Review

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Posted Date: 3 August 2023

doi: 10.20944/preprints202307.0227.v2

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Addressing Phosphorus Waste in Open Flow Freshwater Fish Farms: Challenges and Solutions

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Abstract Legislation and interest to protect and restore freshwater and marine ecosystems from aquaculture's environmental impact is global. However, aquaculture induced eutrophication continues to be a major environmental issue. Open freshwater fish farms in particular, providing fish with phosphorus-rich feeds pollute aquatic ecosystems since water soluble phosphorus, uneaten feed, feces, and metabolic waste from farmed fish increase phosphorus concentration in the adjacent waters. Several intestinal enzymes, transporters, and regulating factors are implicated in dietary phosphorus retention of farmed fish. For example, alkaline phosphatase and other transporters help the anterior intestine absorb phosphorus, while pH, calcium, and vitamin D affect these enzymes and transporters. Intestinal morphology and gut microbiome may also affect this process. Reducing phosphorus pollution from open-flow fish farms requires a thorough understanding of processes that affect nutrient retention and absorption as well as of the impact of dietary factors, anti-nutritional substances, and intestinal morphology. Optimizing feed composition, adding functional feed ingredients, and managing gut health can reduce phosphorus release and improve aquaculture sustainability. Processing and functional feed additives can mitigate anti-nutritional factors and, addressing these issues will reduce aquaculture's environmental impact, ensuring aquatic ecosystem health and global food security.

Keywords: aquaculture nutrition; phosphorus pollution, sustainability; eutrophication

Key Contribution: This review highlights the importance of understanding the mechanisms that affect phosphorus retention and absorption in farmed fish. This understanding is essential for developing strategies to reduce phosphorus pollution from open-flow fish farms and improve aquaculture sustainability.

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1. Introduction

Aquaculture, like other forms of agriculture, has environmental impact. Farmed fish release nitrogen and phosphorus, which, if left untreated in water effluents, enter surface water bodies and cause eutrophication [1]. Fresh water fish farms may also discharge veterinary drugs and antibiotics, harming aquatic biodiversity, accumulating antibiotics, and increasing antibiotic resistance [2,3].

Aquaculture has experienced rapid growth throughout history, driven by the increasing demand for seafood and the over-exploitation of fish stocks. As the industry strives to address food security concerns, fish nutrition plays a vital role in ensuring the sustainability of the sector. To achieve this, researchers are exploring new feed compositions and ingredients that can optimize fish health and performance. Phosphorus holds a dual significance in fish nutrition. Firstly, it is an essential ingredient in fish feeds, since it is required for various physiological processes, including bone formation, energy metabolism, and cellular functions. Adequate phosphorus levels in fish diets are crucial for promoting growth and overall well-being [4–6]. However, phosphorus also presents a potential challenge in terms of environmental pollution. Excessive phosphorus discharge from aquaculture operations can lead to water eutrophication, algal blooms, and other negative impacts on aquatic ecosystems. Phosphorus runoff from fish farms contributes to the nutrient load in surrounding water bodies, which can have detrimental effects on water quality and biodiversity [7,8]. To mitigate these environmental concerns, aquaculture endeavours to optimize phosphorus utilization and minimize its environmental footprint. This involves developing innovative feed formulations that enhance phosphorus digestibility and absorption in farmed fish, thereby reducing phosphorus excretion into the environment [9]. Additionally, techniques such as precision feeding, which aim to match feed supply with the nutritional requirements of fish, help prevent excessive phosphorus discharge [10]. By addressing the dual role of phosphorus as an essential ingredient and a potential parameter of pollution, the aquaculture industry can achieve sustainable growth while minimizing its environmental impact. The efficiency of phosphorus retention or absorption in the fish intestine can be influenced by a complex interplay of dietary, anatomical, and physiological factors. As shown in Figure 1, various factors are implicated in the waste of phosphorus generated by farmed fish. Anatomical and physiological parameters, including active transporters, intestinal alkaline phosphatases, and villi morphology, play essential roles in determining the efficiency of dietary phosphorus absorption and, consequently, the amount of phosphorus wasted by farmed fish [11–15].

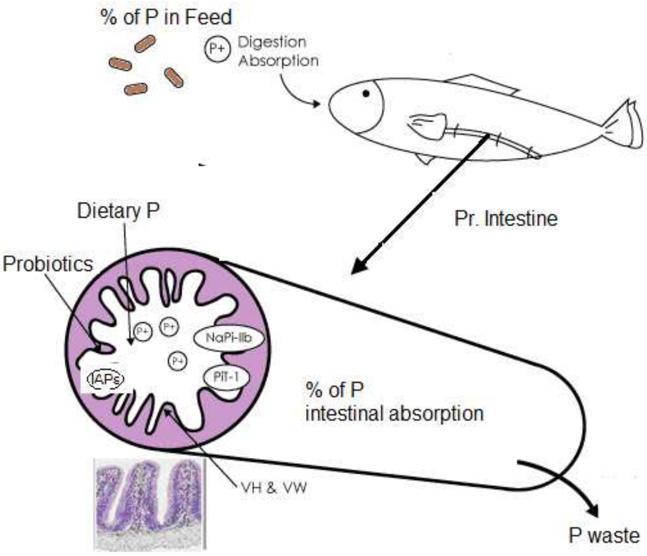

Figure 1. Gut microbiome (epithelium, mucus layer), Active transporters (e.g. PiT-1, NaPi-IIb), Intestinal alkaline phosphatases (IAPs), and Intestinal vilus morphology (V. Height, VH and V. width, VW) are implicated in the efficiency of dietary phosphorus (P+) absorption in the proximal intestinal segment (Pr. Intestine), affecting the waste of P of farmed fish.

Research advancements have identified ways to improve these parameters and reduce phosphorus waste, for example, improved nutrient utilization including phosphorus retention can be achieved through the use of probiotics, which directly or indirectly enhance intestinal phosphorus absorption. Probiotics exert their positive effects on phosphorus absorption in fish by modulating gut health and competing with harmful bacteria [16–18]. By influencing the composition and balance of the gut microbiota, probiotics create a favourable environment for nutrient digestion and absorption, including phosphorus [19–22]. This leads to improved functionality of the intestinal epithelium and enhanced nutrient transport mechanisms, including active transporters responsible for phosphorus uptake [23,24]. Moreover, probiotics outcompete pathogenic bacteria for nutrients and adhesion sites in the fish gut, reducing their presence and maintaining a healthier gut environment [25]. This

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competitive exclusion contributes to optimal nutrient absorption, including phosphorus, which can positively impact the waste of phosphorus in farmed fish. As a result, probiotics not only improve the efficiency of dietary phosphorus absorption by enhancing various anatomical and physiological parameters but also indirectly reduce the waste of phosphorus in farmed fish [23]. By promoting gut health and mitigating the negative influence of harmful bacteria, probiotics contribute to improved intestinal phosphorus absorption and subsequently help reduce the environmental impact of phosphorus waste in aquaculture systems [17,26].

1.1. Phosphorus requirements of fish farmed in open flow aquaculture systems

Phosphorus is an essential nutrient for fish, playing a crucial role in various physiological functions, including bone formation, tissue growth, acid-base balance, energy metabolism, and reproduction. The phosphorus requirements of fish depend on several factors, such as species, life stage, growth rate and water temperature [6,27,28]. Higher phosphorus requirements are associated with growth and skeletal development [5,29,30], and this is particularly interesting for the] aquacultured species. Salmonids and other carnivorous fish species are widely cultivated in open flow aquaculture systems and require high levels of protein in their diet. The protein requirement varies depending on the size and life stage of the fish, but generally ranges from 32-45% of the diet. The phosphorus content of salmonids may vary depending on diets composition but in Europe, it typically ranges from 0.7-1.4% [31,32].

1.2. The environmental impact of aquaculture, with emphasis on open flow fish farms

The demand for farmed fish can lead to increased fish farm production which can result in higher loads of phosphorus influenced by biomass and water flow rate [8,32]. Typically, in temperate climate zones, land-based rainbow trout aquaculture occurs near rivers and at high altitude where it's more likely than agriculture or industry to pollute the aquatic ecosystems. Aquaculture management, flow rates, and other spatial and seasonal factors affect phosphorus release in trout aquaculture. Before discharging, some farms use effluent treatments of varying efficacy, while others use different feeding regimes or discharge diluted waste [33,34].

Intensive aquaculture is frequently based on open flow fish farms [35] which must quickly release the water outflow on neighbouring rivers, allowing for limited time for water treatment and resulting in phosphorus release downstream [8,36]. In most freshwater ecosystems, phosphorus (P) is the limiting nutrient, whereas nitrogen (N) is the limiting nutrient in marine ecosystems. As a result, monitoring anthropogenic sources of phosphorus in freshwater ecosystems is a useful tool for determining the causes of eutrophication and their environmental impact. One possible source for phosphorus in rivers and lakes is aquaculture feed. However, farmed fish require phosphorus in their diet. Diets lacking in phosphorus can lead to severe pathological problems of farmed fish [37–39]. Phosphorus-containing fish feeds can contribute to aquatic pollution by releasing uneaten feed, faeces, and metabolic wastes of farmed fish [40].

There is uncertainty regarding the range of potential ecological parameters affected by phosphorus pollution in aquatic ecosystems; however, fish farm effluents can account for most of downstream river eutrophication [41] with ecological effects such as loss of biodiversity according to nutrient load released and mainly via increased levels of phosphorus [42]. The ecological effect of fish farms is evaluated by monitoring the levels of phosphorus produced by them expressed in kilograms of phosphorus produced by fish farms per metric ton of fish produced. The phosphorus load generated can be estimated with direct measurements of water samples or with fish production and feed records or feed conservation rates (FCR) combined with chemical analyses of feed and fish [43]. Overall, increased efficiency of phosphorus absorption can lead to a decrease in the amount of phosphorus wasted in both soluble and solid forms [44].

