Factors affecting IMTA (Integrated Multi-Trophic Aquaculture) Implementation on Atlantic Salmon (*Salmo salar*) Aquaculture Farms

By

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Abstract

Sickander, O. (2020). Factors affecting IMTA (Integrated Multi-Trophic Aquaculture) implementation on Atlantic salmon (*Salmo salar*) aquaculture farms [graduate project]. Halifax, NS: Dalhousie University.

Aquaculture operations are currently the fastest-growing food production industry, increasing output over 20 times in the past few decades alone. Waste management on "fed" aquaculture farms, like Atlantic Salmon, is a massive issue for management and public perception. Integrated Multi-Trophic Aquaculture (IMTA) is the co-cultivation of species from different trophic levels instead of a single species (monoculture) on an aquaculture farm. From a theoretical perspective, in an IMTA farm, the metabolic waste and uneaten feed from the top-level species like Atlantic Salmon is used by lower-level trophic species like shellfish and macroalgae, minimizing the potential impact of these wastes on the ecosystem. Though this logic has long been used in polycultures in history, there is a theoretic rationale to support it commercially on a much larger scale. However, IMTA is currently not being applied as a mitigation measure in Atlantic Salmon aquaculture facilities. This graduate project explores and investigates current methods, applications, uses, and efficiency of IMTA to address challenges on salmon farms through an in-depth PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method literature review. In addition to completing the literature review, industry experts were surveyed to understand industry perspectives on IMTA effectiveness and the potential for use. The main goal of this research was to determine the current standards and processes of IMTA and if it can be effectively implemented on Atlantic Salmon aquaculture farms in a commercially viable manner.

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1 Introduction

1.1 General Introduction

Aquaculture operations are currently the fastest-growing food production industry, accounting for approximately 52% of seafood for human consumption (FAO, 2020), and supplementing an increasing demand for seafood despite waning wild fishing catches (Mazur & Curtis, 2008). Each type of aquaculture, finfish, shellfish, or seaweed brings differing challenges for both management and potential environmental impacts (Weitzman et al. 2019). International demand for salmonids, and Atlantic salmon (*Salmo salar*) in particular, have increased in the last few decades, currently representing about 19% of total aquaculture worldwide (FAO, 2020).

A long-lasting, primary concern with Atlantic salmon aquaculture is waste management (Alexander et al., 2016). Over the last three decades, the amount of particulate wastes produced by fish farms has been significantly reduced due to the development of more efficient feeds and feeding systems (Islam 2005, Sørensen 2012, Sprague et al. 2016). Nowadays, approximately 5% of feed is estimated to be discarded as waste from salmon-based aquaculture operations (Howarth et al., 2019). Besides feed waste, fish metabolic processes result in additional particulate and dissolved loading. Therefore, the nature of waste at farming sites is a mix of particulates of varying sizes and dissolved matter (Chary et al., 2020). The particulate waste generated can impact the surrounding water body, particularly the benthic environment (Miller & Semmens, 2002). Particulate wastes can create organic loading issues, potentially reducing dissolved oxygen content (Brown, Gowen & McLusky, 1987) and impacting the benthic environment (Sindilariu et al., 2009). These potential effects on the benthos are why benthic fauna is regularly studied and monitored by scientists and regulators as an indicator of aquaculture effects (Brown, Gowen & McLusky, 1987). Contrarily, dissolved waste affects the pelagic environment, potentially causing an excess of nutrients in the water column (Kelly et al., 1996).

The public perceives these potential waste-induced impacts as unfavorable, resulting in an associated negative outlook on Atlantic salmon aquaculture (Barrington et al., 2010a; Ridler et al., 2007). This negative outlook has resulted in some of the public keeping a preference for wild-caught seafood despite waning catches (Claret et al., 2014). Although negative impacts on the environment can occur in all types of aquaculture, the impacts in finfish aquaculture differ from those in extractive species like seaweeds and bivalves (Troell et al., 2009). Extractive species grow and thrive by taking dissolved nutrients or organic matter out of the surrounding water column or benthos (Troell et al., 2009). Due to the reliance on the natural system to provide food for the extractive species, the aquaculture operations for these species tend to cover a larger surface area than their fed counterparts. Given the capacity of extractive species to capture dissolved nutrients and organic matter and, they have been suggested to be farmed together with fed species. In this way, the extractive species could directly use the fed species wastes, mitigating environmental effects, and benefiting from the additional food. This type of aquaculture is called Integrated Multi-Trophic Aquaculture (IMTA), and in this research was defined as "the co-cultivation of species from different trophic levels, as opposed to a single species (monoculture), on an aquaculture farm. From a theoretical perspective, in an IMTA farm, the metabolic waste and uneaten feed from the top-level species like Atlantic salmon is used by lower-level trophic species like bivalves and macroalgae."

Although the configuration of an IMTA farm can vary greatly, three major types of extractive species have been considered in the literature: seaweeds, bivalves, and bottom feeders. Seaweeds can reduce dissolved nutrient loading in the water column (Troell et al., 2009). However, due to the large size requirements for seaweed farms, they could also contribute to the loss of native species, reduce biodiversity, attenuate waves and currents, and create conflicts with other industries like fishing (Nobre et al., 2010). The filtration capacity of bivalve farms could positively mitigate the effects of particulate waste (Troell et al., 2009). However, bivalve farms also, due to their size and spacing, could contribute to loss of native species and reduce biodiversity through top-down control of phytoplankton populations and organic loading through particulate consolidation (Chopin et al., 2001). Although much less commonly covered in the literature, bottom feeders like sea cucumbers could also be incorporated into the IMTA system (Zhang & Kitazawa, 2016). These benthic living species can feed on organic matter from the environment through various mechanisms, which would determine their mitigation potential. Similarly, the potential adverse effects on the environment that would result from their farming would vary greatly by species (Neofitou et al., 2019).

Therefore, a salmon farm that utilizes any of these extractive species could theoretically reduce, at least to some degree, dissolved and particulate wastes, consequently mitigating potential negative impacts. This mitigation potential has been the major argument for developing and implementing IMTA systems (Alexander et al., 2015). In addition to the potential for mitigation, IMTA has also been promoted as a farming strategy to diversify products and minimize operational risks (Carras et al., 2019). Furthermore, industry may benefit from an improved public perception by creating a "higher quality" and more ecologically sustainable product (Ridler et al., 2007). IMTA implementation also generates potential drawbacks in the form of increased cost upfront and over time, increased need for personnel training, development in expertise for each species, and for the integration aspect, among others (Carras et al., 2019). Thus, due to the perceived environmental benefits and subsequent increased complexity and costs, there is a debate about the true benefits and drawbacks of IMTA.

1.2 Management Problem

The management problem addresses growing concerns surrounding proper mitigation of waste discharge from "fed" aquaculture species, particularly Atlantic salmon farming, resulting in potential negative environmental impacts (Chopin et al., 2001). This type of pollution causes an external cost that affects stakeholders interacting with the site daily and society through environmental impacts (Whitmarsh, Cook, & Black, 2006). A proposed solution for waste mitigation in fed aquaculture involves implementing IMTA, the use within the same farming area of extractive species that can use particulate and dissolved waste, consequently mitigating potential negative effects. The concept of IMTA has many theoretical benefits, though it remains not widely implemented in farms across the world.

1.3 Research Aims & Objectives

The goal of this research was to answer the following main question "what are the key factors affecting the implementation of IMTA in Atlantic salmon aquaculture farms?" To achieve this goal, a systematic PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) literature review was carried out to investigate current methods, applications, uses, and mitigation efficiency of IMTA on salmon farms. In parallel, industry experts worldwide were consulted to understand industry perspectives on IMTA effectiveness and its potential implementation. The following sub-questions were answered to address the main research question:

- Sub-Question 1: What is the waste mitigation efficiency (percentage of waste captured by extractive species) of IMTA according to the scientific literature?
- Sub-Question 2: What are the potential advantages and disadvantages of implementing IMTA in salmon farms from an industry perspective?
- Sub-Question 3: What are the barriers (if any) that could compromise the implementation of IMTA in salmon farms from the industry perspective?
- Sub-Question 4: What are the incentives (if any) that could facilitate the implementation of IMTA in salmon farms from the industry perspective?

2 Background

2.1 Aquaculture Classification

Aquaculture can be classified in a wide variety of ways. More specifically, eight general typologies can be given to any aquaculture operation: environment, production, system, cycle, intensity, water temperature, culture, and organism. The combination of these classifications clarifies the aquaculture type and scale. The environment type, namely freshwater, brackish water of seawater, determines the most about the aquaculture system, is restricted to certain species and life stages and requires differing investments. Production type, including the purpose of the production, is also important in deciding whether or not the aquaculture is meant for human consumption, being either commercial or subsistence, or if it is meant to aid in restocking wild organisms, be used in scientific work and even if it is simply for cosmetic reasons (Asche et al., 2013). Systems can be open, closed, or somewhere in-between (Kokou & Fountoulaki, 2018). Open systems have organisms in natural waters, while closed systems use recirculated water though partial recirculation systems also exist (Sindilariu et al., 2009). The life cycle also plays an important type in classification and understanding (Little et al., 2016). The two types of lifecycles, namely open and closed cycles, are defined by whether or not the organism lives its whole life in captivity (closed) or captured from the wild at some point in the process, usually as a juvenile (open). Intensity can be either extensive or intensive, varying based on the human control level and scale of the operation (Prinsloo & Theron, 1999).

Common commercial operations with lots of monitoring and a large scale are classified as intensive. In contrast, small community-run operations with little controls and monitoring mechanisms are classified as more extensive. Whether warm, cool, or cold, water temperature determines what species can be cultivated and what strategy the cultivator should use. Culture type is of great importance, though most commonly, monocultures are used worldwide as they are simplest to implement (Soto, 2009). The classification difference is simple, monocultures use one species, and polycultures use multiple (Soto, 2009). Though polycultures have been around for thousands of years, they remain more popular in Asia than in the western world (Shuanglin et al., 2013). Each has its benefits and downsides, though research in developing effective and adaptable polycultures around the world has only been minimally implemented by industry (Asche et al., 2018). IMTA differs from polyculture, though it has its foundation rooted within the practice. It aims to be a more holistic approach to the concept, combining species from different trophic levels to utilize excess nutritional inputs through extractive processes. The organism type is the most descriptive part of aquaculture. It is likely the first aspect after choosing a determined site. This section has a large diversity, significantly greater than land-based agriculture, with hundreds of viable species across all the different environments possible to cultivate. The main types of organisms fit into three categories: finfish, shellfish, and sea plants. Apart from these three, a wide variety of species can only fit into an “others” category, including commercial corals, rare aquarium species, and even crocodiles (Buenviaje et al., 1994). Atlantic salmon, one of the most commonly reared finfish across the world (FAO, 2020).

2.2 Atlantic Salmon Aquaculture

Salmon is the common name for several species of the family Salmonidae, of which Atlantic Salmon is most consumed. They have a spindle-like body shape with a small head and prominent ventral paired fins (NOAA Fisheries, 2020). The average spawning female lays an average of 7,500 eggs. Though they live on average for two (2) years, they can live up to seven (7) years (NOAA Fisheries, 2020). Atlantic Salmon is currently one of the most cultured finfish globally though it still only represents a small proportion of global protein consumption (FAO, 2020). Atlantic Salmon is both a euryhaline species, with some life stages being in freshwater and others living in saltwater, and iteroparous, surviving after spawning and returning to the sea (NOAA Fisheries, 2020). They are also carnivorous, requiring a higher protein diet than other cultivated species (Lemm et al., 1993).

Aquaculture has existed in communities across the world for thousands of years, with earliest recollections of the process dating back to before 5000 BC (Stickney, 2011). However, Atlantic Salmon cultivation began in the late 1960s in Europe (European Commission, 2020). This development was predominantly due to cage technology improvements and previous improvements in hatchery technologies (European Commission, 2020). The cage and net-pen technology were originally developed more for protected bays and saltwater enclosures. However, continued development made them able to withstand the stresses of the open ocean. By the 1980s cultivation of salmon became a large industry in certain European countries before expanding to other parts of the world in the ’80s (Global Salmon Farming Initiative, 2020). The combination of wild scarcity and great marketing techniques made salmon aquaculture a great success as a luxury product worldwide, eventually leading to the commonality we see today (European Commission, 2020).

There are both land-based and open-net pen systems used to house salmon, though open-net pens are more common (Asche et al., 2018). In land-based systems, there are different challenges based on the need for filtration mechanisms and different monitoring mechanisms to ensure the fish's health (Abreu et al., 2011). By contrast, open-net pens require infrastructure to either be floating or attached to the bottom and do not have to factor in as many monitoring mechanisms due to natural flow through the area based on currents (Michelsen et al., 2019). The salmon farming production cycle takes aquaculturists for approximately three years (Global Salmon Farming Initiative, 2020). In the first year, freshwater controlled environments are used to rear and grow smolts and young salmon before they are significant in size and age to be transitioned into sea cages (Global Salmon Farming Initiative, 2020). These environments are commonly a hatchery system with constant management by trained personnel (Tillotson et al., 2019). Salmon live in the sea cages until they are at a target size, managed through off coast. Once salmon are at a pre-determined size, they are harvested and transported to processing plants (Global Salmon Farming Initiative, 2020). The salmon are prepared for sale at these plants through cleaning and post-harvest processes before being packaged and transported for sale (DFID, 2018).

2.3 Introduction to Integrated Multi-Trophic Aquaculture (IMTA)

As previously stated, many types of aquaculture practices relate closely to the type of species being cultivated. The extractive species, like species of seaweeds and shellfish, could directly use the wastes from the fed species, mitigating environmental effects and benefiting from additional food. This type of aquaculture is called Integrated Multi-Trophic Aquaculture (IMTA) and in this research was defined as “the co-cultivation of species from different trophic levels, as opposed to a single species (monoculture), on an aquaculture farm. From a theoretical perspective, in an IMTA farm, the metabolic waste and uneaten feed from the top-level species like Atlantic salmon is used by lower-level trophic species like bivalve and macroalgae.”

IMTA is a concept closely related to a polyculture, having multiple species being cultured in tandem, though the goals are notably different (Carras et al., 2019). While IMTA focuses more on complementing species and adding balance to the system, a normal polyculture may simply focus on using like species in an attempt to diversify (Neori et al., 2017). This diversification is one reason why an IMTA system is much more difficult to implement successfully than that of a standard polyculture (Whitmarsh et al., 2006). In Asia, there are many variations in how polycultures are implemented (Shuanglin et al., 2013). Though this has not transitioned into western aquaculture practices, the different Asian polyculture examples may better understand species interactions (Chopin et al., 2001). The intensive utilization of space and incorporation of different, varied, and experienced cultivation methodologies into one single system is what enables polyculture to succeed (Shuanglin et al., 2013). It is IMTA’s lack of this understanding and application to the finfish combination with other species that have limited its success and viability around the world (Shuanglin et al., 2013). In either case, industry may benefit from an improved public perception by creating a "higher quality" and more ecologically sustainable product. However, utilizing a more complex IMTA system with finfish, shellfish, sea plant, and invertebrate aquaculture species could help implement sustainable development in both industry and communities.

