



Marine Litter and Aquaculture Gear

White Paper | 28 November 2019



Report Information

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Photo credit: Mowi Ireland. Salmon farming in Lough Swilly, Ireland.

ASC'S FOCUS ON PLASTICS, MARINE LITTER AND GHOST GEAR

The Aquaculture Stewardship Council's (ASC) current standards set criteria for dealing with plastic with requirements for certified farms to implement policies for waste reduction and recycling; and ensuring responsible storing and disposal of waste. ASC is reviewing the need for additional criteria to address the issue of plastics and marine litter, and is in the process of creating a Technical Working Group (TWG) on Marine Litter and Ghost Gear to provide input on future revisions of its standards or guidance documents.

Problems caused by marine litter and aquaculture gear in the aquatic environment include ingestion by animals, entrapment and entanglement of animals, physical impacts on the benthos, disruption and loss of coastal areas, potential human exposure to micro-plastics and chemicals through the food chain, etc.

In August 2018, ASC became the first and only aquaculture body to sign an agreement with the Global Ghost Gear Initiative (GGGI) pledging to develop scientific knowledge of the impact of plastic waste and aquaculture gear used in farming, and to establish best practices that can be applied in ASC's standards.

GGGI is the world's largest cross-sectoral alliance dedicated to finding solutions to the problem of abandoned, lost or otherwise discarded fishing gear (ALDFG, also known as 'ghost gear'). The organisation works globally and locally with a diverse group of stakeholders -- including industry, private sector, academia, governments and NGOs -- to gather data, define best practices, inform policy, and find solutions for issues related to ghost gear.

Through their collaboration, ASC and GGGI are working on developing a refined science-based definition for aquaculture gear and are conducting risk assessments for each type of aquaculture gear.

ASC's proposal for tackling plastic will be based on the 5 R's approach – reduce, re-use, recycle, recover, refuse – to help address, reduce, mitigate and/or eliminate the negative impacts of aquaculture gear and plastic waste resulting from farming activities.

In the future, ASC certified producers will have additional requirements, including the completion of a risk assessment of potential plastic contamination and pollution, and the implementation of procedures to minimise the impact of such components at the farm and on its surroundings. Farms will need to record all used and disposed plastic material; and should implement a plastic waste monitoring programme to ensure waste is disposed of in a responsible manner, recycling or reusing materials when possible.

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ACRONYMS USED

ALDFG Abandoned, lost or discarded fishing gear

ASC Aquaculture Stewardship Council

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

GGGI Global Ghost Gear Initiative

GRP Glass-reinforced plastic

HDPE High density polyethylene

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 tonne

NOWPAP . . . Northwest Pacific Action Plan

PA Polyamide

PC Polycarbonate

PE Polyethylene

PET Polyethylene terephthalate (polyester)

PMMA Polymethyl methacrylate (acrylic)

PP Polypropylene

PS Polystyrene

PVC Polyvinyl Chloride

RAS Recirculated Aquaculture System

SOP Standard Operating Procedure

UHMwPE . . . Ultra-high molecular weight polyethylene

USD United States Dollar

1. INTRODUCTION

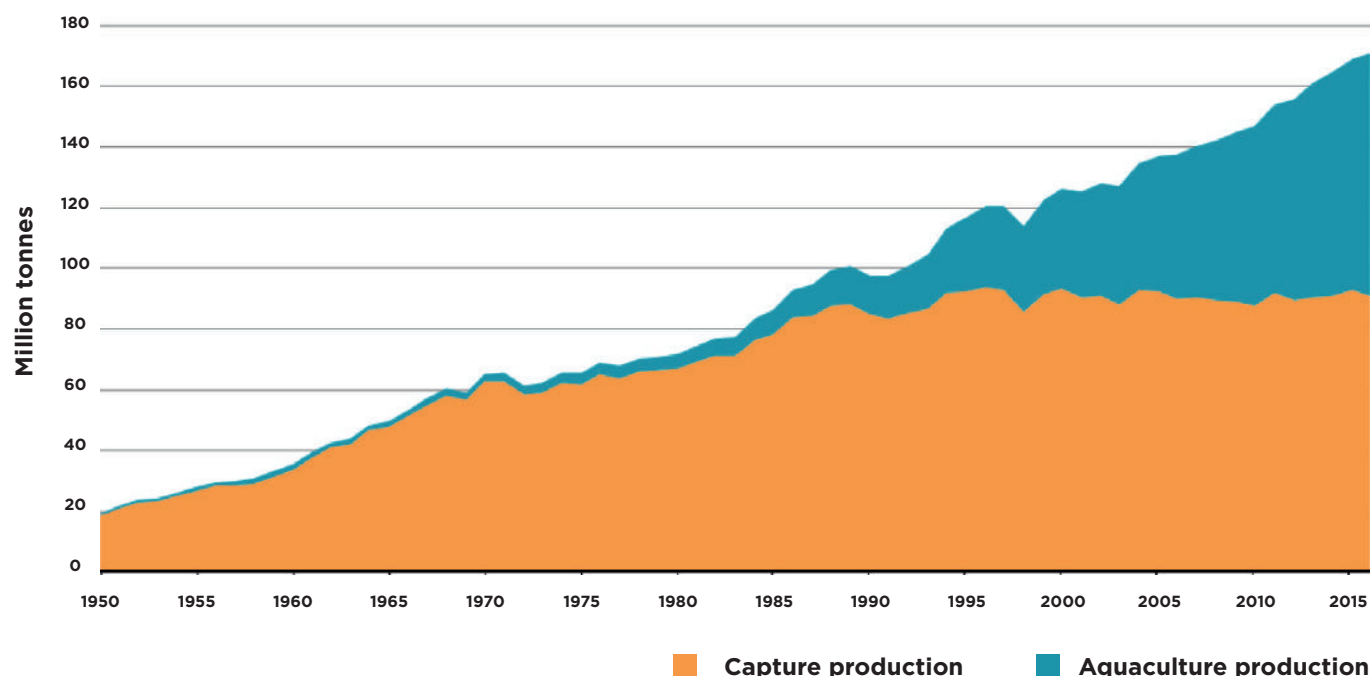


Figure 1: World capture fisheries and aquaculture production

Source: FAO, 2018. Note excludes aquatic mammals, crocodiles, alligators and caimans, seaweeds and other aquatic plants

1.1 BACKGROUND TO THIS WHITE PAPER

1.1.1 Global aquaculture

Global fish production peaked at about 171 million tonnes in 2016, with aquaculture representing 47 percent of the total and 53 percent if non-food uses (including reduction to fishmeal and fish oil) are excluded (see Figure 1 below).