2. Morphological, physiological, and dietary factors affecting phosphorous absorption in fish

2.1. Intestinal morphology and physiological mechanisms

Fish intestine morphometric characteristics, including the surface area, as well as the presence of specialized cells, can reveal an intriguing relationship between anatomy and nutrient absorption efficiency [45–47]. The intestinal phosphorus absorption process in fish can be divided into two main phases: luminal and brush-border absorption. Luminal absorption involves the uptake of phosphorus from the intestinal lumen into enterocytes, while brush-border absorption involves the transport of phosphorus across the brush-border membrane of enterocytes and into the bloodstream [47–49]. Several nutritional experiments have demonstrated the length of villi and the number of goblet cells to be indicators of feed utilization efficiency [50–52]. Rainbow trout (*Oncorhynchus mykiss*) with higher phosphorus retention efficiencies exhibit longer intestinal villi and higher goblet cell densities compared to those with lower phosphorus retention efficiency [51]. Similarly, studies on Nile tilapia (*Oreochromis niloticus*) have explored the effects of dietary phosphorus levels on villi morphology and nutrient retention. Digestibility of protein and phosphorous was associated with intestinal villus length [53]. In fact, a complex interplay of transporters, enzymes, and hormones facilitates the process of phosphorous absorption. So, the anterior part of the intestine is considered as the primary site of dietary phosphorus absorption since it exhibits higher concentration of alkaline phosphatase, an enzyme responsible for phosphate ester hydrolysis, and other phosphorus transporters [13,54]. Several transporters and channels have been identified as playing key roles in intestinal phosphorus absorption in fish. These include sodium-dependent phosphate transporters (NaPi-IIb), which are responsible for the luminal uptake of phosphorus, and type III sodium-dependent phosphate transporters (Pit-1), which mediate brush-border uptake [55,56]. Additionally, calcium-sensing receptor (CaSR), transient receptor potential vanilloid 6 (TRPV6), and plasma membrane calcium ATPase (PMCA) are other transporters involved in regulating phosphorus absorption in fish [13].

Regarding vitamins, cholecalciferol, also known as vitamin D3, is a type of fat-soluble vitamin that plays a crucial role in calcium and phosphate metabolism. Cholecalciferol converted into its active form, calcitriol, regulates the absorption of calcium and phosphate in the intestine and influences their levels in the blood. In the context of trout and other farmed fish, cholecalciferol supplementation has been studied for its effects on plasma phosphate levels and phosphorus utilization and the results indicate that cholecalciferol supplementation can modulate plasma phosphate concentrations affecting the overall phosphorus balance in fish [57].

Intestinal phosphorus absorption in fish can also be affected by Na^{+} ions [54,58] and hormones such as calcitriol, parathyroid hormone, and fibroblast growth factor [23]. Calcitriol stimulates the expression of NaPi-IIb and Pit-1 transporters, while parathyroid hormone inhibits NaPi-IIb expression and stimulates PMCA expression. Fibroblast growth factor 23 inhibits calcitriol production and promotes phosphorus excretion in urine.

2.2. Relationship between fish gut structure and feed conversion efficiency

The relationship between fish gut structure and feed conversion efficiency (FCE) is crucial in understanding the potential for reducing phosphorus release in aquaculture. FCE plays a vital role in both economic viability and environmental sustainability. It refers to the ability of fish to convert feed into body mass, and improving FCE means that less feed is required to produce the desired amount of fish biomass. This reduction in feed input has the potential to decrease the release of phosphorus-rich waste into the surrounding aquatic environment.

The gut structure of fish, including factors such as the length and surface area of the intestine, the thickness of the intestinal wall, and the presence of intestinal villi and microvilli, can significantly impact the digestion and absorption of nutrients from the feed, ultimately affecting Feed Conversion Efficiency (FCE) and phosphorus retention efficiency [59]. Studies have shown that fish with a higher gut surface area or longer intestine tend to exhibit higher FCE, indicating their enhanced ability to digest and absorb nutrients from the feed [60,61].

Moreover, the relationship between FCE and phosphorus pollution in aquaculture is crucial. Low FCE is associated to decreased phosphorus retention efficiency in farmed fish, resulting in increased phosphorus excretion into the water [62–68]. Understanding this relationship enables the creation of effective management strategies to reduce phosphorus pollution in aquaculture systems.

2.3. The role of fish feeds in nutrient uptake with emphasis on phosphorous

This intricate interplay of transporters and dietary factors reflects the complex nature of nutrient absorption in farmed fish. Phosphorus retention can be influenced by several dietary parameters, such as the raw materials used as protein and phosphorus sources, and the ratio of phosphorus to other minerals, such as calcium [30,63,65–67,69–71]. The development of new fish feed formulations allows aquaculture to tailor the nutritional composition of the feed to meet the specific requirements of different fish species and use alternative protein sources to reduce the reliance of aquaculture on fish meal and fish oil. However, efforts to replace fish meal with plant proteins in fish diets face challenges related to the impact on the functional integrity of farmed fish intestines [10,64]. Plant natural defense mechanisms, such as protease inhibitors, phytates, glucosinolates, saponins, tannins, lectins, oligosaccharides, and non-starch polysaccharides, can induce intestinal inflammation [74]. This inflammation is linked to changes in gene expression within the intestine, including the absorption of phosphorus. Furthermore, anti-nutritional factors, such as phytate, can affect how efficiently aquacultured species absorb phosphorus. Phytate is a type of phosphorus present in plant-based feed ingredients commonly used in aquaculture diets. However, many aquatic species have limited ability to digest phytate because they lack the necessary enzyme, called phytase, which is responsible for breaking it down [6]. To mitigate the negative effects of these anti-nutritional factors, fish feed processing methods are employed to neutralize harmful compounds present in plant ingredients and prevent adverse effects on fish. This includes techniques to destroy or reduce the presence of plant natural defense mechanisms. Phytase, for example, an enzyme that can break down phytic acid, is a useful tool that can help fish make the best use of phosphorus available in plant-protein-based feeds. Studies have shown that its addition, can increase the availability of phosphorus in fish diets, leading to improved growth and health [75–80]. Interestingly, the commonly used soybean meal (SBM) in fish diets has been found to impact nutrient absorption, down-regulating the expression of fabp2, a fatty-acid binding protein responsible for lipid absorption in the gut. This disruption in fabp2 expression can interfere with the transport and absorption of lipids, leading to reduced lipid intestinal uptake [81]. Decreased fabp2 expression has been particularly observed in fish experiencing SBM-induced inflammation in the distal portion of the intestine [82,83]. Overall, when fed plant proteins, farmed fish often exhibit intestinal inflammation, which can be addressed by incorporating functional feed additives or employing processing techniques for plant proteins [84,85]. This becomes especially important given the growing trend of substituting fish meal with plant protein in aquafeed.

The physiological mechanisms involved in intestinal phosphorus absorption in farmed fish are complex and multifaceted, and are influenced by various nutritional and physiological factors such as pH, calcium and anti-nutritional factors (Figure 2). Understanding these mechanisms is important for optimizing the formulation of fish diets and improving the efficiency and sustainability of aquaculture production.

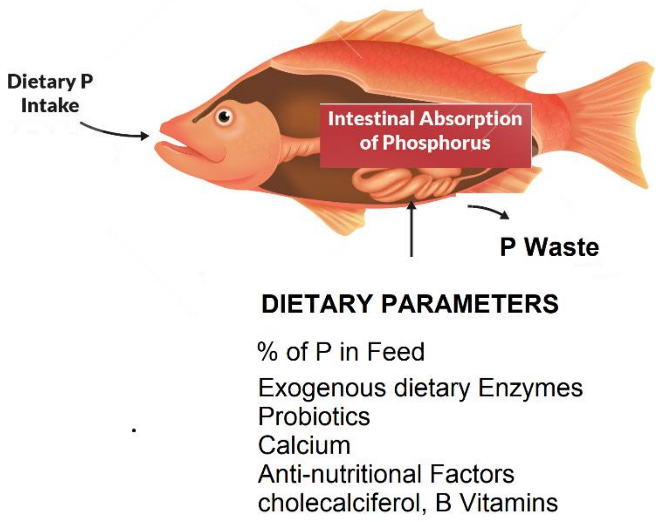

Figure 2. Dietary Factors affecting phosphorus waste of farmed fish [20,64,65,67].

Dietary phosphorus levels can also affect phosphorus absorption in farmed fish, influencing the expression of phosphate transporters like NaPi-IIb and Pit-1 with the highest expression observed in the anterior intestine, followed by the posterior and middle intestines [12,86,87]. Increasing the dietary levels of calcium and vitamin D has been shown to enhance phosphorus absorption by upregulating the expression of sodium-phosphate co-transporters in the fish intestine, particularly in the anterior segment [37,55].

2.4. Effect of probiotics on the environmental impact of freshwater fish farms

The utilization of probiotics in aquaculture offers a promising approach for reducing phosphorus pollution and implementing effective nutrient management strategies in fish farm effluents. Probiotics, particularly *Bacillus* strains, have shown the ability to modulate various water quality parameters, including phosphates [26,87]. This is because probiotics utilize phosphates for their own metabolic processes, effectively decreasing the concentration of this nutrient in aquaculture waters [88]. The positive impact of probiotics on reducing orthophosphate concentrations in treated ponds, thereby removing phosphorus, nitrogen, and organic matter from aquaculture systems illustrates the potential of this method for reducing phosphorus pollution by aquaculture [18,89]. For example, application of commercial probiotics in *Penaeus vannamei* ponds resulted in reduced nitrogen and phosphorus concentrations and increased shrimp yields. Similar findings were reported by Kumar et al. [90,91], who observed a reduction in total NH_4-N, nitrogen, NO_2-N, NO_3-N, and phosphorus concentrations with the use of probiotics.