3 Methods

3.1 Literature Review Methods

A primary literature review was carried out to synthesize the existing literature regarding waste mitigation efficiency on IMTA systems (sub-question 1) and the potential benefits, issues, barriers, and incentives of IMTA implementation (sub-questions 2-4). The search was completed using the keywords "IMTA + salmon" in "ALL Fields" for papers on the online database search tool Scopus on May 5, 2020. No papers were initially omitted by years, language, reviews, or article type. A total of 556 studies were initially identified (Figure 1). This search was then imported into Covidence, an online literature review management tool. From this point, duplicates (n=1) were removed, and the papers went through two additional screening processes. Title and abstract screenings were conducted first to remove papers not related to aquaculture (n=236). Then, full-text reviews were done to determine the eligibility of the remaining papers. Exclusion criteria were based on the following (in brackets the number of papers that were excluded):

- IMTA Focus far from Fish (n=132): these studies focused on aquaculture and IMTA, but not fish species.
- Review (n=53): these studies focused on aquaculture, but reviews were removed from the analysis as the systematic review focused on primary literature.
- IMTA Simply Mentioned (n=48): these studies focused on aquaculture, but IMTA was simply mentioned in a short line of text.
- Lab-Based Study (n=31): these studies focused on aquaculture and, in some cases, also IMTA but focussed on lab-based experiments or theoretical concepts, which did not lend insight into the area of focus in this study.
- IMTA only in the references (n=14): these studies focused on aquaculture information, but IMTA was only found within the reference section.
- Non-English (n=2): despite using English terms in the search, two studies not written in English were removed as they could not be accurately incorporated into the analysis.

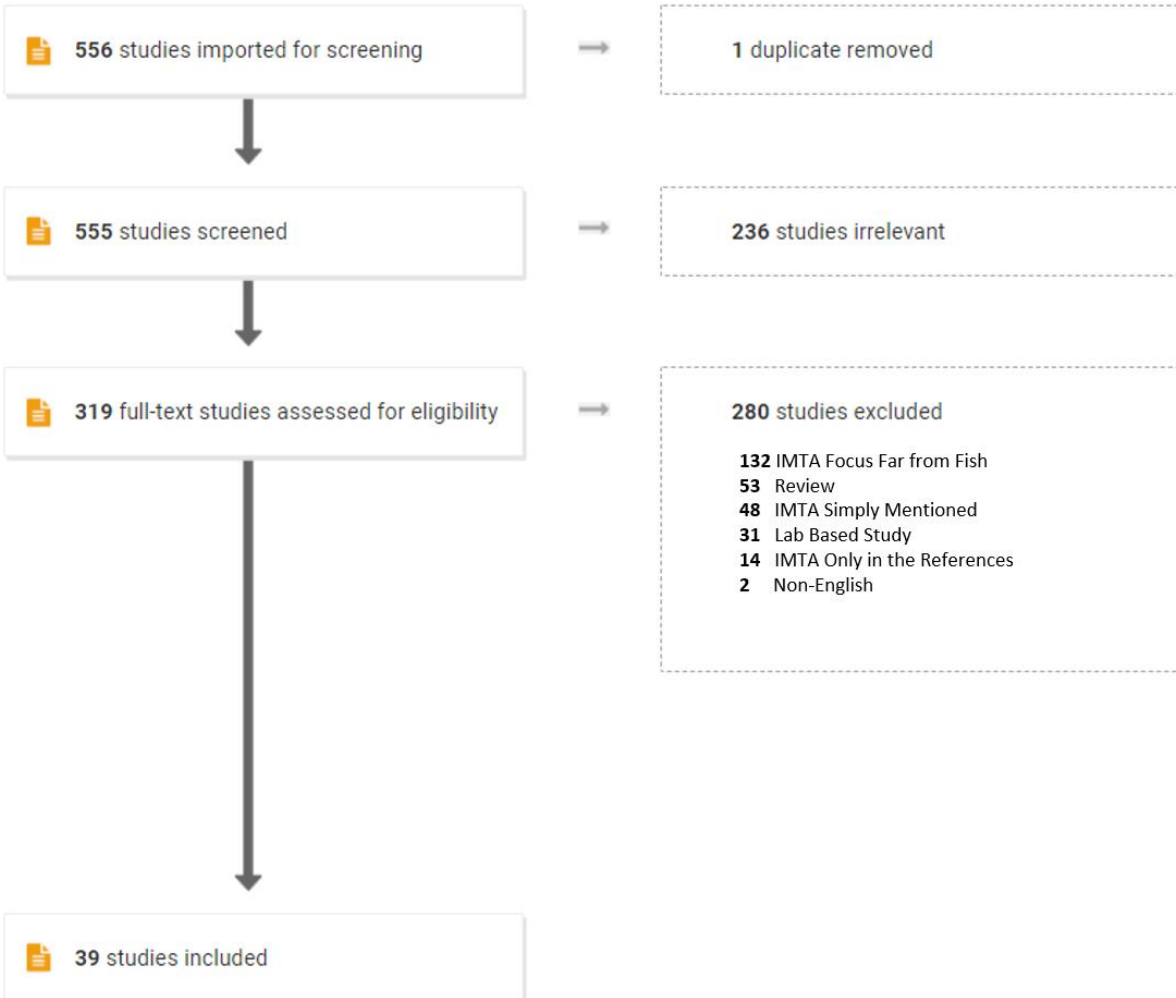

Figure 1. PRISMA systematic review process with three separate screening events corresponding to duplicate, title, abstract, and full-text review screens.

A total of 39 studies were included in the final review and extraction process. The following information was extracted: year, non-extractive species present, extractive species present, country and location of sites, setting (net-pen or land-based), report of mitigation performance for extractive species, and main conclusions of the study. The most representative quote from each study was extracted and classified according the pre-defined topics: potential benefits, perceived issues, potential barriers, and potential incentives. Based on these quotes, each of the pre-defined topics was further divided into two sub-topics: (1) Potential Benefits (Profitability, Viability), (2) Perceived Issues (Scalability, Management), (3) Potential Barriers (Education, Government Support) and (4) Potential Incentives (Wild Species, Future Work). The quotes could be in support of or not supporting each sub-topic.

Finally, the studies were also given a general theme classification of either bioremediation, perception, integration performance, physics, emerging technology, and financial performance. These emerging themes were classified reactively as the studies were read. *Bioremediation* was defined as papers whose sole goal seemed to be improving environmental issues or understanding environmental issues at their site of interest. *Perception* studies looked to understand how the public or other industry members felt about IMTA, fish aquaculture, or both. *Integration performance* studies investigated various species performance or changes in methodology in cultivation on the site itself. *Physics* sought to investigate the physical aspects of IMTA and aspects of the physical environment which could inhibit its success. *Emerging technology* showcased new methodologies or cultivation strategies that could be applied to IMTA systems. *Financial Performance* explored how financially viable an IMTA project was or could be. A table of this data for all extracted papers can be found in Appendix I.

3.2 Industry Survey

The industry survey was created to address sub-questions 2-4 regarding potential benefits, issues, barriers, and incentives for IMTA implementation (Appendix II). The survey questions were formulated using information from reviews, which were omitted from the final review and extraction process of the PRISMA literature review. This likert-based, short (~5 min), and anonymous survey specifically aimed to gather the perspective from industry professionals. Possible benefits captured common ideas of services the IMTA system could offer to the environment and the company implementing it. These included effects on biofouling reduction, waste mitigation, diversification of products, increased profitability, and improvement in public perception. Perceived issues referred to negative effects related to IMTA implementation, including increasing harmful algal bloom frequencies, biofouling frequency, diseases and pest abundances, attraction of wild species, economic constraints, reducing social acceptance, and impacts on farmed products. Potential barriers included aspects that may affect the level that IMTA is implemented or its potential success, including economic, expertise, regulations, and managerial complications. Potential incentives referred to perceived developments that could facilitate IMTA implementation, including flexible regulations, subsidies, positive outlook campaigns, and new ecolabel creation. In addition, a question was used to allow the participants to self-identify their current knowledge of IMTA systems. There was also additional space for respondents to add and explain other categories. This survey was approved by the Marine Affairs Program Ethics Review Standing Committee on May 6, 2020, with the reference MAPERSC# - MAP2020-02.

Survey participants were selected from personnel from Atlantic salmon farming companies from the five leading producer nations (Norway, Chile, Scotland, Canada, and the Faroe Islands) and aquaculture consultants with international exposure focussing on the fields of sustainability, environmental issues, mitigation techniques, and eco-certification. This target population was chosen due to their proximity to Atlantic salmon aquaculture and their understanding of environmental issues and sustainability. The participants were asked to spoke about their personal opinions. Although some of the participants could be from non-English-speaking countries (e.g., Norway, Chile, and the Faroe Islands), the language used in the survey was kept simple, and the expected English proficiency of the participants was assumed not to be a barrier.

Respondents were recruited mainly through emails, targeting companies and individuals identified through websites, or snowballing. Messages on LinkedIn were also used as an additional recruitment tool. Each email provided a definition of IMTA, a detailed explanation of the research goals, and a link to the online survey, which was carried out using Opinio, and hosted on a Dalhousie University secure server. A total of 149 aquaculture and consulting companies were contacted for participation in the survey. In addition, individuals from these companies were contacted through messages totaling 134 emails, with an additional 48 messages sent through LinkedIn. The survey encouraged participants to share either the link or the contact information of potential respondents within the industry. Therefore, the final number for potential participants and participants contacted is unknown.

Although the total amount of companies in the industry could be known, the survey targeted individuals and not the companies themselves. Therefore, it is logistically challenging to determine the potential number of respondents. Given that the number of potential participants is unknown, there was not a target number of respondents to meet a statistically significant level. Accordingly, although the survey is quantitative in nature, the information gathered was mainly used to draw upon expert insights.

4 Results

4.1 Literature Review Overview

4.1.1 Demographic Results

The first paper included in the review was dated from 2007 (Figure 2). The number of publications during 2020 was below the average; however, data collection finished in May 2020, limiting the available studies to only five months worth of data. Despite some peaks in certain years, e.g., 2013, the overall trend is that IMTA publications are increasing over time (Figure 2).

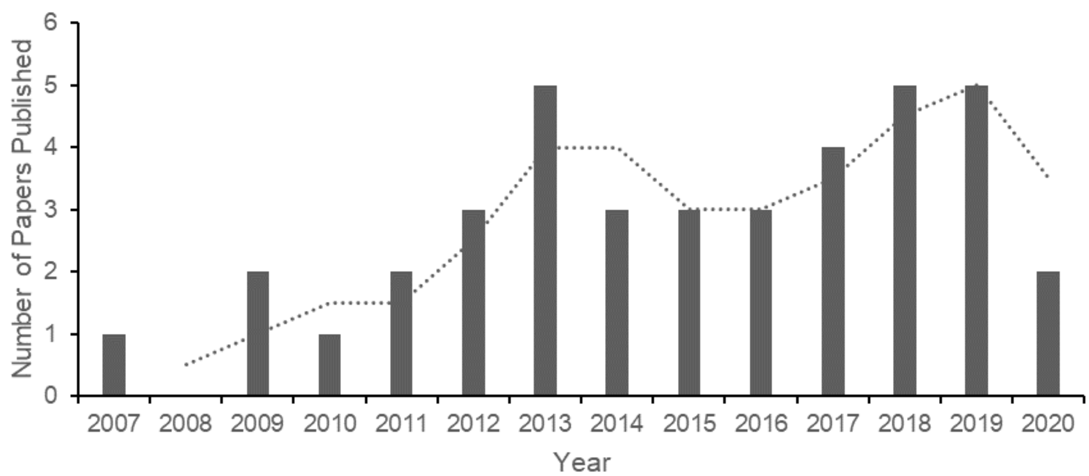

Figure 2 Papers included within the literature review published by year with a two-year moving average (dotted line).

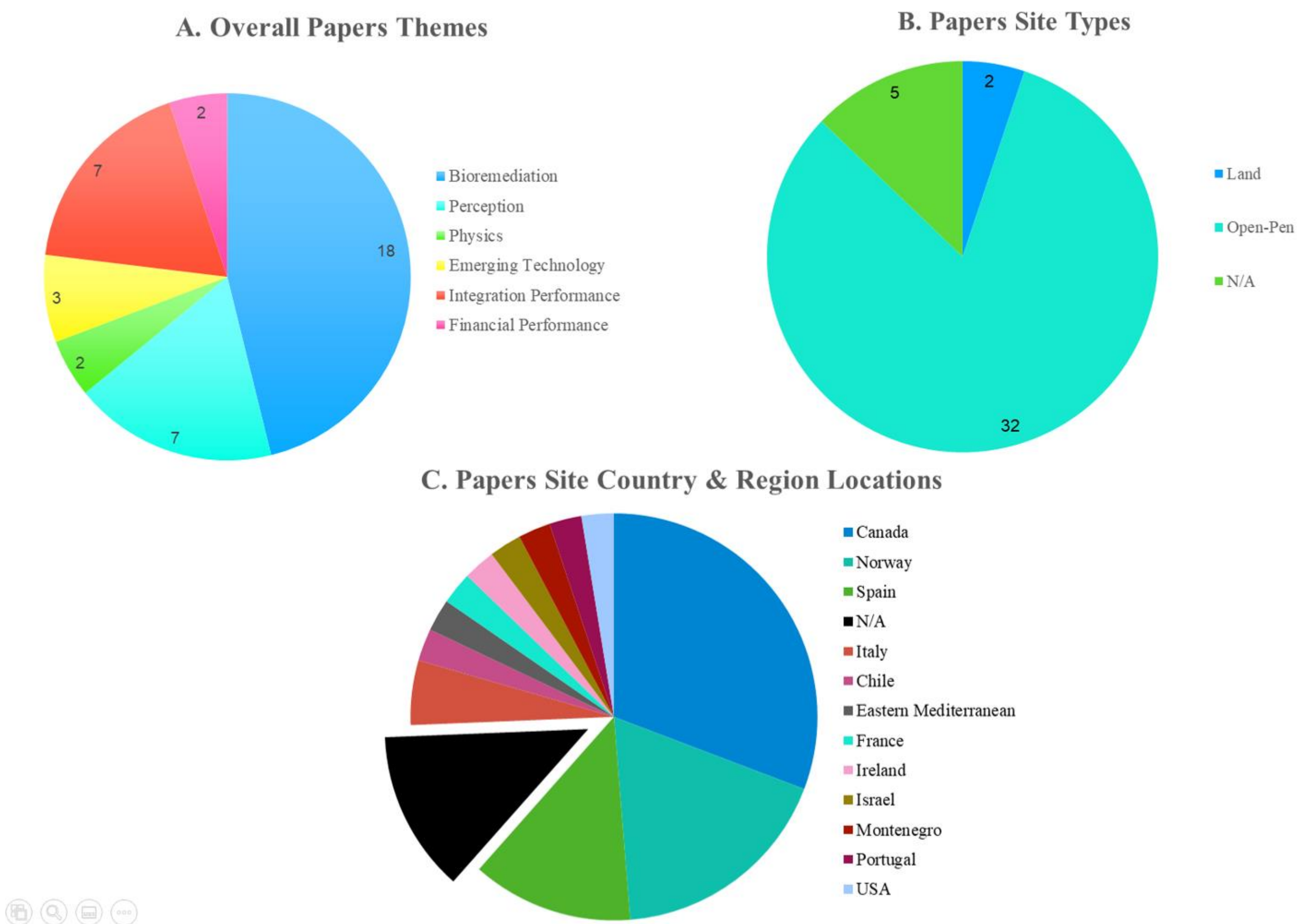

Figure 3 Papers included within the literature review sorted by (A) overall themes as described by the researcher, (B) described site type within the paper, (C) region or country of origin and site.

