other critical infrastructure are maintained and can withstand extreme conditions, training of staff to reduce littering rates, Standard Operating Procedures (SOPs) for high-risk events and if necessary, post-event recovery, responsible decommissioning of reduced / fallowed farming operations.
3. Aquaculture Producer Organisations / Associations	Non-statutory organizations representing aquaculture businesses. Most producer associations or associations are organized around a regional (e.g. transboundary, national or local) and / or a theme (e.g. species or system-based).	Code of Practices specific to aquaculture: spatio-temporal agreements with other marine space users; scheduled maintenance and monitoring of facility and gear losses, communication protocols, feasible EPR schemes based on circular economy.
4. Harbour and port operators	Bodies operating and managing ports servicing aquaculture operations.	Accessible, low-cost gear and litter disposal and sorting facilities; implementing deposit schemes, integration into recycling initiatives; better awareness of responsible disposal opportunities.
5. Aquaculture sector managers & regulators	Statutory management bodies setting policy, plans and regulations for aquaculture activities.	Designation of spatio-temporal restrictions in high-risk areas; development of appropriate farm marking and identification regulations; conduct impact assessment 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.

Stakeholder group	Role	Best practice areas
6. Fisheries, environmental protection & waste management agencies	Body or agency responsible for enforcing aquaculture and associated environmental regulations, including waste management.	Establish registry and database of lost / abandoned aquaculture facilities; registry and database for encountered aquaculture-related debris; enforcement of farm lighting, marking and identification regulations;
7. Aquaculture & marine environment research	Government or private sector organisations 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	Organisations 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 & retailers utilizing seafood products from aquaculture.	Encouraged to ensure that their seafood sourcing avoids high risk aquaculture operations and that they participate in relevant initiatives e.g. equipment recycling where possible.
10. Non-Governmental Organizations	Non-governmental advocates for sustainability and good practices.	Coordination of advocacy, actions and information gathering; contribute to a centralized aquatic debris / ghost fishing information hub / forums; 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 aquaculture, including wild capture fishers, local & indigenous communities, local and regional planners, etc.	Recording and reporting both critical and chronic loss of debris and litter from aquaculture.

Source: Adapted from GGGI, 2021

5. Recommendations for future actions

A number of recommendations can be made to ensure that EU aquaculture is sustainable, responsible and competitive compared to other food production systems in the region. These are aimed at a variety of levels within the hierarchy of the aquaculture sector and are separated into a number of different areas.

5.1 EU-level policy and planning

- **Develop technical guidelines for EU aquaculture**, including minimum standards for installing, operating and decommissioning aquaculture installations. These standards should be multi-purpose (e.g. address issues such as preventing stock escapes, facility marking and lighting, as well as reducing the risk of aquatic debris production) and suitable for national and potential third-party certification.
- Possibly as part of the aforementioned technical guidelines, **develop advice on the scope, content and rigour of risk assessment methodologies for aquatic debris loss and impact** as part of the wider environmental and social impact assessment requirements. Encourage these to be seen as a practical risk reduction strategy, rather than just a regulatory necessity.
- **Ensure aquaculture is fully represented in EU Member State maritime spatial plans** to minimise spatial conflict with other maritime users and therefore reduce the risk of collisions and other unintended damage.
- **Develop systems to link aquaculture component traceability systems with licensing and other permitting / operator identification data.**
- **Work with EU aquaculture producer organisations to 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 and agree how these might be implemented e.g. voluntary, self-certification by the fisheries organization, or third party certified.

5.2 Research and development

- **Develop aquaculture equipment that is easy to decommission and recycle at end of use**. This will include using plastics that have a high recyclability / re-use value and ensuring that different plastic and non-plastic components are easy to disassemble, store and transport.
- **Support a transfer from coastal to offshore aquaculture through the development of large-scale, semi-contained open water systems** that are resilient and adaptable to varied and often extreme weather conditions.
- **Research remote site surveillance and environmental monitoring** that reduces the risk of damage to aquaculture facilities and the consequent production of aquatic debris.
- **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.

5.3 Corporate and farm-level management

- **Encourage businesses to develop pre-emptive contingency plans** to (i) reduce the risk of equipment failure from forecast extreme weather events and (ii) establish the means and methodologies for recovering debris and equipment lost from such events, such as the development of Standard Operating Procedures (SOPs) for high risk events.
- **Aquaculture businesses should develop and maintain inventories of plastics and plastic products used on installations**, with records of both procurement and disposal.
- **Where possible high quality or where appropriate biodegradable plastic components** to both minimize the risk of loss as well as to mitigate the impact after loss has occurred.
- **Staff should be made aware of the pathways, risk and impact of aquatic debris from aquaculture** and provided training in methods to prevent or respond to such events.
- **Organise and fund local clean-up aquatic debris programmes** as part of a CSR strategy. Work with local communities to demonstrate that every effort is made to both reduce the incidence of aquatic debris loss and to recover lost material at appropriate intervals.
- **Work with third-party ecolabel standard holders** (e.g. ASC and others) to develop and apply performance metrics for the management and prevention of aquatic debris from aquaculture.

5.4 Reporting lost debris from aquaculture

- 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. Where appropriate, integrate with other marine debris reporting e.g. from ALDFG.
- **Develop and implement reporting protocols and pathways** in cooperation with aquaculture equipment manufacturers, farm operators, producer and supply chain associations, as well as with maritime and other relevant administrations.

5.5 End-of-life disposal

- **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: (i) the transfer and possible temporary storage need of large aquaculture infrastructure components, bulk feed and other supplies through port facilities, (ii) the landing, temporary storage (including space for sorting and disassembly) and responsible disposal of non-reusable / recyclable end of life aquaculture equipment and (iii) the inclusion of end-of-life aquaculture equipment into Port Waste Management Plans where appropriate.

5.6 Circular economy

- **Encourage and facilitate the development of a circular economy for aquaculture equipment**, including development of extended producer responsibility (EPR), building 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 reuse, buyback, or recycling programmes.
- **Consider the use of financial bonds or withholding taxes to ensure that the costs of responsible disposal** (either through re-purposing, recycling or approved disposal methods) are built into the cost of operation, either through licensing or equipment purchases.
- **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.

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