In collaboration with MarFishEco, Friends of Ocean Action and the World Resources Institute

WORLD ECONOMIC FORUM

Investigating Global Aquatic Food Loss and Waste

WHITE PAPER

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Contents

Foreword

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Aquatic food plays a critical role in global food and nutrition security, and loss and waste of this essential resource is a growing concern worldwide. Previous estimates indicate that one-third of global aquatic food produced for human consumption is lost or wasted. However, these estimates are now assumed to be outdated and potentially inaccurate. This paper provides up-to-date estimates of global edible aquatic food loss and waste across the value chain, from production through to consumption. It offers a comprehensive breakdown across species groups, product types and bilateral international trade routes.

This paper comes at an important time. It contributes to the United Nations (UN) Ocean Decade's ambition to use ocean science and knowledge generation to catalyse new opportunities for sustainable development. It responds directly to the Non-State Actors Call to Action for Transforming Food Systems for People, Nature, and Climate coming out of Conference of the Parties (COP28), and solutions presented in this paper provide tangible approaches to progress to Sustainable Development Goal 12.3, halving per capita global food loss and waste by 2030. This work actions the UN's Food and Agriculture Organization's (FAO) Blue Transformation Roadmap, prioritizing efficient value chains that increase profitability and reduce food waste, and aligns closely with the High Level Panel for a Sustainable Ocean Economy's priority action to minimize waste in aquatic food supply chains.

This work delves into specific loss and waste challenges at each section of the value chain and emphasizes the critical need for targeted interventions that enhance long-term food system resilience. In addition to demonstrating the scale of aquatic food loss and waste, this work highlights key hotspots where significant loss and waste is occurring, and where focused investment in interventions would be most impactful. Additionally, numerous actionable strategies that have already been adopted are showcased, exemplifying successful solutions driven by technological innovation and multistakeholder collaboration.

Using the insights from the quantitative analysis, targeted calls to action for policy-makers, industry and civil society are outlined. We invite all stakeholders engaged in aquatic food value chains to use this paper as a shared community resource to identify priority areas and as a guide for their own transformative actions. In doing so, we can build collective momentum towards reducing aquatic food loss and waste, and work towards the sustainable growth of the aquatic food industry for people, nature and climate.

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Executive summary

Aquatic foods are indispensable for global food security, yet substantial losses occur, which require coordinated action among stakeholders.

23.8
million tonnes

The approximate total of global edible aquatic food loss and waste in 2021

Aquatic foods play a critical role in global food and nutrition security. With projections indicating a continued rise in their consumption, aquatic food loss and waste (FLW) is a growing global concern. While the United Nations Food and Agriculture Organization (FAO) 2011 estimate indicated that 35% of aquatic food directed to human consumption was lost or wasted globally, such estimates are outdated and inadequately aggregated, making it challenging to assess more recent FLW along the aquatic food value chains.

This paper provides updated estimates of global aquatic FLW across different nodes of the value chain, offering a comprehensive breakdown across species groups, product types and continents. The analysis reveals global edible aquatic FLW totalled approximately 23.8 million tonnes (MT) in 2021, equating to 14.8% of total aquatic food produced that year. Globally, processing on land and production of wild-capture fisheries (discards) accounted for 39.08% and 35.38% of aquatic FLW, respectively, the largest proportions generated in 2021. The analysis also highlights specific areas of concern regarding aquatic FLW, emphasizing the urgent need for targeted interventions, particularly on demersal fishes and frozen products, most notably during production and processing in Asia and Europe.

Reducing aquatic FLW is crucial for enhancing long-term food system resilience. While the magnitude of aquatic FLW is significant, there are numerous actionable strategies for FLW mitigation that have already been adopted, driven by technological innovation and multistakeholder collaboration.

Using insights from the analysis and research, this paper outlines targeted calls to action for distinct stakeholder groups comprising policy-makers, industry and civil society. Each stakeholder group holds a crucial role in addressing and mitigating aquatic FLW, emphasizing the collective effort required to combat this global issue.

1 Aquatic food loss and waste: the challenge

The rising demand for aquatic food underscores the international concern about aquatic food loss and waste and the need for mitigation efforts.

Aquatic foods play a key role in ensuring global food and nutrition security. In 2019, the global consumption of aquatic foods was estimated at 158 million tonnes (MT) (see Figure 1),[1,2] more than double the consumption of beef and approximately 50 and 30 MT more than pork and poultry, respectively.[3]

As a source of high-quality protein, 3.3 billion people rely on aquatic foods to provide 20% or more of their average intake of animal protein. Aquatic foods provide a unique source of omega-3 polyunsaturated fatty acids and essential vitamins and minerals, many of which are not readily available through other dietary sources.[4,5] Furthermore, aquatic foods are particularly important for lower- and middle-income countries because it is often the primary and, in some cases, the only source of protein and essential nutrients.[6]

Given the nutritional benefits, aquatic foods are recognized as one of the highest-valued and traded food commodities globally, and records show that its global consumption is now five times greater than six decades ago. This rise in consumption now outpaces the human population growth rate, indicating the increased aquatic foods consumption can be attributed to evolving consumer preferences, advancements in technology, and economic and income growth. Projections indicate this upward trajectory in global consumption will continue, and an estimated total of 181 MT of aquatic foods will be consumed by 2030.[7]

In response to the increasing global population, pressures of traditional land-based agriculture and challenges faced by wild-capture fisheries, aquaculture has emerged as a promising, resilient and sustainable approach to meeting the growing demand for aquatic foods.[8] In 2022, aquaculture contributed 88 MT, or 49%, of worldwide aquatic foods production, underscoring its undeniable importance in ensuring global food and nutrition security and its significant role in supporting sustainable livelihoods for coastal and inland communities.[9]

With increasing efforts to meet the global demand for aquatic foods, the issue of food loss and waste (FLW) has become an international concern.[10] While the terms "food loss" and "food waste" are typically used interchangeably, the United Nations Food and Agriculture Organization (FAO) defines food loss as "food that has unavoidably become unfit for human consumption, leading to a decrease in the quantity or quality of food". Food waste is defined as "the removal of food that is still fit for human consumption by choice due to spoilage or food expiration".[11] While FLW can occur at different stages (aka nodes) along aquatic foods value chains, loss typically occurs earlier in the value chain during production, processing and distribution, while waste occurs during consumption[12] (see Figure 2). At different nodes within the value chain, by-products can also emerge. These secondary products are produced after attaining the desired primary products that are usually destined for human consumption and are often considered inedible (heads, viscera, skin, shells, etc.).

FIGURE 1 **Global production of protein in 2019**

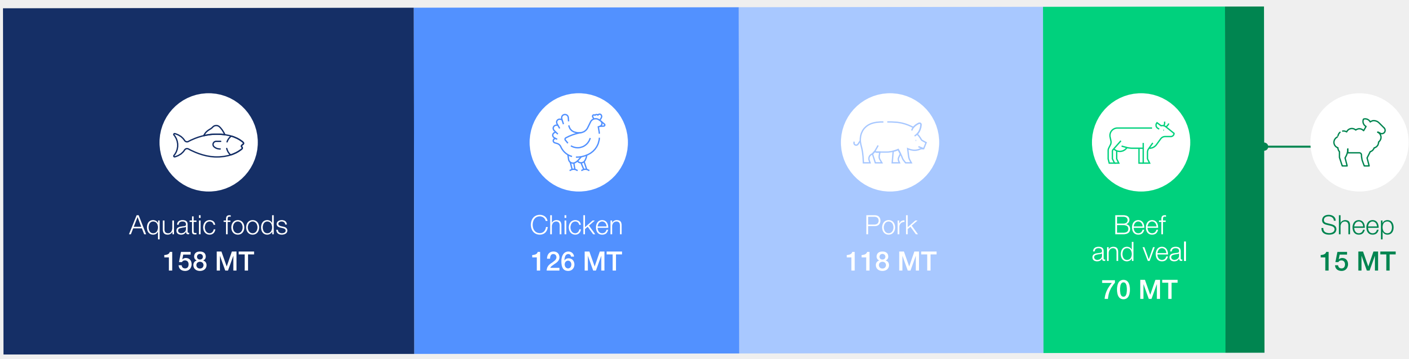
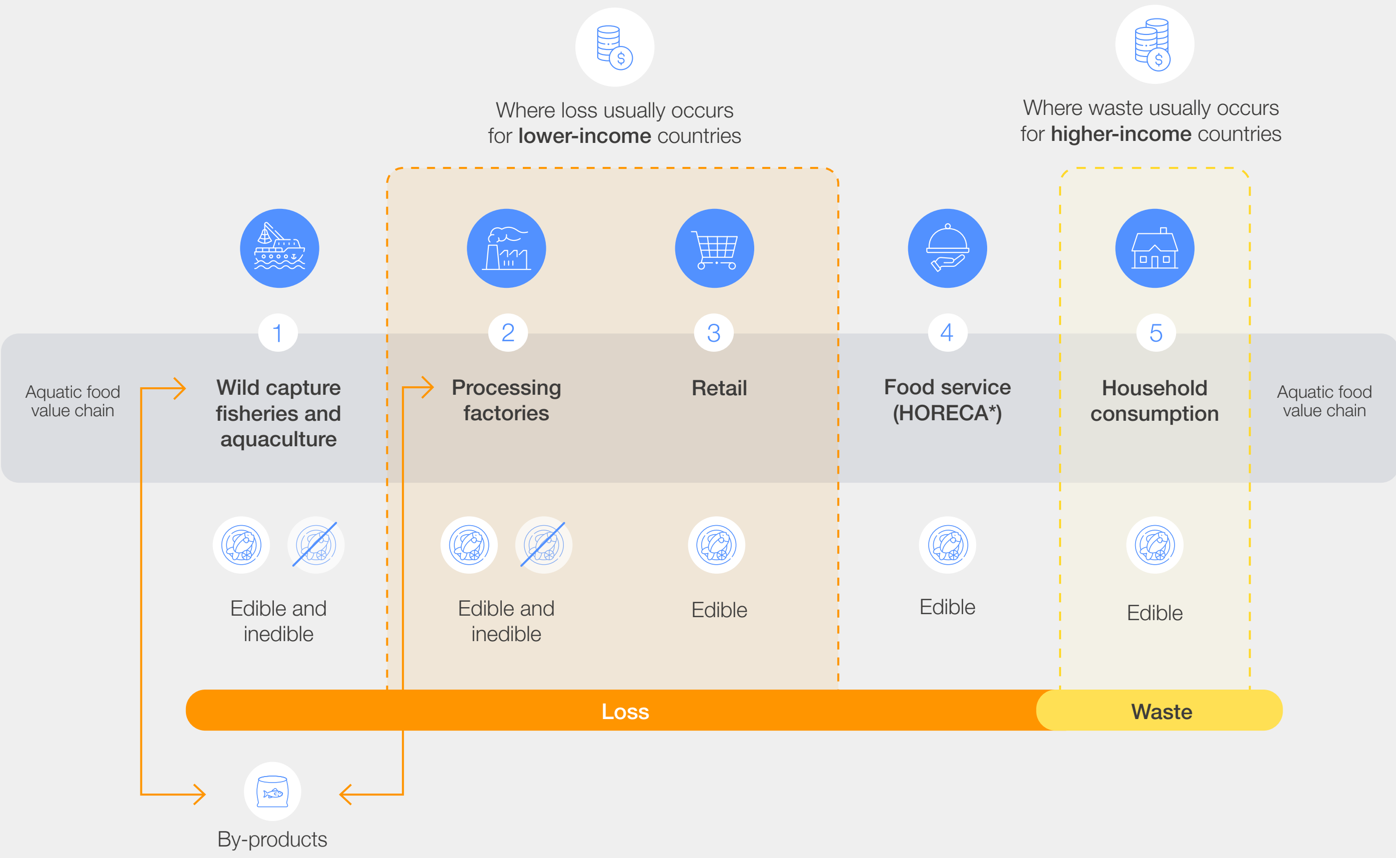