Six themes emerged from the reviewed papers (Figure 3A). *Bioremediation* was the most prevalent theme, with 18 papers, followed by *Perception* and *Integration Performance*, with seven papers each. *Emerging Technology* was the main theme of three papers, and finally, both *Financial Performance* and *Physics* with two studies each (Figure 3A). Regarding site type, most of the studies focused on open-pen sites (82 %), followed by land-based (5 %, Figure 3B). Five (13%) studies did not describe the site type; most of these papers focused on themes of perception, with one of the five focusing on bioremediation. The papers included within the literature review covered a wide range of regions and countries, being the majority from Canada (31%, n=12), followed by Norway (18%, n=7), Spain (13%, n=5), and Italy (5%, n=2; Figure 3C). Finally, Chile, the Eastern Mediterranean region, France, Ireland, Israel, Montenegro, Portugal, and the USA represented 2% each (n=1). Studies without a country of origin or with removed site data represented 13% (n=5) of the papers.

4.1.2 IMTA as a Waste Management Method

The main goal of the literature review was to answer the sub-question, what is the waste mitigation efficiency (percentage of waste captured by extractive species) of IMTA according to the scientific literature? There were, at the completion of the literature review, no studies which explicitly stated that IMTA had a proven and measurable level of mitigation under commercial settings, with many stating that the proposed IMTA methods may work with increased scaling or that many species could contribute to a healthy IMTA operation.

Within "Potential Benefits" (Table 1), the sub-topic of *Profitability* relates to the financial viability of an IMTA operation. Quotes were common regarding the large upfront costs and increased costs due to the lack of expertise seen with creating and running an IMTA based operation. Although many papers suggested the financial viability of IMTA operations, they also commented on other issues such as scalability and finfish species being too high a percentage of profits, which could be holding back the implementation of IMTA. The sub-topic *Viability* relates to how likely the IMTA process is to work. This includes biological viability like access to nutrients and organic particles, effects on the growth performance, and aspects related to the financial viability. Viability was commonly referred to in both negative and positive connotations (Table 1). The positive references spoke to how the IMTA system was able to increase the size of organisms or whether a species could effectively mitigate within an IMTA system. Many of these studies additionally called for more research into the subject matter before conclusions could be made. The negative references spoke to how the IMTA system was not able to either positively impact the growth of the extractive species, potentially negatively impact their health, or not contributing towards mitigation.

Table 1 Quotes related to the pre-defined topic Potential benefits (Profitability, Viability) of integrated multi-trophic aquaculture (IMTA).

Main Author	Year	Sub-Topic	Quote
Abreu	2011	Profitability	"To make it worthwhile, it is necessary to continue to explore new and profitable applications…"
Abreu	2009	Profitability	"It is thus crucial to pay a closer look to the management of this resource and improve its profitability"
Carras	2020	Profitability	"comparing salmon monoculture and IMTA may view the additional revenues from other species under IMTA as not worth the additional operational complexity, capital expenditure, and corresponding risk."
vanOsch	2019	Profitability	"the public is willing to pay a price premium for products produced in a more sustainable method such as IMTA."
Gvozdenović	2017	Viability	"results indicate the possibility that mussels feed on the nutrients from fish farm during periods when little food would naturally be available in water."
Handå	2013	Viability	"suggested a seasonal mismatch regarding direct recycling of the nutrient effluents from salmon aquaculture by macroalgae."
Handå	2012	Viability	"The growth in length and soft tissue matter of the mussels was closely related to season while the localization of mussels at the

			fish farm versus at the reference station was of minor importance to the result.”
Haugland	2019	Viability	“*S. latissima* next to fish farms, … on-site H_2O_2 emissions will most likely harm the cultured seaweeds”
Irisarri	2015	Viability	“lack of a significant enhancement in growth of the bivalves cultured next to finfish”
Irisarri	2015	Viability	“mussels cultured under open-water IMTA … dietary enhancement was within the range of natural variations of seston loads and was not enough to increase the scope for growth and energy reserves compared with monoculture mussels.”
Irisarri	2013	Viability	“This study found no evidence of increased [food quantity] or [food quality] at commercial mussel aquaculture sites located near the two fish cage sites”
MacDonald	2011	Viability	“mussels have the capability of capturing and absorbing excess particulate fish food released from the salmon farm”
Martínez-Espiñeira	2016	Viability	“[IMTA] benefits … in the form of biomitigation of the external costs imposed on the marine environment, would be derived by Canadians”
Ratcliff	2016	Viability	“Metal levels in the seaweeds do not pose a concern over inclusion as a dietary component with the possible exception of arsenic that exceeded some legislative limits.”
Sarà	2009	Viability	“results suggest that fish farm organic waste that is dispersed in the water column may be a food source for bivalve molluscs such as mussels.”
Wang	2013	Viability	“Only a small portion of salmon farm wastes can be incorporated by blue mussels”
Wang	2014	Viability	“the biomass of individual plants at the reference station would be 60 % lower than the plants at the salmon farm”
Weldrick	2016	Viability	“Blue mussels in both cultures and the wild gain excess nutrients, have a higher growth rate due to incorporation of farm effluent and excess feed into their diets.”

Within “Perceived Issues” (Table 2), the *Scalability* sub-topic included the recommendations for the incorporation of IMTA techniques and practices into existing operations. Many of the studies seemed to use small proportions of extractive species, which showed an overall proof of concept but also created a dichotomy of being unable to show proof of concept for scale. From the theoretical perspective, several studies highlighted the potential for scalability, and profitability, although no studies explored it in a real-world case-study. The sub-topic of *Management* regards the issues that arise from the lack of expertise in managing and running an IMTA operation or, at the very least, management of polycultures, especially within the western world. This lack of management expertise, especially regarding best practices for species integration, has been identified as a bottleneck for commercial application (Table 2).

Table 2 Quotes related to the pre-defined topic Perceived Issues (Scalability, Management) of integrated multi-trophic aquaculture (IMTA).

Main Author	Year	Sub-Topic	Quote
Handå	2013	Management	"suggested a seasonal mismatch regarding direct recycling of the nutrient effluents from salmon aquaculture by macroalgae."
Lander	2012	Management	"implementation of IMTA systems requires extensive experimentation into the varied intra- and interspecies interactions, and intersite differences, as well as processes governing the coculture of multiple trophic levels to maximize nutrient use, total product yield, and bioremediative potential of the overall system"
Brager	2014	Scalability	"the potential for enhanced production by co-cultured bivalve filter-feeders at these [IMTA] farms is limited by available space close to net-pens and the periodic availability of low levels of suspended particulate fish wastes"
Broch	2013	Scalability	"due to limitations in space available for future aquaculture leases in the coastal zone, a full bioremediation of Norwegian aquaculture using S. latissimi is unrealistic."
Fossberg	2018	Scalability	"determine scalability of the success of the growth … to a more commercial scale"
MendozaBeltran	2018	Scalability	"Production of 4 t of oysters annually is not small, but remains insignificant in relation to the 240 t of fish produced annually"

Within "Potential Barriers" (Table 3), *Education* was a heavily cited sub-topic throughout many of the papers, and it is defined as the education of the public not only into IMTA processes but also education regarding the identification of IMTA cultured seafood. Many studies stated willingness, when educated, of the general public to explore price premiums upwards of 30% (Carras et al., 2020; van Osch et al., 2017). The literature identified as a major issue how to deliver the knowledge about the impacts and methods of IMTA to the general public in a simple and easily defined manner, and additionally how to make this information available at a glance on produced products. The sub-topic *Government Support* was also highlighted in a portion of the studies, indicating a lack of willingness of the government to adjust existing regulations or make incentives for the promotion of IMTA based sites.

Table 3 Quotes related to the pre-defined topic Potential Barriers (Education, Government Support) of current integrated multi-trophic aquaculture (IMTA).

Main Author	Year	Sub-Topic	Quote
Barrington	2010	Education	"A promotional campaign educating the general public, food distributors, and other industry stakeholders about the positive benefits of IMTA would go a long way in gaining mainstream acceptance of this aquaculture practice."

Martínez-Espiñeira	2015	Education	"successful acceptance of IMTA salmon depends on consumers clearly distinguishing between conventionally farmed salmon and IMTA salmon."
vanOsch	2019	Education	"the public is willing to pay a price premium for products produced in a more sustainable method such as IMTA."
vanOsch	2017	Education	"positive preference for high levels of sustainability and home production location."
Yip	2017	Education	"Results using latent class analysis show that consumers with a strong preference for wild salmon have high marginal values for farmed salmon produced with IMTA"
Kleitou	2018	Government Support	"respondents believe that IMTA has not received adequate support from the governments, industry and funding agencies"
Martínez-Espiñeira	2016	Government Support	"[IMTA] benefits … in the form of biomitigation of the external costs imposed on the marine environment, would be derived by Canadians"

Within "Potential Incentives," *Wild species* is a sub-topic that directly relates to the incorporation of wild, usually non-commercial, organisms into the IMTA process. This has been represented in use in feeds, as new extractive species, and other applications. This process is equally hindered and amplified by the surrounding natural environment and requires a higher degree of expertise and knowledge of the existing natural system the farm exists in. The sub-topic of *Innovation* encompasses all aspects that need to be further developed for the successful implementation of IMTA. While this was understandably present in most studies, some in particular utilized novel concepts which, upon further development, may be beneficial to IMTA development.

Table 4 Quotes related to the pre-defined topic Potential Incentives (Wild Species, Innovation) of integrated multi-trophic aquaculture (IMTA).

Main Author	Year	Sub-Topic	Quote
Ashkenazi	2019	Innovation	"a number of seaweed species can be cultured in series in the same IMTA system … offering potential directions for future land based IMTA operations"
Blouin	2007	Innovation	"further methodological improvements are needed for crop development."
Fernandez-Gonzalez	2018	Innovation	"first look into utilizing naturally occurring species as an incorporation into IMTA was definitely promising.
Lander	2013	Innovation	"Net ecological effectiveness of IMTA and its ability to reduce overall site loading necessitate the addition of a benthic component utilizing deposit feeding organisms as organic extractors of the larger settled benthic particles."
Nelson	2012	Innovation	"[behaviour] did not seem to be as pronounced as it is in the field environment."
Neofitou	2019	Innovation	"has the potential to reduce the organic loading at aquaculture sites"
Ballester-Moltó	2017	Wild Species	"role of wild fish should be considered in environmental impact assessments"

Jansen	2019	Wild Species	"enhancing indigenous species may be a promising approach for benthic cultivation in integrated open water systems."

4.2 Industry Survey Overview

4.2.1 Demographics of Respondents

The survey was completed by 32 respondents; however, as respondents could skip questions, the respondent numbers vary with each question. Accordingly, a percentage rather than the number of respondents was used throughout the analysis. The field of expertise of the respondents was diverse, with 50% of the participants self-identified as experts in sustainability, followed by environmental issues (46%), technological development (32%), mitigation techniques (29%), and feed development and eco-certification (14% each). 54% of respondents also self-identified themselves with expertise in other fields such as technical, consultant, community ecology, oceanography, fish health, and innovation, among others. There was a wide range of respondent knowledge levels about IMTA. Approximately 22% were self-identified experts on the subject matter, 48% had some knowledge, 15% basic knowledge, 7% little knowledge, and finally, 7% had no knowledge of IMTA.

4.2.2 Analysis of Responses

Most respondents felt that the majority of suggested "Potential Benefits" (Figure 4) had some likelihood to happen, with only the potential of reducing biofouling on aquaculture equipment having a variable answer that spread below a neutral response. The mitigation of waste was the most likely benefit with a range from likely to extremely likely, and a median response of extremely likely. Both the improvement of public perception of the farm and farm products and the diversification of company profits were also perceived within the likely to extremely likely range, although in these cases, the median was likely. The prospect of IMTA implementation potentially reducing instances of harmful algal blooms in the surrounding area ranged between neutral and likely, likely being the median response. As stated above, the potential for IMTA to reduce instances of biofouling on aquaculture equipment spread from unlikely to likely, with a median response of neutral. Finally, the overall likelihood that IMTA implementation could generate no benefits was disputed by many respondents with a median response of not at all likely (Figure 4).

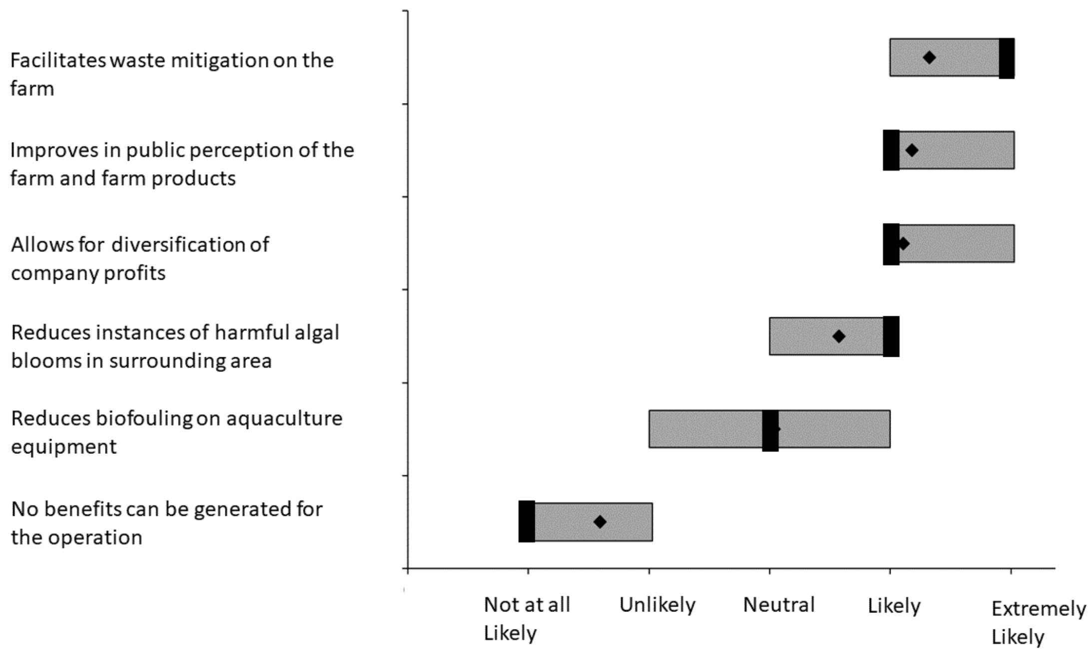

Figure 4 Box plot of responses to statements about Potential Benefits for IMTA implementation on a likert scale from not at all likely to extremely likely. The box identifies the first and third quartile, the thick line represents the median, and the diamond represents the mean.