Global aquaculture production (including aquatic plants) in 2016 was 110.2 million tonnes, with the first-sale value estimated at USD 243.5 billion (FAO, 2018). The total production included 80.0 million tonnes of food fish, 30.1 million tonnes of aquatic plants as well as 37,900 tonnes of non-food products

(USD 214.6 million). Farmed food fish production included 54.1 million tonnes of finfish, 17.1 million tonnes of molluscs and 7.9 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 percent, respectively). Nevertheless, aquaculture continues to grow faster than other major food production sectors. Annual growth declined to a moderate 5.8 percent during the period 2001–2016, although double-digit growth still occurred in a small number of individual countries, particularly in Africa from 2006 to 2010.



Photo credit: © Regal Springs Tilapia

1.1.2 Marine Litter from aquaculture

Over the last decade or so there has been considerable attention brought to the scale of abandoned, lost and discarded fishing gear (ALDFG) and the impacts on the marine environment through ghost fishing, entanglement and habitat damage (Macfadyen et al, 2009). This attention has been revitalised in recent years by the growing realisation of the scale and potentially catastrophic impact of plastic pollution and its accumulation in the marine ecosystem, and the contribution of ALDFG to this global problem. However, given that aquaculture now supplies over half the seafood produced worldwide, the Aquaculture Stewardship Council (ASC) considers it important that this issue is also examined at farm level, especially given the continued expansion of global aquaculture development.

The ASC has developed a number of standards that allow the third-party certification of aquaculture systems around seven principles and criteria to minimise environmental and social impacts. At present this does not currently include a common criterion that covers debris from aquaculture, although some standards do include some relevant areas such as the 'handling and disposal of hazardous materials and wastes' (Shrimp, Criterion 7.7) or 'managing non-biological waste from production' (Salmon, Criterion 4.5). ASC is now considering including the issue of marine debris from aquaculture in their standard and therefore commissioned UK-based consultants Poseidon Aquatic Resource Management Ltd (Poseidon) to prepare a White Paper on the subject.

1.2 OBJECTIVE

The key objective of this White Paper is to present the ASC with an authoritative discussion on the threat posed by plastic pollution in the marine environment and the potential contribution of aquaculture-derived debris to this problem. This will then enable ASC to determine the scope and nature of amendments to the ASC Principles and Criteria to address this global issue.

1.3 SCOPE

The scope of this White Paper is as follows:

- World-wide
- Land-based, inter-tidal and offshore aquaculture production facilities, covering finfish, shellfish and macro-algae (seaweed)
- All forms of infrastructure components or solid waste, with an emphasis on plastic debris
- Downstream physical and environmental impacts of abandoned, lost or discarded materials

It should be noted that this White Paper does not cover the other environmental impacts of aquaculture facilities and operations such as disturbance, chemical or biological pollution (e.g. chemotherapeutant or metabolic wastes) or genetic issues arising from stock escapes. It covers aquaculture production site facilities only and does not cover any upstream (e.g. feed or cage manufacture) or downstream (e.g. processing or distribution) issues.

1.4 METHODOLOGY

A key part of our methodology is to compile and review all published material on the subject of the use of plastic in aquaculture, how this might be lost into the marine environment and the impacts this might have. A full reference list can be found in Appendix A. The structure of this White Paper was agreed with ASC beforehand. Although there is some review of marine litter from aquaculture (e.g. Moore, 2014; and Lusher et al, 2017) it appears that there has not been a systematic analysis of how plastic is used in aquaculture and how it might be lost into the environment. Therefore we have tried to examine these in a sequential manner and have attempted to identify what plastics are used in different forms of aquaculture, the main causes for the loss of these into the marine environment and the pathways by which they arrive there.

Whilst we have provided an overview of the impact of plastics on the marine environment, we have not examined this in detail as this is covered extensively by other authors (e.g. Andrady, 2011; Beaumont et al, 2019; Boucher, 2017; Galloway et al, 2017; Thevenon et al. 2014).

2. PROBLEM STATEMENT



2.1 OVERVIEW

Plastic, typically organic polymers of high molecular mass, is a material that is malleable and so can be moulded 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 re-shaped and (ii) thermosets (e.g. polyurethane) that after initial heating cannot be re-melted 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 their greatest strengths – their durability (their chemical structure renders 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 marine environment, not only for coastal areas of developing countries that lack appropriate waste management infrastructures, but also for the world's oceans as a whole because slowly degrading large plastic items generate microplastic (particles smaller than 1 to 5 mm) particles which spread over long distances by wind-driven ocean surface layer circulation (Thevenon et al, 2014).

The United Nations Environment Program (UNEP) and the European Commission 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). 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). An estimated 4.8–12.7 million metric tons of plastic entered the world's oceans from land-based sources in 2010 alone, and the flux of plastics to the oceans is predicted to increase by an order of magnitude within the next decade (Jambeck et al., 2015). While, over time, this plastic may fragment into microplastics, the vast majority is expected to persist in the environment in some form over geological timescales (Andrady, 2015). Though removing some marine plastic is possible, it is time intensive, expensive, and inefficient (Beaumont et al, 2019)

Awareness of this problem has been growing in recent years, with increasing public pressure for action, both in terms of reducing the flow of plastic into the aquatic environment through less single-use plastic consumption, increased recycling as well as clearing up the beaches and oceans of existing material.