FIGURE 2 | **Schematic showing the difference between food loss and food waste along a typical (simplified) aquatic food value chain**



*Hotels/restaurants/catering

Note: Production of aquatic food includes wild capture fisheries and aquaculture.

Reducing FLW is essential to improving the sustainability of global food systems and the overall well-being of the planet, economy and livelihoods.[13,14,15] Target 12.3 of the 2030 Sustainable Development Goals (SDGs) calls for halving per capita global food waste at retail and consumer levels by 2030 and significantly reducing food loss along value chains. FLW is also a significant contributor to global warming as food thrown into landfills is converted into greenhouse gases (GHG), particularly methane, which has a global warming potential 25 times higher than that of carbon dioxide.[16] While of significant concern, little is known about the global magnitude of FLW, especially aquatic foods. Without this knowledge, understanding where to direct efforts to better mitigate FLW remains challenging.

In 2011, the FAO estimated that 35% of aquatic foods directed to human consumption was either lost or wasted globally.[17] This and many associated estimates are outdated, aggregated to large aquatic foods groups and product types, and based on significant assumptions and limitations.[18] This makes them difficult to use for identifying where FLW is occurring along aquatic foods value chains. In fact, Love et al[19] estimated the total edible aquatic FLW for the United States was 43-55% lower than previous estimates made by the FAO.

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Variations in FLW between global regions are known to be linked to differences in income levels, urbanization and economic growth.[20] This makes global estimates of aquatic FLW variable and challenging. In lower- and middle-income nations, most aquatic FLW occurs during post-harvest and processing, largely attributed to inadequate handling practices, technological limitations driven by financial constraints and insufficient infrastructure for cold transport and storage.[21] In contrast, higher-income nations generate large proportions of their aquatic FLW during consumption, primarily driven by consumer behaviour and attitudes to waste.

This paper offers a comprehensive exploration of global aquatic FLW across various value chain stages. By providing updated estimates of edible aquatic FLW across species groups, product types and continents, the paper pinpoints global and intra-continental hotspots of FLW.[22] For estimates of both edible and inedible aquatic food loss refer to the Annex published alongside this paper. Through this analysis, the paper describes interventions that can be adopted to mitigate aquatic FLW while outlining recommendations for immediate actions that can be taken to address this global issue.

2 Drivers of loss and waste along the value chain

Aquatic food loss and waste spans diverse nodes along the value chain, offering unique challenges and opportunities for mitigation.

The landscape of aquatic FLW is multifaceted and stretches across numerous nodes within the value chain. From discards at sea to onshore processing, retail, food service and household consumption, each stage presents unique challenges and opportunities in mitigating loss and waste. The section below describes each of these nodes.

2.1 Fisheries discards at sea

Wild capture aquatic foods value chains often begin onboard a fishing vessel. This is where the first forms of aquatic food loss happen in the form of fisheries discards. The discards are the portion of fishery catches that are not considered valuable enough to keep and are therefore thrown back overboard whole.[23]

Unfortunately, most discarded fish are typically returned to the sea dead or die shortly after release[24,25] due to physical trauma,[26] or increased susceptibility to predation.[27] The mortality associated with fisheries discards is a significant contributor to the overall loss of aquatic foods in the early stages of the value chain.

This loss has important ecological impacts on the populations of discarded species and associated marine ecosystems.[28,29,30] It also represents an important loss of protein and micronutrients, much of which could have been consumed by humans or aquaculture and agriculture animals.[31] Fisheries discards are particularly significant in non-selective multi-species fisheries, where non-target species are readily caught.

BOX 1 What about aquaculture?

Aquaculture involves the cultivation of aquatic organisms either during part of or throughout their life cycle.[32] The scope of aquaculture operations ranges from small household enterprises to multinational companies with large footprint operations spanning multiple continents. Aquaculture systems can also be diverse, from low-input operations using inland tanks, basic equipment and simple feeds through to open-water cage systems with highly mechanized equipment employing advanced feeding, harvesting and processing technologies.[33] Aquaculture facilities are primarily categorized into three major types: tanks (suitable for freshwater, brackish water or saltwater), ponds (used for freshwater or brackish water cultivation) and net-pens (specifically designed for open-water cultivation).

Aquaculture operations have a myriad of factors that can impact loss, including mortality within the culture systems, disease, escapes, parasites and deformity, that may deem individuals unfit for sale to the human consumption market. Mortality can be driven by imbalances in water chemistry, improper feeding regimes and handling,[34] or external impacts like extreme temperatures or contamination from land run-off.

In many cases, the feed used in aquaculture operations relies upon fishmeal and fish oil (FMFO) ingredients, which usually come from small, wild-caught pelagic fish species.[35] The use of certain FMFOs may be defined as a loss of aquatic foods if such ingredients are potentially consumable for humans.

As global aquaculture continues to grow, new technologies and production strategies will underscore the future of enhanced production efficiency, reduced losses and improved sustainability and resilience of the industry (see table below).

New research and strategies aimed at enhancing aquaculture production and reducing loss of aquatic foods

Focus area	Description
Alternative protein sources in fishmeal	Exploration of alternative protein sources for aquaculture feed, such as plant-based protein, microalgae and insect meal, offers more sustainable approaches than traditional fishmeal production. Feeding cultured fish with microalgae-based feeds has demonstrated the ability to improve growth performance and increase the activity of antioxidants compared to feeding fish with a diet lacking microalgae.[36]
Handling technique training	Skill training is crucial in minimizing stress during harvesting processes. Training courses and certificates on best management practices can provide valuable guidance to operators, helping them reduce losses resulting from improper handling.[37,38]
Selective breeding/ genetic modification	Selective breeding programmes aimed at the genetic improvement of aquatic species can enhance stocks' overall robustness and productivity. These programmes involve breeding species with desirable traits, such as disease resistance and faster growth, to achieve improved genetic characteristics.[39] Over generations, this can lead to more resilient individuals and, thus, reduced loss.[40,41]
Sensor technology and disease detection	Integrating sensor technologies for real-time monitoring and early disease detection plays a pivotal role in quickly identifying diseases. This allows for timely intervention, preventing widespread outbreaks and minimizing associated losses.[42]

Aquaculture offers a more controllable alternative to wild capture aquatic foods sources, enabling high yields of desired aquatic animals with great scope to minimize loss through technological development, training and investment. Despite its advantages, aquaculture is not immune to losses, and operational factors play a crucial role. Consequently, there is a vested interest in improving operational efficiency to mitigate such loss. Therefore, pursuing innovation and investment will be essential for the sustainable and efficient development of aquaculture operations, aiming for the lowest possible loss levels.

2.2 At-sea fish processing

For the aquatic species that make it onboard and are not discarded, processing these fish is often the next form of loss in the aquatic foods value chain. At-sea processing can involve a variety of different processes, including heading, gutting, cutting, filleting, de-boning, peeling, washing and packing (see Table 1).[43] These processes produce many different forms of waste such as fish heads, tails, viscera, blood, scales and other organic materials.[44] These products ultimately have two journeys – back to the sea along with the discarded organisms or into the hold for later use as by-products if they have additional market value to the fishers.

The primary reasons to process at sea are to help extend shelf life[45] and to efficiently prepare the catch for the land-based value chain. By processing animals as soon as possible and storing them on ice, the number of subsequent stages necessary to further prepare the animals for their destination markets is minimized.[46] Less processing stages means less handling and less chance for changes in temperature that could potentially lead to a degradation in product quality.