In general, "Perceived Issues" (Figure 5) had larger response ranges than "Potential Benefits." The most relevant issue for IMTA implementation was the higher economic investment, with responses ranging from neutral to likely and a median response of likely. The effect on the attraction of wild fish and other species was also between neutral and likely, although the median response dropped to neutral. All the remaining issues, namely increase of diseases and pests, decrease of social acceptability, impact on fish growth, increase in algal blooms, decrease of quality of the farmed product, and increase in biofouling, resulted in a median response of unlikely. Therefore, despite the ranges in responses, the participants did not consider these aspects as issues for IMTA implementation. Considering the perceived issues of IMTA implementation as a whole, the respondents were split between unlikely and likely, being neutral the median response (Figure 5).

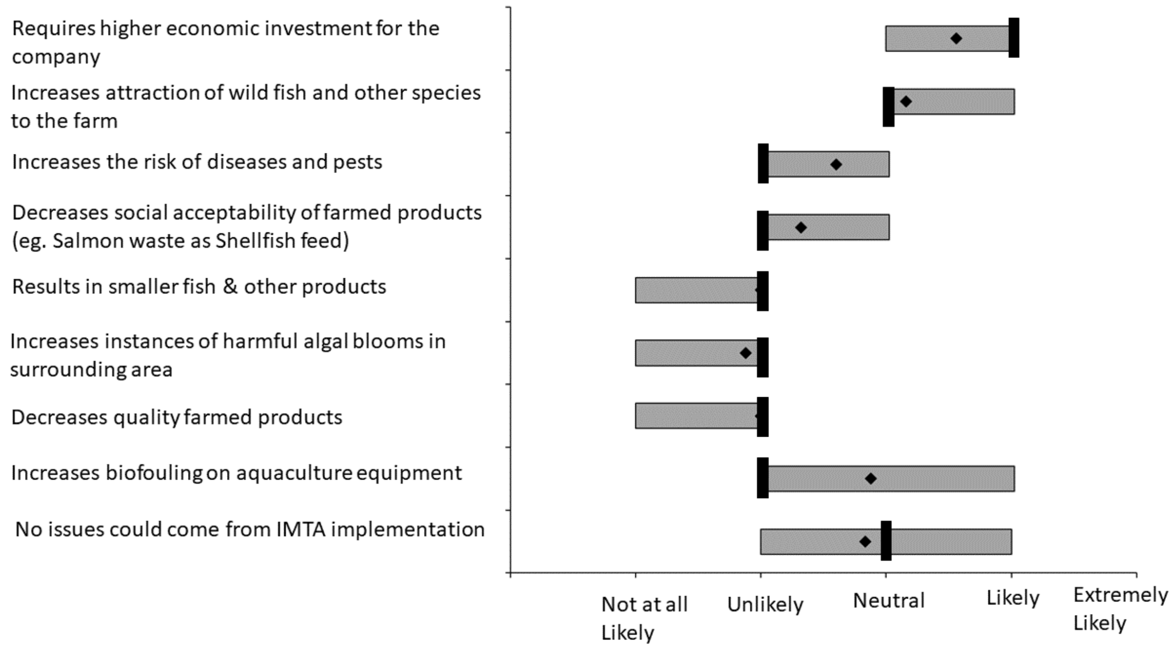

Figure 5 Box plot of responses to statements about Perceived Issues for IMTA implementation on a likert scale from not at all likely to extremely likely. The box identifies the first and third quartile, the thick line represents the median, and the diamond represents the mean.

The responses about statements related to "Potential Barriers" (Figure 6) were, like in the potential benefits section, very limited in range. All presented barriers, namely regulatory issues, lack of expertise, overall unrealistic implementation, managerial and economic barriers, had median responses of likely (Figure 6). Therefore, despite the different ranges for responses, overall, respondents felt as if all presented barriers were likely to affect IMTA implementation. Among these barriers, regulatory issues were the largest barrier indicated by respondents, with responses mainly between likely and extremely likely to affect IMTA implementation. Respondents were the most unsure about whether IMTA implementation could be prevented by barriers, although the responses ranged from unlikely to neutral, being neutral the median response. Overall, all barriers are deemed likely to affect the implementation of IMTA (Figure 6).

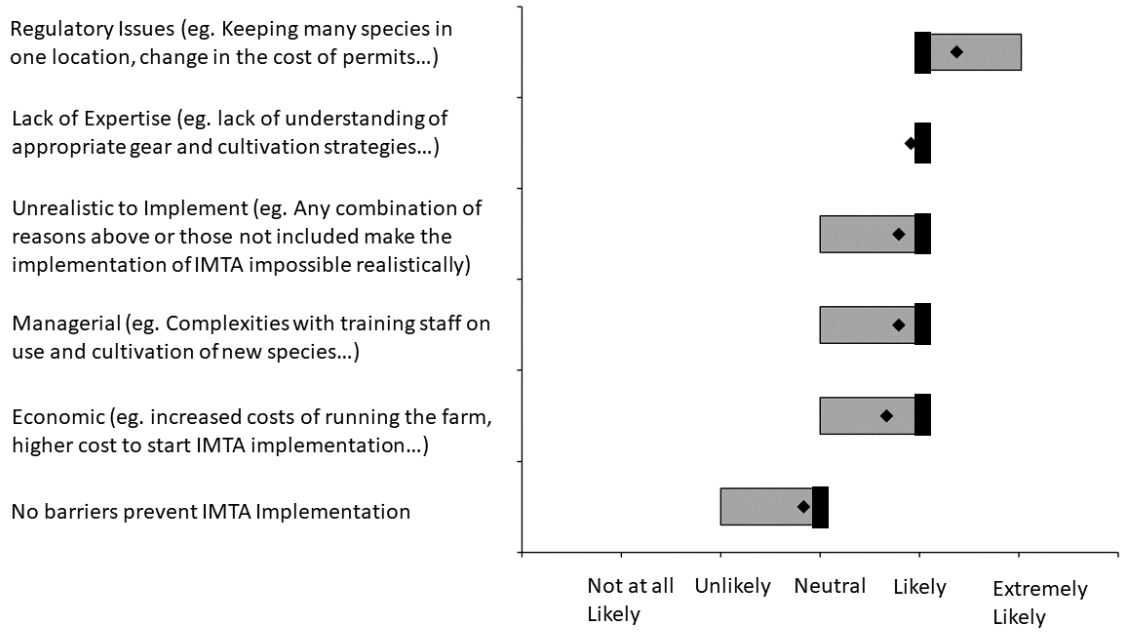

Figure 6 *Box plot of responses to statements about Potential Barriers for IMTA implementation on a likert scale from not at all likely to extremely likely. The box identifies the first and third quartile, the thick line represents the median, and the diamond represents the mean.*

The responses about statements related to "Potential Incentives" (Figure 7) had little variation among responses for most of the answers. All presented incentives, namely government subsidies, positive campaigning, flexible regulations, ecolabel creation, and collaboration mechanism development, had median responses of likely. Government subsidies were the most valued incentive. Finally, respondents found it unlikely that incentives could not facilitate the implementation of IMTA (Figure 7).

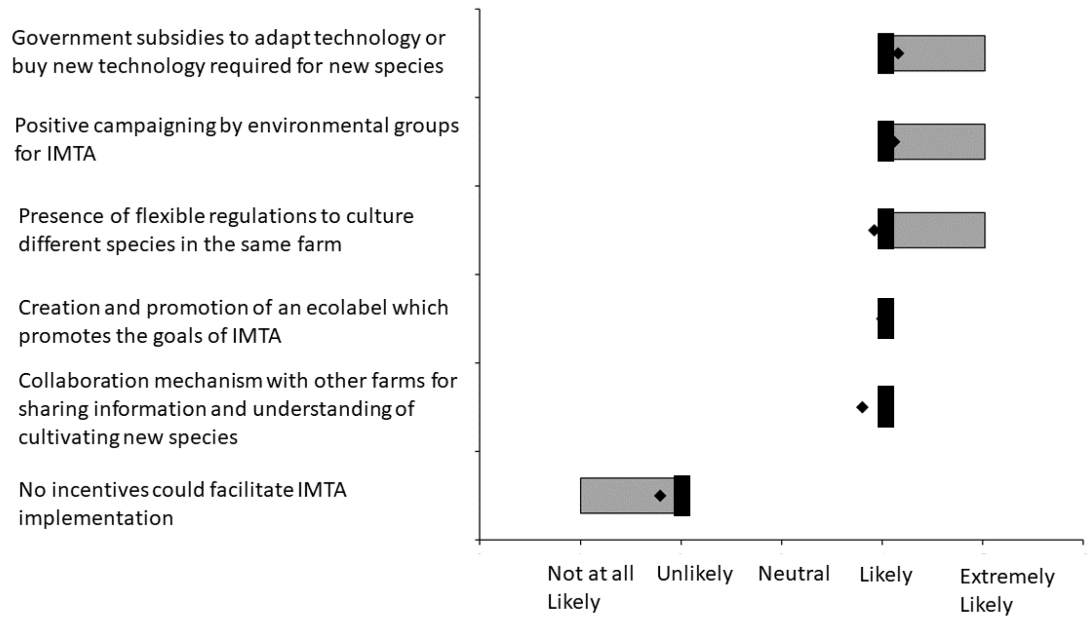

Figure 7 Box plot of responses to statements about Potential Incentives for IMTA implementation on a likert scale from not at all likely to extremely likely. The box identifies the first and third quartile, the thick line represents the median, and the diamond represents the mean.

5 Discussion

Aquaculture is an important activity for coastal development and is vital for seafood production. IMTA has been proposed as a farming approach that could mitigate the potential negative environmental effects of fed aquaculture. This study contributes to update the current scientific understanding of the mitigation capacity of IMTA. It identifies the benefits, issues, barriers, and incentives for IMTA implementation from an industry perspective.

5.1 Does IMTA Mitigate?

When looking into the concept of mitigation of waste in IMTA systems, mixed messaging is present in the literature. Different levels of mitigation were observed throughout the studies and across different extractive species. The literature review covered a range of extractive organisms from seaweeds, bivalves, sea cucumbers, and polychaetes (Abreu et al., 2009; Chary et al., 2020; Jansen et al., 2019; Nelson et al., 2012; Neofitou et al., 2019).

Seaweeds were the least controversial group of extractive species with a resounding acknowledgment of their capacity to extract dissolved nutrients in IMTA sites (Abreu et al., 2009, 2011; Ashkenazi et al., 2019; Broch et al., 2013; Fossberg et al., 2018; Handå et al., 2013; Wang et al., 2014). The Sugar Kelp (*Saccharina latissima*) was the most commonly studied species, although other common genus like *Gracilaria, Laminaria, Ulva, Porphyra, and Hypnea* were also present (Abreu et al., 2009, 2011; Ashkenazi et al., 2019; Haugland et al., 2019; Ratcliff et al., 2016). Although seaweeds were able to perform as expected and sometimes outperformed those growth rates within IMTA systems, the spatial location of the extractive species played a vital role in this performance, highlighting the role of water circulation in nutrient delivery (Fossberg et al., 2018; Wang et al., 2014).

The literature about the mitigation potential of bivalves, with the Blue Mussel (*Mytilus edulis*) being the most common species, revealed conflicting results. Although the concentration and size of particulate waste could limit mussel extractive capabilities (Cranford et al., 2013), evidence of utilization of fish waste products by mussels was present through many studies (Gvozdenović et al., 2017; MacDonald et al., 2011; Sarà et al., 2009; Wang et al., 2013; Weldrick & Jelinski, 2016). Furthermore, increased bivalve growth was also observed in IMTA systems (Aguado-Giménez et al., 2014); although this increase in growth was not consistent across the literature (Handå et al., 2012; Irisarri et al., 2015; Wang et al., 2013). Accordingly, mussels can feed on waste, but this ingestion does not necessarily result in increased growth (Gvozdenović et al., 2017; Lander et al., 2012; Wang et al., 2013). Similar to seaweeds, spatial location plays a significant role in bivalve performance, being underneath the finfish cage the ideal location, as vertical fluxes of particulate matter dominate in IMTA sites (Filgueira et al., 2017).

Studies that focussed on sea cucumbers and polychaetes also indicated their potential to use particulate matter from fish farms. The most common sea cucumber in the IMTA literature was *Holothuria tubulosa*, although other species like *Cucumaria frondosa* and *Holothuria scabra* were also used (Chary et al., 2020; Nelson et al., 2012; Neofitou et al., 2019). Like the sea cucumbers, a study that focussed on the colonization and incorporation of wild polychaetes solely for remediation purposes echoed the same potential as sea cucumbers (Jansen et al., 2019).

Accordingly, the scientific literature acknowledges that the extractive species can use the waste from fish farms; the issue is the required biomass of extractive species to become significant from a mitigation standpoint. Recent research on seaweeds has found this biomass to change based on many factors such as species and culture density and concluded that full mitigation might not be physically possible due to the large biomass of seaweeds that would be required (Reid et al., 2013). The scale of the required biomass of extractive species was also a present issue with mussels (Cranford et al., 2013), sea cucumbers (Cary et al., 2020), and polychaetes (Jansen et al., 2019). Furthermore, no studies in the literature explored the mitigation potential in fully implemented IMTA farms, which suggests that the proof of concept at the farm scale is currently lacking. Therefore, extractive species in IMTA sites can use the waste of fish aquaculture, although a precise quantification of the net mitigation is currently missing in the literature.

5.2 Benefits

Although mitigation, as one of the main expected benefits of IMTA, has not been demonstrated in the literature (see above), industry members responded with an "extremely likely" outlook regarding the potential benefit of facilitating waste mitigation. The mismatch between the scientific literature and the industry responses could result from extrapolation. Industry understands the biology and ecology of extractive species, like mussels eating particulates and nutrient sequestration by seaweeds. The extrapolation of their knowledge from the individual to the farm-scale could give a positive outlook on IMTA potential, despite the lack of proof of concept at the farm scale.