Probiotic supplementation in fish feed offers several physiological and anatomical benefits that positively impact nutrient absorption including phosphorus retention. The elongation of villi, stimulated by probiotics, results in an increased absorptive surface area, thereby enhancing nutrient bioavailability. Specific strains of probiotics can stimulate the elongation of villi in the midgut and hindgut of fish, as evidenced by a comparison of probiotic-treated groups with control groups [21,92–96]. The production of short chain fatty acids (SCFAs) by probiotic bacteria further stimulates the production of gastrointestinal peptides, enhancing nutrient absorption capacity and ultimately contributing to improved growth performance [97–99].

In addition to the above, there is emerging evidence that probiotics can have a positive effect on gut health [25] and positively influence enzyme levels through various physiological pathways, ultimately improving fish digestion and nutrient utilization [100]. For example, probiotics may directly influence the cells lining the intestinal tract, such as enterocytes or goblet cells, which are responsible for intestinal enzyme synthesis and secretion [23,24,93]. It can be assumed that probiotics can promote the expression and release of digestive enzymes by these specialized cells, leading to higher enzyme levels in the gut consequently affecting the utilisation of nutrients including phosphorus [20].

2.5. The modulatory effect of temperature and metabolism on intestinal absorption of phosphorus in farmed fish

Apart of the nutritional parameters, phosphorus absorption in farmed fish is influenced by several factors, including water temperature and fish size [101]. Temperature in open flow fish farms can vary seasonally but also other factors such as fish size, feeding regimes, water flow may change, contributing to a range of interactions affecting phosphorus release from freshwateropen flow fish farms. Bermudes et al., [102] found that increasing water temperature resulted in a significant increase in phosphorus absorption in juvenile barramundi (*Lates calcarifer*). Growth rate is significantly affected by thermal condition and by parameters of growth [103]. The changes in phosphorus requirements with temperature, fish size and life stage highlight the importance of considering the growth trajectory and physiological status of fish when formulating diets and managing phosphorus levels in their aquaculture systems. For example, body size affects the physiological processes and energy metabolism, triploid fish may exhibit higher phosphorus requirements [104] ; larvae and juvenile fish exhibit significant phosphorus requirements due to their rapid growth and increased tissue turnover [39]; larger fish have greater skeletal mass and overall body size, which necessitates dietary absorption of phosphorus [6], whereas at older stages, gonadal development can also result in increased phosphorus requirement [105]. The above parameters can also interact with temperature, low temperature resulting in poor nutrient absorption and lower retention of dietary phosphorus, while high temperatures in increase metabolic rate and nutrient requirements, potentially leading to increased feed intake and pollution [106].

Water temperature also affects the expression of genes related to nutrient absorption in the rainbow trout intestine [107]. The relationship between temperature and gene expression in fish intestine is complex and influenced also by diet, fish size, and water quality. High-protein diets and higher water temperatures influence specific gene expression related to amino acid and glucose transport [108,109].

3. Current and Potential strategies for reducing phosphorus pollution of FW fish farms

3.1. Phosphorus waste reduction initiatives

Technological developments are playing a significant role in reducing the ecological aquaculture systems, including addressing phosphorus pollution. Several advancements have emerged to improve water treatment efficiency and minimize the environmental impact of aquaculture effluents [110]. Open flow aquaculture systems may face greater challenges in managing and controlling phosphorus pollution compared to closed Recirculating Aquaculture Systems (RAS), nevertheless, there are some similar principles of mechanical and biological filtration which can be applied to treat aquaculture effluents and minimize downstream phosphorus pollution. These include sedimentation and settling ponds which can reduce the organic load and particulates from the effluents before they are discharged downstream in the aquatic ecosystem. The construction of wetlands or the cultivation of algae downstream of open flow fish farms can offer natural filtration mechanisms to utilize vegetation and soil to filter and absorb nutrients, including phosphorus, from the effluents. By promoting the growth of specific algae or plants, phosphorus can be effectively removed from the aquaculture effluents [111].

Nutrient management and feed optimization is also a highly effective method for reducing phosphorus pollution in fish farms [112] and the industry has made significant strides in this regard; the level of phosphorus in fish feeds has been significantly reduced and feeding regimes have been optimized to reduce the phosphorus content of aquaculture wastes [9,113,114]. For example, supplementary feeding with cereals, such as wheat and other grains, is commonly practiced in semi-intensive aquacultural ponds for species like common carp. Cereals provide a low cost and readily available source of energy in fish feeds, but they contain antinutritional substances, including enzyme

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inhibitors, phytoestrogens, and oligosaccharides, which can reduce feed intake and nutrient bioavailability. These factors hinder phosphorus digestion and utilization, leading to slower growth and increased excreta in the water. Heat treatment, grinding, and removal of hulls can mitigate the impact of antinutritional factors and improve feed digestibility. Furthermore, the use of pelleted or extruded feeds enhances digestibility, minimizes water pollution, and promotes better fish growth. Applying thermal and mechanical treatments to supplementary feeds prior to their use in aquaculture ponds can help reduce undigested or poorly digested feed, further improving efficiency and decreasing environmental impacts [115,116].

As a result, significant progress has been made in the past through the implementation of phosphorus waste reduction initiatives that have been developed and refined over the years [117,118]. These initiatives have relied on the application of best management practices, optimization of feeding regimes, and the utilization of low-phosphorus feed ingredients. Moreover, promising results have been reported by incorporating feed supplements such as a-ketoglutarate [119] phytase enzymes [21,119,120], organic acids [74,121], and low-phosphorus plant protein combinations [122]. These strategies offer promising avenues to not only reduce phosphorus waste but also optimize fish growth and foster sustainable freshwater aquaculture practices. Likewise, exogenous enzymes can serve as a safe and efficient bio-additive to regulate various aspects of fish performance and reduce phosphorus pollution into the environment [79]. It can be concluded that incorporating exogenous enzymes into fish feed has the potential to improve growth performance, digestibility, feed utilization, whole-body composition, immune performance, and subsequently reduce phosphorus pollution in open flow freshwater fish farms.

3.2. Management strategies for reducing phosphorous pollution from aquacultures

In fact, aquaculture – environment interaction is an interesting paradox. On one hand, aquaculture effluents containing excess nutrients into surrounding waters contributeto phosphorus release with detrimental effects on ecosystems' ecological state. Aquaculture, on the other hand, is susceptible to the effects of eutrophication, as excessive phosphorus levels can disrupt the ecological balance and the water quality, fish health and growth. Recognizing this paradox, legislative initiatives are being implemented to address phosphorus pollution from various sources, including aquaculture and agriculture, to mitigate environmental impacts and promote sustainable aquaculture practices [123].

As a result, there are a variety of emerging or refined management strategies that can be used to reduce phosphorus pollution from aquaculture, including developing existing and new approaches such as substituting fish meal with plant proteins and also reducing the amount of phosphorus in the feed [69], optimizing feeding regimes to reduce feed conversion ratio (FCR) or Daily Feed Intake, using water treatment technologies to remove phosphorus from wastewater, and developing sustainable aquaculture practices that reduce the environmental impact of fish farming [124–127]. However, the feasibility and effectiveness of these strategies depend on various factors, such as the type of aquaculture system, the type of fish being farmed, and the local environmental conditions. Phosphorus removal in open flow aquaculture systems within rivers is a critical concern for maintaining water quality and mitigating environmental impacts (Figure 3).

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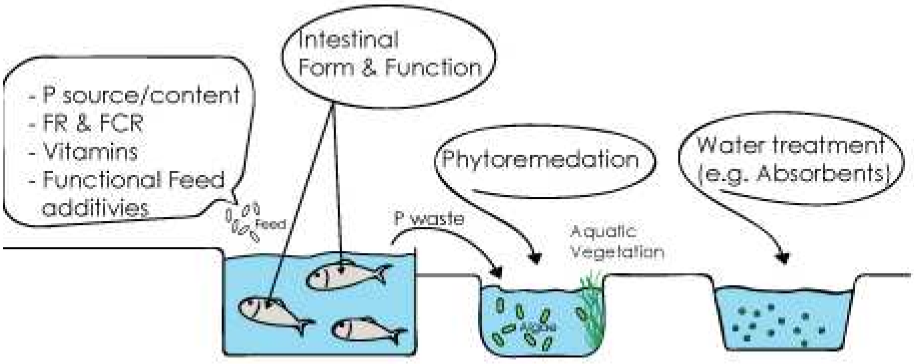

Figure 3. Interactions and Strategies for Phosphorus Management in Freshwater Fish Farms.

Phytoremediation

Emerging solutions such as phytoremediation and adsorbents/ filtration offer promising approaches to address phosphorus pollution. These methods are based on aquatic plants, mechanical and biological filters to remove excess phosphorus from the water [128–133]. Phytoremediation in river aquaculture can also be based on the use of floating aquatic plants, such as water hyacinth (*Eichhornia crassipes*) and duckweed (*Lemna* spp.), which have demonstrated effective nutrient removal capabilities [111,132]. These plants can be strategically placed in the aquaculture system or in constructed wetlands along the flow path of the river to help mitigate phosphorus pollution. Another example involves the utilization of effluent collected after wastewater treatment with *Rhodopseudomonas sphaeroides*. This effluent can be reutilized for microbial feed, medicament, and aquaculture water, specifically for the culture of common Carp [46]. The integrated system of wastewater treatment and the use of effluent containing *R. sphaeroides* offers several benefits for common Carp culture. Studies have shown that common Carp raised in effluent containing *R. sphaeroides* exhibit improved survival rates, increased yield, and enhanced whole-body composition compared to control groups and this effect is attributed to the presence of B vitamins in the effluent with *R. sphaeroides*, which enhance the activity of various enzymes and genes related to digestion, immunity, and antioxidant defense mechanisms [46]. Furthermore, the presence of *R. sphaeroides* in the effluent contributes to the improvement of aquaculture water quality, leading to reduced water pollution and wastewater discharge.

