Aquaponics

The current state in Finland and trends for the future

TOBIAS LIPSEWERS (PHD), FINNISH AQUAPONICS SOCIETY / SUOMEN AKVAPONINEN VILJELY RY (REGISTERED ASSOCIATION, HTTPS://SAVRY.ORG)

TOBIAS.LIPSEWERS@GMAIL.COM

PHOTO OF THE AUTHOR BY DR. ADRIAN BISCHOFF-LANG.

Introduction

Aquaponics (AP) is a production system of aquatic organisms and plants where >50 % of nutrients sustaining the optimal plant growth derives from waste originating from feeding the aquatic organisms [1]. A variety of aquatic organisms can be produced: e.g., fish, crustaceans, bivalves, amongst others. Nevertheless, a large part of this article focuses on fish as an example for these organisms. AP is the combination of aquaculture and hydroponics. The latter is a widely used technique to grow plants in a nutrient solution without the use of soil. In AP, this nutrient solution is the nutrient-rich effluent water from the fish rearing unit of the facility. Beside or instead of plants also algae can be grown given a suitable set-up of the AP-farm. The underlying principle of AP matches key aspects of the circular economy model, where (e.g.) waste production is decreased, and the environmental footprint is improved. The need to focus on sustainability was adopted by the European Union (EU) and, for instance, the Finnish government. However, AP is currently not on the roadmap to improve the sustainability of the Finnish aquaculture industry (Jouni Vielmä, personal communication, 2021).

AP has multiple advantages for the consumer and the environment:

- Extended product range and improved profitability: Multiple foodstuffs can be produced as part of this ecosystem (potentially zero-waste) approach.
- Improved food safety: No antibiotics, pesticides, and other harmful substances can be used in order to maintain a good health status of the facility's ecosystem. The microbiome (biofilter) of the AP system can absorb harmful compounds such as ammonia from the rearing water and transform them into bioavailable nutrients, which are required for as well as reduced by phototrophic growth. This bioremediation of the water improves the growth and health of the fish as well as the quality of the water that is redirected to the fish tanks.
- Increased sustainability due to a land-based recirculating system: For instance, eutrophication and over-fishing of natural waters are counteracted. Additionally, the bioremediation of the nutrient-rich effluent from the fish farming unit of the AP-system significantly reduces the water-use compared to other food production methods.
- Increased local production: Reduced emissions (e.g., carbon dioxide [CO_2]) due to shorter transport chains and reduced need for imported food.
- High quality standards due to the highly controlled rearing environment, assuming, for instance, the use of appropriate feed.
- Improving the local economy: Creation of new possibilities for the labour market and research (in rural, urban, and coastal areas). This is relevant for people who work in commercial fisheries and pond-based fish farms, when the corresponding permissions (e.g., for the use of surface water) will be reduced in the future.

In addition, AP food production is independent of weather extremes, increasing with climate change; crisis- safe because it is not affected by, for instance, collapsing transport chains; HAB (Harmful Algae Bloom)-safe because of the strictly monitored water quality (especially valid for indoor farms).

Figure 1:
This is a grocery store (REWE) in Wiesbaden (Germany) with a roof-top aquaponics farm (A). Inside this facility (B), fish and basil are produced and represent a prime example of regionally produced and marketed food.

Credit: https://www.rewe.de/nachhaltigkeit/nachhaltig-einkaufen/green-farming/

Figure 1-A

Credit: https://mediacenter.rewe.de/themen/rewe-green-farming

Figure 1-B

For example, the productivity of aquaculture (in natural waters) is threatened by environmental factors: HAB's are a major threat to, e.g., sea-based fish farms [2] and climate change negatively affects various aspects of the aquaculture industry [3]. These risks to food safety and production, which are essential aspects for the growing human population, can be reduced or even eliminated by focusing more on recirculating aquaculture systems (RAS) and AP in the future.

Of course, the intensification of land-based fish-farming should consider the well-being of farmed animals (e.g., stocking densities and quality of feed) and impacts on the environment (e.g., feed production and wastewater treatment). Thus, the approach of having more but smaller AP farms could be one direction for the future, which would also enhance regional food production.