Industry members also agreed with the idea that IMTA could benefit from the diversification of profits; however, the literature review questioned whether incorporating IMTA methodologies to existing farms would impact profitability (Abreu et al., 2009, 2011; Carras et al., 2020). A profitability analysis requires analyzing the ratio between the leading financial species and the extractive species in the system (Abreu et al., 2009). Under current ratios and IMTA implementation ideas, the additional revenues from extractive species under IMTA are not worth the additional operational complexity, capital expenditure, and corresponding risk (Carras et al., 2020). On that same note, the public was willing to pay a premium for IMTA products, indicating that a holistic assessment of profitability should explore the price premium as a potential benefit (van Osch et al., 2017). The willingness to pay a premium (van Osch et al., 2017) supports industry member's perspective, who believed that IMTA could improve public perception of farming activities.

Although with a lower likelihood than the benefits mentioned above, other potential benefits that industry identified were the potential reduction of algal blooms. The literature was noticeably inconclusive on the matter (Fossberg et al., 2018; Nelson et al., 2012; Wang et al., 2014). Finally, the effect of IMTA on biofouling was met with greater uncertainty by an industry participant. The literature echoes this uncertainty with most of the references highlighting the need for further research in this area (Ballester-Moltó et al., 2017; Blouin et al., 2007; Brager et al., 2014; Byrne et al., 2018; Kleitou et al., 2018; Lander et al., 2012). Additional benefits identified by industry members, but not found in the literature, included the generation of community co-management opportunities and the support of locals livelihoods close to IMTA facilities. Finally, a benefit that can be difficult to quantify, ecosystem services, was also commented on, with respondents issuing a reminder that the extractive species also have inherent value due to their service to the surrounding environment.

5.3 Issues

Industry concluded that the primary perceived issue for IMTA implementation was the economic cost. This issue has been identified in the literature with a greater initialization investment and higher overall costs over time, dissuading the implementation (Lander et al., 2012). This is likely due to the scale between the fed and extractive species being not significant enough to derive noticeable economic benefits (Fossberg et al., 2018; Mendoza Beltran et al., 2018). In addition to the upfront cost, two major aspects drive this mismatch in scale. First, fed species can be farmed at a higher density than extractive species, increasing the profitability per area (Mendoza Beltran et al., 2018). Second, as it was stated above, the location of the extractive species biomass is critical for mitigation, but also for enhancing the growth of the extractive species, which limits the available space for optimal performance of the extractive species (e.g., Brager et al. 2014). This mismatch between the scale of extractive and fed species was consistently referenced as a central issue in the literature, but also in comments from industry participants, as a disincentive for IMTA implementation. This agreement from both the literature and industry identifies cost reduction as an area for improvement to aid in IMTA implementation.

The attraction of wild fish and other species to the IMTA operation was perceived to have a "neutral" effect by industry members. Although there is work on both finfish (Uglem et al., 2014) and shellfish (Callier et al., 2018) facilities, there is little work exploring the effects of IMTA on wild species (Ballester-Moltó et al., 2017). All the other potential issues were not considered as real issues by industry representatives represented by their "unlikely" outlook on each. This includes an increased risk of diseases and pests, decreased IMTA farmed products' social acceptability, increased instances of harmful algal blooms, and decreased quality of farmed products. These questions were explicitly asked to gain insight into perspectives on the potential negative side-effects of IMTA, although they are not currently covered in the scientific literature.

5.4 Barriers

Regulatory issues were the most prevalent potential barrier to IMTA implementation cited by industry members, with respondents echoing the lack of governmental support for innovative production measures like IMTA. This lack of government support has also been identified in the literature as a potential barrier to IMTA implementation (Kleitou et al., 2018). The lack of government support could also play a role in other barriers such as the lack of expertise and managerial and economic hurdles related to IMTA implementation, according to industry participants.

The lack of expertise is intertwined with managerial barriers, both of which were also prevalent barriers showcased within the literature (Handå et al., 2013; Lander et al., 2012). In addition, mismatches in growth cycles between the seaweeds and fed species constitute additional managerial barriers (Handå et al., 2013). The expertise managerial barrier constitutes a lack of the training necessary to succeed in an IMTA setting, as within industry the skilled training does not currently exist to facilitate IMTA management.

This lack of expertise is additionally somewhat related to public education about aquaculture in general, and IMTA in particular, which was identified in the literature as a barrier to gain mainstream acceptance and understanding of the IMTA process (Barrington et al., 2010b). The limited education compromises the ability of consumers to discern the differences between monoculture and IMTA products and consequently make informed consumption decisions (Martínez-Espiñeira et al., 2015). Education could also be linked to economic barriers because, as it was stated above, the public could be willing to pay a premium for IMTA products (van Osch et al., 2017). Given the predominance of economic aspects in the discourse from industry participants, the impact of non-direct aspects such as education cannot be overlooked.

5.5 Incentives

As expected, the most relevant incentives identified by industry participants mirror the most relevant barriers. Accordingly, government subsidies and flexible regulations were highlighted as incentives that could facilitate implementation. Similarly, positive campaigning by environmental groups and the promotion and creation of an ecolabel for IMTA products mirror the educational barrier identified previously. Industry participants also agree that developing a collaboration mechanism with other farms to share information and understand the cultivation of new species could be an incentive that could overcome the expertise, managerial and economic barriers. Although sharing knowledge was not prominent in the literature as an incentive, many studies called for the need for innovation as a way to facilitate IMTA implementation (Ashkenazi et al., 2019; Blouin et al., 2007; Fernandez-Gonzalez et al., 2018; Lander et al., 2012; Nelson et al., 2012). This innovation could range from something as simple as incorporating more benthic species (Fernandez-Gonzalez et al., 2018; Nelson et al., 2012) to conceptual changes regarding farming. As one respondent stated,

> *"The traditional way of doing IMTA (very close to the fish farm - 50-100m) is NOT the way to go, IMTA has been limited to doing all at one site, but IMTA could be also be applied in an Ecosystem approach so that within a defined area you could plan aquaculture activities by reserving space for [example] a salmon farm but with the area also allow for a shellfish farm and a kelp farm or extractive species. These sites may have separate ownership, but the net bay effect is IMTA, and the claim could be shared. Each of these species has separate expertise required, and a salmon company may not have processing and marking ability for mussels or seaweed and therefore may not put necessary focus on it whereas an ecosystem approach would allow others to pick up these pieces."*

Given the relevance of the positioning of the extractive species for mitigation purposes (e.g., Filgueira et al., 2017; Fossberg et al., 2018; Wang et al., 2014), some aspects of the mitigation potential could be compromised, although other synergies could emerge. Furthermore, this approach would require tackling several barriers, such as regulatory, lack of expertise, and education simultaneously; however, the exploration of these innovative ideas may trigger new conditions for IMTA implementation.

5.6 Limitations of this study

There are two main limitations associated with this study, the scope of the literature review, and the recruitment success of individuals in industry. Due to the nature of the literature review, using Scopus as a single source for scientific literature, there is a limited scope of studies covered in this study. Despite being a well respected and commonly used tool within the academic community, Scopus does not search through all academic papers and grey literature, which can be critical to capture industry reports. Furthermore, given the economic implications, some of the outcomes regarding IMTA could have proprietary implications and may not be public. Although not relevant for the scope of this study, but perhaps crucial for IMTA in general, this review focused on salmon farming as fed species.

Therefore, some of the gaps identified in this study may have been already answered in other works tackling other species.

It is also important to note that the survey results are not representative of the whole Atlantic Salmon aquaculture industry. In addition to the response rate, estimated to be under 20%, the participants were informed of the topic before beginning the survey, potentially skewing respondents to those who know or care about IMTA. The field of expertise of respondents was diverse, which can affect their perceptions, although the majority were in sustainability and environmental issues with additional expertise in other fields. Therefore, it is important to reiterate that the industry opinion, although informative, does not necessarily represent the whole Atlantic Salmon industry.

5.7 Recommendations

Both the scientific literature on IMTA and industry members seem to have differing views about IMTA mitigation potential and realistic implementation. This research showed the need for real-world examples of commercial level IMTA implementation. As a first step, the development and implementation of demonstration farms, which can showcase a "proof of concept" for mitigation at the commercial scale, is needed. Furthermore, similar bottlenecks for implementation were identified in the scientific literature and by industry members. Accordingly, based on the outcomes of this research, it is recommended the promotion of (1) demonstration farms at the commercial scale utilizing academic guidance to evaluate mitigation capacity, (2) flexible regulations from governmental bodies, (3) support from government to alleviate the financial burdens of an IMTA transition from a traditional monoculture, (4) supporting and developing innovative ideas for realistic implementation, (5) training programs for skilled personnel who could work and manage IMTA farms, and (6) public educational programs to understand the differences between culture types and origins of the fish on their plates.

5.8 Conclusions

Aquaculture is becoming increasingly important globally, and the need for more sustainable approaches for aquaculture is evident. The main goal of IMTA is to reduce adverse environmental effects through the balance of different trophic level species. Although the industry perceives mitigation as a viable benefit of IMTA, current literature challenges this perception reporting difficulties on scaling up the culture of extractive species to reach a meaningful mitigation level. Without a more precise picture regarding mitigation, the major benefits are the diversification of profits and improved public perception of the process; however, these benefits are not unanimously supported by the literature. In addition, major economic issues on capital and maintenance costs constitute bottlenecks for implementation. However, the burden of the development of the IMTA industry does not solely lie on economic aspects. The lack of governmental support and commitment to implementation and innovation were repeatedly referenced among the literature review papers and the industry survey. This lack of governmental support for innovative ideas and flexible regulations to alleviate the financial pressures for implementing IMTA provides a fundamental issue to the industry. Despite speculations on its viability, the fact that IMTA is not commonly implemented at the commercial scale constitutes a barrier for industry adoption. The next steps for IMTA could be related to the development of demonstration sites at the commercial level to showcase actual viability from a financial and managerial, economic, and environmental standpoint.

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Appendix I – Literature Review Rough Notes

Main Author	Year	Main Non-Extractive Species	Other Non-Extractive Species	Main Extractive Species	Other Extractive Species	Location - Country	Location - Specific	Setting (Open-pen, Land…)	Report of Performance (growth of extractive species)	Main Take Aways + Quotes	Emerging Theme
Abreu	2011	N/A	N/A	Gracilaria vermiculophylla	N/A	Portugal	Ria de Aveiro lagoon	Land	great overall performance, though may require adaptations to the culture conditions to adapt to year round growth, most beneficial IMTA species are Gracilaria, Ulva and kelp species,	Relative to other systems producing G.V the IMTA system had similar productivity though had a higher C:N ratio than other cultivative species. This is proof of the extractive capabilities of the species and the capacity for incorporation into and IMTA system. The biomass produced in the IMTA system could be applied to supplement fish feed though this may be difficult to incorporate into existing facilities. Due to the fact that harvesting G.V naturally is not enough to meet industry demands and the loss in productivity from stocking too highly, incorporation into the IMTA system may be a suitable answer.	Bioremediation
Abreu	2009	Atlantic Salmon (Salmo salar)	N/A	Gracilaria chilensis	N/A	Chile	Los Lagos	Open-Pen	those G.C which were close to the salmon cages always outperformed those held much further away or in isolated sites. Those close to the sites say photosynthetic performance increases resulting in higher yields and health.	Different algal species showcase differing N uptake preferences. Though the Gracilaria genus of speciees are efficicent for IMTA capabilities due to their ability to uptake ammonia and nitrate from the surrounding area. The area used for growth of the seaweeds sdoes not need to be relatively close to the farm either with high growthrates seen upwards of 1km from a 1500 ton, 1 ha salmon farm. Best results were at 800 m outperforming the farther an closer long lines. This is likely due to suspended organic matter reducing water quality which must be taken into accoutn as well when planning an IMTA facility. Incorporation of G.C on salmon farms also has already begun cost reduction due to the obligation of incluidng environmental costs within companies budgets.	Bioremediation

Aguado-Gime´nez	2014	Gilthead Seabream (Sparus aurata)	Seabass (Dicentrarchus labrax)	Flat Oyster (Ostrea edulis)	N/A	Spain	San Pedro Santa Pola	Open-Pen	O.E was able to utelize fish farm wastes extremely effectively with a refuction in particulatte and dissolved wastes in the system and a higher growth than those separate from the system.	The aspect of integreation had no effect on fish yields, while O.E yields were higher than expected in both cases of flesh weight and total weight. This is seen as a direct advantage of the integrated system over a monoculture. Fatty acid's useas a biomarker helpe to determine the sources of feed in the mollusks system and could be applied to other systems. By increasing water quality there couls also be a net positive effect on wild fish which have been shown to congregate around fish farm and feed on the excess feed and waste within the system.	Bioremediation
Ashkenazi	2019	Gilthead Seabream (Sparus aurata)	N/A	Ulva rigida	Gracilaria conferta, Hypnea musciformi	Israel	Mediterranean Sea	Land	in single species set ups, the growth rates of each were all similar to each other, though in general U. rigida had the highest yield comparatively. Each species removed a significant amount of nitrogen from the system thou U. rigida uptook 100% of the nitrogen within the system on average per day. Seaweeds in the integrated tanks also had a higher nutrient content with higher protein and lower carbohydrate content (for UR and HM). There was no apparent NO3 uptake during any of the experiemnts by the seaweeds indicating accumulation.	The concept of the combining of various seaweeds into one culture is new and novel. IMTA based seaweeds increased growth rates (severely increased) compared to their counterparts also show the value of utelizing seaweeds within the IMTA system. It may be concluded that a stocking density of 1 kg Ulva m2 is sufficient for optimal nitrogen assimilation as well as for rapid algal growth rates. Teh change in nutrient composition with a higher protein level and lower carbohydrate level could also have impications for nutrition and food management. thsi could haev been due to the liekly fish droppings and constant loss of tisssue due to shedding, hwoever still is very important to scknowledge. Likewise, seaweeds in the low nutrient environment had a significant increase in carbohydrate content while also having a reduction in protein content and specific growth rates (SGR). Though the GC had a lower growth rate and uptake rate, they may be important when considering biomitigation as they are hardier and can store nitrogen for longer than UR. Diverse seaweed assemblages seemed to haev an advantage over singular species ones, each occupuying a niche within the system and increasing their respective net nutrient uptake rates.	Bioremediation