Adsorbents and filtration systems

Adsorbents and filtration systems are effective approaches for mitigating phosphorus in river-based aquaculture and reducing eutrophication impacts. Modified clays or activated carbon, acting as adsorbents, can bind to phosphorus particles in water, facilitating their removal. Similarly, filtration systems equipped with specific media or membranes can capture phosphorus particles. Zeolites, for instance, have demonstrated potential in removing phosphorus from aquaculture effluents [129]. Additionally, biomaterials derived from lodgepole pine have been utilized to reduce aquaculture waste and mitigate micronutrient-induced eutrophication. Treating rainbow trout effluents with these biomaterials for up to 60 minutes resulted in the removal of 150 to 180 grams of phosphorus per metric ton, providing a method for eutrophication reduction in aquaculture [130]. The economic costs associated with these strategies can be a determinant of their potential applications in aquaculture. It is important to conduct thorough economic feasibility studies and cost-benefit analyses specific to each aquaculture operation to determine the financial viability and return on investment of these solutions [132]. Factors such as potential cost savings from reduced water pollution, improved fish health, and regulatory compliance should also be considered.

3.3. The role of Probiotics

Efforts to reduce the organic load of fish farms can utilize probiotics which can affect phosphorus dynamics released by fish farms through their interaction with the intestinal microbiota of farmed fish. By incorporating probiotics into the fish diet or introducing them into the water column, it is possible to modulate the composition and activity of the gut microbiota, thereby enhancing the digestive capacity of fish in relation to phosphorus assimilation and utilization. Probiotics, when added to the fish diet or introduced into the water column, can alter gut microbiota and enhance the digestive capacity of fish. As a result of the improved functionality of the intestinal epithelium and enhanced nutrient transport mechanisms facilitated by probiotics, nutrients, including phosphorus, are assimilated more efficiently. This enhanced assimilation leads to a reduction in phosphorus wastes, which is a critical issue in freshwater fish farms due to its environmental impact [8,17,36]. By increasing the efficiency of nutrient utilization, the amount of phosphorus excreted into the environment can be minimized. Following probiotic administration, the gut microbiota can contribute to enhance nutrient utilisation of feed components and synthesize vitamins and amino acids, which can improve the nutritional value of the feed and enhance the digestion and absorption efficiency of nutrients. Several studies have shown that probiotics and prebiotics, which can promote the growth of beneficial gut bacteria, can improve the feed conversion efficiency and growth performance of fish. Certain strains of probiotic bacteria, when administered to aquaculture systems, have shown promise in improving phosphorus utilization and assimilation and reducing its release into the surrounding water [16,17].

Additionally, probiotics can also promote the growth of beneficial bacteria in the gut of fish, leading to enhanced nutrient absorption and utilization. This can result in improved feed conversion efficiency and reduced waste production, including phosphorus excretion. However, the effectiveness of probiotics in reducing phosphorus pollution can vary depending on several factors, such as the specific probiotic strains used, the aquaculture system's characteristics, and the feed composition.

Apart from the traditional method of administering probiotics through diet, they can also be introduced into the aquatic environment, either by adding them to the water column or incorporating them into filtration systems [16,17]. This alternative approach allows probiotics to exert their effects on gut function and directly interact with the aquaculture water and sediment, potentially enhancing their remediation effects. For example, a study by Yi et al. [131] investigated the use of commercial probiotics immobilized on different carriers for aquaculture water and sediment remediation. Probiotics immobilized within oyster shells, vesuvianite, and walnut shells reduced nutrient content of aquaculture water and sediment. Likewise, through competitive exclusion, the application of a mixture of probiotics, such as lactic acid bacteria, phototrophic bacteria, and yeast, can inhibit the growth of pathogenic and harmful bacteria in fish farms, as well as reduce phosphorus wastes. Jówiakowski et al. [109] reported a significant decrease (77.6%) of phosphorus concentrations in the water from the aquaculture pond following the application of a mixture of probiotics. These findings suggest that probiotics can not only function as dietary components but also contribute to bioremediation efforts, ultimately improving water quality parameters and reducing nutrient loads in aquaculture effluents. However, further research is still needed to optimize the use of probiotics for phosphorus management in freshwater aquaculture, as their effectiveness can vary depending on factors such as probiotic strains, aquaculture system characteristics, and feed composition. Table 1, presents an overview of some issues and parameters which are implicated in phosphorus pollution and remedation strategies.

Table 1. Issues of Phosphors pollution and strategies for Reducing Phosphorus Pollution in open water Freshwater Fish Farms.

Issue	Main Contributing Parameter	Possible remediation
Phosphorus Pollution in Open Flow Fish Farming	Phosphorus in fish feeds and feed conversion rate	New fish feed formulations, Improved efficiency of intestinal phosphorus absorption. [10,68,75–79,83,84,112–114,117]
Gut Health and Nutrient Absorption	Feeding regime, substitution of fish meal, Intestinal inflammation.	Pre and probiotics, Fuctional feed additivies and Fish health management [94–97,100,104,119,122]
Efficient aquaculture Effluent treatments	Water flow rate, fish density	Phytoremedation and Filtering. [46,88,109,111,124,126–135]

4. Conclusion and Perspectives

The data reviewed in the previous sections indicate finally that phosphorus retention efficiency of different farmed fish species can vary due to factors such as their physiological characteristics, feeding habits, and digestive physiology. The phosphorus requirements and absorption mechanisms can differ among fish species, with some species having specialized adaptations in their intestines.

While several methods and strategies can contribute to reducing phosphorus pollution from fish farms, a holistic approach encompassing various factors should be considered. Cost analysis [134], proper feed management [45], water quality monitoring, and nutrient cycling play pivotal roles in effectively addressing phosphorus-related environmental concerns [17]. By understanding the mechanisms of phosphorus absorption, dietary factors, anti-nutritional substances, and intestinal morphology, we can optimize aquaculture practices to reduce phosphorus release.

Author Contributions: Conceptualization, C.N., and M.K.; methodology, C.N., M.K. and M.T.; software, T.M.; validation, M.K.. and E.G.; formal analysis, M.K.; investigation, C.N., M.K., T.M.; resources, C.N. and H.K.; writing—original draft preparation, C.N. and M.K.; writing—review and editing, K.N. E.G. and H.K.; visualization, C.N., M.K. and E.G.; supervision, C.N.; project administration, K.N.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ahmed, N.; Thompson, S.; Glaser, M. Global Aquaculture Productivity, Environmental Sustainability, and Climate Change Adaptability. *Environmental management* **2019**, *63*, 159–172.
2. Lulijwa, R.; Rupia, E.J.; Alfaro, A.C. Antibiotic Use in Aquaculture, Policies and Regulation, Health and Environmental Risks: A Review of the Top 15 Major Producers. *Reviews in Aquaculture* **2020**, *12*, 640–663.
3. Mavraganis, T.; Constantina, C.; Kolygas, M.; Vidalis, K.; Nathanailides, C. Environmental Issues of Aquaculture Development. *Egyptian Journal of Aquatic Biology and Fisheries* **2020**, *24*, 441–450.
4. Fontagné, S.; Silva, N.; Bazin, D.; Ramos, A.; Aguirre, P.; Surget, A.; Abrantes, A.; Kaushik, S.J.; Power, D.M. Effects of Dietary Phosphorus and Calcium Level on Growth and Skeletal Development in Rainbow Trout (Oncorhynchus Mykiss) Fry. *Aquaculture* **2009**, *297*, 141–150.
5. Sugiura, S. Effects of Dietary Phosphorus Restriction on Phosphorus Balance in Rainbow Trout Oncorhynchus Mykiss. *Aquaculture Science* **2015**, *63*, 245–253.
6. Lall, S.P.; Kaushik, S.J. Nutrition and Metabolism of Minerals in Fish. Animals 2021, 11, 2711 2021.
7. Varol, M.; Balcı, M. Characteristics of Effluents from Trout Farms and Their Impact on Water Quality and Benthic Algal Assemblages of the Receiving Stream. *Environmental Pollution* **2020**, *266*, 115101.
8. Mavraganis, T.; Tsoumani, M.; Kolygas, M.; Chatziefstathiou, M.; Nathanailides, C. Using Seasonal Variability of Water Quality Parameters to Assess the Risk of Aquatic Pollution from Rainbow Trout Fish Farms in Greece. *International Journal of Energy and Water Resources* **2021**, *5*, 379–389.