TABLE 1

Globally important commercial species and the corresponding processing methods each typically undergo to distinguish the edible portion from the by-product or loss (discarded) portion[47]

Species category	Species (common name)	Evisceration (gutting)	De-heading	Skinning	Trimming (cutting fins and belly flaps)	Filleting (or portion creation)	Gill removal/ bleeding
Demersal	Cod, hake, haddock	✓	✓	✓	✓	✓	
	Alaskan pollock	✓	✓			✓	
	Atlantic cod	✓	✓				
	Patagonian toothfish	✓	✓	✓	✓	✓	
Pelagic	Mackerel, herring, blue whiting	✓				✓	
	Skipjack tuna						✓
	Yellowfin tuna						✓
Shellfish	Squid	✓					
	Crab		✓				
	Prawn		✓			✓	

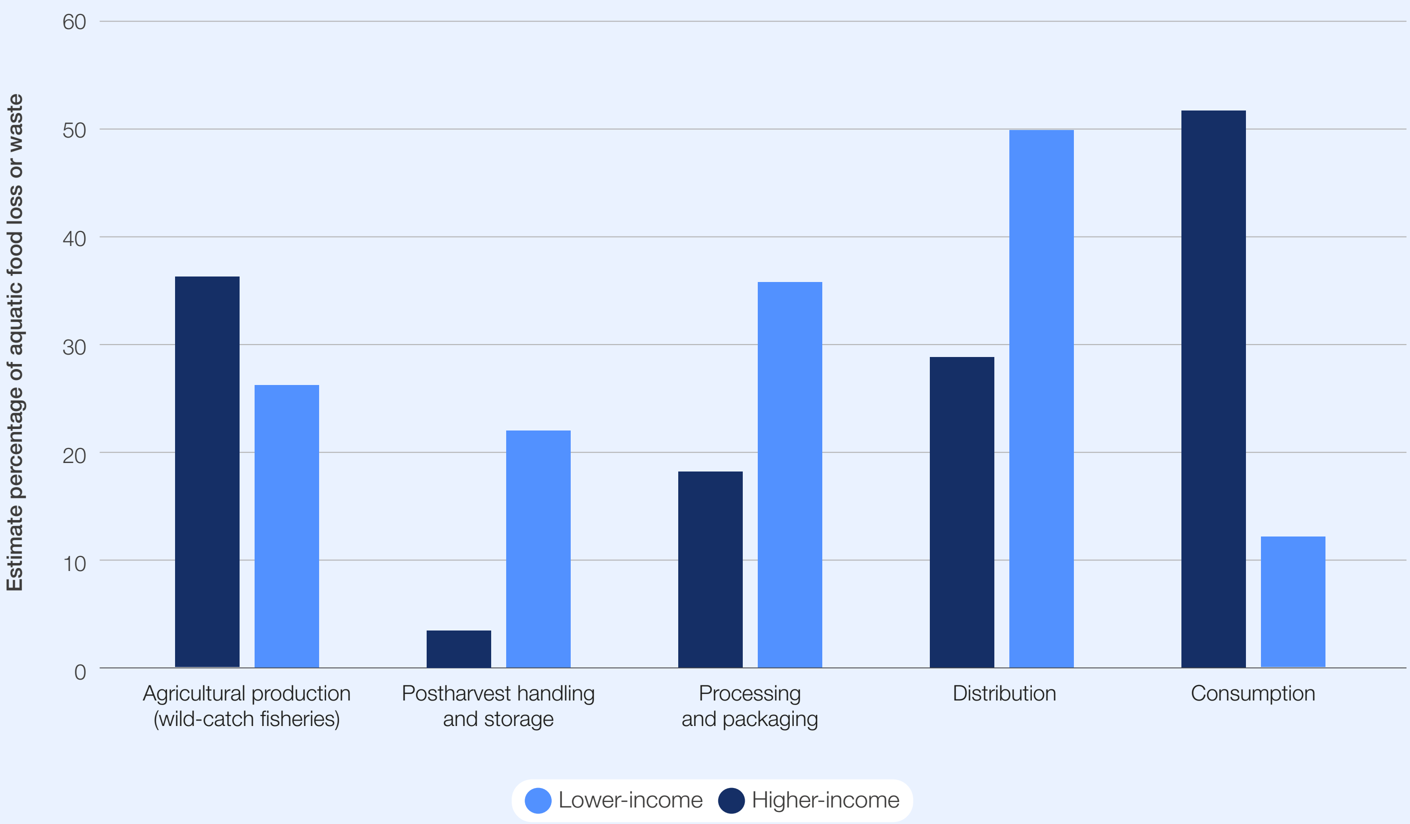
It is easy for large-scale fisheries (LSF) that involve large vessels, far-reaching fishing operations and state-of-the-art technologies to take centre stage in discussions regarding aquatic foods production. This is because of the significant quantity of fish such operations are able to catch and their high economic turnovers.[48] However, small-scale fisheries (SSF), characterized by localized operations in coastal waters with low tech, still warrant discussion. These small operations produce 37 MT of aquatic foods globally per year, which represents approximately 40% of global catches. This substantial production of aquatic foods underscores the importance of SSF in ensuring food security in coastal communities and worldwide. SSF also employ around 90% of individuals working in global fishing and in developing nations, SSFs and subsistence fishing collectively sustain the livelihoods of around 492 million people. This shows their vital role in shaping cultural identities and influencing coastal communities' social structures, heritage and trade.[49] All these points highlight the importance of SSF in conversations surrounding aquatic FLW.

A 2014 estimate of post-harvest fish losses in SSFs ranged between 20% and 75%. The large range of this estimate is indicative of the common data limitations of working with the small-scale fisheries sector, the huge diversity of these operations and the ways aquatic foods are lost or wasted in SSF value chains.[50]

Efforts to quantify aquatic food loss in SSFs classify post-harvest losses into four categories: physical, quality, nutritional and market losses.[51,52] In lower- and middle-income nations, post-harvest loss and deterioration in quality accounts for over 70% of total losses in aquatic foods value chains.[53] The primary causes of quality losses are absences or inadequacies in value chain cold storage from outdated technologies, insufficient transport, poor handling practices and a lack of training to improve these issues.[54] This leads to the processing of fish catches in substandard conditions, which gives rise to issues such as microbial contamination and spoilage and ultimately loss during the processing, packaging and distribution in SSF value chains, particularly in lower-income countries (see graph below).

SSFs are pivotal in global fisheries production, food security and sustaining livelihoods. However, poor access to capital investment, technology and training means they often suffer from significant post-harvest losses across the value chain. Efforts to quantify aquatic food loss in SSFs, however, remain a challenge. Collecting more comprehensive, global data on SSF post-harvest loss will help contribute to a more holistic understanding of global aquatic FLW and inform more effective and practical interventions to combat them.

Estimated proportions of aquatic FLW at each node in the value chain for higher-income versus lower-income regions



Note: Europe (including Russia), North America, Oceania and Industrialized Asia are herein considered high-income regions. Sub-Saharan and North Africa, West and Central Asia, South and South-East Asia and Latin America are considered lower-income regions.

Source: Adapted from Gustavsson, J., C. Cederberg and U. Sonesson, *Global Food Losses and Food Waste: Extent, Causes and Prevention*, FAO, 2011.

2.3 Processing on land

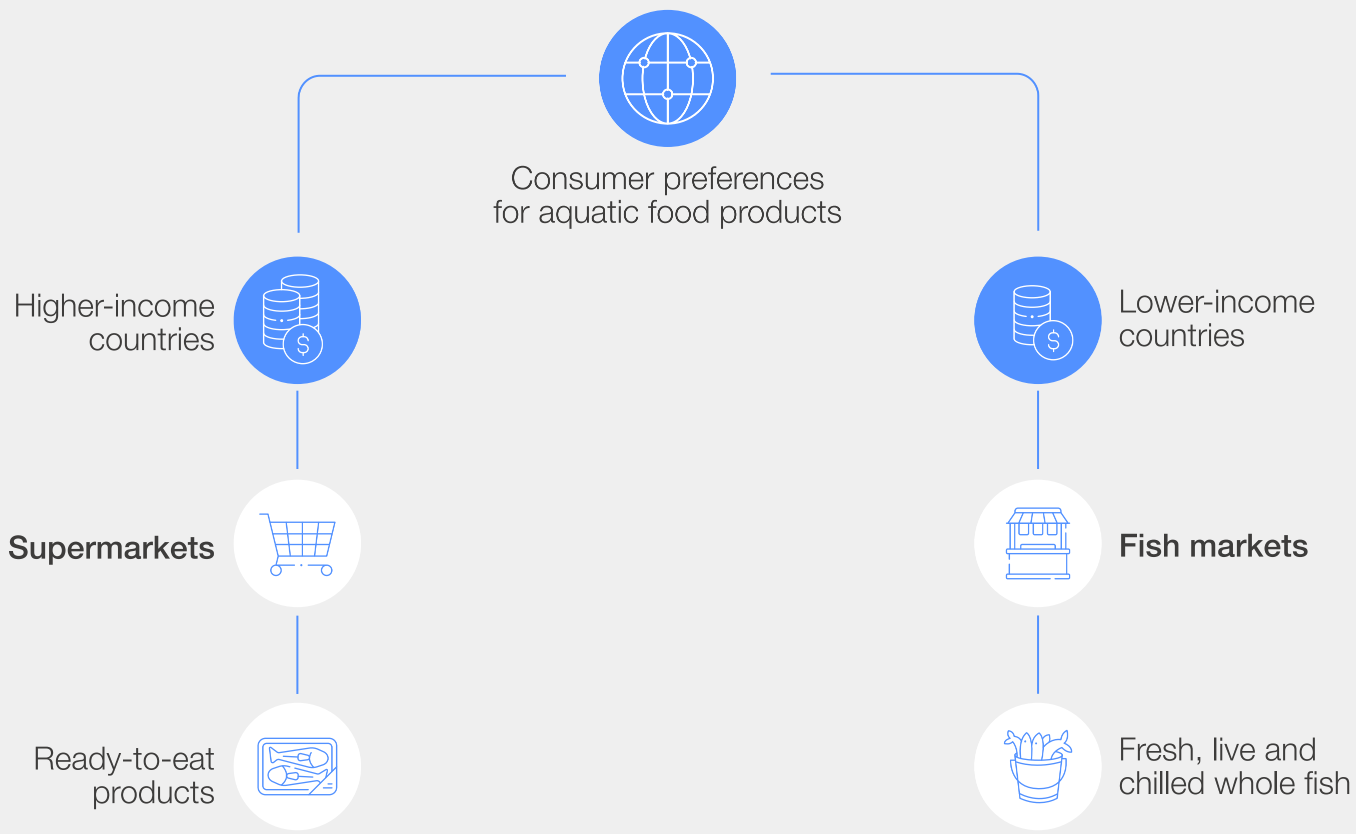
Once a fishing vessel reaches land, catches are offloaded quickly and often transported to processing facilities for further processing. This processing usually involves turning the at-sea products into the more common aquatic foods product forms seen on supermarket shelves like frozen, canned in brine and smoked items. The loss associated with further transforming the catches depends on the demands of the market (see Figure 3). In higher-income countries like North America, Australia and many European countries, consumers often prefer products that are easy and convenient to prepare and consume, like filleted, canned and ready-to-eat products[55,56] of large pelagic species such as tuna, demersal whitefish like cod and haddock, and salmon and prawns.[57] Conversely, in lower-income countries, preferences often tend towards fresh, live and chilled whole fish, driven by both a lack of access to highly processed produce and traditions of consuming the whole fish.

