Reducing Phosphorus Pollution of Freshwater Fish Farms

Subjects: Environmental Sciences

Contributor: Cosmas Nathanailides, Markos Kolygas, Maria Tsoumani, Evangelia Gouva, Theodoros Mavraganis, Hera Karayanni

Water soluble phosphorus, uneaten feed, feces, and metabolic waste from farmed fish increase phosphorus concentrations in adjacent waters. In open freshwater fish farms, in particular, the effects can be more immediate, as excess phosphorus is introduced directly into ecosystems. Several intestinal enzymes, transporters, and regulating factors have been implicated in farmed fish dietary phosphorus retention. To reduce phosphorus pollution from open flow fish farms, a thorough understanding of the processes that affect nutrient retention and absorption, as well as the impact of dietary factors, anti-nutritional substances, and intestinal morphology, is required.

Keywords: aquaculture nutrition ; phosphorus pollution ; sustainability ; eutrophication

---

1. Phosphorus Waste Reduction Initiatives

Technological developments are playing a significant role in reducing the ecological impact of aquaculture systems, including addressing phosphorus pollution. Several advancements have emerged to improve water treatment efficiency and minimize the environmental impact of aquaculture effluents [1]. 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 in 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 [2].

Nutrient management and feed optimization is also a highly effective method for reducing phosphorus pollution in fish farms [3], 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 [4][5][6]. For example, supplementary feeding with cereals, such as wheat and other grains, is commonly practiced in semi-intensive aquaculture 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 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 the 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 [7][8].

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 [9][10]. These initiatives have relied on the application of best management practices, the 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 [11] phytase enzymes [11][12][13], organic acids [14][15], and low-phosphorus plant protein combinations [16]. These strategies offer promising avenues to not only reduce phosphorus waste, but also to 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 [17]. It can be concluded that incorporating exogenous enzymes into fish feed has the potential to improve growth performance, digestibility, feed utilization, whole-body composition, and immune performance, subsequently reducing phosphorus pollution in open flow freshwater fish farms.

2. Management Strategies for Reducing Phosphorous Pollution from Aquacultures

In fact, the aquaculture–environment interaction is an interesting paradox. On one hand, aquaculture effluents containing excess nutrients discharged into surrounding waters contribute to phosphorus release, with detrimental effects on the ecological state of the ecosystem. Aquaculture, on the other hand, is susceptible to the effects of eutrophication, as excessive phosphorus levels can disrupt the ecological balance, as well as 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 [18].

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 reducing the amount of phosphorus in the feed [19], optimizing feeding regimes to reduce 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 [20][21][22][23]. 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 1**).

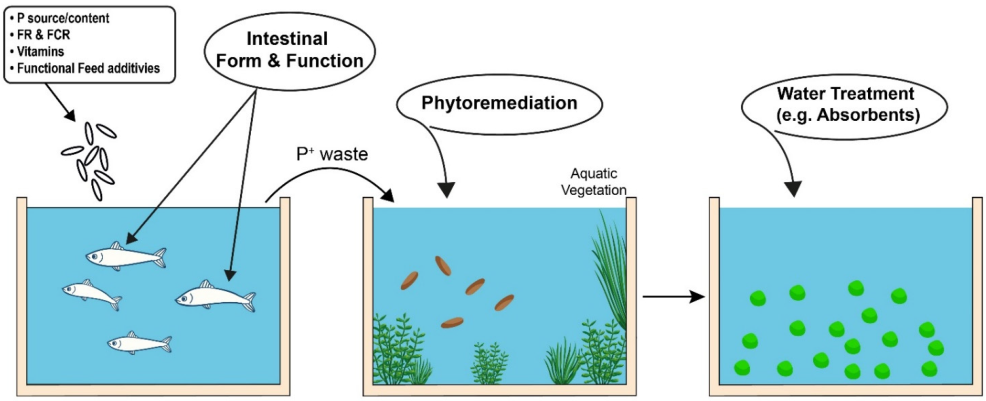

Figure 1. Interactions and strategies for phosphorus management in freshwater fish farms.