9. Wilfart, A.; Garcia-Launay, F.; Terrier, F.; Soudé, E.; Aguirre, P.; Skiba-Cassy, S. A Step towards Sustainable Aquaculture: Multiobjective Feed Formulation Reduces Environmental Impacts at Feed and Farm Levels for Rainbow Trout. *Aquaculture* **2023**, *562*, 738826.
10. Glencross, B.; Fracalossi, D.M.; Hua, K.; Izquierdo, M.; Mai, K.; Øverland, M.; Robb, D.; Roubach, R.; Schrama, J.; Small, B. Harvesting the Benefits of Nutritional Research to Address Global Challenges in the 21st Century. *Journal of the World Aquaculture Society* **2023**, *54*, 343–363.
11. Aslaksen, M.A.; Kraugerud, O.F.; Penn, M.; Svihus, B.; Denstadli, V.; Jørgensen, H.Y.; Hillestad, M.; Krogdahl, Å.; Storebakken, T. Screening of Nutrient Digestibilities and Intestinal Pathologies in Atlantic Salmon, Salmo Salar, Fed Diets with Legumes, Oilseeds, or Cereals. *Aquaculture* **2007**, *272*, 541–555.
12. Dai, Y.-S.; Pei, W.-L.; Wang, Y.-Y.; Wang, Z.; Zhuo, M.-Q. Topology, Tissue Distribution, and Transcriptional Level of SLC34s in Response to Pi and PH in Grass Carp Ctenopharyngodon Idella. *Fish Physiology and Biochemistry* **2021**, *47*, 1383–1393.
13. Denstadli, V.; Skrede, A.; Krogdahl, Å.; Sahlstrøm, S.; Storebakken, T. Feed Intake, Growth, Feed Conversion, Digestibility, Enzyme Activities and Intestinal Structure in Atlantic Salmon (Salmo Salar L.) Fed Graded Levels of Phytic Acid. *Aquaculture* **2006**, *256*, 365–376.
14. Lallès, J.-P. Intestinal Alkaline Phosphatase in the Gastrointestinal Tract of Fish: Biology, Ontogeny, and Environmental and Nutritional Modulation. *Reviews in Aquaculture* **2020**, *12*, 555–581.
15. Rossi Jr, W.; Allen, K.M.; Habte-Tsion, H.-M.; Meesala, K.-M. Supplementation of Glycine, Prebiotic, and Nucleotides in Soybean Meal-Based Diets for Largemouth Bass (Micropterus Salmoides): Effects on Production Performance, Whole-Body Nutrient Composition and Retention, and Intestinal Histopathology. *Aquaculture* **2021**, *532*, 736031.
16. Jahangiri, L.; Esteban, M.Á. Administration of Probiotics in the Water in Finfish Aquaculture Systems: A Review. *Fishes* **2018**, *3*, 33.
17. Nathanailides, C.; Kolygas, M.; Choremi, K.; Mavraganis, T.; Gouva, E.; Vidalis, K.; Athanassopoulou, F. Probiotics Have the Potential to Significantly Mitigate the Environmental Impact of Freshwater Fish Farms. *Fishes* **2021**, *6*, 76.
18. Yanbo, W.; Zirong, X. Effect of Probiotics for Common Carp (Cyprinus Carpio) Based on Growth Performance and Digestive Enzyme Activities. *Animal feed science and technology* **2006**, *127*, 283–292.
19. Adeoye, A.A.; Yomla, R.; Jaramillo-Torres, A.; Rodiles, A.; Merrifield, D.L.; Davies, S.J. Combined Effects of Exogenous Enzymes and Probiotic on Nile Tilapia (Oreochromis Niloticus) Growth, Intestinal Morphology and Microbiome. *Aquaculture* **2016**, *463*, 61–70.
20. Maas, R.M.; Verdegem, M.C.; Debnath, S.; Marchal, L.; Schrama, J.W. Effect of Enzymes (Phytase and Xylanase), Probiotics (B. Amyloliquefaciens) and Their Combination on Growth Performance and Nutrient Utilisation in Nile Tilapia. *Aquaculture* **2021**, *533*, 736226.
21. Wang, M.; Yi, M.; Lu, M.; Gao, F.; Liu, Z.; Huang, Q.; Li, Q.; Zhu, D. Effects of Probiotics Bacillus Cereus NY5 and Alcaligenes Faecalis Y311 Used as Water Additives on the Microbiota and Immune Enzyme Activities in Three Mucosal Tissues in Nile Tilapia Oreochromis Niloticus Reared in Outdoor Tanks. *Aquaculture Reports* **2020**, *17*, 100309.
22. Wang, Y.; He, Z. Effect of Probiotics on Alkaline Phosphatase Activity and Nutrient Level in Sediment of Shrimp, Penaeus Vannamei, Ponds. *Aquaculture* **2009**, *287*, 94–97.
23. Elsabagh, M.; Mohamed, R.; Moustafa, E.M.; Hamza, A.; Farrag, F.; Decamp, O.; Dawood, M.A.; Eltholth, M. Assessing the Impact of Bacillus Strains Mixture Probiotic on Water Quality, Growth Performance, Blood Profile and Intestinal Morphology of Nile Tilapia, Oreochromis Niloticus. *Aquaculture nutrition* **2018**, *24*, 1613–1622.
24. Islam, S.M.; Rohani, M.F.; Shahjahan, M. Probiotic Yeast Enhances Growth Performance of Nile Tilapia (Oreochromis Niloticus) through Morphological Modifications of Intestine. *Aquaculture Reports* **2021**, *21*, 100800.
25. Cámara-Ruiz, M.; Balebona, M.C.; Moriñigo, M.Á.; Esteban, M.Á. Probiotic Shewanella Putrefaciens (SpPdp11) as a Fish Health Modulator: A Review. *Microorganisms* **2020**, *8*, 1990.
26. Hlordzi, V.; Kuebutornye, F.K.; Afriyie, G.; Abarike, E.D.; Lu, Y.; Chi, S.; Anokyewaa, M.A. The Use of Bacillus Species in Maintenance of Water Quality in Aquaculture: A Review. *Aquaculture Reports* **2020**, *18*, 100503.
27. Kraft, C.E. Estimates of Phosphorus and Nitrogen Cycling by Fish Using a Bioenergetics Approach. *Canadian Journal of Fisheries and Aquatic Sciences* **1992**, *49*, 2596–2604.
28. Sambraus, F.; Hansen, T.; Daae, B.S.; Thorsen, A.; Sandvik, R.; Stien, L.H.; Fraser, T.W.; Fjelldal, P.G. Triploid Atlantic Salmon Salmo Salar Have a Higher Dietary Phosphorus Requirement for Bone Mineralization during Early Development. *Journal of Fish Biology* **2020**, *97*, 137–147.
29. Jahan, P.; Watanabe, T.; Satoh, S.; Kiron, V. A Laboratory-Based Assessment of Phosphorus and Nitrogen Loading from Currently Available Commercial Carp Feeds. *Fisheries science* **2002**, *68*, 579–586.

30. Ye, C.-X.; Liu, Y.-J.; Tian, L.-X.; Mai, K.-S.; Du, Z.-Y.; Yang, H.-J.; Niu, J. Effect of Dietary Calcium and Phosphorus on Growth, Feed Efficiency, Mineral Content and Body Composition of Juvenile Grouper, Epinephelus Coioides. *Aquaculture* **2006**, *255*, 263–271.
31. Chatvijitkul, S.; Boyd, C.E.; Davis, D.A. Nitrogen, Phosphorus, and Carbon Concentrations in Some Common Aquaculture Feeds. *Journal of the World Aquaculture Society* **2018**, *49*, 477–483.
32. Mavraganis, T.; Thorarensen, H.; Tsoumani, M.; Nathanailides, C. On the Environmental Impact of Freshwater Fish Farms in Greece and in Iceland. *Annual Research & Review in Biology* **2017**, 1–7.
33. Bergheim, A.; Brinker, A. Effluent Treatment for Flow through Systems and European Environmental Regulations. *Aquacultural Engineering* **2003**, *27*, 61–77.
34. Moraes, M.A.B.; Carmo, C.F.; Tabata, Y.A.; Vaz-Dos-Santos, A.M.; Mercante, C.T.J. Environmental Indicators in Effluent Assessment of Rainbow Trout (Oncorhynchus Mykiss) Reared in Raceway System through Phosphorus and Nitrogen. *Brazilian Journal of Biology* **2016**, *76*, 1021–1028.
35. Rico, A.; Vighi, M.; Van den Brink, P.J.; ter Horst, M.; Macken, A.; Lillicrap, A.; Falconer, L.; Telfer, T.C. Use of Models for the Environmental Risk Assessment of Veterinary Medicines in European Aquaculture: Current Situation and Future Perspectives. *Reviews in Aquaculture* **2019**, *11*, 969–988.
36. Tahar, A.; Kennedy, A.M.; Fitzgerald, R.D.; Clifford, E.; Rowan, N. Longitudinal Evaluation of the Impact of Traditional Rainbow Trout Farming on Receiving Water Quality in Ireland. *PeerJ* **2018**, *6*, e5281.
37. Sugiura, S.H. Phosphorus, Aquaculture, and the Environment. *Reviews in Fisheries Science & Aquaculture* **2018**, *26*, 515–521.
38. Fjelldal, P.G.; Hansen, T.; Albrektsen, S. Inadequate Phosphorus Nutrition in Juvenile Atlantic Salmon Has a Negative Effect on Long-Term Bone Health. *Aquaculture* **2012**, *334*, 117–123.
39. Fraser, T.W.; Witten, P.E.; Albrektsen, S.; Breck, O.; Fontanillas, R.; Nankervis, L.; Thomsen, T.H.; Koppe, W.; Sambraus, F.; Fjelldal, P.G. Phosphorus Nutrition in Farmed Atlantic Salmon (Salmo Salar): Life Stage and Temperature Effects on Bone Pathologies. *Aquaculture* **2019**, *511*, 734246.
40. Beveridge, M.C.; Brummett, R.E. Aquaculture and the Environment. *Freshwater Fisheries Ecology* **2015**, 794–803.
41. Webb, J.A. Effects of Trout Farms on Stream Macroinvertebrates: Linking Farm-Scale Disturbance to Ecological Impact. *Aquaculture Environment Interactions* **2012**, *3*, 23–32.
42. Camargo, J.A. Positive Responses of Benthic Macroinvertebrates to Spatial and Temporal Reductions in Water Pollution Downstream from a Trout Farm Outlet. *Knowledge & Management of Aquatic Ecosystems* **2019**, 16.
43. Chapman, D.V. *Water Quality Assessments: A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring*; CRC Press, 2021;
44. Igwegbe, C.A.; Obi, C.C.; Ohale, P.E.; Ahmadi, S.; Onukwuli, O.D.; Nwabanne, J.T.; Bia\lowiec, A. Modelling and Optimisation of Electrocoagulation/Flocculation Recovery of Effluent from Land-Based Aquaculture by Artificial Intelligence (AI) Approaches. *Environmental Science and Pollution Research* **2023**, *30*, 70897–70917.
45. Bakke, A.M.; Glover, C.; Krogdahl, Å. Feeding, Digestion and Absorption of Nutrients. In *Fish physiology*; Elsevier, 2010; Vol. 30, pp. 57–110.
46. Wu, P.; Xie, L.; Wu, X.; Wang, Y.; Wu, Y.; Li, N.; Zhang, Y.; Chen, Z. Effect of Rhodopseudomonas Sphaeroides–Treated Wastewater on Yield, Digestive Enzymes, Antioxidants, Nonspecific Immunity, and Intestinal Microbiota of Common Carp. *North American Journal of Aquaculture* **2019**, *81*, 385–398.
47. Debnath, S.; Roy, S.; Saikia, S.K. Absorption of Macronutrients in Teleost. *Current Approaches in Science and Technology Research Vol. 6* **2021**, 62–68.
48. Ndiaye, W.N.; Deschamps, M.-H.; Comeau, Y.; Chowdhury, K.; Bunod, J.-D.; Letourneau-Montminy, M.-P.; Vandenberg, G. In Situ Chelation of Phosphorus Using Microencapsulated Aluminum and Iron Sulfate to Bind Intestinal Phosphorus in Rainbow Trout (Oncorhynchus Mykiss). *Animal Feed Science and Technology* **2020**, *269*, 114675.
49. Coloso, R.M.; King, K.; Fletcher, J.W.; Hendrix, M.A.; Subramanyam, M.; Weis, P.; Ferraris, R.P. Phosphorus Utilization in Rainbow Trout (Oncorhynchus Mykiss) Fed Practical Diets and Its Consequences on Effluent Phosphorus Levels. *Aquaculture* **2003**, *220*, 801–820.
50. Vidakovic, A.; Langeland, M.; Sundh, H.; Sundell, K.; Olstorpe, M.; Vielma, J.; Kiessling, A.; Lundh, T. Evaluation of Growth Performance and Intestinal Barrier Function in Arctic Charr (Salvelinus Alpinus) Fed Yeast (Saccharomyces Cerevisiae), Fungi (Rhizopus Oryzae) and Blue Mussel (Mytilus Edulis). *Aquaculture nutrition* **2016**, *22*, 1348–1360.
51. Vidakovic, A.; Huyben, D.; Sundh, H.; Nyman, A.; Vielma, J.; Passoth, V.; Kiessling, A.; Lundh, T. Growth Performance, Nutrient Digestibility and Intestinal Morphology of Rainbow Trout (Oncorhynchus Mykiss) Fed Graded Levels of the Yeasts Saccharomyces Cerevisiae and Wickerhamomyces Anomalus. *Aquaculture Nutrition* **2020**, *26*, 275–286.
52. Caspary, W.F. Physiology and Pathophysiology of Intestinal Absorption. *The American journal of clinical nutrition* **1992**, *55*, 299S-308S.