2.4 Retail

Once catches have undergone processing and are ready for the market, they enter the retail node of the value chain. Here, aquatic food loss occurs when a product becomes contaminated, spoiled or exceeds its “sell-by” date. For retailers in higher-income nations, loss is often recorded in generic categories like “disposal” or “sold with reduced price”. These can be further broken down into more specific categories that describe the reason for the loss. Recording the reasons for loss is important as it helps retailers analyse their loss statistics and work to reduce contamination issues, improve shelf-life and better match supply with demand.

If a product cannot be sold but is still classified as safe to eat, some retailers choose to reduce loss further by offering these products as donations to charity for human consumption or alternative use such as aquaculture/agricultural feedstuffs, or fertilizers. Such uses, however, rely on a retailer’s internal policies and procedures and the national laws governing the use of animal products.[58]

FIGURE 3 **Comparison of market demands between higher- and lower-income countries**



2.5 Food service

The next node of the aquatic foods value chain is food service. This node comprises sale and consumption in hotels, restaurants and catering (HORECA) establishments. Aquatic foods can enter the food service node of the value chain directly from processors or retailers; the former is usually more common with larger orders.

The main factors that can contribute to aquatic food loss during food service are excess inventory, improper handling and storage, and human error in food preparation. These are often a result of poor stock rotation from manual inventory management methods and the necessity for surplus food during service hours, poor equipment or facilities and lacks in training.[59]

2.6 Household consumption

Household consumption is generally considered the final node of the aquatic foods value chain. In this node, aquatic food loss is referred to as aquatic foods waste. Here, various sources of aquatic foods waste emerge, most notably from consumers purchasing or cooking more than they need and disposing of unconsumed food. Food waste at this node is exacerbated by limited or poor storage capacities and misunderstandings related to expiration dates that result in the disposal of still-edible food.[60]

Cultural differences in consumption habits significantly impact food waste at the household level and vary greatly with geography. For instance, in lower- and middle-income countries, using the whole fish is often customary and resulting in less waste compared to higher-income country households that are often more accustomed to semi- or fully-prepared products that already have loss associated with them through processing. It is, however, noteworthy that the demand for processed food is rising among urban populations in certain lower- and middle-income countries, so such preferences are ever-changing.

3 Quantifying aquatic food loss and waste

In 2021, global edible aquatic FLW totalled 23.8 MT.

This section of the report provides updated estimates of global edible aquatic FLW in 2021. It begins by presenting aggregated statistics across the value chain, followed by detailed breakdowns across species groups, product types and continents. This examination serves to pinpoint specific areas of concern regarding aquatic FLW. The global total estimate does not include losses associated with processing at sea, aquaculture production or small-scale fisheries due to lack of reliable data. The total stated here should therefore be considered a conservative estimate of total edible aquatic food loss and waste. For more detailed insights, including refined results for each node and information on the data sources and methodologies used, refer to the Annex published alongside this paper.

3.1 Total quantities

In 2021, global edible aquatic FLW totalled approximately 23.8 MT (23,813,445 tonnes) (see Figure 4),[61] which equates to 14.8%[62] of total edible aquatic foods produced (see Figure 5).

FIGURE 4 **Estimation of global edible aquatic FLW along the value chain**

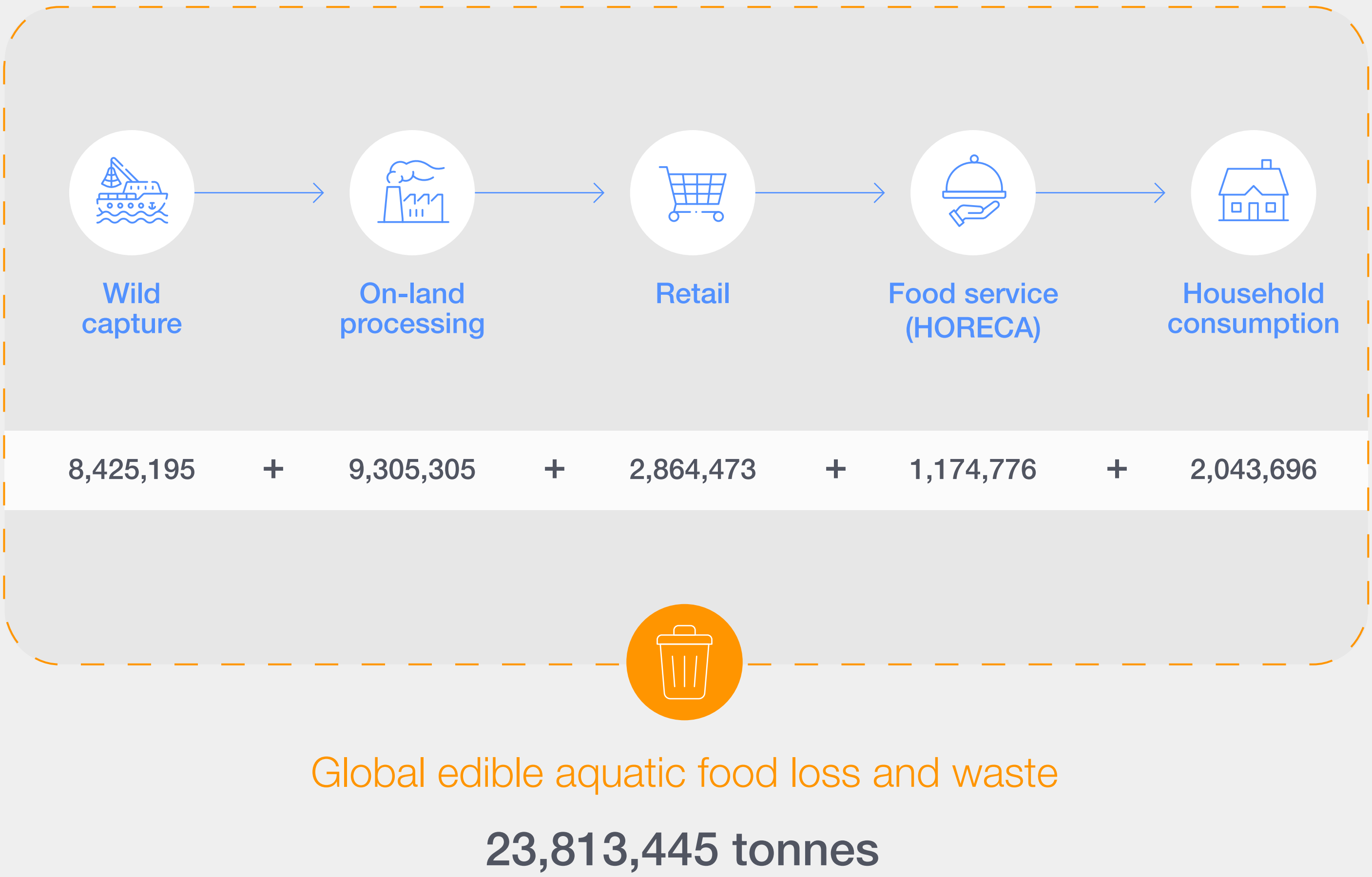
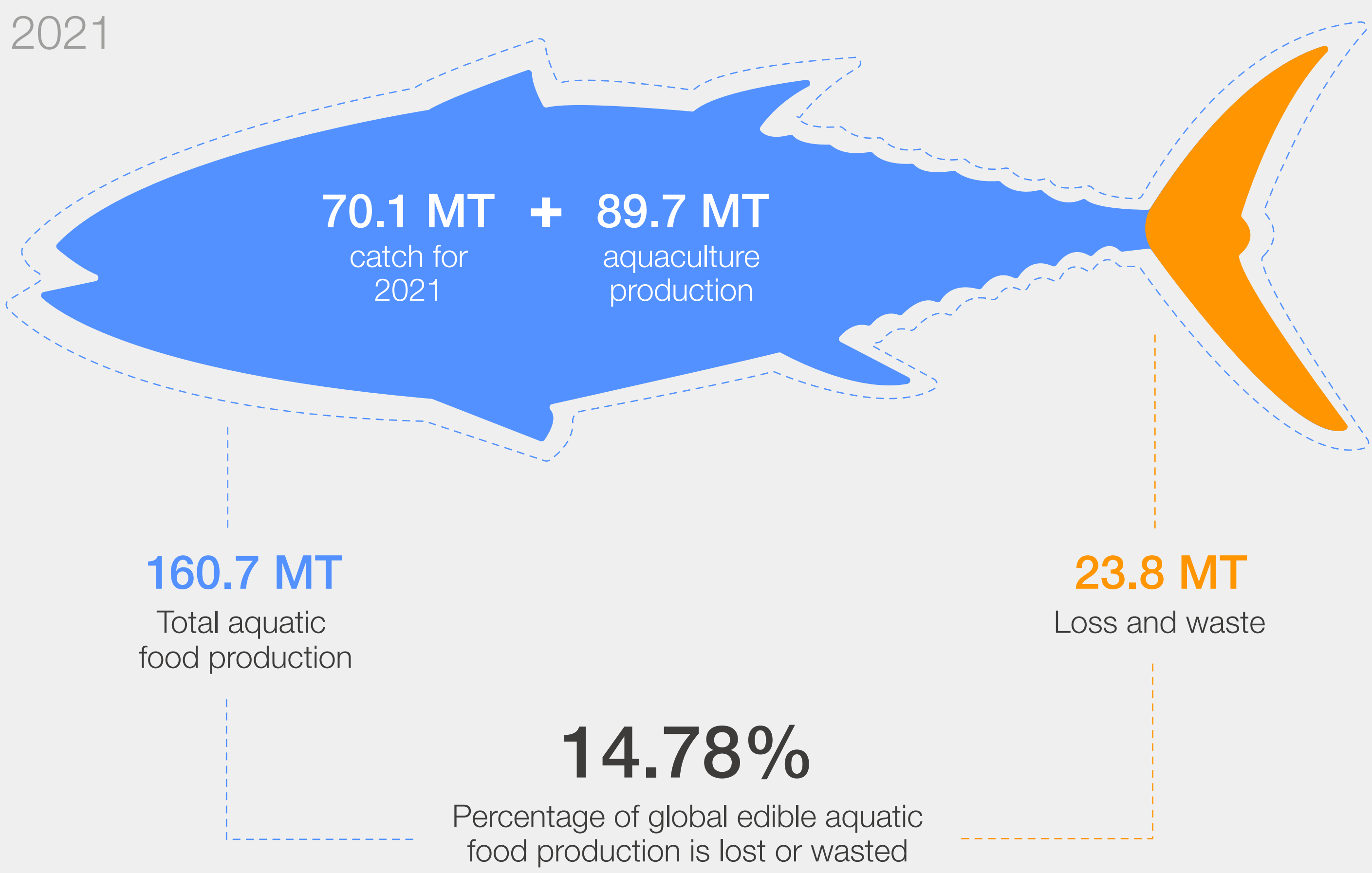


