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The rise of aquaculture by-products: Increasing food production, value, and sustainability through strategic utilisation

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ABSTRACT

Since 2000, the use of wild fish inputs in the production of farm raised fish outputs, also known as the Fish In: Fish Out (FI:FO) ratio, has been a primary concern of the sustainability dialogue surrounding aquaculture production. Far less attention has been placed on the sustainability of downstream processing, including how by-products are managed. This paper contributes new information on the current utilisation of aquaculture by-products in a case study on the Scottish Atlantic salmon industry. The findings show that there is considerable potential to increase the sustainability of the industry through maximising human edible yield by strategically managing by-products. Supporting the movement towards the full utilisation of by-products, this paper goes a step further by emphasising the need to maximise their use in human consumption and select animal feeds, highlighting the economic, food security, and environmental benefits of doing so. Through exploratory scenarios based on the case study, the paper identifies that Scotland could increase food production from fish farming by over 60%, increase by-product revenue by 803%, and increase the industry bottom-line by over 5%, all without having to put any new cages in the water, or use any more marine resources. As the aquaculture industry moves into a new era of production and processing, where a diverse range of products can be produced from a single species, sustainability will be sought throughout the value chain. It is hoped that the ideas raised within this paper will encourage further discussion and collaboration on this topic going forward.

1. Introduction

With an estimated one-third of all food produced for human consumption being lost or wasted [19], calls to limit waste and recover edible food are growing. The United Nations (UN) Sustainable Development Goals (SDGs) call for a reduction in food loss during production, and throughout the supply chain, through to consumption [63]. The US Environmental Protection Agency's *Food Recovery Hierarchy* (Fig. 1) prioritises more sustainable food management practices through preventing and diverting wasted food grade products [64]. Similarly, Article 4 of the revised EU Waste Framework Directive (2008) outlines a 'waste hierarchy' highlighting the financial and environmental benefits of reducing, reusing and recycling materials versus sending them to landfill [60].

Aquaculture is a necessary industry to ensure future global access to seafood. There is increasing realisation that the success of aquaculture production goes hand in hand with adopting more sustainable practices. Sustainability, as used in this paper, refers to a process-driven journey of continual improvements that seeks to create more resource efficient products that maintain functional ecosystems [58]. Efforts are being made to increase the efficiency of aquaculture as a food production system by maximising the edible yield of products through genetic improvement, and better processing technology [7,25,42,61,66,68]. However, there is a limit to these improvements, and in both seafood production and processing, use of aquaculture by-products is now increasingly considered to be important for improving economic and environmental efficiency, as well as food security [14,30,34,68]. Furthermore, in aquaculture, as in other food production sectors, slim processing margins mean that innovation in the utilisation of by-products becomes a key factor for remaining competitive and maintaining long-term profitability.

For this paper, by-products will be defined as all the raw material, edible or inedible, left over following the preparation of the main product [17]. For finfish, by-products typically include trimmings, skins, heads, frames (bones with attached flesh), viscera (guts) and blood (Fig. 2).

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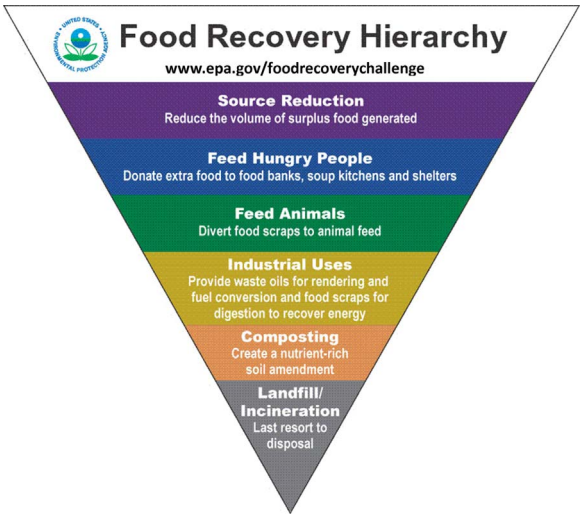

Fig. 1. Food recovery hierarchy [64]. 1.5 column.

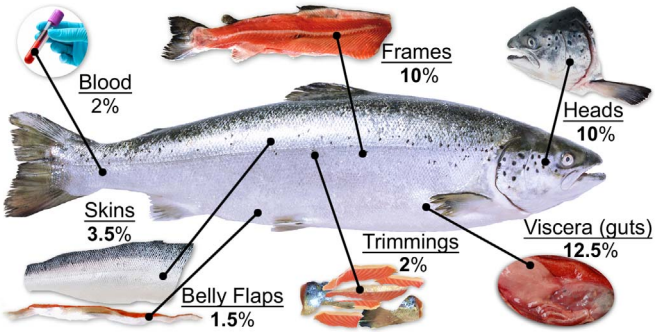

Fig. 2. Atlantic Salmon by-product fractions as a percentage of the total wet weight. Compiled from FAO [14], Rustad [40], Liaset et al. [24], Sandnes et al. [43]. 1.5 column.