There are various research and commercial facilities world-wide that already operate on large-scale using the principle of AP. One example from Northern Europe is the company Agtira in Härnösand [4] but also, e.g., in Berlin, Wiesbaden (Germany; Fig. 1 A/B, [5]), and Vienna (Austria) locally produced AP products are already consumed. AP can also be combined with other approaches, such as vertical farming and roof-top gardening. The latter is highly interesting and forward-looking for supermarkets and other larger buildings with flat roofs [e.g., 5].

Different types (e.g., from low to high tech) of AP-systems exist. A so-called deep water raft culture, where the roots of the plants grow directly into the fish tank or a tank filled with the nutrient-rich effluent water of the fish unit of the facility, is an example of a rather simple and coupled AP-system (Fig. 2).

The demand for alternative and innovative food production methods will increase in the future, especially considering the ongoing climate change, eutrophication and pollution of natural waters as well as the increasing consumption of fish. The transition to more sustainable production systems (e.g., AP) will ensure food provision with low environmental pressure near highly populated areas with severe environmental issues such as the catchment areas of some Finnish inland waters (Harri Kuosa, personal communication, 2021). The benefits of AP compared to other methods were recently studied also in Finland. It was found that the

Credit: https://www.hydroponicsfactory.com/deep-water-culture.html.