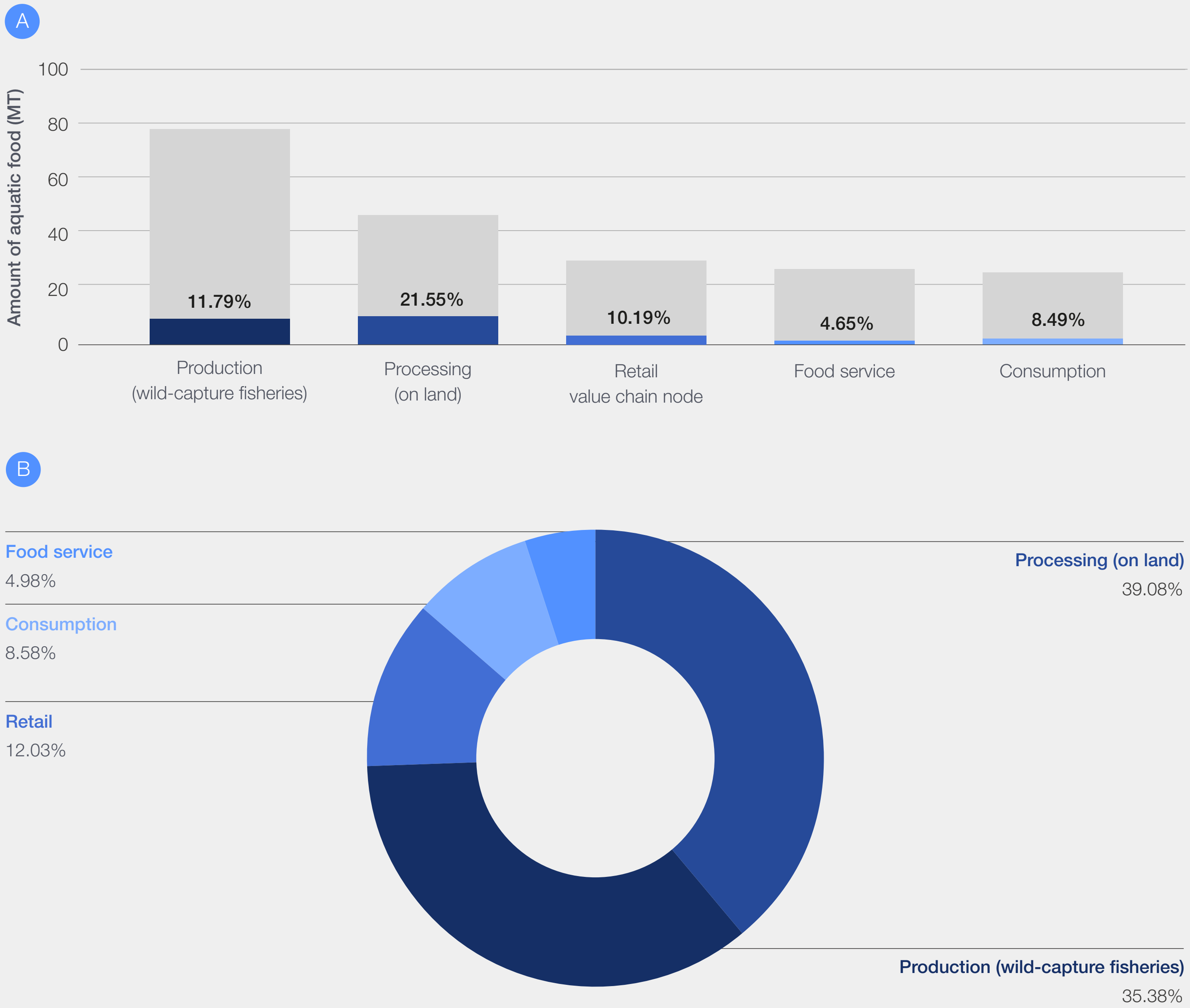
FIGURE 5 | **Percentage of global edible aquatic foods production that is lost or wasted**



Across the value chain, production (discards from wild-capture fisheries) produced 8.4 MT of edible loss, representing 11.79% of global catch. Processing (on land) produced 9.3 MT of edible loss, which represented 21.55% of total live weight traded (see Figure 6). These two value chain nodes were associated with the highest amounts of edible loss. Food service produced the lowest amount of edible loss at 1.2 MT, which represented 4.65% of aquatic foods products associated with food service.

Globally, processing (on land) and production (discards from wild-capture fisheries) generated the highest percentages of edible loss, respectively (see Figure 6). Food service generated the lowest percentage of edible loss.

FIGURE 6 | **Global edible aquatic FLW by value chain node (A)**
Percentage of global edible aquatic FLW by value chain node (B)



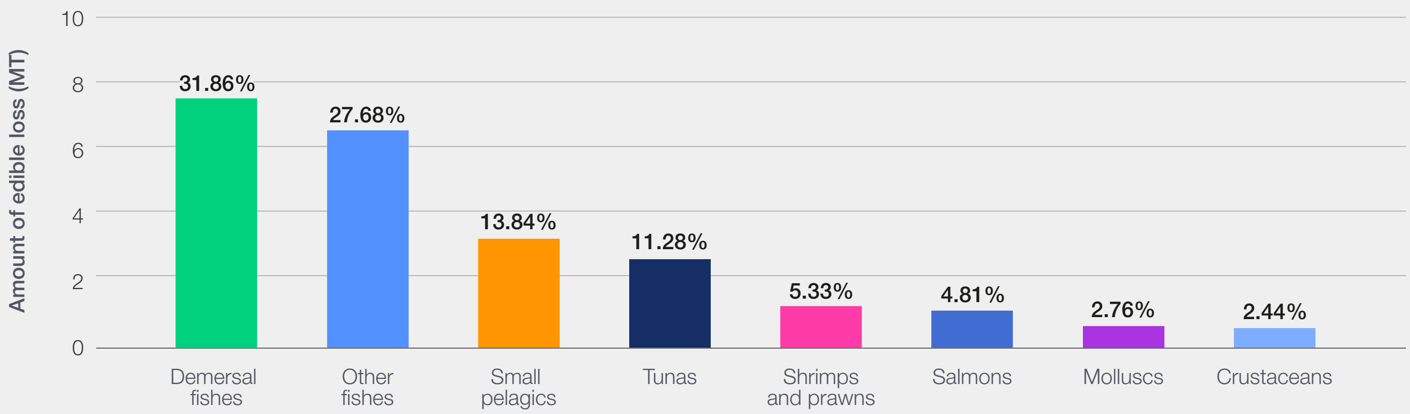
Note: In panel A, the coloured bars represent the amount of edible loss (percentage of MT) compared to the total amount of aquatic foods produced for the corresponding value chain node. In panel B, the size of each pie segment represents the percentage of total global edible loss across the value.