53. Adeshina, I.; Akpoilih, B.U.; Udom, B.F.; Adeniyi, O.V.; Abdel-Tawwab, M. Interactive Effects of Dietary Phosphorus and Microbial Phytase on Growth Performance, Intestinal Morphometry, and Welfare of Nile Tilapia (Oreochromis Niloticus) Fed on Low-Fishmeal Diets. *Aquaculture* **2023**, *563*, 738995.
54. Rimoldi, S.; Bossi, E.; Harpaz, S.; Cattaneo, A.G.; Bernardini, G.; Saroglia, M.; Terova, G. Intestinal B0AT1 (SLC6A19) and PEPT1 (SLC15A1) MRNA Levels in European Sea Bass (Dicentrarchus Labrax) Reared in Fresh Water and Fed Fish and Plant Protein Sources. *Journal of nutritional science* **2015**, *4*, e21.
55. Sugiura, S.H.; McDaniel, N.K.; Ferraris, R.P. In Vivo Fractional Pi Absorption and NaPi-II MRNA Expression in Rainbow Trout Are Upregulated by Dietary P Restriction. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology* **2003**, *285*, R770–R781.
56. Sugiura, S. Identification of Intestinal Phosphate Transporters in Fishes and Shellfishes. *Fisheries Science* **2009**, *75*, 99–108.
57. Vielma, J.; Lall, S.; Koskela, J.; Mattila, P. Influence of Low Dietary Cholecalciferol Intake on Phosphorus and Trace Element Metabolism by Rainbow Trout (Oncorhynchus Mykiss, Walbaum). *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology* **1999**, *122*, 117–125.
58. Terova, G.; Gini, E.; Gasco, L.; Moroni, F.; Antonini, M.; Rimoldi, S. Effects of Full Replacement of Dietary Fishmeal with Insect Meal from Tenebrio Molitor on Rainbow Trout Gut and Skin Microbiota. *J Animal Sci Biotechnol* **2021**, *12*, 30, doi:10.1186/s40104-021-00551-9.
59. Thaib, A.; Handayani, L.; Hanum, A.; Nurhayati, N.; Syahputra, F. Evaluating the Addition of Starry Triggerfish (Abalistes Stellaris) Bone Charcoal as a Feed Supplement to the Growth Performance and Intestinal Villi Length of Nile Tilapia (Oreochromis Niloticus). *Depik* **2021**, *10*, 194–200.
60. Ringø, E.; Olsen, R.E.; Gifstad, T.; Dalmo, R.A.; Amlund, H.; Hemre, G.-I.; Bakke, A.M. Prebiotics in Aquaculture: A Review. *Aquaculture Nutrition* **2010**, *16*, 117–136.
61. Stevens, E.D.; Devlin, R.H. Gut Size in GH-Transgenic Coho Salmon Is Enhanced by Both the GHtransgene and Increased Food Intake. *Journal of Fish Biology* **2005**, *66*, 1633–1648.
62. Bureau, D.P.; Cho, C.Y. Phosphorus Utilization by Rainbow Trout (Oncorhynchus Mykiss): Estimation of Dissolved Phosphorus Waste Output. *Aquaculture* **1999**, *179*, 127–140.
63. Morales, G.A.; Azcuy, R.L.; Casaretto, M.E.; Márquez, L.; Hernández, A.J.; Gómez, F.; Koppe, W.; Mereu, A. Effect of Different Inorganic Phosphorus Sources on Growth Performance, Digestibility, Retention Efficiency and Discharge of Nutrients in Rainbow Trout (Oncorhynchus Mykiss). *Aquaculture* **2018**, *495*, 568–574.
64. Liu, X.; Sha, Z.; Wang, C.; Li, D.; Bureau, D.P. A Web-Based Combined Nutritional Model to Precisely Predict Growth, Feed Requirement and Waste Output of Gibel Carp (Carassius Auratus Gibelio) in Aquaculture Operations. *Aquaculture* **2018**, *492*, 335–348.
65. Avila, E.M.; Basantes, S.P.; Ferraris, R.P. Cholecalciferol Modulates Plasma Phosphate but Not Plasma Vitamin D Levels and Intestinal Phosphate Absorption in Rainbow Trout (Oncorhynchus Mykiss). *General and comparative endocrinology* **1999**, *114*, 460–469.
66. Avila, E.M.; Tu, H.; Basantes, S.; Ferraris, R.P. Dietary Phosphorus Regulates Intestinal Transport and Plasma Concentrations of Phosphate in Rainbow Trout. *Journal of Comparative Physiology B* **2000**, *170*, 201–209.
67. Lock, E.-J.; Waagbø, R.; Wendelaar Bonga, S.; Flik, G. The Significance of Vitamin D for Fish: A Review. *Aquaculture nutrition* **2010**, *16*, 100–116.
68. Omar, S.S.; Anwar, A.Y.; El-Haroun, E.R.; Davies, S.J. Evaluation of Protein Enriched Co-Products Originating from Wheat Fermentation in Diets of Common Carp Cyprinus Carpio to Examine Effects on Growth Response, Mineral Retention, Haematological Status and Intestinal Integrity. *Aquaculture Nutrition* **2021**, *27*, 1336–1351.
69. Milián-Sorribes, M.C.; Tomás-Vidal, A.; Peñaranda, D.S.; Carpintero, L.; Mesa, J.S.; Dupuy, J.; Donadeu, A.; Macías-Vidal, J.; Martínez-Llorens, S. Estimation of Phosphorus and Nitrogen Waste in Rainbow Trout (Oncorhynchus Mykiss, Walbaum, 1792) Diets Including Different Inorganic Phosphorus Sources. *Animals* **2021**, *11*, 1700.
70. Chanpaisaeng, K.; Teerapornpuntakit, J.; Wongdee, K.; Charoenphandhu, N. Emerging Roles of Calcium-Sensing Receptor in the Local Regulation of Intestinal Transport of Ions and Calcium. *American Journal of Physiology-Cell Physiology* **2021**, *320*, C270–C278.
71. Jin, J.; Chu, Z.; Ruan, R.; Liu, W.; Chen, X.; Li, C. Phosphorus Absorption and Excretion in Hybrid Sturgeon (Huso Dauricus♀ X Acipenser Schrenckii♂) Intubated with Different Ca/P Ratios. *Fishes* **2022**, *7*, 138.
72. Santigosa, E.; García-Meilán, I.; Valentin, J.M.; Pérez-Sánchez, J.; Médale, F.; Kaushik, S.; Gallardo, M.A. Modifications of Intestinal Nutrient Absorption in Response to Dietary Fish Meal Replacement by Plant Protein Sources in Sea Bream (Sparus Aurata) and Rainbow Trout (Onchorynchus Mykiss). *Aquaculture* **2011**, *317*, 146–154.
73. Hernando, N.; Wagner, C.A. Mechanisms and Regulation of Intestinal Phosphate Absorption. *Comprehensive Physiology* **2011**, *8*, 1065–1090.