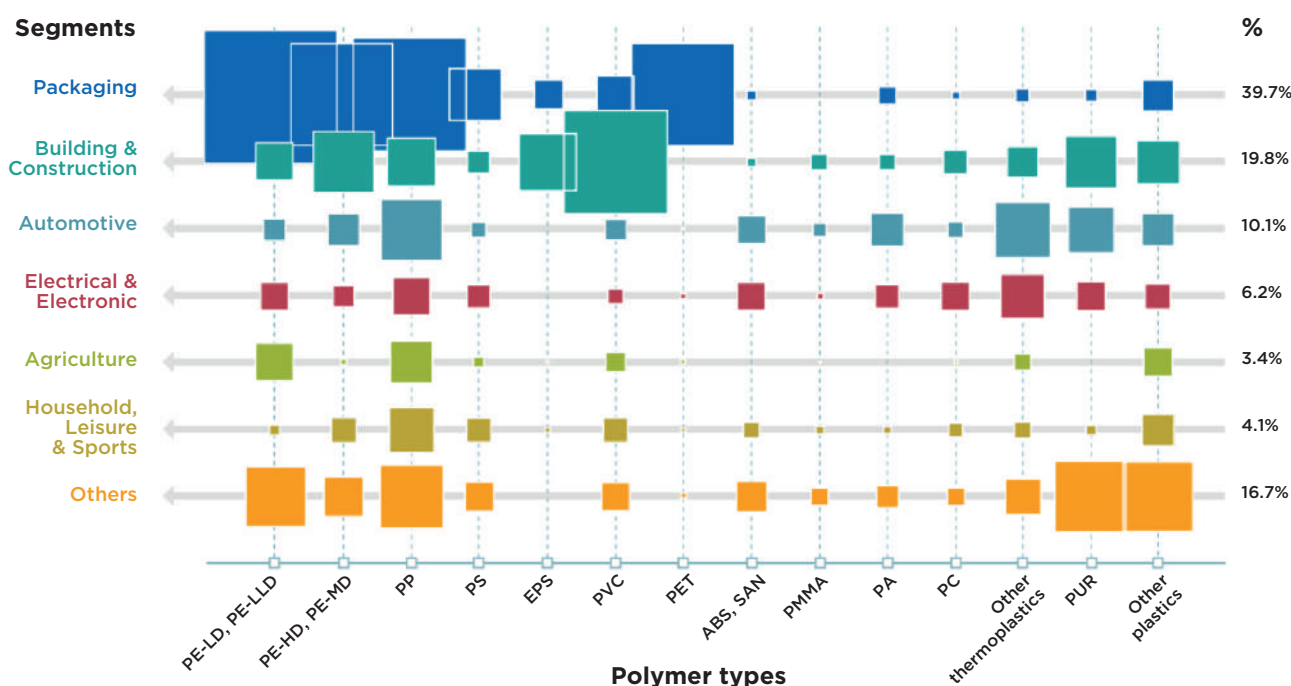


Figure 2: European plastic converter demand by segment and polymer types in 2017

Source: PlasticsEurope, 2018

2.2 SOURCES AND CHARACTERISTICS OF MARINE PLASTIC POLLUTION

Global production of plastics is around 348 million tonnes per year (PlasticsEurope, 2018). China is the world's largest producer (29.4%), with the rest of Asia producing 20.7%, Europe 18.5%, NAFTA¹ 17.7% and the Middle East & Africa 7.1%.

In Europe nearly 40% of plastic demand is for packaging, mainly polyethylene (PE) and polypropylene (PP) (see Figure 2). Building and construction takes nearly 20% (mainly polyvinyl chloride PVC), automotive industries (mainly thermoplastics) with household, leisure & sports 4.1%, mainly PP.

In Europe, more than a third of plastics produced each year are used to make disposable items, packaging or other short-lived products that facilitate the transport of a wide range of food, drinks and other goods which

are discarded within a year of manufacture (Hopewell et al., 2009). It has been estimated that plastics account for around 10% by weight of the municipal waste stream (Barnes et al., 2009) with less than 10% of the plastic produced being recycled. According to Andrady (2011), low-density polyethylene accounts for around 21% of plastics found in the marine environment (mainly from plastic bags, six-pack rings, bottles, netting, drinking straws), high-density polyethylene 17% (milk and juice jugs) and polypropylene (rope, bottle caps and netting).

Eunomia (2016) estimates that primary microplastics² releases are between 0.5 and 1.41 million tonnes/year with a central value of 0.95 million tonnes/year annually. Boucher and Friot (2017) conducted a detailed analysis of the source of primary microplastics in the marine environment. 35% were derived from the washing of synthetic textiles, 28% from vehicle tyre erosion and 24% from city dust. Other sources included road markings, marine coatings, personal care products and plastic pellets. Essentially, according to Boucher and Friot, household activities release 77% of primary microplastics and industry 23%.

¹ NAFTA North American Free Trade Agreement area (Canada, Mexico and the United States of America).

² Primary microplastics are plastics directly released into the environment in the form of small particulates.

2.3 FATE AND IMPACTS OF MARINE PLASTIC POLLUTION

Global estimates of plastic litter in the marine environment is around 27 to 66.7 million tonnes. Eunomia (2016) estimates that 12.2 million tonnes of plastic enters the marine environment annually, similar to the 4.8–12.7 million tonnes estimated in 2010 by Jambeck et al., 2015 above.

This is mainly land-based (74%), fishing litter (9.4%), primary microplastics (7.8%) and shipping litter (4.9%). Of this:

- 94% ends up on the sea floor (approx. 70 kilogrammes kg/square kilometre km)
- 5% ends up on the shoreline (approx. 2,000 kg/km)
- 1% remains on the ocean surface (18 kg/km)

Beaumont et al (2019) examined the global ecological, social and economic impacts of marine plastic and calculated that the economic costs of marine plastic, as related to marine natural capital, are conservatively conjectured at between USD 3,300 and USD 33,000 per tonne of marine plastic per year, based on 2011 ecosystem service values and marine plastic stocks. Given this value includes only marine natural capital impacts, the full economic cost is likely to be far greater.

They examined the impact on different types of biota (see horizontal axis in Figure 3 below) and how this might relate to provisioning, regulatory and cultural services (vertical axis). This suggests that the main impacts are on birds (via ingestion), fish (via both entanglement and ingestion) and invertebrates (entanglement 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.

Lusher et al (2017) looked specially 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. 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 a category of microplastics known as nanoplastics (1-100 nm), 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. Furthermore, plastics often contain potentially toxic additives that impart certain desirable qualities to plastic polymers. Microplastics 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 nanoplastics.