3.2 Per species group

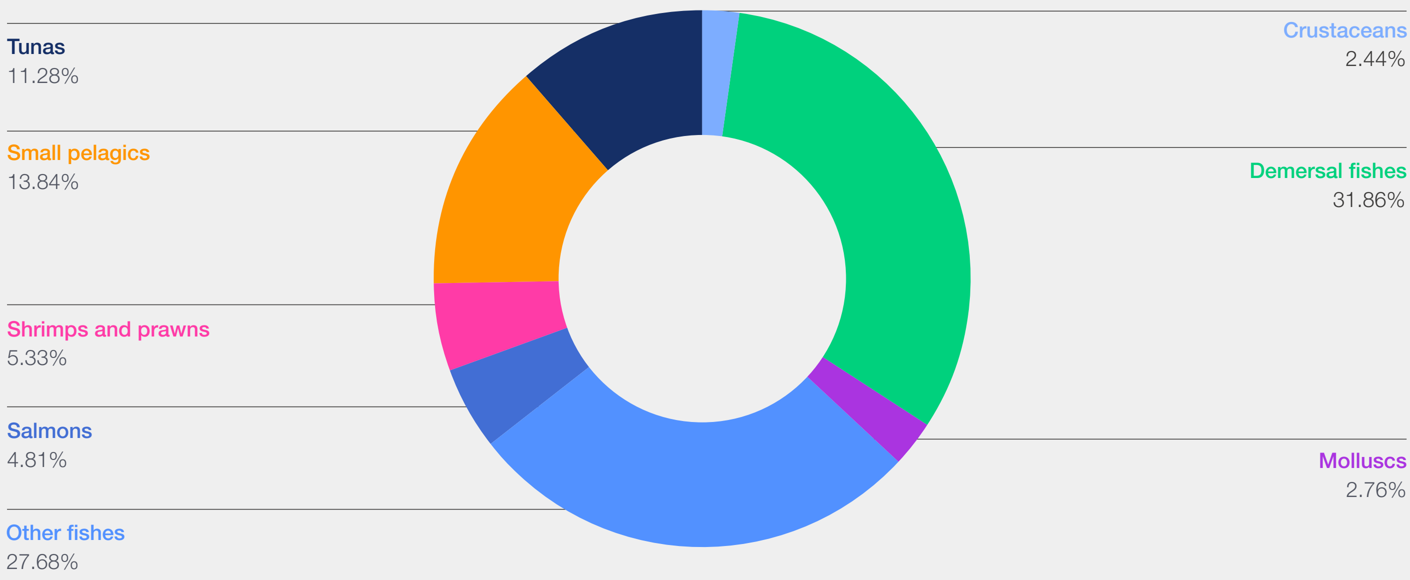
Edible aquatic FLW varied along the value chain depending on the species group (see Figure 7). Demersal fishes (7.6 MT and 31.86% of total edible loss) produced the highest amount of edible loss, while crustaceans (0.58 MT and 2.44% of total edible loss) produced the lowest amount of edible loss aggregated across the entire value chain (see Figure 7A and B). Disregarding the group "other fishes", demersal fishes generated the highest percentage of edible loss across most of the value chain nodes (production: 25.11%, processing: 45.21%, retail: 19.39% and consumption: 24.12%), except for food service where small pelagic fishes generated the highest percentage of edible loss (21.46%) (see Figure 7C). Molluscs generated the lowest percentage of edible loss across most of the nodes (processing: 0.92%, retail: 1.39%, food service: 1.08%, consumption: 1.86%), except for production, where salmon generated the lowest percentage of edible loss (1.39%).

FIGURE 7 **Global edible loss and waste by species (A and B) and across the value chain (C)**

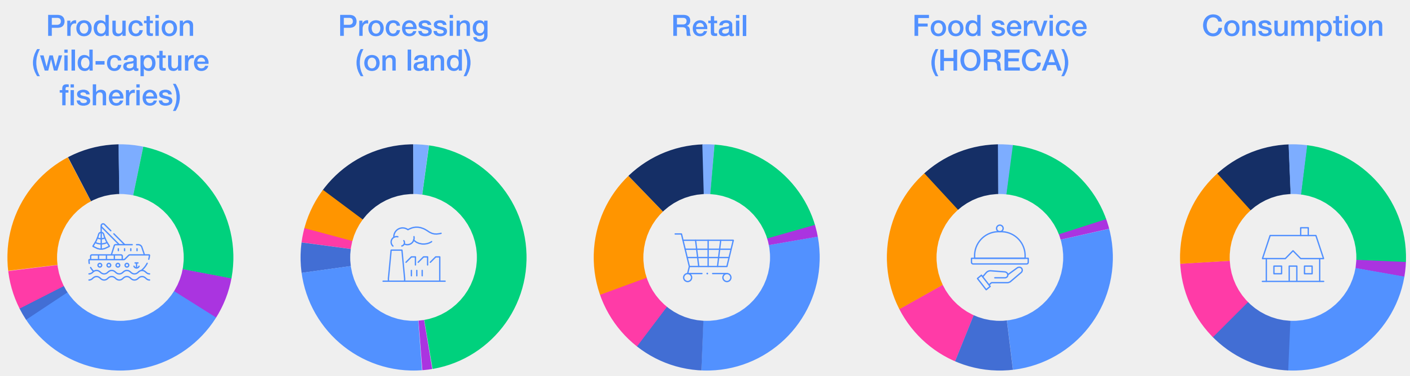
A



B



C

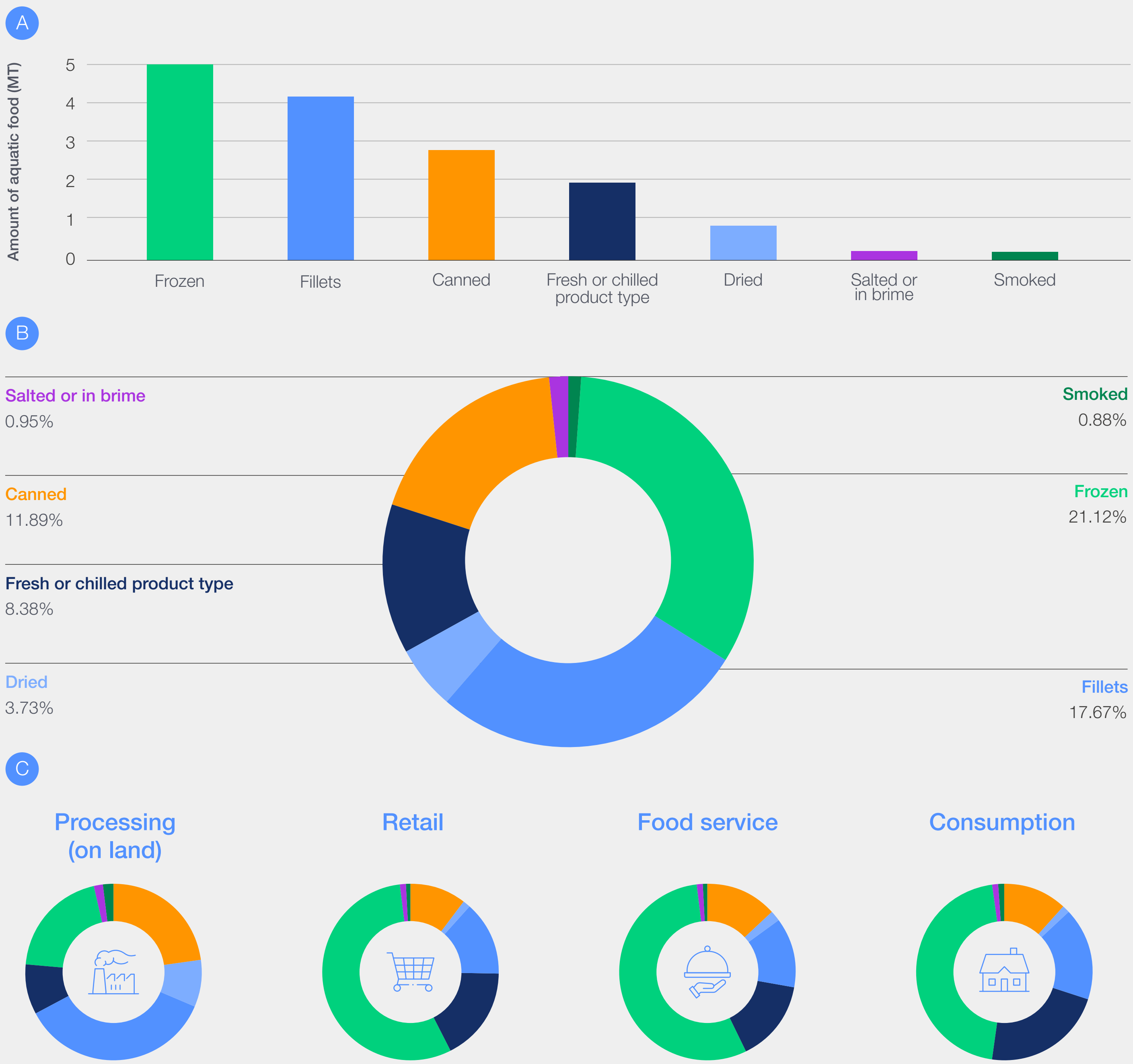


Note: In panel A, numbers represent the amount of aquatic FLW in MT for each species group. In panels B and C, the size of each pie segment represents the percentage of edible loss across the value chain (B) and generated at each node (C) globally by species group.

3.3 Per product type

Global edible aquatic FLW varied along the value chain depending on product type as well (see Figure 8). Frozen products (5.0 MT and 21.12% of total edible loss) produced the highest amount of edible loss, while smoked products (0.21 MT and 0.88% of total edible loss) produced the lowest amount of edible loss aggregated across the entire value chain (see Figure 8A and B). Similarly, frozen products generated the highest percentage of edible loss for most nodes of the value chain (retail: 55.96%, food service: 55.40%, consumption: 45.35%), except for processing in which fillets generated the highest percentage of edible loss (35.75%) (see Figure 8C). Across the value chain, smoked products generated the lowest percentage loss for all nodes (retail: 0.61%, food service: 0.63%, consumption: 0.89%), except processing, where products salted or in brine generated the lowest percentage of edible loss (1.70%).