Ballester-Moltó	2017	Gilthead Seabream (Sparus aurata)	Wild Fish	N/A	N/A	Spain	El Campello	Open-Pen	N/A	Particulate wastes derived from cage fish farming are a trophic resource used by wild fish. Consumption was determined according to the difference between the particulate matter exiting the cages and that reaching 5 m away at three different depths, in the presence and absence of wild fish. Wild fish around the experimental cages were counted during feeding and non-feeding periods. The mean contribution of wild fish to the removal of particulate wastes was about 18% of the total particulate wastes exiting the cages. Mediterranean fish farms show a wide spatial and temporal variability with regard to wild fish assemblages aggregated around them. Spatial variability has been attributed to coastal geomorphology, seabed topography, distance from the coast, and habitat diversity in the vicinity of the farms while temporal variability seems to be related to seasonal conditions and fish phenology. Faeces are the main fraction of solid wastes produced throughout the fish farming process however their nutritional value is very low. This waste is exceptionally ingested by wild fish, and in such a case by low trophic level species, mainly herbivores though most species show a preference for feed particles and against faeces. The role of wild fish should be considered in environmental impact assessments. Aggregated wild fish around farms should be protected from exploitation by local fisheries because they provide a useful 'ecosystem service' to farmers by reducing the impact of lost feed on the benthos.	Bioremediation
Barrington	2010	Atlantic Salmon (Salmo salar)	N/A	Blue Mussel (Mytilus edulis)	Kelp	Canada	Bay of Fundy	Open-Pen	N/A	Focus group sessions with several segments of the population (restaurateurs, residents of communities near aquaculture facilities, and the general population) were held and the participants' knowledge of, and opinions on, IMTA were recorded. Most participants felt that IMTA had the potential to reduce the environmental impacts of salmon farming, benefit community economies, and improve industry competitiveness and sustainability. All felt that seafood produced in IMTA systems would be safe to eat and 50% of the participants were willing to pay 10% more for these products if labelled as such. The participants felt that IMTA appears to be an improvement over current monoculture practices and would be cautiously welcomed in the marketplace. A promotional campaign educating the general public, food distributors, and other industry stakeholders about the positive benefits of IMTA would go a long way in gaining mainstream acceptance of this aquaculture practice.	Perception

Blouin	2007	Atlantic Salmon (Salmo salar)	N/A	Porphyra umbilicalis	N/A	USA	Cobscook Bay, Maine	Open-Pen	Nets in traditional Porphyra mariculture are seeded with conchospores derived from the conchocelis phase, and spend a nursery period in culture tanks or calm coastal waters until they reach several centimeters in length. In the experiment there was a slower than anticipated growth rate of algae.	Rafts of seeded nets were deployed in Cobscook Bay, Maine, at two distances from salmon aquaculture pens and at a control site on a nearby, fallow aquaculture site (no salmon). There was no difference in nitrogen content of harvested thalli; however, both the density and the surface area of harvested thalli were different among the sites. P. umbilicalis is asexually reproductive year-round, but the number and viability of neutral spores vary throughout the year. close proximity of the P. umbilicalis rafts in BC to the salmon pens led to increased diatoms, amphipods and detritus that were found on the nets, particularly at the NE treatment. Definitely useful in integration, though only for sites already producing seaweed products	Innovation
Brager	2014	Atlantic Salmon (Salmo salar)	Sablefish (Anoplopoma fimbria)	Blue Mussel (Mytilus edulis)	N/A	Canada	British Columbia, New Brunswick	Open-Pen	mussel farms close to the farms depleted approximately 10-15% of the leftover feed and waste apricles which entered the area.	Despite the large sample numbers obtained, consistent detection of waste particle enhancement was confounded by the apparently small effect size and natural seston patchiness. These results suggest that any farm-induced effect on the surrounding particle field at the study sites would be highly localized and episodic. Consequently, the potential for enhanced production by co-cultured bivalve filter-feeders at these integrated multi-trophic aquaculture farms is limited by available space close to net-pens and the periodic availability of low levels of suspended particulate fish wastes. Elevated levels of particulate matter in surface waters around fish net-pens may reflect farmderived enhancement and/or natural detrital and inorganic matter variability. Results reported herein on the near- and far-field distribution of suspended particles do not support the concept of the presence of a 'waste plume'. Evidence suggest waste dispersion in all directions depending on cyclical changes in many characteristis.	Physics
Broch	2013	Atlantic Salmon (Salmo salar)	N/A	Sugar Kelp (Saccharina latissima)	N/A	Norway	Bjugn	Open-Pen	Due to the differing seasonal growth patterns of fish and kelp, there was a mismatch between the maximum effluent of NH4+-N from the fish farm and the maximum uptake rates in S. latissima. This resulted in much lower than anticipated uptake effects fo SL. (0.34%) per hectare of SL. The estimation is that with a higehr amount of growth seasons that number could jump to 10% or possibly higher depending on conditions.	salmon farms in souther norway were modelled to ascertain the true production potential of an IMTA system with Sugar kelp. The error of misaligning the growting seasons and the short duration of the model in the experiment outlines the importance of utelizing proper parameters during estimations. The results also indicate a seasonal mismatch between fish farm effluents and uptake rates in S. latissima, suggesting that additional extractive species with complementary uptake rates should be included for optimization of IMTA. Therefore, and due to limitations in space available for future aquaculture leases in the coastal zone, a full bioremediation of Norwegian aquaculture using S. latissima is unrealistic. SL is likely not a good candidate for IMTA.	Bioremediation

Byrne	2018	Atlantic Salmon (Salmo salar)	N/A	Pacific Oysterr (Crassostrea gigas)	N/A	Canada	British Columbia	Open-Pen	All the measured size variables grew significantly over time. Much alrger than the reference site. There was however no general interaction between bivalves and sealice densities though larval denstiites were almost always lower in experimental cages with oysters than without them. Overall, pacific oyester may be a good IMTA species due to growth and not remediation potential of sea lice.	Salmon louse reduction was assessed monthly by comparing the water-borne density of larval sea lice among three bivalve cages and three controls (non-bivalve cages), and by examining oyster digestive tracts for L. salmonis DNA using PCR. All seven oyster-size variables increased significantly over time with significant effects of depth and position around the farm. In general, oysters at 1 and 3 m were significantly larger than those at 6 m. Side of the fish cage was used as a blocking factor in the experimental design and had a significant effect on final oyster size; at the end of the stuy, oysters at the farm were either significantly larger or not significantly different than oysters at the reference site, depending on the side of deployment. There was no significant variation in mean larval density due to time or treatment (bivalve versus non-bivalve). Larval lice densities were highest in January 2014. However, at that time there was no evidence of L. salmonis DNA in oyster digestive tissues.	Bioremediation
Carras	2020	Atlantic Salmon (Salmo salar)	N/A	Blue Mussel (Mytilus edulis)	Sugar Kelp (Saccharina latissima)	Canada	Bay of Fundy	Open-Pen	N/A	capital budgeting and investment appraisal approach to compare the financial performance of two hypothetical aquaculture projects located in the Bay of Fundy, New Brunswick: an open net-pen, Atlantic salmon monoculture farm and a salmon, blue mussel, and kelp IMTA operation.The biological, technical, economic, and financial data, figures, and assumptions used in our study are anchored in academic, industry, and government papers/reports/studies, statistical databases, and conversations with industry operators and researchers. Expected valuation of an IMTA farm of the same overall size as a standard salmon farm is estimated at over 25% higher without the exploration of price premiums though there is significant research which states that consumers in North America and Europe would eb willing to pay mroe for IMTA based fish. Under the guise of a mortality event, IMTa comes out on top once again. the net financial returns from salmon, mussel, and kelp IMTA on the east coast of Canada are superior to those from salmon monoculture when it is assumed that the quantity of salmon produced remains unchanged after IMTA adoption. previous studies may have underestimated the costs of IMTA. Canadian stakeholders have doubts about IMTA's profitability, ecological sustainability, technical viability, and additional operational complexity. Technical uncertainty and insufficient organizational and managerial expertise with IMTA were seen as the key barriers to IMTA adoption. a potential investor comparing salmon monoculture and IMTA may view the additional revenues from other species under IMTA as not worth the additional operational complexity, capital expenditure, and corresponding risk.	Financial Performance

Chary	2020	Red Drum (Sciaenops ocellatus)	N/A	sea cucumber (Holothuria scabra)	N/A	France	Mayotte	Open-Pen	assition of sea cucumbers added approx 1% more aquatic weight to the system. They were maret size after 365 days and had in their system evidence of waste products from the red drum monoculture above them. An estimated rememdiation of the cucumbers was abut 3% of the total waste outputted from the system. Increases in scope and breadth of the amount of cucumbers could in the future represent a grater bioremediation value, though the scale would have to be similar to the fish above them.	Given the current limits to stocking density observed for sea cucumbers, its co-culture in sea cages suspended beneath finfish nets may decrease slightly (by 0.73%) farm net particulate waste load and benthic impact. The monoculture and IMTA showed little difference in impact because of the large difference in production scales of finfish and sea cucumber species. Removing 100% of finfish feces particulate waste requires cultivating sea cucumber at scale similar to that of finfish (1.3 kg of sea cucumber per kg of finfish). Nonetheless, LCA showed trends in IMTA performance: lower eutrophication impact and net primary production use but higher cumulative energy demand and climate change impacts, generating an impact transfer between categories. Intensification of sea cucumber culture could increase local and global environmental benefits, but further research is necessary to design rearing units that can optimize production and/or bioremediation and that can be practically integrated into existing finfish monoculture units.	Bioremediation
Fernandez-Gonzalez	2018	Seabass (Dicentrarchus labrax)	N/A	Amphipods	N/A	Spain	Málaga	Open-Pen	amphipod collection was found to not vary based on depth and a constant concentration throughout the water column. The nutritional concentrations of many important nutrients such as calcium (Ca), potassium (K), magnesium (Mg) and sodium (Na). Were found to be within suitable amounts to be included as a portion or partial ingredient in aquaculture based feeds with the future extension being the potnetial for human consumption as well.	Collection of amphipods which naturally occur in the environment and then get reinvested within the systema s a feed source is novel. Collection yielded grat results even with losses of equipment durign the experiment. This would consolidate the need for feed development to be under the operating authority of the fish farms themselves, though proposes some serious challenges as well. The economic potential of the amphipod collectiona and feed conversion is unclear as well as the rate at which amphipods would be collected, for how long during the year and if this varies heavily by location. While there is stilla a lot of work to do, a first look into utelizing naturally occuring species as an incorporation into IMTA was definitely promising.	Innovation

Fossberg	2018	Atlantic Salmon (Salmo salar)	N/A	Sugar Kelp (Saccharina latissima)	N/A	Norway	Western	Open-Pen	The proportion of salmon derived nitrogen available for the kelp showed a clear decline with distance from the farm. Accordingly, the kelp cultivated near the salmon cages grew faster during the spring season, and growth rate decreased with increasing distance from the farm. All the kelp performed well, scaling up to 25HA wpi;d produce 60% more product than comparitive kelp farms with the higher yield being attributed to the salmon farm. Achieving balance however would require 220 Ha of kelp within that same vicinity which is not exactly possible. Ovverall it would uptake and account for approx 12% of the waste.	S. latissima was cultivated 100, 200, and 1,000 m east and 1,000 m west of a 5,000 tons salmon farm. The proportion of salmon derived nitrogen available for the kelp showed a clear decline with distance from the farm. Accordingly, the kelp cultivated near the salmon cages grew faster during the spring season, and growth rate decreased with increasing distance from the farm. From this a model was generated to determine scaleability of the success of the growth in the experiment to a more commercial scale.	Bioremediation
Gvozdenović	2017	Gilthead Seabream (Sparus aurata)	Seabass (Dicentrarchus labrax)	Mytilus galloprovincialis	N/A	Montenegro	Boka Kotorska Bay	Open-Pen	The most intense growth of mussels was recorded in spring, and the least intense in summer. After 13 months, monitored individuals at all three locations achieved commercial size. The growth rate was very similar at all sites. The condition index showed spatial and temporal differences.The highest mortality rate was recorded at the NBL site, probably due to the effects of fouling organisms.	The growth rate and condition index were monitored during a 13-month study at three different sites: 1) close to fish cages (NBL), 2) 100 m removed from fish cages (NUD), 3) at a monoculture mussel farm (SVN) around 8 km far away from cages. There was an indication that during the colder months the mussels did feed on fish effluent, but most other information surrounding the results are unclear.	Bioremediation

Handå	2013	Atlantic Salmon (Salmo salar)	N/A	Sugar Kelp (Saccharina latissima)	N/A	Norway	Tristein	Open-Pen	significantly increased growth of sporophytes at salmon farm compared to the controla t the referrence station. Close to the salmon farm (4km) significantly longer 5 out of 10 sampling months at 2 m depth, and in 9 out of 10 months at 5 m depth in August. In November - sporophytes showed similar growth rates and lengths at the fish farm and at the reference station, while the February-sporophytes grew faster at 5 and 8 m depths at the fish farm than at the reference station, with significantly longer blades at 5 m depth at the fish farm than at the reference station at peak lengths in June	While nutrient recycling and increased growth of macroalgae in integration with fish aquaculture have been thoroughly documented for landbased systemswer studies have been performed in the sea. These results are consistent with similar studies showing a faster growth of macroalgae in IMTA with salmon in Canada, Scotland and Chile. Meanwhile, a faster growth of the August-sporophytes at the reference station than at the fish farm from November to February, and similar growth rates of November sporophytes at the farm and at the reference from November to June, suggested a seasonal-dependent effect with a more positive growth response of macroalgae deployed in August and February than in November. Furthermore, the significantly longer August-sporophytes at 2 and 5 m, but not at 8 m depth, at the fish farm than at the reference station at peak lengths in June, with the sporophytes at 5 m depth being significantly longer than those at 8 m depth, suggesteda depth-dependent growth response in IMTA in the order 5 m N 2 m N 8 m over the year, although the sporophytes at 8 m depth grew fastest from February to June, and faster at the fish farm than at the reference station. One the one hand, the results suggest that IMTA with salmon can be a sound strategy to obtain enhanced growth in length of macroalgae in Norwegian coastal waters. One the other hand, the depth- and seasonaldependent growth response emphasizes that the potential for with salmon and macroalgae as well as the potential for bioremediation services needs to be assessed holding the seasonality of the macroalgae, with a rapid spring growth, up against the salmon production pattern with higher fish biomass and feed use with a corresponding increase in nutrient discharge in late summer and autumn.	Bioremediation