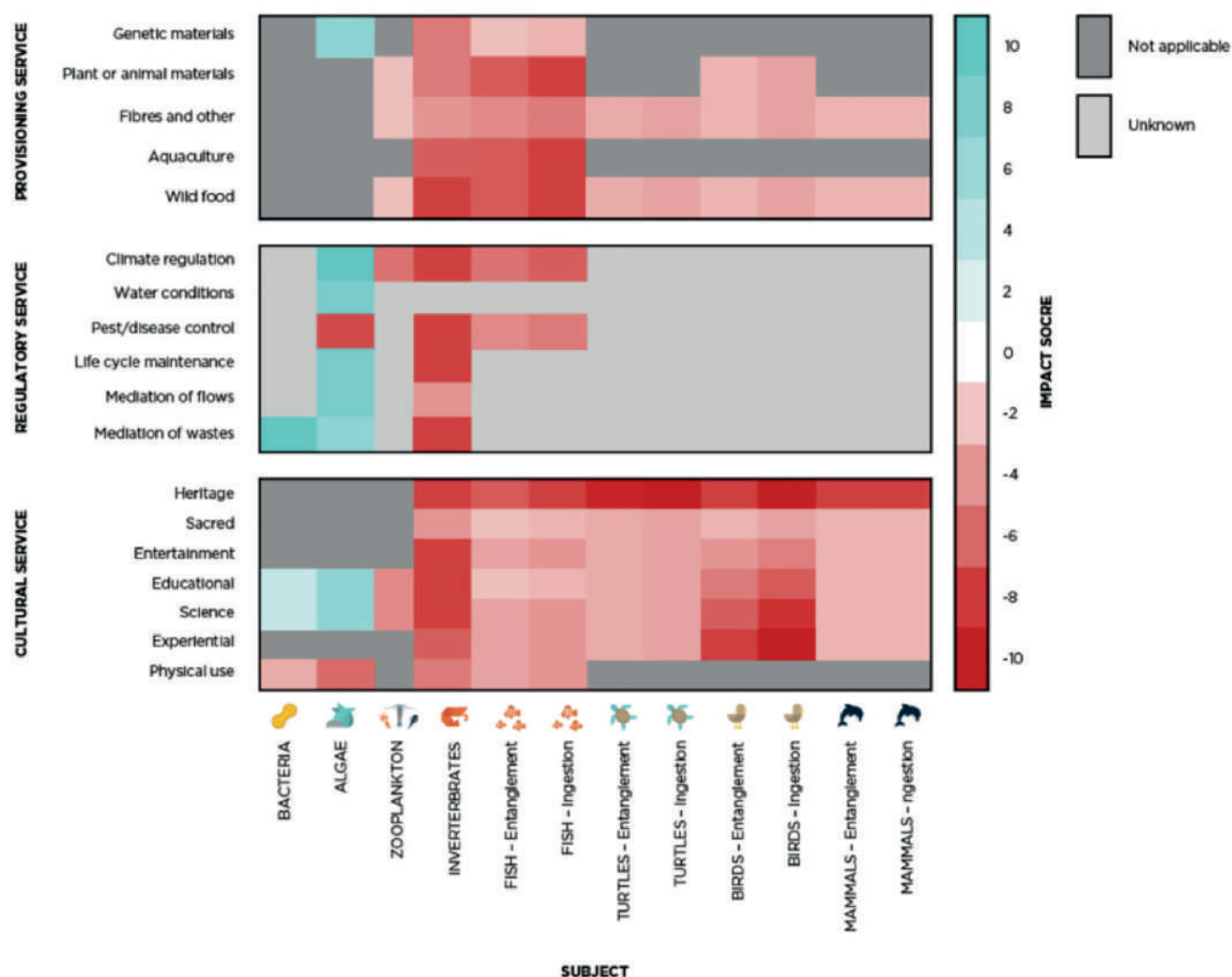


Figure 3: Ecosystem impacts of marine plastic on biota (horizontal axis) and services (vertical axis)

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 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.

3. MARINE LITTER AND AQUACULTURE GEAR DUE TO AQUACULTURE



This section of the paper draws upon scientific and industry experience to characterise the level of use of plastics by aquaculture and how it might be lost into the marine environment.

3.1 USE OF PLASTIC MATERIALS IN AQUACULTURE

Like any other industry, aquaculture makes extensive use of plastics in both the equipment and for packaging the various inputs. Indeed, plastics are an excellent material for use in a hostile aquatic environment, where resistance to abrasion, durability and resistance to rust improves the longevity and reliability of equipment, and

its lightweight nature reduces handling and associated costs. The ability to mould plastics into specific shapes means it is ubiquitous across a fish farm, from high-density polyethylene (HDPE), polystyrene foam-filled sea cage collars to polymer-coated cage nets to plastic harvest bins. The purpose of this section is therefore to attempt to classify the ways in which plastics are used by different forms of aquaculture. As discussed earlier in Section 1.3, the scope of this analysis is limited to the aquaculture production facilities and their various inputs and immediate products.

3.1.1 Classification of aquaculture facilities

For the purpose of this White Paper we have classified aquaculture production into a series of different systems:

Table 1: Classification of aquaculture systems

System	Description
Open-water cages and pens	Plastic, metal or wooden floating collars with suspended net enclosures anchored in sea and fresh waters. Used for grow-out worldwide for a variety of species e.g. salmon, yellowtail. Conducted in the open environment.
Suspended ropes / longlines	Longlines, suspended from buoys, or rafts with rope droppers, both anchored to the seabed. Used for grow-out of shellfish e.g. mussels, oysters and scallops (often in suspended lantern nets) worldwide. Includes off-bottom seaweed farming on longlines. Conducted in the open environment.
Coastal and inland ponds	Open-water ponds fed by pumped sea water or abstracted river water. Mainly used for grow-out of shrimp and nurseries and grow-out of finfish in tropical areas, as well as carp, trout and other freshwater fish in temperate areas. Wastewater drains into the open environment.
Tanks (inc. recirculated aquaculture systems RAS)	Usually higher density farming of a wide range of species in many different conditions. Usually in an enclosed area with increasing levels of water re-use, covering hatcheries, nurseries and increasingly, grow-out. Full or partial wastewater drainage into the open environment, depending of level of recirculation / re-use ³ .
Other systems	Variety of different systems including bottom culture, farming in lagoons, use of inter-tidal racks, etc. Conducted in the open environment.

³ Re-use can be in other agricultural systems, such as hydroponics.



3.1.2 Use of plastic in aquaculture

Plastic is widely used in aquaculture system components as it is light, reasonably strong and cheap, unaffected by sea water corrosion and can be formed to different shapes, including solid blocks, fibres 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 overleaf is conducted in two steps:

- 1. Plastic use in different aquaculture systems.** The first table (**Table 2**) looks at the various constituent components of each of the four aquaculture systems described previously and examines how plastic is used in each of these.
- 2. Overview of different plastics used in aquaculture.** Based on the above, the second table (**Table 3**) examines how different plastics are used in aquaculture and looks at their key characteristics in terms of their strengths and weaknesses.

3.2 PATHWAYS OF PLASTIC POLLUTION FROM AQUACULTURE

3.2.1 Basic causes

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

1. Mis-management: the loss of plastic through mis-management can take a number of forms, including:

a. Poor waste management: considerable plastic waste might be generated by aquaculture, including feeds sacks, plastic wrapped consumables, disposable equipment (e.g. plastic & plastic coated gloves). These different waste streams need to be disposed of responsibly, requiring safe and secure waste collection (e.g. not vulnerable to scavengers and 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, often exposed coastal pond sites.

b. Poor siting, installation and maintenance: as can be seen from the earlier section, plastic is 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, and 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 loss of plastic components to the marine environment.

c. Inadequate recycling: many plastic aquaculture components have a finite life e.g. nets. At present recycling opportunities for plastics from aquaculture

are limited, and often complicated by both the number of different plastics used and complicating factors like anti-foulant 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, with differing levels of decommissioning and clean-up. Abandoned farms – of which there are many – are subject to vandalism, natural depreciation and decay, all of which may result in waste plastic being lost into the marine environment.

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

2. Deliberate discharge: in some cases waste plastic may be deliberately discarded or abandoned, especially if the costs of removal or collection are deemed too high. This suggests that poor waste management in general is likely to be a higher risk in less profitable aquaculture operations. Vandalism is also a possible cause of equipment failure, for instance cutting floating cage nets to release fish into the wild.

3. Extreme weather: extreme weather in the form of large storms and extreme temperatures are 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, washing everything out to sea. Freezing temperatures can also be a major hazard by coating structures with ice, causing them to sink or break apart.