FIGURE 8 **Global edible loss and waste by product type (A and B) and across the value chain (C)**

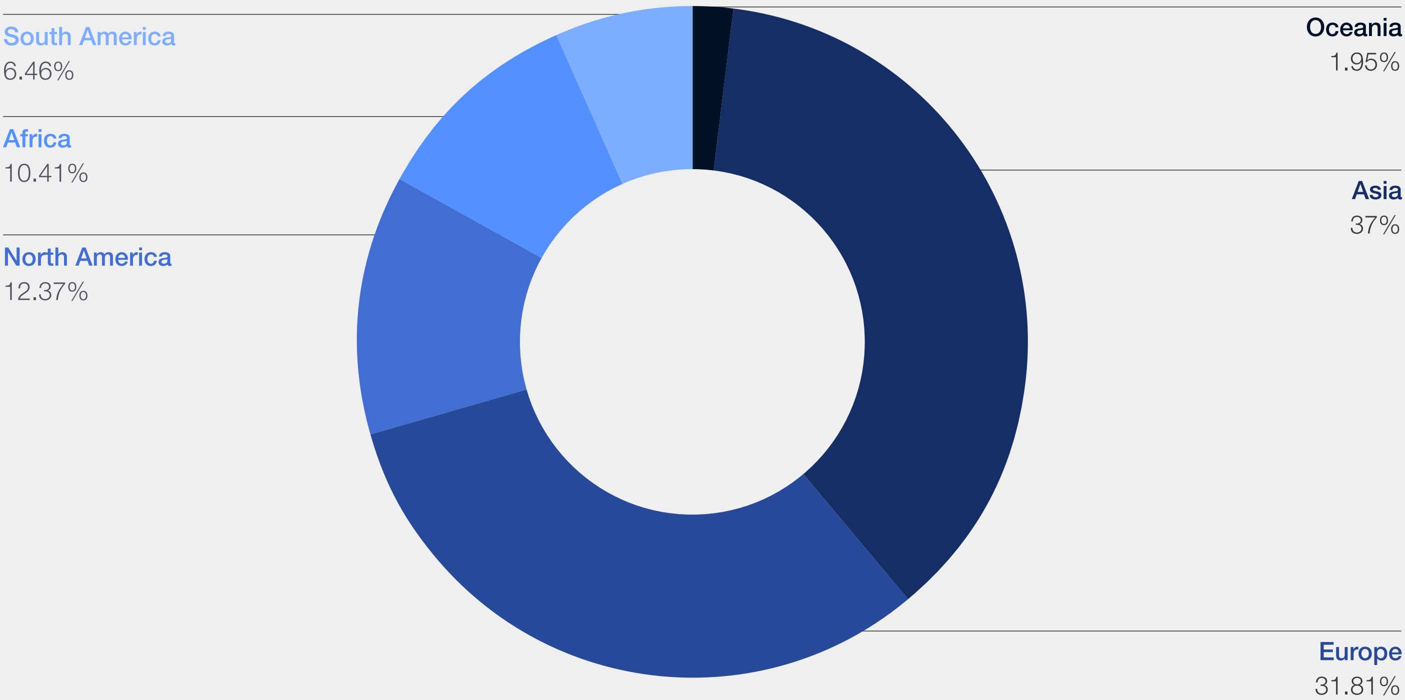


Note: In panel A, numbers represent the amount of aquatic FLW in MT for each product type. In panels B and C, the size of each pie segment represents the percentage of edible loss across the value chain (B) and generated at each node (C) globally per product type.

3.4 Global hotspots

Global edible aquatic FLW was highly variable across continents. Asia was associated with the highest level of edible loss (37% of total edible loss), followed by Europe (31.81% of total edible loss), North America (12.37% of total edible loss), Africa (10.41% of total edible loss), South America (6.46% of total edible loss) and Oceania (1.95% of total edible loss) (see Figure 9). For estimates of an absolute number of loss per continent, see the Annex published alongside this paper.

FIGURE 9 **Global edible aquatic FLW by continent**



Note: The size of each pie segment represents the percentage of edible loss associated with each continent.

Production from Asia and processing associated with aquatic foods trade in Asia and Europe generated the highest percentage of edible loss globally in 2021 (see Table 2). Oceania retail, food service and consumption generated the lowest percentages of edible loss globally in 2021.

TABLE 2 **The percentage of edible aquatic food loss globally by continent and value chain node**

Continent	Production (wild-capture fisheries)	Processing (on land)	Retail	Food service (HORECA)	Household consumption
Africa	3.18	3.93	1.71	1.44	0.15
Asia	14.04	15.66	4.42	0.56	2.32
Europe	6.33	17.51	3.47	0.85	3.64
North America	2.96	6.96	0.35	1.16	0.94
Oceania	0.6	1.23	0.04	0.04	0.04
South America	2.57	3.59	0.1	0.1	0.1

Note: Colours denote the relative levels of edible loss. Red denotes high, and yellow denotes low.

3.5 Intra-continental hotspots

Within each continent, processing generated the highest percentage of edible aquatic food loss (see Table 3). Production generated the next highest level of edible loss for all continents. Africa, Asia and Europe retail generated higher percentages of edible loss than in North America, Oceania and South America. Africa and North America food service generated higher percentages of edible loss than Europe, Oceania, Asia and South America.

TABLE 3 **Percentage of edible loss along the value chain by continent**

Continent	Production (wild-capture fisheries)	Processing (on land)	Retail	Food service (HORECA)	Household consumption
Africa	30.56	37.76	16.46	13.8	1.43
Asia	37.93	42.33	11.95	1.52	6.27
Europe	19.91	55.06	10.91	2.67	11.45
North America	23.94	56.27	2.82	9.35	7.61
Oceania	30.83	63.25	1.97	1.9	2.04
South America	39.77	55.52	1.57	1.51	1.62

Note: Percentages represent the proportion of edible loss corresponding to a given node and continent with respect to total edible loss generated by the corresponding continent. Red denotes high percent edible loss, and yellow denotes low percent edible loss.

Demersal fishes generated the highest percentage of edible loss compared to other species groups within Asia, Europe, North America and South America (see Table 4). For Africa, excluding other fishes, small pelagic fishes generated the highest percentage of edible loss; for Oceania, tunas generated the highest percentage.

TABLE 4 **Percentage of edible loss by continent and species group**

Continent	Crustaceans	Demersal fishes	Molluscs	Other fishes	Salmons	Shrimps and prawns	Small pelagics	Tunas
Africa	0.67	14.12	2.26	35.35	1.31	2.19	31.75	12.34
Asia	2.96	25.88	3.15	36.49	2.09	5.41	10.55	13.48
Europe	1.57	47.83	1.36	18.76	8.43	3.06	9.2	9.8
North America	5.07	43.44	2.72	14.12	4.91	9.59	10.36	9.8
Oceania	1.42	32.79	1.83	18.41	1.65	1.16	6.98	35.76
South America	0.79	33.03	3.82	18.25	2.91	7.56	16	17.63

Note: Percentages represent the percentage of edible loss corresponding to a given species group with respect to total edible loss generated by the corresponding continent. Red denotes high percent edible loss, and yellow denotes low percent edible loss.

Frozen products generated the highest percentage of edible loss in Africa and Asia, while fillets generated the highest percentage in Europe, North America and South America. In Oceania, canned products generated the highest percentage of edible loss (see Table 5).

TABLE 5 **Percentage of edible loss by continent and product type**

Continent	Canned	Dried	Fillets	Fresh or chilled	Frozen	Salted or in brine	Smoked
Africa	17.02	5.55	5.84	1.73	37.1	1.88	0.32
Asia	11.72	2.72	19.76	3.5	23.62	0.57	0.17
Europe	13.87	6.13	25.08	14.49	17.12	1.48	1.91
North America	15.05	2.82	29.06	10.6	17.03	0.75	0.76
Oceania	25.2	0.39	21.62	2	18.61	0.49	0.86
South America	16.91	2.73	18.60	7.96	13.19	0.58	0.17

Note: Percentages represent the percentage of edible loss corresponding to a given species group with respect to total edible loss generated by the corresponding continent. Red denotes high percent edible loss, and yellow denotes low percent edible loss.

4 Interventions for tackling aquatic food loss and waste

Technological innovation and collaborative efforts continue to expand practical solutions for reducing aquatic food loss and waste.

The results presented herein highlight the significant magnitude of global aquatic FLW. There are, however, many practicable ways to reduce aquatic FLW, the number of which is ever-increasing thanks to technological innovation and multistakeholder collaboration (see Figure 10). While the numbers surrounding loss and waste should not be ignored, they should be used positively to indicate where actionable and constructive change can truly happen. Different intervention types with corresponding examples are provided to indicate current ways in which aquatic FLW are being reduced.

FIGURE 10 **Different intervention types that can be used to help mitigate aquatic FLW**

Note: This is not an exhaustive list of potential interventions.

4.1 By-product use

The most logical step to reduce aquatic FLW is by-product use. While the aquatic foods industry produces food for human consumption, it also produces a wide array of valuable by-products derived from both edible and inedible parts of aquatic species. Aquatic foods by-products are useful raw materials for FMFO used in aquacultural and agricultural feeds, compost, silage, fertilizer and biofuel, as well as pet food[63,64,65,66] and have shown promising application in pharmaceuticals and nutraceuticals,[67] biomedicine and cosmetics[68] and biodegradable materials.[69] The use cases of aquatic foods by-products are continually emerging, often driven by technological advances and market demands.

Advances in by-product use have brought considerable improvements in product yield in the aquatic foods industry. For instance, Icelandic producers of cod fillets have seen their product yield increase by as much as 20% over the past two decades thanks to the use of the head, bones, skin and intestines.[70] Through technological advances and shifts in market demand, by-product use represents a crucial step forward in the concerted effort to reduce aquatic FLW.

4.2 Infrastructural improvements

Aquatic foods are highly perishable, and their value chains should be consistently temperature-controlled from production through to consumption. Yet, maintaining optimal post-harvest temperatures across the value chain can be challenging, particularly in longer chains with numerous intermediary stages. This challenge becomes more pronounced in contexts that lack the infrastructural needs to ensure consistent temperature-controlled conditions for products. Integrating the right equipment at the right node in the value chain can help significantly reduce post-harvest losses.