2.1. Phytoremediation

Emerging solutions such as phytoremediation and adsorbents/filtration offer promising approaches to address phosphorus pollution. These methods are based on the use of aquatic plants and mechanical and biological filters to remove excess phosphorus from the water [24][25][26][27][28][29]. 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 [2][28]. 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 [30]. The integrated system of wastewater treatment and the use of effluent containing *R. sphaeroides* offer several benefits for the culture of common carp. 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 those of the control groups. 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 [30]. Furthermore, the presence of *R. sphaeroides* in the effluent contributes to the improvement in aquaculture water quality, leading to reduced water pollution and wastewater discharge.

2.2. Adsorbents and Filtration Systems

Adsorbents and filtration systems are effective approaches for mitigating phosphorus and reducing eutrophication impacts in river-based aquaculture. 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 for removing phosphorus from aquaculture effluents [25]. 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 min resulted in the removal of 150 to 180 g of phosphorus per metric ton, providing a method for eutrophication reduction in aquaculture [26]. 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 the return on investment of these solutions [28]. Factors such as potential cost savings from reduced water pollution, improved fish health, and regulatory compliance should also be considered.

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 the 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 [31][32][33]. 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 the nutrient utilization of the 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 FCE 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 [32][34].

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 and reduced waste production, including phosphorus excretion. However, the effectiveness of probiotics in reducing phosphorus pollution can vary depending on several factors, including 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 [32][34]. 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. [27] investigated the use of commercial probiotics immobilized in different carriers for aquaculture water and sediment remediation. Probiotics immobilized within oyster shells, vesuvianite, and walnut shells reduced the nutrient content in 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. [35] reported a significant decrease (77.6%) in phosphorus concentrations in the water from an aquaculture pond following the application of a mixture of probiotics. These findings suggest that probiotics can not only function as dietary components, but they can 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 bacterial strains, aquaculture system characteristics, and feed composition. **Table 1** presents an overview of some issues and parameters which are implicated in phosphorus pollution and remediation strategies.

Table 1. Phosphorus pollution in open water freshwater fish farms: issues and possible remediation.

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 [3][5][6][9][17][36][37][38][39][40][41][42][43]**

Issue	Main Contributing Parameter	Possible Remediation
Gut health and nutrient absorption	**Feeding regime, substitution of fish meal, intestinal inflammation**	**Pre and probiotics, functional feed additives, and fish health management** [11][16][44][45][46][47][48][49]
Efficient aquaculture effluent treatments	**Water flow rate, fish density**	**Phytoremediation and filtering** [2][20][22][23][24][25][26][27][28][29][30][35][50][51][52].

References

1. 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. Aquac. Eng. 2010, 43, 83–93.
2. 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 J. Fish. Aquat. Res. 2022, 18, 1–11.
3. Cho, C.Y.; Bureau, D.P. A Review of Diet Formulation Strategies and Feeding Systems to Reduce Excretory and Feed Wastes in Aquaculture. Aquac. Res. 2001, 32, 349–360.
4. 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.
5. Sugiura, S.H.; Marchant, D.D.; Kelsey, K.; Wiggins, T.; Ferraris, R.P. Effluent Profile of Commercially Used Low-Phosphorus Fish Feeds. Environ. Pollut. 2006, 140, 95–101.
6. Huang, C.-L.; Gao, B.; Xu, S.; Huang, Y.; Yan, X.; Cui, S. Changing Phosphorus Metabolism of a Global Aquaculture City. J. Clean. Prod. 2019, 225, 1118–1133.
7. Hlaváč, D.; Adámek, Z.; Hartman, P.; Másílko, J. Effects of Supplementary Feeding in Carp Ponds on Discharge Water Quality: A Review. Aquac. Int. 2014, 22, 299–320.
8. 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. Aquac. Int. 2016, 24, 1681–1697.
9. 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.
10. Muhammetoglu, A.; Kocer, M.A.T.; Durmaz, S. Evaluation of Different Management Scenarios for Trout Farm Effluents Using Dynamic Water Quality Modeling. Environ. Monit. Assess. 2022, 194, 312.
11. 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.
12. 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. Aquac. Rep. 2020, 17, 100309.
13. Priya; Virmani, I.; Pragya; Goswami, R.K.; Singh, B.; Sharma, J.G.; Giri, B. Role of Microbial Phytases in Improving Fish Health. Rev. Aquac. 2023. Available online: https://onlinelibrary.wiley.com/doi/epdf/10.1111/raq.12790 (accessed on 24 August 2023).
14. Behera, B.K. Nutritional Biotechnology to Augment Aquaculture Production. In Advances in Fisheries Biotechnology; Springer: Berlin/Heidelberg, Germany, 2022; pp. 231–243.
15. Herath, S.S.; Satoh, S. Environmental Impact of Phosphorus and Nitrogen from Aquaculture. In Feed and Feeding Practices in Aquaculture; Elsevier: Amsterdam, The Netherlands, 2015; pp. 369–386.
16. Sarker, P.K. Microorganisms in Fish Feeds, Technological Innovations, and Key Strategies for Sustainable Aquaculture. Microorganisms 2023, 11, 439.
17. 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. Aquac. Nutr. 2020, 26, 213–224.