Table 2: Plastic use in different aquaculture systems

System	Key plastic components	PM MA	EPS	FRP	HD- PE	LLD- PE	LD- PE	Nylon	PE	PET	PP	PVC	UHM w-PE
Open-water cages and pens	Floating collars (inc. handrails)				✓							✓	
	Collar floatation		✓										
	Buoys (in mooring systems)				✓		✓		✓				
	Ropes (in mooring systems)							✓		✓	✓		
	Net enclosures				✓			✓			✓		✓
	Predator and other nets				✓			✓	✓				
	Feeding systems (pipes & hoppers)			✓	✓							✓	
Suspended ropes / longlines	Buoys (in mooring systems)				✓		✓		✓				
	Ropes (in longlines & mooring systems)				✓			✓		✓	✓		
	Raft floatation		✓		✓								
	Stock containment (nets/meshes)				✓			✓			✓		✓
Coastal and inland ponds	Pond liners				✓	✓	✓						
	Sampling / harvest nets				✓			✓			✓		✓
	Plastic green / poly housing						✓						
	Aerators / pumps				✓							✓	
	Feeding systems (pipes, feeders & trays)			✓	✓							✓	
Tanks (inc. recirculated aquaculture systems RAS)	Spawning, incubation & stock holding tanks			✓	✓								
	Pipework (inc. connectors, valves)			✓	✓							✓	
	Office / laboratory fixtures & fittings	✓	✓				✓	✓				✓	

Table 3: Overview of different plastics used in aquaculture

Material	Use in aquaculture	Characteristics	
		In use / recyclability	When lost
Acrylic (PMMA)	Incubation jars, containers, laboratory equipment	Lightweight, shatter-proof thermoplastic alternative to glass. Recyclable.	Slow levels of abrasion.
Expanded polystyrene (EPS)	Fish boxes, insulation material, floatation	Extremely light and can be formed into specific shapes. Mainly expanded polystyrene (EPS) used to fill floatation devices (inc. net collars), either by extrusion (within a plastic or metal shell) or as blocks. Is very light and has high insulation properties. Recyclable (see NOWPAP MERRAC, 2015)	Very buoyant, so accumulates on beaches. Easily abrades and breaks into smaller and smaller pieces ⁴ .
Fibre-reinforced plastic (FRP)	Fish transportation tanks, boats, floats, plastic gadgets	Includes glass-reinforced plastic (GRP). Difficult to recycle.	Will splinter in time.
High-density Polyethylene (HDPE)	Floats for cages, twines and ropes, net webbing, monofilament for making nets and hapas, storage tanks, pipes and fittings for water supply, aeration, drainage, pools for water holding, tubs, buckets, trays, basins, and different components of aquaculture implements, laboratory wares	Tough, chemically resistant rigid thermoplastic. Linings 12-100 mm. Commonly recycled.	Will fragment, abrade and weather leading to secondary microplastic formation ⁵ .
Linear low-density polyethylene (LLDPE)	Pond liners	Very flexible, but strong plastic. Linings 0.5 – 40 mm.	Will fragment, abrade and weather leading to secondary microplastic formation.
Low-density polyethylene (LDPE)	Small-scale pond linings, greenhouse canopy poly cover, fish seed transportation carry bags	The most common type of plastic sheeting. It is a flexible sheeting form (0.5 – 40 mm). Due to its flexibility is conforms well to a variety of surfaces but is not as strong or dense as some other types of plastic sheeting. Increasingly recyclable.	Will fragment, abrade and weather leading to secondary microplastic formation.
Nylon (Polyamide, PA)	Twine and ropes, fish nets	Strong, elastic and abrasion resistant.	Will fragment, abrade and weather leading to secondary microplastic formation.
Polyethylene (PE)	Rope, fish transport bags	Cheap rope material.	Will fragment, abrade and weather leading to secondary microplastic formation.
Polyethylene terephthalate (PET) or polyester	Rope	More expensive, strong but inelastic, water resistant rope material. Also used to make plastic bottles. Readily recyclable.	Will fragment, abrade and weather leading to secondary microplastic formation.
Polypropylene (PP)	Twines and rope, crates, feed sacks, tubs, buckets, trays, basins, laboratory wares	Reasonably cheap floating rope but abrades fairly easily. Increasingly recycled.	Will fragment, abrade and weather leading to secondary microplastic formation.
Polyvinyl chloride (PVC)	Pipe and fittings, aeration pipeline, hosepipes and fittings, valves, cage floats, cage collars, drums, jerry cans, prawn shelter, fish handling crates, etc.	Tough and weathers well. Rarely recycled. Should not be burnt as releases toxins.	Will fragment, abrade and weather leading to secondary microplastic formation.
Ultra-high molecular weight polyethylene (UHMwPE)	Ropes and nets	Expensive, very light and strong.	Unknown, but stronger than most materials.

3.2.2 Pathways and risk

Having examined the major causes of plastic loss from aquaculture, we now look at the main pathways for plastic from aquaculture into the marine environment, with a view on the risk involved.

This pathway element of this review examines the way in which (i) plastics 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 marine environment.

The risk element examines the likelihood of this happening. This is not a formal risk analysis which is out of the scope of this white paper. It should be noted that risk analysis in aquaculture is a specialist subject that has been extensively studied (see Bondad-Reantaso et al, 2008) but has rarely covered risks associated with plastic loss and the subsequent impacts. This review is conducted for the different aquaculture systems identified in the previous text. The risks are summarised in Table 4 on page 20.

Open-water cages and pens

The open-water farming of finfish in sea cages or pens accounts for the majority of salmon farming around the world, as well as 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 often sited in sheltered areas, they are often exposed to harsh wind and wave conditions that can lead to equipment failure and loss. This is usually direct into the sea, where the strong currents chosen to maximise water exchange will rapidly disperse debris into the marine environment.

The most likely causes of plastic loss are extreme weather, poor waste management and installation wear and failure (due to poor siting, installation and /or maintenance). Extreme weather, mostly in the case of large storm events, can cause moorings to fail, resulting in cages (e.g. collars and nets) being damaged or destroyed. Some elements such as intact elements of the cage collar can be recovered, but net segments, feeding systems, ropes and buoys may be lost. In addition any polystyrene used to increase cage / raft buoyancy may also be lost, often in a fragmented and unrecoverable manner. 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 Styrofoam (EPS), plastic bags and plastic fragments⁶. Microplastic fragments were attributed to the use of EPS in buoys for aquaculture facilities in Korea (Heo et al, 2013; GESAMP, 2015). 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 or reception facilities or due to poor awareness on the part of staff. Cages can also be damaged or vandalised, most often by poachers or recreational fishermen wanting to release caged stock. In addition marine cages may be vulnerable to damage from non-farm vessels, especially if sited in or adjacent to a busy navigational route.

