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EDITED AND REVIEWED BY
David Little,
University of Stirling, United Kingdom

*CORRESPONDENCE
Nanna Roos
nro@nexs.ku.dk

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Spotlight: aquaculture for human nutrition and health outcomes

Nanna Roos*

Sustainable Nutrition and Health, Department of Nutrition, Exercise and Sports (NEXS), University of Copenhagen, Copenhagen, Denmark

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Global challenges for human health and well-being

Global food and health challenges are significant and complex. The sustainable management of aquatic foods is essential to support the urgently needed global shift toward sustainable and healthy diets across populations and continents. Fish and other aquatic foods have long been recognized as an important source of high-quality protein, lipids and micronutrients, promoting human health and well-being. However, approaches to alleviating malnutrition and promoting healthy diets have largely ignored the role of aquaculture in supplying aquatic foods. A key barrier for policymakers in considering aquatic foods in health-promoting strategies is the enormous complexity and diversity of the aquatic food systems.

Research that addresses these gaps in understanding the complex linkages between aquaculture, aquatic resources and human nutrition and health is needed to reveal the potential of aquaculture-driven food systems to benefit human well-being in all aspects.

To build an interdisciplinary academic space for research that addresses all aspects of the connection between aquaculture and human nutrition and health, the human nutritional and health outcomes section of the Frontiers in Aquaculture is dedicated to publishing research that focuses on the nexus of aquaculture-driven aquatic food systems and human nutrition and health.

Alleviating malnutrition

Malnutrition in its various forms affects billions of people, challenging health through the shifting nutritional needs through the life course, from the critical '1000 days' of pregnancy and early infancy, through childhood and adulthood to the years of old age. Malnutrition covers a wide range of unbalanced diets that affect short- and long-term health status. Overnutrition, which leads to overweight and obesity affects 2.5 billion people who are at risk of non-communicable diseases (NCDs) such as cardiovascular disease, diabetes and cancer. Undernutrition leads to an estimated 3 million preventable deaths annually in children under 5 years of age, due to insufficient nutrition and micronutrient deficiencies. Hundreds of millions of children suffering from early-life malnutrition will not reach their potential, both in school and later in life. Women who do not meet their nutritional needs risk giving birth to unhealthy children, closing the lifelong loop of malnutrition. These challenges come at a high cost to individuals and society.

Aquatic foods are among the most nutritious in the world, and aquaculture-driven food systems have untapped potential to be a part of the solution to alleviating malnutrition, in

both high- and low-income settings. The vast diversity of aquatic food resources is a treasure for human nutrition if managed sustainably, ensuring security and accessibility for the dependent populations. Fishing, hunting and harvesting from inland and marine waters supply 3 billion people with aquatic foods as the primary source of animal protein. Aquatic foods provide vital nutrients of high biological value, yet the paradox we face is that populations most dependent on them are also among the most vulnerable to undernutrition. Aquaculture offers new opportunities to increase the availability and accessibility of aquatic foods, and in the best-case scenario increasing access and consumption to meet nutritional needs.

To realize the potential of aquaculture for human nutrition, health and well-being, it is important to consider that aquaculture favors selected fast-growing species. When aquaculture is integrated into complex aquatic food systems, such as in river basins and coastal communities, the introduction of aquaculture is likely to change the composition of the aquatic foods in the diet. Replacing traditional dishes that include a variety of wild fish and other aquatic foods with cultured species will change their nutritional value.

Research is necessary to understand the dynamics and nutritional implications associated with shifting dietary patterns in populations where aquaculture is developing, and how such dietary shifts increase or reduce intakes of macro- or micronutrients.

More research is needed to fully understand and document the direct nutritional impacts of foods supplied from aquaculture systems. The nutrient composition and the biological value of cultured, semi-cultured and wild species should be understood in the context of the nutritional needs, deficiency risk, food safety and food culture of the populations affected. The impact of aquatic food systems on nutrition can be studied in terms of *food intakes* and their contribution to diets; *intakes of critical nutrients* and the impact on *nutritional and developmental status*, for instance child growth and cognition, micronutrient status, NCD risks etc. Health impacts of aquatic food systems can also be studied in designs that investigate indirect pathways of *nutrient-sensitive aquaculture systems* through inter-mediate steps such as empowerment to feed and consume healthy diets; affordability of nutrient-dense aquatics; or procurement of aquatic products through social or humanitarian programs to reach vulnerable groups (e.g. school feeding programs, therapeutic feeding and food aid).

Promoting human health

Aquatic foods are recognized and documented for their health-promoting properties. In particular, marine sources are unique in their lipid profiles as they contain the long-chain polyunsaturated fatty acids (LCPUFA) docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), which have been documented to have direct biological health-promoting properties. LCPUFA in the diet lowers the risk of cardiovascular disease and may reduce the risk of other NCDs such as diabetes and cancer.