74. Behera, B.K. Nutritional Biotechnology to Augment Aquaculture Production. In *Advances in Fisheries Biotechnology*; Springer, 2022; pp. 231–243.
75. Liebert, F.; Portz, L. Nutrient Utilization of Nile Tilapia Oreochromis Niloticus Fed Plant Based Low Phosphorus Diets Supplemented with Graded Levels of Different Sources of Microbial Phytase. *Aquaculture* **2005**, *248*, 111–119.
76. Cao, L.; Yang, Y.; Wang, W.M.; Yakupitiyage, A.; Yuan, D.R.; Diana, J.S. Effects of Pretreatment with Microbial Phytase on Phosphorous Utilization and Growth Performance of Nile Tilapia (Oreochromis Niloticus). *Aquaculture Nutrition* **2008**, *14*, 99–109.
77. Yigit, N.O.; Bahadir Koca, S.; Didinen, B.I.; Diler, I. Effect of Protease and Phytase Supplementation on Growth Performance and Nutrient Digestibility of Rainbow Trout (Oncorhynchus Mykiss, Walbaum) Fed Soybean Meal-Based Diets. *Journal of Applied Animal Research* **2018**, *46*, 29–32.
78. Dias, J.; Santigosa, E. Maximising Performance and Phosphorus Utilisation of Warm Water Fish through Phytase Supplementation. *Aquaculture* **2023**, *569*, 739360.
79. Zheng, C.C.; Wu, J.W.; Jin, Z.H.; Ye, Z.F.; Yang, S.; Sun, Y.Q.; Fei, H. Exogenous Enzymes as Functional Additives in Finfish Aquaculture. *Aquaculture Nutrition* **2020**, *26*, 213–224.
80. Medeiros, L.; Nornberg, B.; Azevedo, R.; Cardoso, A.; Rosas, V.T.; Tesser, M.B.; Pedrosa, V.F.; Romano, L.A.; Wasielesky Jr, W.; Marins, L.F. Dietary Addition of Recombinant Bacillus Subtilis Expressing a Fungal Phytase Increases Phosphorus Fixation in Muscle of Pacific White Shrimp Litopenaeus Vannamei. *Aquaculture International* **2023**, 1–14.
81. Venold, F.F.; Penn, M.H.; Krogdahl, Å.; Overturf, K. Severity of Soybean Meal Induced Distal Intestinal Inflammation, Enterocyte Proliferation Rate, and Fatty Acid Binding Protein (Fabp2) Level Differ between Strains of Rainbow Trout (Oncorhynchus Mykiss). *Aquaculture* **2012**, *364*, 281–292.
82. Perera, E.; Yúfera, M. Soybean Meal and Soy Protein Concentrate in Early Diet Elicit Different Nutritional Programming Effects on Juvenile Zebrafish. *Zebrafish* **2016**, *13*, 61–69.
83. Hernández, A.J.; Roman, D. Phosphorus and Nitrogen Utilization Efficiency in Rainbow Trout (Oncorhynchus Mykiss) Fed Diets with Lupin (Lupinus Albus) or Soybean (Glycine Max) Meals as Partial Replacements to Fish Meal. *Czech Journal of Animal Science* **2016**, *61*, 67–74.
84. Yang, Y.-H.; Wang, Y.-Y.; Lu, Y.; Li, Q.-Z. Effect of Replacing Fish Meal with Soybean Meal on Growth, Feed Utilization and Nitrogen and Phosphorus Excretion on Rainbow Trout (Oncorhynchus Mykiss). *Aquaculture International* **2011**, *19*, 405–419.
85. Vélez-Calabria, G.; Peñaranda, D.S.; Jover-Cerdá, M.; Llorens, S.M.; Tomás-Vidal, A. Successful Inclusion of High Vegetable Protein Sources in Feed for Rainbow Trout without Decrement in Intestinal Health. *Animals* **2021**, *11*, 3577.
86. Chen, P.; Tang, Q.; Wang, C. Characterizing and Evaluating the Expression of the Type IIb Sodium-Dependent Phosphate Cotransporter (Slc34a2) Gene and Its Potential Influence on Phosphorus Utilization Efficiency in Yellow Catfish (Pelteobagrus Fulvidraco). *Fish physiology and biochemistry* **2016**, *42*, 51–64.
87. Aas, T.S.; Terjesen, B.F.; Sigholt, T.; Hillestad, M.; Holm, J.; Refstie, S.; Baeverfjord, G.; Rørvik, K. -a; Sørensen, M.; Oehme, M. Nutritional Responses in Rainbow Trout (Oncorhynchus Mykiss) Fed Diets with Different Physical Qualities at Stable or Variable Environmental Conditions. *Aquaculture Nutrition* **2011**, *17*, 657–670.
88. Rao, V.A. Bioremediation Technology to Maintain Healthy Ecology in Aquaculture Ponds. *Fishing Chimes. September* **2002**, *22*, 39–42.
89. Sunitha, K.; Padmavathi, P. Influence of Probiotics on Water Quality and Fish Yield in Fish Ponds. *International Journal of Pure & Applied Sciences & Technology* **2013**, *19*.
90. Kumar, N.J.P.; Srideepu, K.; Reddy, H.M.; Reddy, S.K. Effect of Water Probiotic (Pro-W) on Litopenaeus Vannamei Culture Ponds of Nellore, Andhra Pradesh, India. *International Journal of Environmental Sciences* **2016**, *6*, 846–850.
91. Martínez Cruz, P.; Ibáñez, A.L.; Monroy Hermosillo, O.A.; Ramírez Saad, H.C. Use of Probiotics in Aquaculture. *International Scholarly Research Notices* **2012**, *2012*.
92. Amoah, K.; Huang, Q.; Dong, X.; Tan, B.; Zhang, S.; Chi, S.; Yang, Q.; Liu, H.; Yang, Y. Paenibacillus Polymyxa Improves the Growth, Immune and Antioxidant Activity, Intestinal Health, and Disease Resistance in Litopenaeus Vannamei Challenged with Vibrio Parahaemolyticus. *Aquaculture* **2020**, *518*, 734563.
93. Standen, B.T.; Rawling, M.D.; Davies, S.J.; Castex, M.; Foey, A.; Gioacchini, G.; Carnevali, O.; Merrifield, D.L. Probiotic Pediococcus Acidilactici Modulates Both Localised Intestinal-and Peripheral-Immunity in Tilapia (Oreochromis Niloticus). *Fish & shellfish immunology* **2013**, *35*, 1097–1104.
94. Yeganeh Rastekenari, H.; Kazami, R.; Shenavar Masouleh, A.; Banavreh, A.; Najjar Lashgari, S.; Sayed Hassani, M.H.; Ghorbani Vaghei, R.; Alizadeh Roudposhti, M.; Hallajian, A. Autochthonous Probiotics Lactococcus Lactis and Weissella Confusa in the Diet of Fingerlings Great Sturgeon, Huso Huso: Effects on Growth Performance, Feed Efficiency, Haematological Parameters, Immune Status and Intestinal Morphology. *Aquaculture Research* **2021**, *52*, 3687–3695.