⁶ Styrofoam, which is intensively used as floatation device by mussel farms, was very abundant in the northern region but rarely occurred 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.

Suspended rope or longline aquaculture of bivalves

Bivalves are often farmed on ropes suspended from floating rafts or from buoyed longlines. Depending upon the species and system used, these are usually placed in bays or channels where there is sufficient spat or other feed available, water exchange to remove organic matter and water of sufficient depth (typically 15 – 30 metres). Like finfish cage, these bivalve farm sites are vulnerable to extreme weather and possible conflict with other users in coastal bay areas.

The causes and pathways of plastic lost from rope or longline aquaculture is very similar to that from finfish cages, in that many of the plastic components are included in the floating rafts or other suspension methods. The main difference is that these systems lack nets, although they do include long lengths of plastic rope which is vulnerable to abrasion (thus generating microplastics) and loss.

Coastal and inland ponds

Aquaculture pond systems are situated in flat coastal or inland areas using an adjacent water supply to fill earthen or lined ponds. The rate of water flows

depends upon the species being farmed. In the case of trout the ponds tend to be small with a constant exchange of water, whilst carp and shrimp require less water exchange and intermittent water top-ups. In both cases the ponds are occasionally drained e.g. during harvest or for de-silting 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, but this is relatively rare and mainly for small-scale, extensive systems in developing countries. Most employ some form of pumping system to raise water from the sea into a header channel or tank whereby it drains through gravity into the ponds and then out back to the sea via various control points. Coastal pond aquaculture can be on a very large scale, with hundreds of hectares under cultivation. Where there is insufficient clay content in the soil plastic liners have to be used (see photo of National Aquaculture Group's farm in Al Lith in Saudi Arabia below).



Figure 4: Large shrimp farm in Saudi Arabia (National Aquaculture Group, Al Lith)

Table 4: Causal risk analysis for plastic loss from different aquaculture systems

Aquaculture system	Mis-management					Deliberate discharge	Extreme Weather
	Poor waste management	Poor siting, installation & maintenance	Inadequate recycling	Farm de-commissioning	Lack of awareness & training		
Open-water cages & pens	High Exposed 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.
Suspended ropes / cages							
Coastal ponds	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)	High High cost to restore land (e.g. fill in ponds).	Medium Often in developing countries.	Low Limited plastic volumes and disposal opportunities	High Vulnerable to storm surges, inland flooding and storm land-falls.
Open-water cages & pens	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.
Open-water cages & pens	Low Small sites with good access/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 requires skilled, trained staff.	Low Smaller sites, usually with access to waste collection.	Low Mostly enclosed and away for high risk environments.

Colour code: Low Low to Medium Medium Medium to High High

The largest cause of plastic loss in coastal ponds sites is through extreme weather. In order to reduce pumping costs, most coastal pond farms are built close to the sea and just above the high-water mark and are thus vulnerable to storm surges and flooding from upstream water courses. For example the Indian and Bangladesh coasts within the Bay of Bengal are frequently exposed to cyclones which cause storm surges of over 3 metres and whose effects are exacerbated by heavy rain and inland flooding (Katare et al, undated). In China over 55,000 hectares of coastal fish ponds were damaged by typhoons⁷ between 1949 and 2000 (Xu et al, 2005). Such events will wash unsecured equipment into

the sea, often adjacent to sensitive habitats such as coral reefs, mangrove and coastal wetland areas. As many coastal pond systems are found in developing countries, awareness of the impacts of lost plastics and the need to ensure they are stored and disposed of responsibly is often lacking, as is the infrastructure for plastic collection and recycling. Another issue is that of farm decommissioning - large areas of coastal pond farms have been abandoned for various reasons (e.g. financial, pond siltation, storm damage) and have been left to deteriorate, allowing large items such as pond liners to disintegrate and disperse into the environment.

⁷ Also known as a cyclone (Indian & south Pacific Oceans) or hurricane (Atlantic and NE Pacific Oceans)

Inland aquaculture ponds tend to have lower waste issues. They are less vulnerable to storm events, although can be overwhelmed by flooding, especially if 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, although they are likely to have better access to waste collection and disposal services. They also tend to be in better soils with a higher clay content, and thus don't normally need the pond liners required on sandy coastal soils.

Tanks (inc. RAS)

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



Figure 5: Glass-reinforced plastic tanks used in a UK hatchery

Source: Purewell Fish Farming Equipment Ltd

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

Despite the extensive use of plastic in tank-based aquaculture, the risk of their loss to the marine environment is low (see Table 4). In most cases they are situated in a building or secure area to prevent theft and to protect these often intensive systems 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 easily decommissioned 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 suite of a former pizza factory. When the farm ceased operations the site was converted to a brewery).

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



3.3 THE QUANTITY OF MARINE PLASTIC POLLUTION PRODUCED BY AQUACULTURE

There are few figures on the contribution of aquaculture to the marine plastic load. Indeed, this is extremely difficult to estimate as there is no monitoring at farm, local or national levels. In addition plastic leakage may vary from farm to farm (depending on the level of awareness and waste management protocols), is usually low level (e.g. through the constant abrasion of ropes and other plastic components) and may result

from periodic spikes as a consequence of extreme weather events. Sundt et al (2014) considers that microplastics generated from abrasion in an aquaculture unit to be “in the range of a few kilograms”.

The only detailed calculation of plastic use and decommissioning rates come from Norway. A consultation between manufacturers and waste management companies in 2011 estimated around 13,300 tonnes of plastic waste generated by Norwegian aquaculture in 2011 (see Sundt et al, 2014), of which 21% is recycled (see Table 5 below), mainly the nets. MOWI, one of Europe’s largest salmon farmers, state that they recycled 303 tonnes of nets in 2018⁸.

⁸ See <https://mowi.com/blog/2019/04/15/reduce-reuse-recycle-managing-plastic/>

Table 5: Estimates of plastic waste generated by Norwegian aquaculture in 2011

Source (plastic type)	Total waste in 2011 in mt	Recycled volume in 2011 in mt (% recycled)	Potential risk for littering in Norway (comments by MEPEX, 2014)
Marine cage collars (PE)	7,000	500 (7%)	Medium/low: High value of equipment, but also high cost for collection, equipment thus sometimes stored or reused for other, alternative use, with a medium/ low risk for littering.
Feeding pipes (PE)	800	150 (19%)	Medium/low: High cost for collection, sometimes stored or reused for other, alternative use.
Cage nets (PA)	2,500	1,500 (60%)	Medium/low: Delivered to net- washing, some destroyed nest get lost.
Ropes (PP)	3,000	600 (20%)	Medium: Lost or discarded no regular take back system. Lower value
TOTALS	13,300	2,750 (21%)	

Source: Sundt et al, 2014

EUNOMIA (Sherrington et al, 2018) use the data reported in Sundt et al (2014) to estimate that roughly plastic waste from Norwegian aquaculture equates to 2.3 tonnes per employee or 11kg per tonne of output production and if raised against FAO production figures, is around 30,000 tonnes per annum. Sundt (2018) reports that new investigations in Norway have found that 25,000 tons of plastic from aquaculture is discarded at sea annually, specifically floating collars, plastic pipes, but also nets, feed hoses and ropes. According to EUROSTAT⁹ statistical data, the Norwegian production is 1.4 million tonnes and EU-28 aquaculture production of about 1.3 million tonnes.