Handå	2012	Atlantic Salmon (Salmo salar)	N/A	Blue Mussel (Mytilus edulis)	N/A	Norway	Tristein	Open-Pen	The growth in length correlated significantly to feed use at the fish farm (r=0.89) and to the concentration of suspended particulate matter (SPM) (r= 0.53) in the autumn–winter period (Oct–Feb) (pb0.05). The mussels at the reference station showed a significantly faster growth in length compared to the mussels at all stations at the fish farm during the summer, while mussels at the FW station grew faster than the mussels at the reference station during the spring (pb0.05). The length growth was faster for mussels at the reference station than for mussels at the FW and FE100 stations (pb0.05), while no significant differences were found between mussels at the reference and the FE stations for the entire year.	The results suggest that the combined production of mussels and salmon can be seen as a strategy to maintain a higher soft tissue content of mussels during autumn and winter. Quantification of the mussel's assimilation capacities of farm-derived wastes at realistic scale and under different environmental conditions is needed. We see this change in not the size of the mussles used in IMTA settings, but the texture of soft tissue matter and it's dry weight. This increase in soft tissue during the autumna dn winter seasons could help in the long run to reduce overwinter losses on higher altitude farms and could lead toa different taste and texture of final products.	Integration Performance
Haugland	2019	Atlantic Salmon (Salmo salar)	N/A	Sugar Kelp (Saccharina latissima)	N/A	Norway	Hjellestad	Open-Pen	Jeuvenile SK had a very high mortality when exposed to the salmon lice therapeutant for 1hr or more. Even 15d post exposure noticing degredation on fronds and other parts of the kelp was common. Only those plants with extremely high initial biomass were able to stay functioning 15d after the treatment. Photosynthetic performance was also heavily reduced up to 95% reduction in photosynthetic capability.	H2O2 (hydrogen peroxide), is a common sea-lice therapeutant in salmon farming, though has strong effects on the survival and photosynthetic performance of sugar kelp. Prolonged effects were seen 125days after exposure with an extremely high mortality rate. Pairing with a dispersion model should yield appropriate estiamtions on natural populations in close proximity to salmon farms or potentially those cultured in the interist of IMTA based work.	Integration Performance

Irisarri	2015	Atlantic Salmon (Salmo salar)	N/A	Blue Mussel (Mytilus edulis)	N/A	Spain	N/A	Open-Pen	Results showed no differences in seston, chlorophyll and physiochemical characteristics of the water among rafts. Maximum growth and Condition Index (CI) occurred during spring–summer (April–August), when mussels had access to greater food quality and quantity. Mussels cultivated close to the cages showed similar shell length weight and CI compared with mussels distant from the fish farm. Average shell length, meat dry weight and CI at harvest were 76.31 mm, 2.51 g and 23%. Bivalves cultured distant from the fish cages displayed 26% higher biomass than the other raft at the end of the experiment. Differences in biomass were explained by the significantly higher recruitment of mussel seed observed at the raft distant from the fish cages from June to November	tested if mussels Mytilus galloprovincialis cultured at two depths (1 and 6 m) in a raft, moored 170 m from a fish farm had greater growth than bivalves held 550 m from the fish cages. Reduec mussel performance of those in close priximity to the cages could have been due to a succession of storms during the month of November caused resuspension events that resulted in a dilution of the organic particles and overall quality of the seston by increments in the inorganic material. d no enhancement on the growth of mussel Mytilus planulatus when cultured at 70 and 100 m from a salmon farm, compared with mussels at 500 and 1200 m from fish cages.The disparity between this study and previous IMTA experiments that found enhanced growth of co-cultured mussels may reside in the different environmental conditions and design of openwater IMTA systems.	Integration Performance

Irisarri	2015	Atlantic Salmon (Salmo salar)	N/A	Blue Mussel (Mytilus edulis)	N/A	Canada	Bay of Fundy	Open-Pen	Dietary indicators included bulk measurements of seston quantity and nutritional quality, proximate analysis (PA), fatty acid (FA) and stable isotope (SI) composition. Mussel tissue indicators consisted of PA and FA composition. Mussel performance was assessed from physiological integrations (scope for growth, SFG), growth efficiency (K2) and condition index (CI). All measurements were made over 2 days at a commercial IMTA farm and a monoculture mussel farm in the Bay of Fundy (Canada). Significant detected in seston quantity and quality were within the range of natural spatial variability. The SFG of IMTA mussels was lower (28.71 J h1) than monoculture mussels (38.71 J h1) and reflected site differences in natural food availability and composition that affected absorption rate. PA of mussel organs didn't reflect a significant fish feed contribution to the mussel diet. However, dietary enhancement and assimilation of fish feed waste was demonstrated by significantly higher levels of feed FA biomarkers	The assimilation and egestion of fish feed FA biomarkers confirmed that some feed waste was being incorporated andpartially bio-mitigated by IMTA mussels. However, the comparable PA and the lower SFG measured for IMTA mussels indicated that feed waste constituted a small part of the mussels' diet and did not compensate for the temporary lower quality of the seston during resuspension events. These results suggest that uneaten feed particles may increase the SFG in IMTA systems experiencing food scarcity. We consider that a multi-indicator approach could provide a more holisti vision of the effectiveness and benefits of integrated fed-extractive IMTA aquaculture under different environmental conditions.	Integration Performance

Irisarri	2013	Atlantic Salmon (Salmo salar)	Red Sea Bream (Pagellus bogaraveo)	Blue Mussel (Mytilus edulis)	Mytilus galloprovincialis	Canada, Spain	Bay of Fundy, Ría Ares-Betanzos	Open-Pen	Seston parameters were generally similar at the mussel sites close to the fish cages and at the reference sites. However, significantly higher particulate inorganic matter coupled with lower food quality (seston organic content) observed at the sites close to the fish cages suggested occasional sediment resuspension events in the Ría de Ares-Betanzos and the Bay of Fundy. y, 20% lower absorption efficiency was measured for mussels in the proximity to the cages during the resuspension events. No significant differences in absorption efficiency were detected between the fish cages and the reference sites outside the resuspension events. Consequently, differences in absorption efficiency were attributed to natural variations in seston organic content, and absorption increased with increasing food quality. The results showed no evidence of increased organic content of the seston resulting from proximity to the fish-farm. It was concluded that proximity of cultured mussels to the fish cages did not result in an enhancement of the absorption efficiency.	Essentially, the mussels had a different composition due to feeding on the seston from the fish cages. Mussels were found to uptake nutrients from the farms and had reduced feeding brought on by resuspension events. Proof of concept of IMTA working in absence of best methods. Differences in the AE of mussels held close and distant to the fish cages can be explained by natural spatial and temporal differences in seston quality. Coastal resuspension dynamics were the most likely explanation for the site differences detected and these short-term changes in particulate inorganic matter are likely to affect any coastal area. Near-shore particle gradients were independent of the presence–absence of fish pens and decreased the filter-feeder's absorption efficiency. Thus, the success of the integrated culture would, in part, be conditioned by the food quality available for the filter-feeders.	Bioremediation

Jansen	2019	Atlantic Salmon (Salmo salar)	N/A	Polychaetes	N/A	Norway	Bergen	Open-Pen	Trays were quickly colonized within half of the deployment period. Abundance estimated may be incorrectly determining amount of polychaetes and will vary by species. Differences in abundance on trays varied significantly from tray to tray indicating results are not easily replicated which may hinder putting them into practice. Tray substrate type may be to blame for this.	Ther was clear evidence of healthy polachaete populatios on the trays with fast recruitment and generational time. Though a major issue was the differences in abundance fromt ray to tray and substrate to asubstrate. That being said there was also evidence of bioremediation and healthy polachaete populations due to prevalence of 3D cultivation structures and increased biomass production. The deployment of benthic trays has been shown to attract dense communities, indicating that the alternative IMTA concept of enhancing indigenous species may be a promising approach for benthic cultivation in integrated open water systems.	Innovation
Kleitou	2018	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	the opinions of 34 farmers and scientists with substantial experience of IMTA from 12 European countries have been obtained. A broad spectrum of IMTA impediments has been identified. These have been separated into nine major categories; namely Biological, Conflicts, Environmental, Interest, Legislation, Market, Operational, R&D, and Vandalism. The importance of each category was found to vary among different locations and regions of Europe indicating the need for site-specific targeted approaches. Nevertheless, factors from several categories were raised in all countries/IM A configurations which highlights that for IMTA to be further developed and adopted, the involvement of stakeholders and personnel from several disciplines is necessary (i.e. biologists, economists, engineers, farm managers, modellers, regulators, stakeholders and statisticians). This work identifies many of the challenges that European IMTA is likely to encounter, and proposes areas that are likely to benefit from focused research and development.	Perception
Lander	2012	Atlantic Salmon (Salmo salar)	N/A	Blue Mussel (Mytilus edulis)	N/A	Canada	Bay of Fundy	Open-Pen	Mussels grown at 0 m and 200 m performed significantly better ($P < 0.05$) in all growth parameters compared with mussels grown at a reference site outside the aquaculture influence. Differences in growth and condition index were most pronounced in the fall and winter, when ambient seston concentrations were low. Results of a second study in which growth rates for individually tagged mussels was monitored for a 6-mo period confirmed that there is a significant growth benefit for mussels in integrated aquaculture with salmon	mussels grown close to the salmon cages experienced higher growth rates than those aprt from the cages. This confirms assumptions, though goes against many of the papers previously read which indicated no change in performance. May be attributed to correct distance placement from the farm, another instance where best practices may need to be understood. What is the optimal distance that benefits both growth and bioremediation?	Integration Performance

									compared with mussels grown 500 m away at a reference site.		
Lander	2013	Atlantic Salmon (Salmo salar)	N/A	Blue Mussel (Mytilus edulis)	N/A	Canada	Bay of Fundy	Open-Pen	N/A	Long-term temporal cycles indicate overall increases in particulate organic matter (POM) at aquaculture cage locations compared to reference locations independent of time of year. Spatially, POM levels increase 2 to 4 times over ambient levels adjacent to cages, but drop to ambient levels after distances of 10 m from the cage. Daily POM levels are higher at salmon farm cages than reference locations and often correlate strongly with daily fish feeding regimes. The majority of particles from the aquaculture cages are small (1–10 µm), within the utilizable size range for the blue mussel and of very high quality (up to 90% organic content). Pulses of organic enrichment from salmon farms are a dependable and bioavailable food source for the blue mussel when grown directly within the particle plume generated from the farm.	Physics

MacDonald	2011	Atlantic Salmon (Salmo salar)	N/A	Blue Mussel (Mytilus edulis)	N/A	Canada	Bay of Fundy	Open-Pen	Significantly higher feeding were recorded for mussels held at the salmon farms than their counterparts at the reference locations indicating higher feeding activity. TPM, POM and energy content of the particles were significantly elevated at the three salmon farms compared to the three reference locations, however there was no significant difference in chlorophyll a concentrations. This confirms that increases in concentrations and the energy content of suspended particles sampled at the three farms were associated with fish food effluent and not a localized increase in phytoplankton concentration.	Proof of concept of mussels feeding on organic dissolved particles when close to a fish farm and effluent. This stud identified that the mussels were in fact feeding on effluent and not on phytoplankton or increased matter in the water from other sources.	Bioremediation

Martínez-Espiñeira	2015	Atlantic Salmon (Salmo salar)	N/A	Blue Mussel (Mytilus edulis)	N/A	Canada	Bay of Fundy	Open-Pen	N/A	What the the biomitigative value of IMTA to the consumer and how do they understand the difference resulting from IMTA vs farmed vs wild? Consumers who prefer wild salmon to farmed salmon, not surprisingly, purchase farmed salmon less frequently in general than other consumers. The interaction between wild and IMTA, although positive, is not significant. This suggests that, although those who prefer wild salmon would clearly appreciate the difference between IMTA salmon and conventionally farmed salmon, this translates only into a strong negative effect on the demand for the latter, while the use of IMTA techniques does not seem enough to convince them that farmed salmon is a better choice than wild salmon. Basically, knowing that a cleaner IMTA option for farmed salmon was available would turn these consumers farther away from conventionally farmed salmon in p rticular but would not be enough to significantly attract them to farmed salmon in general. Those who had already heard about IMTA salmon when completing our survey tend to purchase farmed salmon significantly less frequently than the average consumer. This suggests that perhaps most of the information received before the survey about IMTA had made consumers wary of farmed salmon. It might be particularly important, as a policy recommendation, to assuage concerns based on wrongly perceived similarities between IMTA and mad cow disease, for example. Fears relating to this disease and genetically modified foods (or "Frankenfish") had, for instance, been raised by participants in a study conducted by the Canadian Department of Fisheries and Oceans. Being a fisher does not seem to be a significant driver of any type of demand for farmed salmon. On the other hand, hunters would consume less of both types of farmed salmon once IMTA becomes available. Not surprisingly, members of environmental organizations would demand significantly less conventionally farmed salmon if able to purchase IMTA salmon. Our results indicate that successful acceptance of IMTA salmon depends on consumers clearly distinguishing between conventionally farmed salmon and IMTA salmon. Since the two types of farmed salmon are not close substitutes, the distinguishing element can be easily highlighted through proper labeling, which, itself, has a significant positive effect on the demand for IMTA salmon.	Perception

Martínez-Espiñeira	2016	Atlantic Salmon (Salmo salar)	N/A	Blue Mussel (Mytilus edulis)	N/A	Canada	Bay of Fundy	Open-Pen	N/A	Several studies have valued the externalities associated with aquaculture practices other than IMTA, . However, analyses of IMTA systems that account for external costs and benefits are very scarce, in particular those that are not focused on estimating the premia that seafood consumers would pay for the IMTA version of a given product. a comparison could be made between our results and the benefits of IMTA production estimated through the contingent behavior analysis conducted on the subsample of respondents who stated that they had purchasedfarmed Atlantic salmon in the previous twelve months. The higher values yielded by the contingent behavior study20 highlight the fact that considering the environmental effects of one's consumption (even if hypothetical) as a regular consumer of a product purchased in a supermarket can be quite different from considering one's benefit from a public policy that addresses those environmental impacts, being a consumer or not. The objective of this study was the estimation of the non-use benefits, in the form of decreased external costs imposed on the marine environment, that would be derived by Canadians from the adoption of IMTA techniques in Atlantic salmon farming or, by extension, the adoption of any production technology (other than IMTA specifically) that secures a similar environmental performance. The estimations yield a lower bound for this benefit to households who do not purchase salmon habitually of about $43 [$8,$69] million/year for the next five years.	Perception
MendozaBeltran	2018	Seabass (Dicentrarchus labrax)	Gilthead Seabream (Sparus aurata)	Pacific Oysterr (Crassostrea gigas)	N/A	Italy	Genoa	Open-Pen	N/A	Monoculture fish production leads to nutrient emissions that are expected to be reduced in IMTA fish production. Deterministic results show that IMTA performs better than monoculture for all impacts per kilo of fish produced and eutrophication is the impact category with the largest improvement. On the other hand, uncertainty results and specifically NHST results showed that impacts re not significantly different for both technologies, except for climate change, which was found to be significantly lower under the IMTA system per kilo of fish produced. The lack of significance and differences between both systems can in part be explained by the scale of production o fish/shellfish species. Production of 4 t of oysters annually is not small, but remains insignificant in relation to the 240 t of fish produced annually. there is also an integration effect, which refers to the alignment of IMTA processes within the already existing monoculture production processes. A big challenge for any IMTA system is spatial proximity and temporal synchronization of the species productive cycles. calculation of the same impacts including relative uncertainties due to inventory data and due to the choice of allocaion method showed that there was no significant difference between the impacts of the systems, primarily due to the different scales of production between the two species. An increase in oyster seeding volume may wel provide a more robust statistically provable benefit.	Financial Performance