The nutritional profile of fish and other aquatic foods varies between species and the environment in which the organisms were raised. When aquatic foods originate from aquaculture, the specific aquaculture practices will determine the nutrient profiles. The selection of species to be cultured, feed ingredients and environmental parameters of the production site, such as salinity, will impact the nutritional profile of the aquatic food reaching the consumer.

Rigorous, hypothesis-driven research is essential to advance our understanding of the human health benefits derived from aquaculture production systems. To improve the understanding of the linkages between aquaculture production and the health of populations, conceptual and context-specific studies are needed. Well-designed human studies that assess health impacts or associations with outcomes of aquaculture food systems are important. Such studies rely on short- and long-term biological response parameters, such as blood fatty acid or lipid profiles, child growth and cognition, body composition, pregnancy and birth outcomes, disease and life expectancy such as long-term educational and income achievements. Also, research may apply animal or *in vitro* models if the methods applied are validated to be relevant for human outcomes. Studies designed to assess intermediate steps towards ultimate long-term human health endpoints – such as the risk of NCDs - are important for understanding the links and gaps in the aquaculture-human health nexus. Such research can support hypotheses to fill the gaps in understanding the dynamics of complex aquatic food systems.

Such research will inform consumers, producers, and policymakers in promoting nutrient-sensitive aquaculture that contributes to human health and well-being.

Green transition

Aquaculture and the broader aquatic food systems have a key role to play in the green transition. Research into aquatic production in the context of climate change must consider the nutritional and health significance in the context of planetary health and sustainability. Sustainable utilization of high-quality proteins and lipids is important to achieve sustainable food systems. Aquaculture cultivates a range of species with very different feeding biology, ranging from species that feed on organisms at the bottom of the food chain such as microalgae, plankton, plants and invertebrates, to species with predatory biology that rely on protein- and lipid-dense feed. The early days of salmon farming, for example, relied purely on feeding fish from wild fish stocks, compromising sustainability by converting 'fish to fish'. Research has supported the transition to more plant-protein-based feed to save costs and marine resources. Replacing marine-derived oils with vegetable oils may impact the nutritional and health profile of cultured fish. Consumers are aware of the environmental impact of food and the unique health benefits of LCPUFAs. Evidence-based communication and certification are important to preserve consumer trust in aquaculture foods.

Research should continue to provide evidence to support the green transition of aquaculture production, documenting its implications on human nutrition and health. Documenting that aquaculture production is sustainable will promote consumer confidence that aquatic foods are the right choice for a sustainable and healthy diet.

The question remains whether a much larger proportion of marine resources can be used for direct human consumption rather than for fishmeal for animal feed. Research and innovation to support the diversion of fishmeal from animal feed to the production of high-quality fish powders and protein concentrates for human use would help the food sector to make much greater use of fish-based proteins. The aquatic food sector has huge untapped potential to make new contributions to the green transition to sustainable diets through research and innovation in high-quality proteins suitable as human food ingredients. Such ingredients should be documented for their acceptability and impact on human nutrition and health in relevant populations. A stable supply of high-quality fish-based ingredients, based on sustainable aquatic sources, and produced by small- and large-scale producers in a socially responsible way, will scale up the applications that put aquatic food at the heart of the green transition.

Food safety and bioactivity

Food safety from production to consumer is essential for the safety and the trust of the consumers. Knowledge about the risks of accumulation of toxins in aquatic foods has discouraged some consumers from regular consumption. Food safety regulations should be in place to protect the consumers, but consumers should be empowered to weigh the nutritional and health benefits against potential risks. Novel approaches are needed to ensure transparency of the food safety, nutritional and health properties of aquaculture products, for all consumers.

For aquatic foods to reach consumers, processing is necessary along the value chain. Throughout human history, traditional food processing methods such as drying, smoking, fermenting, salting, and cooling have been developed to preserve highly perishable aquatic foods. Preservation is beneficial for human nutrition and health, ensuring that seasonal catches or harvests are available for consumption year-round. Processing technologies can have negative health consequences: for example, smoking foods can induce the formation of carcinogenic nitrosamines, and salting can increase the risk of high blood pressure due to excessive salt consumption. Sun-drying of fish is the most common traditional preservation method in low-income populations, often compromising food safety. Research into efficient scalable drying methods can have an immense impact on human nutrition and health. Fish fermentation is widely used for fish sauce and traditional preservation. Fermentation and other biotechnological solutions should be studied for their potential bioactivity and impact on human health. Research should address the balancing of benefits and risks, recognizing that insufficient preservation compromises health through microbial contamination, transmission of parasites, and the formation of toxins such as histamine.

We welcome interdisciplinary and disciplinary research that addresses the nexus of aquaculture and human nutrition, health and well-being. To reveal the full potential of aquaculture, we invite submissions that conceptualize approaches to embrace the complexity of aquatic food systems and human nutrition and health, in addition to human intervention studies, context-specific dietary studies, food quality studies in the context of nutrition and health needs, and novel ideas to build research that addresses all knowledge gaps.

Author contributions

NR: Writing – original draft, Writing – review & editing.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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