Applying the production rates to the absolute annual loss of plastic waste from aquaculture in Norway leads to 22,809 tonnes for the EU-28.

However the fate of the un-recycled material is not known. It is presumed that the majority of plastic material is used as spare equipment, given to local communities or will go to a landfill where there may be potential for loss into the marine environment. The actual quantity ending up in the marine environment has not been fully calculated at a global level.

EUNOMIA estimated the fishery and aquaculture waste from the European Economic Area (EEA) to be between 3,000 and 41,000 tonnes per annum, of which around 72% is likely to be plastic and 7% is deliberately discarded. They estimated that 15% of the total plastic waste from fishing and aquaculture gear is lost to the environment, this number was considered to be a reasonable figure by fellow researchers (Violl et al 2018). Based on this figure, the total plastic waste from fishing and aquaculture gear leads to a range between 9,888 and 22,685 tons of plastic waste from fishing and aquaculture entering the European seas.

In our view the contribution of plastic debris from global aquaculture is not at the same magnitude as that from capture fisheries. This said, it may be a locally important source in some areas (e.g. in Southern Chile – see Hinojosa & Thiel, 2009; Hinojosa et al, 2011) and more importantly, given the growth in aquaculture worldwide, is likely to become a more significant source over time, especially in the case of a climate change-induced increase in the frequency of major storm events (Dabbadie et al, 2018).

4. DISCUSSION



As stated earlier in this paper, there is very little specific information currently available on the contribution of aquaculture to the plastic load in the marine environment. The focus has been mainly on land-based sources and, to a certain extent, from capture fisheries (see Macfadyen et al, 2009) and other sea-based sources. Given that aquaculture production is currently increasing at around 6% per annum it is evident that this situation needs to be addressed.

Plastic is an extremely versatile and useful material, and will no doubt be continued to be used in aquaculture for many years to come. However, with the growing awareness of the impact of plastics in the marine ecosystem and its persistent nature, there is a need to identify the drivers and pathways for aquaculture-related plastic loss and put in place measures to reduce this to the absolute minimum possible. The inclusion of this issue in third-party certification such as the ASC aquaculture standards is an important approach.

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

The causes of plastic loss from aquaculture are also varied. Low level 'leakage' can occur from inter-tidal and sub-tidal installations just through the working of components in what is 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, under-specification and a lack of maintenance. There is also a 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.

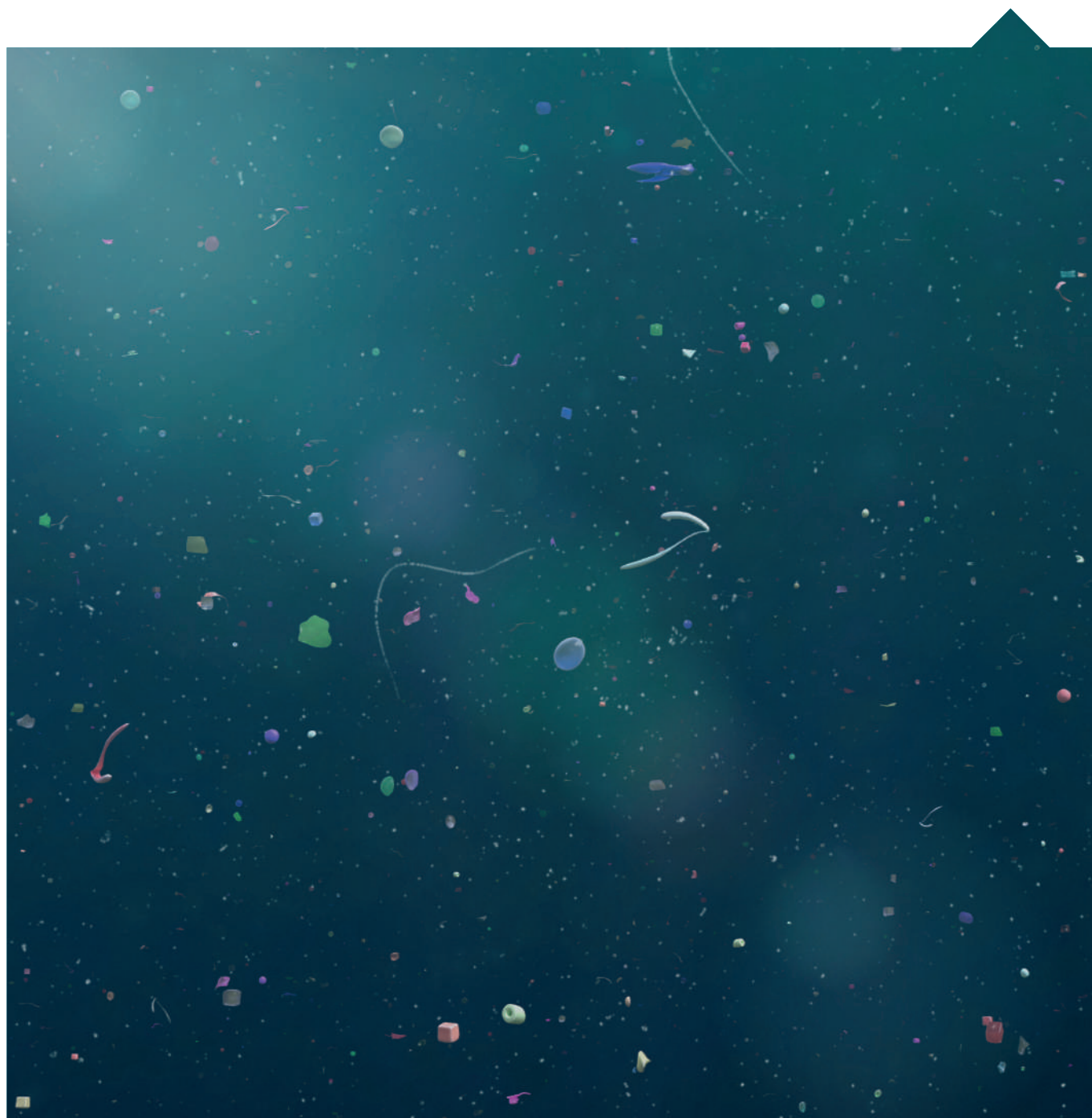
Probably the main reason for marine litter from aquaculture is extreme weather and the catastrophic impact on facilities. In the case of inter or sub-tidal facilities this means entire components e.g. cages, nets, rafts and plastic containers being lost directly into the sea. Whilst some major components are likely to be recovered, smaller items are likely to be permanently lost. Similarly coastal pond farms are vulnerable to large storms and associated tidal surges or 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 remain the main cause of marine-related litter from aquaculture.