95. James, G.; Das, B.C.; Jose, S.; VJ, R.K. Bacillus as an Aquaculture Friendly Microbe. *Aquaculture International* **2021**, *29*, 323–353.
96. Thurlow, C.M.; Williams, M.A.; Carrias, A.; Ran, C.; Newman, M.; Tweedie, J.; Allison, E.; Jescovitch, L.N.; Wilson, A.E.; Terhune, J.S. Bacillus Velezensis AP193 Exerts Probiotic Effects in Channel Catfish (Ictalurus Punctatus) and Reduces Aquaculture Pond Eutrophication. *Aquaculture* **2019**, *503*, 347–356.
97. Reda, R.M.; Selim, K.M. Evaluation of Bacillus Amyloliquefaciens on the Growth Performance, Intestinal Morphology, Hematology and Body Composition of Nile Tilapia, Oreochromis Niloticus. *Aquaculture International* **2015**, *23*, 203–217.
98. Zhou, Y.-L.; He, G.-L.; Jin, T.; Chen, Y.-J.; Dai, F.-Y.; Luo, L.; Lin, S.-M. High Dietary Starch Impairs Intestinal Health and Microbiota of Largemouth Bass, Micropterus Salmoides. *Aquaculture* **2021**, *534*, 736261.
99. Nimalan, N.; Sørensen, S.L.; Fečkaninová, A.; Koščová, J.; Mudroňová, D.; Gancarčíková, S.; Vatsos, I.N.; Bisa, S.; Kiron, V.; Sørensen, M. Supplementation of Lactic Acid Bacteria Has Positive Effects on the Mucosal Health of Atlantic Salmon (Salmo Salar) Fed Soybean Meal. *Aquaculture Reports* **2023**, *28*, 101461.
100. Encarnação, P. Functional Feed Additives in Aquaculture Feeds. In *Aquafeed formulation*; Elsevier, 2016; pp. 217–237.
101. Zhang, J.; Dong, Y.; Song, K.; Wang, L.; Li, X.; Tan, B.; Lu, K.; Zhang, C. Effects of the Replacement of Dietary Fish Meal with Defatted Yellow Mealworm (Tenebrio Molitor) on Juvenile Large Yellow Croakers (Larimichthys Crocea) Growth and Gut Health. *Animals (Basel)* **2022**, *12*, doi:10.3390/ani12192659.
102. Bermudes, M.; Glencross, B.; Austen, K.; Hawkins, W. The Effects of Temperature and Size on the Growth, Energy Budget and Waste Outputs of Barramundi (Lates Calcarifer). *Aquaculture* **2010**, *306*, 160–166.
103. Jobling, M. Fish Culture: The Rearing Environment. In *Finfish aquaculture diversification*; CABI Wallingford UK, 2010; pp. 33–60.
104. Martinez-Llorens, S.; Peruzzi, S.; Falk-Petersen, I.-B.; Godoy-Olmos, S.; Ulleberg, L.O.; Tomas-Vidal, A.; Puvanendran, V.; Odei, D.K.; Hagen, Ø.; Fernandes, J.M. Digestive Tract Morphology and Enzyme Activities of Juvenile Diploid and Triploid Atlantic Salmon (Salmo Salar) Fed Fishmeal-Based Diets with or without Fish Protein Hydrolysates. *PloS one* **2021**, *16*, e0245216.
105. Bruce, J.R. Changes in the Chemical Composition of the Tissues of the Herring in Relation to Age and Maturity. *Biochemical Journal* **1924**, *18*, 469.
106. Preston, D.L.; Lamb, R.W. Effects of Trout Aquaculture on Water Chemistry of Tropical Montane Streams in Ecuador. *River Research and Applications* **2021**, *37*, 1562–1566.
107. Volkoff, H.; Rønnestad, I. Effects of Temperature on Feeding and Digestive Processes in Fish. *Temperature* **2020**, *7*, 307–320.
108. Hassaan, M.S.; Nagar, A.G.E.; Salim, H.S.; Fitzsimmons, K.; El-Haroun, E.R. Nutritional Mitigation of Winter Thermal Stress in Nile Tilapia by Propolis-Extract: Associated Indicators of Nutritional Status, Physiological Responses and Transcriptional Response of Delta-9-Desaturase Gene. *Aquaculture* **2019**, *511*, 734256.
109. Jóźwiakowski, K.; Czernaś, K.; Szczurowska, A. Preliminary Results of Studies on the Purification of Water in a Pond Using the SCD Probiotics Technology. *Ecohydrology & Hydrobiology* **2009**, *9*, 307–312.
110. Martins, C.I.M.; Eding, E.H.; Verdegem, M.C.; Heinsbroek, L.T.; Schneider, O.; Blancheton, J.-P.; d'Orbcastel, E.R.; Verreth, J.A.J. New Developments in Recirculating Aquaculture Systems in Europe: A Perspective on Environmental Sustainability. *Aquacultural engineering* **2010**, *43*, 83–93.
111. Khairunisa, H.; Hasan, Z.; Herawati, H.; Lili, W. Effectiveness of Water Hyacinth (Eichhornia Crassipes) and Water Spinach (Ipomoea Aquatica) to Reduce Nitrate and Phosphate Concentrations in Cimulu River Water, Tasikmalaya City, Indonesia. *Asian Journal of Fisheries and Aquatic Research* **2022**, *18*, 1–11.
112. Cho, C.Y.; Bureau, D.P. A Review of Diet Formulation Strategies and Feeding Systems to Reduce Excretory and Feed Wastes in Aquaculture. *Aquaculture research* **2001**, *32*, 349–360.
113. Sugiura, S.H.; Marchant, D.D.; Kelsey, K.; Wiggins, T.; Ferraris, R.P. Effluent Profile of Commercially Used Low-Phosphorus Fish Feeds. *Environmental pollution* **2006**, *140*, 95–101.
114. Huang, C.-L.; Gao, B.; Xu, S.; Huang, Y.; Yan, X.; Cui, S. Changing Phosphorus Metabolism of a Global Aquaculture City. *Journal of Cleaner Production* **2019**, *225*, 1118–1133.
115. Hlaváč, D.; Adámek, Z.; Hartman, P.; Másílko, J. Effects of Supplementary Feeding in Carp Ponds on Discharge Water Quality: A Review. *Aquaculture International* **2014**, *22*, 299–320.
116. Hlaváč, D.; Anton-Pardo, M.; Másílko, J.; Hartman, P.; Regenda, J.; Vejsada, P.; Baxa, M.; Pechar, L.; Valentová, O.; Všetičková, L. Supplementary Feeding with Thermally Treated Cereals in Common Carp (Cyprinus Carpio L.) Pond Farming and Its Effects on Water Quality, Nutrient Budget and Zooplankton and Zoobenthos Assemblages. *Aquaculture international* **2016**, *24*, 1681–1697.
117. MacMillan, J.R.; Huddleston, T.; Woolley, M.; Fothergill, K. Best Management Practice Development to Minimize Environmental Impact from Large Flow-through Trout Farms. *Aquaculture* **2003**, *226*, 91–99.

118. Muhammetoglu, A.; Kocer, M.A.T.; Durmaz, S. Evaluation of Different Management Scenarios for Trout Farm Effluents Using Dynamic Water Quality Modeling. *Environmental Monitoring and Assessment* **2022**, *194*, 312.
119. Ai, F.; Wang, L.; Li, J.; Xu, Q. Effects of A-Ketoglutarate (AKG) Supplementation in Low Phosphorous Diets on the Growth, Phosphorus Metabolism and Skeletal Development of Juvenile Mirror Carp (Cyprinus Carpio). *Aquaculture* **2019**, *507*, 393–401.
120. Priya; Virmani, I.; Pragya; Goswami, R.K.; Singh, B.; Sharma, J.G.; Giri, B. Role of Microbial Phytases in Improving Fish Health. *Reviews in Aquaculture* **2023**.
121. Herath, S.S.; Satoh, S. Environmental Impact of Phosphorus and Nitrogen from Aquaculture. In *Feed and feeding practices in aquaculture*; Elsevier, 2015; pp. 369–386.
122. Sarker, P.K. Microorganisms in Fish Feeds, Technological Innovations, and Key Strategies for Sustainable Aquaculture. *Microorganisms* **2023**, *11*, 439.
123. Brownlie, W.J.; Sutton, M.A.; Reay, D.S.; Heal, K.V.; Hermann, L.; Kabbe, C.; Spears, B.M. Global Actions for a Sustainable Phosphorus Future. *Nature Food* **2021**, *2*, 71–74.
124. Sindilariu, P.-D.; Schulz, C.; Reiter, R. Treatment of Flow-through Trout Aquaculture Effluents in a Constructed Wetland. *Aquaculture* **2007**, *270*, 92–104.
125. Stojanović, K.; Živić, M.; Marković, Z.; \DJor\djević, J.; Jovanović, J.; Živić, I. How Changes in Water Quality under the Influence of Land-Based Trout Farms Shape Chemism of the Recipient Streams—Case Study from Serbia. *Aquaculture International* **2019**, *27*, 1625–1641.
126. Luo, G. Review of Waste Phosphorus from Aquaculture: Source, Removal and Recovery. *Reviews in Aquaculture* **2022**.
127. True, B.; Johnson, W.; Chen, S. Reducing Phosphorus Discharge from Flow-through Aquaculture I: Facility and Effluent Characterization. *Aquacultural Engineering* **2004**, *32*, 129–144.
128. Alfeus, A.; Gabriel, N.N. Applications of Aquatic Plants in the Remediation of Aquaculture Wastewater: An Opportunity for African Aquaculture. In *Emerging Sustainable Aquaculture Innovations in Africa*; Springer, 2023; pp. 327–339.
129. Van Rijn, J.; Tal, Y.; Schreier, H.J. Denitrification in Recirculating Systems: Theory and Applications. *Aquacultural engineering* **2006**, *34*, 364–376.
130. Bare, W.R.; Struhs, E.; Mirkouei, A.; Overturf, K.; Small, B. Engineered Biomaterials for Reducing Phosphorus and Nitrogen Levels from Downstream Water of Aquaculture Facilities. *Processes* **2023**, *11*, 1029.
131. Do, T.Q.; Tran, T.T.T.; Nguyen, T.T.; Van Dinh, V. Assessment of enhanced phytoremediation of shrimp aquaculture wastewater by endophytic bacteria-inoculated floating treatment wetlands. *International Aquatic Research*, **2021**, *13*(4), 253. DOI:10.22034/iar.2021.1939004.1186
132. Paolacci, S.; Stejskal, V.; Toner, D.; Jansen, M. A. Integrated Multitrophic Aquaculture; Analysing Contributions of Different Biological Compartments to Nutrient Removal in a Duckweed-Based Water Remediation System. *Plants*, *11*(22), **2022**, 3103. doi.org/10.3390/plants11223103
133. Yi, M.; Wang, C.; Wang, H.; Zhu, X.; Liu, Z.; Gao, F.; Ke, X.; Cao, J.; Wang, M.; Liu, Y. The in Situ Remediation of Aquaculture Water and Sediment by Commercial Probiotics Immobilized on Different Carriers. *Water Reuse* **2021**, *11*, 572–585.
134. Adler, P.R.; Summerfelt, S.T.; Glenn, D. M.; Takeda, F. Mechanistic approach to phytoremediation of water. Ecological Engineering, **2023**, *20*, 251-264.
135. Mohd Nizam, N.U.; Mohd Hanafiah, M.; Mohd Noor, I.; Abd Karim, H.I. Efficiency of Five Selected Aquatic Plants in Phytoremediation of Aquaculture Wastewater. Appl. Sci. **2020**, *10*, 2712. https://doi.org/10.3390/app10082712.