While human consumption options for some by-product types, such as viscera, bones and blood remain limited, there are many avenues for value addition. Indeed, far from being 'waste', marine by-products have been found to contain valuable minerals, vitamins, protein and lipid fractions (Table 1), which can be applied in a range of products and markets [2,14,35,39].

Within terrestrial livestock industries the value-addition of the 'fifth quarter' (processing by-products) has been integral to both traditional artisanal and industrial practice, with both financial and environmental benefits [21,27,67]. The processing expertise, technology and infrastructure developed by the poultry industry, provides useful insights for the aquaculture industry as it continues to refine its resource use throughout the supply chain [4].

Compared with its terrestrial counterparts, the seafood sector has been slow to reduce its discards. To facilitate improvement, there is a need for further infrastructure investment and policy support to incentivise resource efficiency, along with greater transparency on the current uses of by-products within the sector [15]. Nonetheless, there has been some promising movement toward a value-added approach with certain species and regions. In Iceland, Iceland Ocean Cluster has worked to create new products from fish processing waste, resulting in twice the value for 40% of the catch [49]. Norway was one of the earliest countries to recognise seafood by-products as a resource, with laws encouraging their use as early as 1639, resulting in products such as fertilisers, animal feeds, and fish oil [6]. Today, Norway has developed streamlined modern processing facilities to manage over 650,000 tonnes(t) of seafood by-products each year [31], and the Norwegian Atlantic salmon industry utilises around 90% of its by-products [31,68]. In Vietnam, Pangasius by-products are well separated and directed to specific industries for value addition, and globally, growing interest is being placed on adopting strategies for other finfish and shellfish species [30].

Here, the strategic utilisation of aquaculture by-products is explored further, based on current practice in the Scottish salmon industry (SSI), assessing how it can achieve greater sustainability. The paper begins with a brief exploration of the history and development of the Fish In: Fish Out (FI:FO) concept, a common focal point in the dialogue on sustainable seafood and marine resource use. The paper reflects on the FI:FO concepts effectiveness as a driver in the current context, and proposes that the strategic management of aquaculture by-products should be an integral part of the sustainability dialogue going forward. The paper then develops a model of current and potential uses of processing by-products, based on case study data from the SSI, in which scenarios for additional economic value and food production can be achieved through strategic by-product management. Through the findings and recommendations presented, this paper aims to provide insights relevant to policy makers and industry stakeholders, and to encourage continuous improvement towards more responsible and sustainable practice.

2. Background and context

In recent years, aquaculture has been presented as both a solution to [56], and a causative factor of [29], the world's dwindling marine resources. While aquaculture can relieve pressure on wild fisheries through producing alternative fish for human consumption, the production of those fish often requires inputs from wild fish stocks in the form of feed ingredients. The paradox stems from the diversity of farmed species and husbandry systems. Species such as algae, shellfish, and herbivorous fish, typically require few inputs [65], whereas intensively raised higher trophic species, such as salmon, require complete feeds that have conventionally contained a high proportion of marine ingredients [54].

Table 1
By-product uses. 1.5 column.

By-Product	Valuable components	Current uses
Heads	proteins, peptides, lipids, collagen, gelatine, minerals including calcium, flavour	food, fish meal, fish oil, food grade hydrolysates, animal grade hydrolysates, pet food, nutraceuticals, cosmetics
Frames (bones, flesh, fins)	proteins, peptides, lipids, collagen, gelatine, minerals including calcium, flavour	food, fish meal, fish oil, food grade hydrolysates, animal grade hydrolysates, pet food, nutraceuticals, cosmetics
Trimmings	proteins, peptides, lipids	food, fish meal, fish oil, food grade hydrolysates, animal grade hydrolysates, pet food
Viscera	proteins, peptides, lipids, enzymes such as lipases	food grade hydrolysates, animal grade hydrolysates, fish meal, fish oil, fuel, fertilisers
Skin (with belly flap)	collagen, gelatine, lipids, proteins, peptides, minerals, flavour	fish meal, fish oil, cosmetics, food, fish meal, nutraceuticals, cosmetics, leather, fuel, fertilisers
Blood	proteins, peptides, lipids, thrombin & fibrin	fuel, fertiliser, therapeutants
Mortalities	proteins, peptides, lipids, collagen, gelatine, calcium and other minerals, flavour	animal feed (fur animals), zoo animal feed, fuel, fertilisers

Ramírez [35], Rustad [39], Suresh and Prabhu [53], Kurtovic and Marshall [23], Rothwell et al. [36], Sharp et al. [46].