Tank-based 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 whilst 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 or extreme weather) or discarded (deliberately disposed of at sea e.g. because there is not enough space to store it, the gear is damaged or gear disposal facilities back at port are insufficient). In aquaculture it is caused either by facility or waste mis-management, deliberately discarded or lost (e.g. from extreme weather).

Finally, whilst it is currently impossible to even estimate the contribution of aquaculture to the marine plastic stock, it is evident that it is probably localised and relatively low compared to capture fisheries. However with the likely continued growth of

aquaculture, its contribution will increase unless more preventive measures are taken to reduce plastic use, reuse and recycle end of life plastic components and recover lost plastics and other aquaculture-derived debris where practical.



5. RECOMMENDATIONS



Our recommendations are in two forms. Firstly, we look at generic recommendations to identify and describe measures available to reduce marine litter from aquaculture, obstruct the pathways to the marine environment and the reduce the contribution to marine plastic pollution by aquaculture. Secondly, we look at the approach that ASC might take to revise and add additional requirements to their standards, and thereby encourage responsible behaviour by the aquaculture industry and its stakeholders.

5.1 MEASURES TO REDUCE THE CONTRIBUTION OF AQUACULTURE TO THE MARINE PLASTIC STOCK

ASC's proposal for tackling plastic is based on the '5 R's' approach – Reduce, Re-use, Recycle, Recover, Refuse – to help address negative impacts of aquaculture gear and plastic waste from aquaculture. We have therefore framed our recommendations regarding the 5 R's as follows.

5.1.1 Reduce

- Reduce plastic abrasion levels by:
 - o Ensuring physical infrastructure components (e.g. anchors, mooring systems, cage collars, longline systems) are appropriate for the physical and chemical environment.
 - o Use alternative materials or higher specification plastics e.g. PET or UHMwPE that are resistant to abrasion, and are stronger and lighter than, say, PE.

- Reduce the risk of equipment failure by:
 - o Ensuring that maintenance regimes are in place and followed and that equipment and fittings are replaced within their expected lifetime.
 - o Develop contingency plans for expected extreme weather conditions e.g. removal of vulnerable equipment.
 - o Monitor weather forecasts and implement contingency plans when necessary.
- Reduce the risk of aquaculture operations contributing to the marine plastic stock by preparing a formal risk assessment examining both low-level risks (e.g. plastic packaging being blown into the water) and high-level risks (e.g. vulnerability to extreme weather) in order to develop management and mitigation measures to reduce these risks.
- Develop staff environmental awareness training to motivate better practises. Develop Standard Operating Procedures (SOPs) for maintenance, contingency and other regimes, again to promote good practice.

5.1.2 Re-use

- Maximise re-use of plastics. This may mean buying high specification items rather than cheap single-use alternatives¹⁰, and possible investment in recovery, cleaning and re-distribution.
- Ensure there are the systems in place to facilitate re-use of plastics and other materials. This could include waste collection points, wash plants, storage and inventory systems.
- Again, develop management and staff awareness of the need for re-using (rather than replacing from new) equipment and fittings, even if it requires additional training.

¹⁰ An example might be buying re-usable gloves rather than the commonly used single use latex versions.

5.1.3 Recycle

- Engage with equipment suppliers to maximise the use of recyclable plastics in aquaculture equipment. Obtain information on what plastics are used and in what components to assist sorting and recycling.
- Develop a recycling policy and associated management systems, e.g.
 - o Develop a plastics inventory to track recyclable plastic and their status on site.
 - o Establish facilities and SOPs for decommissioning equipment and recovering plastic (and other) components for recycling.
- Larger companies should consider working with aquaculture small-medium enterprises (SMEs) to collect recyclable waste and add to their own managed waste streams.

5.1.4 Recover

- Develop SOPs for locating and recovering lost or abandoned aquaculture equipment. This could be for:
 - o Recurrent litter collection within and outside the site to clear any items lost during routine operations
 - o Emergency recovery of lost equipment / debris after accidents, severe weather events and other unexpected events. This may require preparations in the form of SOPs, caching of diving equipment, etc.
 - o For key equipment that is at risk of loss, embedding of GPS transmitters and other tracking devices.
- Develop decommissioning plans for farm sites that are closing down that ensure that all plastic elements are disposed of responsibly e.g. sold on to other businesses, recycled, etc.

5.1.5 Refuse

- Develop a formal plastic use policy that reduces and where possible eliminates (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.

5.2 DEVELOPING THE ASC STANDARD TO ENCOURAGE RESPONSIBLE USE OF PLASTICS IN AQUACULTURE

As mentioned earlier, the ASC standard could be developed to include benchmarking for the responsible use of plastics in aquaculture, including reducing the risk of it being lost to the marine environment. It is worth noting that the Marine Stewardship Council (MSC) standard for responsible fisheries does not currently include waste management or the loss of fishing gear in its standard¹¹, although it is implicit within the habitats and ecosystem performance indicators.

Based on the above analysis, we suggest that ASC focus their benchmarking on the following:

1. Evidence of circular planning, including in procurement (equipment, packaging and other consumables), waste management, promoting recycling rates and planning for site and facility decommissioning. This should include evidence of risk assessment and minimisation including the low and high-level loss of plastic into the marine environment.
2. Evidence of proactive facility management, including sub-tidal infrastructure lighting and marking and inclusion in navigation mapping, maintenance schedules, equipment replacement regimes and quality assurance.
3. Evidence of contingency planning in case of extreme weather events and other potential catastrophes. This should include pre-planning, immediate response and subsequent recovery activities, where possible.
4. Evidence of management and staff awareness and capacity to manage facilities so that plastic use is minimised, losses reduced, and end of life plastics recycled where possible.
5. Evidence of ensuring traceability to assist the identification of recovered aquaculture gear. This could include the embedding of unique identifiers, maintenance of equipment inventories and use of traceability systems, including blockchain traceability tools.
6. Develop equivalence with existing global, regional and national initiatives, regulations and certification schemes to reduce plastic use and to encourage their recycling. An example of this are the NYTEK Regulations¹² in Norway.

¹¹ MSC is currently consulting on how gear loss, and resulting 'ghost fishing' can be explicitly included in the standard

¹² Regulations on requirements for technical standards for floating aquaculture plants (NYTEK Regulations)
<https://lovdata.no/dokument/SF/forskrift/2011-08-16-849>

APPENDIX A: REFERENCES AND BIBLIOGRAPHY



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