18. 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. Nat. Food 2021, 2, 71–74.
19. 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.
20. Sindilariu, P.-D.; Schulz, C.; Reiter, R. Treatment of Flow-through Trout Aquaculture Effluents in a Constructed Wetland. Aquaculture 2007, 270, 92–104.
21. 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. Aquac. Int. 2019, 27, 1625–1641.
22. Luo, G. Review of Waste Phosphorus from Aquaculture: Source, Removal and Recovery. Rev. Aquac. 2023, 15, 1058–1082.
23. True, B.; Johnson, W.; Chen, S. Reducing Phosphorus Discharge from Flow-through Aquaculture I: Facility and Effluent Characterization. Aquac. Eng. 2004, 32, 129–144.
24. 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: Berlin/Heidelberg, Germany, 2023; pp. 327–339.
25. Van Rijn, J.; Tal, Y.; Schreier, H.J. Denitrification in Recirculating Systems: Theory and Applications. Aquac. Eng. 2006, 34, 364–376.
26. 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.
27. 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. Int. Aquat. Res. 2021, 13, 253.
28. 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 2022, 11, 3103.
29. 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.
30. 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. N. Am. J. Aquac. 2019, 81, 385–398.
31. 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. Int. J. Energy Water Resour. 2021, 5, 379–389.
32. 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.
33. 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.
34. Jahangiri, L.; Esteban, M.Á. Administration of Probiotics in the Water in Finfish Aquaculture Systems: A Review. Fishes 2018, 3, 33.
35. Jóźwiakowski, K.; Czernaś, K.; Szczurowska, A. Preliminary Results of Studies on the Purification of Water in a Pond Using the SCD Probiotics Technology. Ecohydrol. Hydrobiol. 2009, 9, 307–312.
36. 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. J. World Aquac. Soc. 2023, 54, 343–363.
37. 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. Aquac. Nutr. 2021, 27, 1336–1351.
38. 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.

39. 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). Aquac. Nutr. 2008, 14, 99–109.

40. 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. J. Appl. Anim. Res. 2018, 46, 29–32.

41. Dias, J.; Santigosa, E. Maximising Performance and Phosphorus Utilisation of Warm Water Fish through Phytase Supplementation. Aquaculture 2023, 569, 739360.

42. 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 J. Anim. Sci. 2016, 61, 67–74.

43. 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). Aquac. Int. 2011, 19, 405–419.

44. 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. Aquac. Res. 2021, 52, 3687–3695.

45. James, G.; Das, B.C.; Jose, S.; VJ, R.K. Bacillus as an Aquaculture Friendly Microbe. Aquac. Int. 2021, 29, 323–353.

46. 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.

47. 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. Aquac. Int. 2015, 23, 203–217.

48. Encarnação, P. Functional Feed Additives in Aquaculture Feeds. In Aquafeed Formulation; Elsevier: Amsterdam, The Netherlands, 2016; pp. 217–237.

49. 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.

50. Rao, V.A. Bioremediation Technology to Maintain Healthy Ecology in Aquaculture Ponds. Fish. Chimes 2002, 22, 39–42.

51. Adler, P.R.; Summerfelt, S.T.; Glenn, D.M.; Takeda, F. Mechanistic approach to phytoremediation of water. Ecol. Eng. 2023, 20, 251–264.

52. 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.