Nelson	2012	Atlantic Salmon (Salmo salar)	N/A	Sea cucumber (Cucumaria frondosa)	Blue Mussel (Mytilus edulis), Sugar Kelp (Saccharina latissima)	Canada	Bay of Fundy	Open-Pen	Unlike many species that seem to beha e and respond equally well in the laboratory environment as they do in the field C. frondosa does not appear to be one of them.We noticed that their behavior, particularly opening and extending their tentacles, did not seem to be as pronounced as it is in the field environment. It is unknown whether this change in behavior would have any impact on their physiological condition and absorption efficiency.	The orange-footed sea cucumber (Cucumaria frondosa) is being examined as a potential extractive species to remove additional particulate organic waste in some of the larger particle size categories. Sea cucumbers were exposed to natural (IMTA sites and natural seston) particles and enhanced laboratory diets where the organic content (OC) of the food and faeces were determined to estimate absorption efficiency (AE). AE ranged between 68 and 85% for all the experimental trials but averaged 70±3% when evaluating their response to only the natural diets. Sea cucumbers were capable of consuming aquaculture waste material when exposed to it in the laboratory and when deployed at an IMTA site, feeding directly upon the particulates released. There was a strong positive relationship (R2=0.82) between food and faeces OC, making it possible to predict the faecal OC from the food supply OC. AE was not as readily predictable from the food supply OC although there was a significant positive relationship between food OC and AE. Sea cucumbers are efficient in absorbing organic material (70± 3%) within the range (>30 and b50% OC) they are typically exposed to in their natural environment. When challenged with particulate material of higher organic content (>60% OC), such as cultured microalgae or salmon food and faeces they exhibit equal or enhanced (>80%) AE's. Our results show that C. frondosa has a great deal of potential to become an effective organic extractive IMTA species a d aid in the reduction of organic loading occurring at aquaculture sites.	Bioremediation
Neofitou	2019	Seabass (Dicentrarchus labrax)	Gilthead Seabream (Sparus aurata)	Sea cucumber (holothuria tubulosa)	N/A	Eastern Mediterranean	Pagasitikos Gulf	Open-Pen	80% mean survival rate. The strong positive relationship which detected between the absorption efficiency and the reduction rate so in the field as in the laboratory study indicates the perfect degree of association betwixt them	Sea cucumbers have been found to be capable of capturing and eating excess salmon feed and faeces and has the potential to reduce the organic loading at aquaculture sites. C. frondosa are well suited as an organic extractive IMTA species as they are capable of consuming aquaculture waste both within the laboratory environment and when feeding directly on IMTA sites. the feeding activity of H. tubulosa seemed to reduce the total organic matter and organic carbon concentration of the fish farm biodeposits, demonstrating their potential as an important organic-reducing component. When Europe is ready for IMTA development, this species could play a significant ecological and economical role for the sustainability of aquaculture in the Mediterranean region.	Bioremediation

Ratcliff	2016	Atlantic Salmon (Salmo salar)	N/A	Laminaria digitata	N/A	Ireland	West-Coast	Open-Pen	Cultivation in an IMTA context raised the content of Cu, Mn and V relative to that in mono-cultivated seaweeds however concentrations of metals were within the range of those from algae collected from undisturbed wild populations. Metal levels in the seaweeds do not pose a concern over inclusion as a dietary component with the possible exception of arsenic that exceeded some legislative limits.	Seaweeds are integral to IMTA in providing the inorganic nutrient extraction component of the system, however it is unknown whether their close proximity to other aquaculture operations facilitates increased metal accumulation. It does facilitate it but not in any way relevant or significant compared to wild or monoculture cultivation.	Bioremediation
Sarà	2009	Seabass (Dicentrarchus labrax)	Gilthead Seabream (Sparus aurata)	Mytilus galloprovincialis	N/A	Italy	Sicily	Open-Pen	Mussels cultivated close to cages, reached a higher total length, wet and ash free weight than mussels cultivated far from farms.	Fully corroberated the idea of IMTA benefits due to distance and proximity to and from the farm. fouling abundance and biomass was higher closer to cages than at far sites. Moreover, our results suggest that fish farm organic waste that is dispersed in the water column may be a food source for bivalve molluscs such as mussels. As filter feeders, they are essentially generalist consumers of POM.	Integration Performance

vanOsch	2019	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	The profiles of the green and local consumer reflect respondents’ preferences for the CE attributes sustainability and production location, whereas the determined and flexible profiles reflect how easily an individual shifts to an alternative product based on the product attributes. Interestingly, the proportion of the public assigned to the profile of green consumer (28%) is comparable to the proportion of consumers labelled green consumers by the OECD [59] (27%). As the determined buyer class covers a relatively large proportion of the respondents in Ireland (39%), Norway (48%) and the UK (39%) the general public of the sampled countries seems to be characterised as determined buyers rather than as a flexible buyer. t the public is willing to pay a price premium for products produced in a more sustainable method such as IMTA. The creation of an ecolabel as demonstrated in this survey could simultaneously fulfil multiple functions; for the public, they provide previously hidden information on the environmental impact of a product, allowing them to maximize their utility; for a producer, thy provide the opportunity to differentiate their product and increase their market value; while governments use ecolabels as a policy instrument to stimulate environmentally friendlier production to reach policy goals.	Perception
vanOsch	2017	Atlantic Salmon (Salmo salar)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Results were obtained for preferences and willingness to pay for different sustainability labels and for locally produced salmon using both conditional logit and random parameter logit models. Both models showed a positive preference for high levels of sustainability and home production location. RPL model marginal WTP estimates of €6.33 for Irish produced salmon and €1.72, €3.65 and €9.26 for 10%, 20% and 30% more sustainably-produced salmon, respectively were estimated. The Irish public acknowledges marine environmental impacts associated with aquaculture and regards IMTA aquaculture as a potential solution. Respondents to the survey did not consider themselves to be informed enough to make a good decision when purchasing salmon, and expressed the wish to receive more information on environmental pressures resulting from production of the goods offered. Low ecolabel use rates were paired with low recognition rates for the main ecolabels on the seafood market. This may relate to the fact that the scarce uptake of marine ecolabels has been attributed to a variety of factors, including saturation of the market and lack of transparency of the labels’ criteria, resulting in consumer confusion and low credibility of existing eco-labelling schemes. Sustainability labels should take into account all impacts of a product's life cycle using evaluation methods that are both reliable and verifiable.	Perception

Wang	2013	Atlantic Salmon (Salmo salar)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	C, N and P were consistently lost to surroundings substantiating previous claims of feed and energy loss to the environment. The results show a loss of 57% N, 25% P, 40% of C was lost to the environment. Faeces lost also had ntritional value placed in them. The results indicate a strong candidate for iMTa due to food composition and availability. indicated that salmon faeces have a poorer nutritional value than salmon feed and some microalgae, but that this particular food source still can be adequate to support the growth of bi valves in an IMTA system. The bi valves may benefit more from salmon feed and faeces in nutrient-limited areas than in areas with high phytoplankton biomass. Only a small portion of salmon farm wastes can be incorporated by blue mussels (Wang et al. 2012), and the major salmon feed and faecal particles sink and accumulate in sediments near cages.). These wastes may be better exploited by deposit-feeding organisms such as sea cucumbers	Bioremediation
Wang	2014	Atlantic Salmon (Salmo salar)	N/A	Sugar Kelp (Saccharina latissima)	N/A	Norway	Tristein	Open-Pen	The juvenile sporophytes showed better growth at 5 m depth than at 2 and 8 m depths and showed a strong seasonal variation in growth. June and throughout the summer, epiphytes covered the sporophytes, which resulted in tissue losses and a decrease in length. The plants at the salmon farm stations were longer than the plants at the reference station, and this difference was significant during the entire year. S. latissima showed slow growth in length from August to March and rapid growth from March to June. The growth rate at the salmon farm stations were higher than at the reference station, except for the periods of October–January and February–March.	a successful integration of S. latissima with salmon farming. The increased DIN supply from the salmon farm resulted in better growth of S. latissima and the length of S. latissima increased by 50 % when integrated withthe salmon farm compared to the reference station. the biomass of individual plants at the reference station would be 60 % lower than the plants at the salmon farm station after 11 months of cultivation. For the large-scale cultivation of S. latissima for one growing season from August to June, a harvest of 220~340 t wet weight ha−1 of S. latissima at the salmon farm station is possible	Bioremediation

Weldrick	2016	Sablefish (Anoplopoma fimbria)	N/A	Blue Mussel (Mytilus edulis)	N/A	Canada	British Columbia	Open-Pen	Farm-sampled mussels had the least intraspecific isotopic variation compared to musels sampled at the reference site. The interaction between time (i.e. sampling dates) and site did not significantly affect the isotopic composition of mussels; however significant variation was detected in δ15N values as a function of sampling date and particulate organic matter. A two-source isotopic mixing model indicated that marine particulate organic matter and IMTA farm effluent were approximately equal in importance (~46 % and ~54 %, respectively) to the diet of IMTA-retrieved mussels. Uptake of IMTA farm waste by M. edulis supports their use as economic extractives while also mitigating farmed sablefish (Anoplopoma fimbria) nutrient loading to the aquatic environment.	Blue mussels in both cultures and the wild gain excess nutrients, have a higher growth rate due to incorporation of farm effluent and excess feed into their diets.	Integration Performance
Yip	2017	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Using a discrete choice experiment we estimate marginal willingness-to-pay of 39.0% and 15.7% for IMTA and CCA, respectively, as a premium added to the price of conventionally farmed Atlantic salmon. Results using latent class analysis show that consumers with a strong preference for wild salmon have high marginal val es for farmed salmon produced with IMTA or CCA, but the average consumer from this group would be unlikely to purchase it. Overall, 44.3% and 16.2% of the respondents preferred IMTA or CCA to conventional salmon farming, respectively, and IMTA was preferred to CCA when respondents were asked to choose one.	Perception

Appendix II – Final Survey Questions

Q1: All questions will be based on your current understanding of Integrated Multi-Trophic Aquaculture (IMTA). For the purposes of this research the following definition of IMTA will be used. IMTA is the co-cultivation of species from different trophic levels, as opposed to a single species (monoculture), on an aquaculture farm. From a theoretical perspective, in an IMTA farm, the metabolic waste and uneaten feed from the top-level species like Atlantic Salmon is used by lower-level trophic species like shellfish and macroalgae. Did you know what IMTA was before taking this survey?

- Yes
    - If Yes, did the definition match your previous understanding?
- No

Q2: How would you rate your knowledge and experience in IMTA?

- Expert
- Some Experience
- Basic Knowledge
- Little Knowledge
- No Experience or Knowledge

Q3: What field(s) do you work in? Please check all that apply.

- Sustainability
- Feed Development
- Environmental Issues
- Mitigation Techniques
- Eco certification
- Technological Development
- Other (describe): _______________

Q4: For the following list of possible benefits that IMTA might offer, please choose the response that best corresponds with your opinion, based on your current understanding of IMTA.

Potential Benefit	Not at all Likely	Unlikely	Neutral	Likely	Extremely Likely
Facilitates waste mitigation on the farm	O	O	O	O	O
Allows for diversification of company profits	O	O	O	O	O

Improves in public perception of the farm and farm products	O	O	O	O	O
Reduces biofouling on aquaculture equipment	O	O	O	O	O
Reduces instances of harmful algal blooms in surrounding area	O	O	O	O	O
No benefits can be generated for the operation	O	O	O	O	O
Other (describe): ______________________________	O	O	O	O	O

Q5: For the following list of perceived issues that might arise if IMTA is to be implemented, please choose the response that best corresponds with your opinion, based on your current understanding of IMTA.

Potential Issues	**Not at all Likely**	**Unlikely**	**Neutral**	**Likely**	**Extremely Likely**
Requires higher economic investment for the company	O	O	O	O	O
Increases attraction of wild fish and other species to the farm	O	O	O	O	O
Increases the risk of diseases and pests	O	O	O	O	O
Decreases social acceptability of farmed products (eg. Salmon waste as Shellfish feed)	O	O	O	O	O
Results in smaller fish & other products	O	O	O	O	O
Increases instances of harmful algal blooms in surrounding area	O	O	O	O	O
Decreases quality farmed products	O	O	O	O	O
Increases biofouling on aquaculture equipment	O	O	O	O	O

No issues could come from IMTA implementation	O	O	O	O	O
Other (describe): ________________________________	O	O	O	O	O

Q6: For the following list of potential barriers to IMTA implementation, please choose the response that best corresponds with your opinion, based on your current understanding of IMTA.

Potential Barriers	**Not at all Likely**	**Unlikely**	**Neutral**	**Likely**	**Extremely Likely**
Economic (eg. increased costs of running the farm, higher cost to start IMTA implementation…)	O	O	O	O	O
Lack of Expertise (eg. lack of understanding of appropriate gear and cultivation strategies…)	O	O	O	O	O
Regulatory Issues (eg. Keeping many species in one location, change in the cost of permits…)	O	O	O	O	O
Managerial (eg. Complexities with training staff on use and cultivation of new species…)	O	O	O	O	O
Unrealistic to Implement (eg. Any combination of reasons above or those not included make the implementation of IMTA impossible realistically)	O	O	O	O	O
No barriers prevent IMTA Implementation	O	O	O	O	O
Other (describe): ________________________________	O	O	O	O	O

Q7: For the following list of potential incentives to facilitate the implementation of IMTA on salmon farms, please choose the response that best corresponds with your opinion, based on your current understanding of IMTA.

Potential Incentives	**Not at all Likely**	**Unlikely**	**Neutral**	**Likely**	**Extremely Likely**

Government subsidies to adapt technology or buy new technology required for new species	O	O	O	O	O
Positive campaigning by environment al groups for IMTA	O	O	O	O	O
Presence of flexible regulations to culture different species in the same farm	O	O	O	O	O
Creation and promotion of an ecolabel which promotes the goals of IMTA	O	O	O	O	O
Collaboration mechanism with other farms for sharing information and understanding of cultivating new species	O	O	O	O	O
No incentives could facilitate IMTA implementation	O	O	O	O	O
Other (describe): ________________________________	O	O	O	O	O

Q8: This study is using a "snowballing" method to distribute among related researchers and upper managers. If you know anyone that fits that description would you be willing to give us their information and/or forward them the email with the attached survey? (Yes/No)

- If Yes, could you write their contact information in the box below

Name: E-mail: Phone number or other:

Q9: Do you have any additional comments?