For small-scale fisheries in lower-income contexts, introducing solar-powered freezers can significantly reduce post-harvest loss by helping maintain cold temperatures from fish landing sites through to final markets while maintaining low operating costs.[71] In large-scale fisheries in higher-income countries, infrastructural improvements can be made to the type of freezing technologies used, particularly at the earliest stages of the value chain. Vessels equipped with blast freezers can quickly freeze catches, minimizing the risk of bacterial growth, oxidation and enzymatic reactions – all contributing to aquatic foods deterioration and, ultimately, loss.[72] Ensuring a continuous cold chain from the point of production to the consumer through investments in refrigeration, freezing, transport and storage facilities is critical to mitigating aquatic food loss along the value chain.

4.3 Emerging technologies

Emerging technologies like artificial intelligence (AI), big data analytics, blockchain and 3D printing are proving to play a critical role in the future of the aquatic foods value chain.[73] These innovative solutions are helping revolutionize multiple aspects of aquatic foods value chains, including enhancing transparency and traceability, improving market trend predictability and supply chain inefficiencies, optimizing production processes and developing automated, custom packaging methods.

AI and big data analytics, specifically, are showing huge promise in aquaculture production by optimizing feed and disease management and increasing production yields by decreasing mortality.[74] AI is also being used successfully to enhance the distribution of products along value chains by optimizing supply chain logistics and demand forecasting,[75] helping to reduce unnecessary carriage and unforeseen losses from poor sales. The integration of emerging technologies can revolutionize the aquatic foods value chain, offering innovative opportunities to assess and mitigate aquatic FLW more efficiently.

4.4 Markets, trends and diversification

The creation of new markets and product diversification offer promising opportunities to reduce aquatic food loss and optimize resource use. Promoting the consumption of undervalued products can help reduce market demands on products that are prone to producing more aquatic food loss. The creation of new markets and innovative product offerings often draws on inspiration from cultural practices and cuisines. One such example is the growing trend in tinned fish in the US market, inspired by Spanish canned fish (conservas). This trend increased sales of canned fish from $2.3 billion in 2018 to more than $2.7 billion in 2023.[76] Canning has been shown to be an efficient processing method, marked by relatively minimal loss and waste compared to other more popular products in the US, like fillets.

Fish collars, known as "kama" in Asian countries, are another example of marketing success and changing tastes in aquatic foods markets. Kama have long been celebrated as a culinary delicacy, yet their market potential was originally overlooked in many Western countries. Recently, however, these flavourful and nutritious parts of the fish are now gaining recognition and popularity worldwide.[77] Such examples promote the more complete use of aquatic foods products, reducing loss and waste that would have once typically been discarded parts. Exploring new markets, innovative product offerings and promoting culturally-inspired consumption represents a shift towards optimized resource use and ultimately a reduction in aquatic FLW.

4.5 Investing in skills and knowledge

Investing in skills and knowledge building is a crucial strategy to help reduce aquatic FLW. Imparting best practices in handling, processing, storage, transport and marketing can help ensure the highest quality aquatic foods reaches consumers. For this reason, the FAO has developed an online course and best practice handbooks for academics, researchers, programme officers and technical specialists focused on FLW in fish value chains.[78,79] The course provides an overview of key concepts related to fish loss and waste, describing important causes as well as possible solutions, and outlines three fish loss assessment methods.

Skills training of industry stakeholders will help drive sustainability in aquatic foods systems but also confer economic advantages to many. This can help incentivize investment in technological upgrades that will further improve loss and waste reduction. In a similar vein, investing in consumer awareness and education of the benefits of reducing aquatic FLW, and promoting consumption and preparation habits that increase use will help reduce waste at the household consumption node of the value chain.

4.6 Industry collaboration

Encouraging collaboration to decrease aquatic FLW at different scales and stages of the value chain promotes a culture of collective responsibility for waste reduction.

Collaborative initiatives, such as industry associations, research consortia and public-private partnerships can help aquatic foods stakeholders to cooperate to better identify best practices, technologies and policies to minimize loss and waste. An example of such collaboration operating at a broad is Champions 12.3. This is a coalition of executives from governments, businesses, international organizations, research institutions, farmer groups and civil society with the collective goal of mobilizing action and accelerating progress towards achieving SDG target 12.3 (halving per capita global food waste at retail and consumer and significantly reducing food loss along value chains) by 2030. While not specifically directed towards aquatic foods, Champions 12.3[80] forges a path to reduced loss and waste at a high level of interdisciplinary, international engagement.

Bringing together stakeholders from across the value chain, from producers to retailers, also creates an opportunity to make use of collective knowledge and develop comprehensive solutions. A great example of this is the emergence of the Ocean Cluster network, championed by Iceland,[81] which has spearheaded the worldwide movement known as the 100% Fish Initiative. A recent addition to this network is the Namibia Ocean Cluster, which aims to bring together Namibian seafood stakeholders to collaborate on maximizing the use of post-harvest loss.[82]

A new node in food value chains that is now helping to reduce loss and waste has recently emerged thanks to multistakeholder collaborations between retailers and technology start-ups. New companies that use mobile technology and digital supply chain data can redirect leftover, expiring soon or misshapen food destined for landfill to consumers, social enterprises and charities at discount prices or for free.[83]

Encouraging collaboration to decrease aquatic FLW at different scales and stages of the value chain promotes a culture of collective responsibility for waste reduction rather than solely burdening individual stakeholder groups. Collaborative efforts can enhance resource efficiency, reduce waste generation and enhance value retention within the system. Partnering across various stakeholders in the value chain proves effective in innovating solutions to longstanding challenges. Moreover, such collaborations facilitate identifying, measuring and targeting interventions for FLW issues through innovative and sustainable practices.

4.7 Policy and regulatory frameworks

Policy and regulatory frameworks are needed to reduce aquatic FLW, yet the general approach across the policy space is based on voluntary guidelines, principles and frameworks that include detailed standards, recommendations and best practices for industry operation. Such guidelines help the industry make more informed decisions, but they are not enforceable, making it challenging to ensure adoption and measure uptake and progress of such initiatives. The *Codex Alimentarius Code of Practice for Fish and Fishery Products*,[84] established by the FAO and World Health Organization (WHO), is a good example of this. The codex offers comprehensive guidance on handling, processing and marketing of fish and fishery products to ensure safety and quality. Although it is internationally recognized, it is not enforceable and serves primarily as a reference for regulatory bodies and industry stakeholders to promote best practices.

If comprehensive guidelines are promoted correctly, widely and for long enough, they act to spur policy and legislative developments. The *Code of Practice for Fish and Fishery Products*, Annex III Section VII in European Commission Regulation No 853/2004[85] outlines specific rules that EU Member States must abide by related to the handling and hygiene of aquatic foods products. The establishment of this regulation highlights that while guidelines themselves cannot be guaranteed to drive change in aquatic FLW, with enough momentum and outreach, their voluntary adoption can lead to policy formation and eventual positive legislative change.

The aquatic FLW legislative landscape still lags behind and is sparser than that of the FLW landscape for agricultural commodities. This presents an opportunity for aquatic foods value chains to learn from others and highlights a key need for continued policy efforts aimed at specifically enhancing aquatic foods safety and quality across the value chain.

5 Calls to action

Policy-makers, industry and civil society must take action to enhance efforts to mitigate aquatic food loss and waste effectively.

Based on the research and findings presented herein, the following section outlines a series of targeted recommendations and calls to action, aimed at distinct stakeholder groups, that will be crucial in facilitating reductions in aquatic FLW.

5.1 Policy-makers

- Strategic policies must be enacted to **incentivize adjustments in market demand** towards species and products associated with lower levels of loss. This must happen concurrently with the expansion of product portfolios available to consumers.
- Policy-makers must create an **environment that is conducive to innovative businesses** and initiatives in loss and waste management and by-product use.
- Policy-makers must also **invest in robust data collection mechanisms** and **encourage interdisciplinary collaboration** to provide the necessary foundation for evidence-based decision-making and effective loss and waste reduction strategies.
- **Educational programmes and initiatives** must be supported at broad regional scales to disseminate information on best practices and improve by-product use, empowering stakeholders to bridge skills gaps and enhance efficiency along the aquatic foods value chain to adopt such practices.

5.2 Industry

– Industry stakeholders must **measure, report and set targets to reduce loss and waste throughout value chains**. This involves developing applicable data collection and measurement tools and using advanced data analytics and machine learning algorithms to gain valuable insights and identify optimization areas. Ultimately, these efforts can decrease operational expenses, increase economic returns and reduce loss and waste.

– Fishing operators must **innovate and collaborate with gear technologists** to improve the selectivity of fishing gear and minimize the catch of undesirable (and therefore discarded) species.

– **Processing and handling techniques and storage facilities must be evaluated** thoroughly and benchmarked against current loss rates across different value chains. Where opportunities for improvement are highlighted, they must be invested in to ensure increased yields and improved quality and freshness that can be maintained across the full value chain.

5.3 Civil society

– Non-government organizations (NGOs) must **raise awareness of FLW among consumers** through education programmes and initiatives. These efforts should focus on the issue of FLW and strategies consumers can adopt to reduce it.

– **Embracing cultural food preparation and consumption traditions** that use the whole fish can minimize food waste associated with consumption of aquatic foods. NGOs should emphasize cultural food preparation and consumption traditions when designing programmes and initiatives aimed at educating consumers on ways to reduce FLW.

– Consumers hold significant purchasing power, **shaping market demand and influencing businesses** to prioritize preferred products. Choosing species and/or products that produce less aquatic FLW can drive market demand for such products.

Final remarks

This paper emphasizes the necessity of addressing aquatic FLW. The identified areas along aquatic foods value chains highlight key intervention points, with recommendations emphasizing market demand adjustments, data collection advancements and increased by-product use. Initiatives to shift market demand towards species and processing methods with lower associated loss and enhanced data collection mechanisms offer promising avenues for reducing waste and increasing resource efficiency.

Moreover, interdisciplinary collaboration emerges as a crucial driver for progress, underscoring the need for concerted efforts among diverse stakeholders to implement innovative solutions and drive systemic change within the aquatic foods industry. Through collaborative action and targeted interventions, the industry can work towards achieving SDGs while ensuring the economic viability and environmental sustainability of aquatic foods systems.

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Endnotes

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