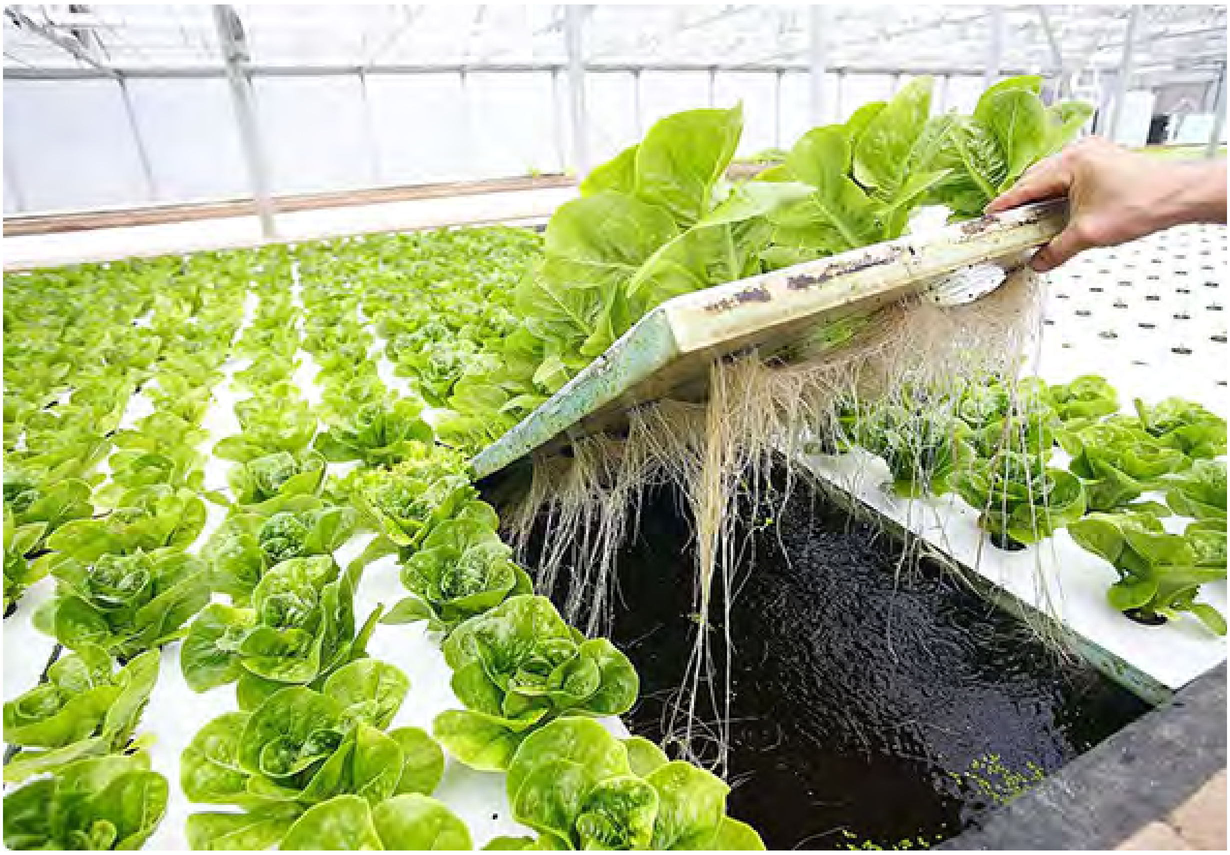


Figure 2:
An example of aquaponics. This is a so-called deep-water raft culture, where the roots of the plants grow directly into a fish tank, or a tank filled with the nutrient-rich effluent water of the fish-rearing unit.

growth of spinach (*Spinacia oleracea)* did not differ between AP and hydroponic systems but an earlier onset of nitrification, improved fish growth, and lower concentrations of the off-flavour molecule geosmin in the fish fillet (*Oncorhynchus mykiss*) were detected in AP produce compared to RAS [6].

This article presents 1) the current state of AP in Finland (research and industry); 2) the introduction of a new non-profit non-governmental organisation (NGO) aiming to promote AP and contribute to a more sustainable future to the community of aquaculture researchers and producers; and 3) promising future directions of AP in terms of an improved sustainability in the food and feed industry, legislation, product development, suitable fish species in connection to the current consumer behaviour, and profitability of modern (Finnish) aqua farms.

The approach

In order to identify the current state of AP and gain insights related to the fish consumption in Finland, qualitative research was carried out in 2021 and 2022. This study was based on literature research and internet search. As published scientific articles on AP in Finland are scarce, the presented facts are partially based on an update of an unpublished case study (Ceder 2020, Master‘s thesis) by conducting interviews (personal and E-mail communication). Furthermore, relevant web pages such as the website of the European Union [EU] on agriculture and related topics [7] were studied.

In total, at least 15 Finnish institutions were contacted (universities, universities of applied sciences, and research institutes). Additionally, the Finnish Food Authority was contacted to gain insights on the current national food legislation. Entrepreneurs and researchers working on AP and related fields (by that time) were consulted to extend the overview on the AP activities in Finland. Therefore, the companies and institutions were consulted regarding their AP-related activities and plans, the type of systems they use, and the purpose of the systems (e.g., food production). The internet and literature research were also done to gain knowledge on developments regarding consumer behaviour as well as innovative (secondary) products, with potential to improve the profitability of fish farms by expanding the product range.

The current status of AP in Finland

AP-related activities were limited in Finland at the time of the assessment (qualitative research in 2021 and 2022). To the best of the author's knowledge, neither alternative sources of animal protein (e.g., fish) nor other foodstuffs are commercially produced in Finland using this technique at the moment. Table 1 shows the purely AP-relevant findings of this online search- and interview-based study.

Institution / Company	Location	AP-activities
LUKE	Jyväskylä	Research: Modelling tools
U Jyväskylä	Jyväskylä	Research: Small-scale systems to, e.g., compare different variables of products (leafy greens and *O. mykiss*) produced with AP and RAS
U Eastern Finland	Kuopio	Research: Small-scale systems to study, e.g., nutrient dynamics
Company	Helsinki	Business: Decorative systems for recreation and education

Table 1: The aquaponics (AP)-related activities in Finland identified by a qualitative study between 2021 and 2022. LUKE = Natural Resources Institute Finland, U = University, *O. mykiss* = *Oncorhynchus mykiss* (rainbow trout), RAS = Recirculating Aquaculture System.

During the time of the study, three research groups working on AP-related topics were identified (Table 1). In addition, one Helsinki-based company was using the principle of AP (Table 1 and Fig. 3). Unfortunately, this enterprise stopped its business in the later part of 2022.

The presented results show that applying the principle of AP in Finland was not widespread at all. The extensive literature research and interviews by Ceder (2020) did not reveal other researchers and entrepreneurs working on AP than presented here. In fact, two of the companies mentioned by Ceder, stopped their activities between 2020 and 2022 (one of them mentioned above).

The major obstacles for AP in Finland are the energy costs, availability of renewable energy, and willingness of Finnish consumers to pay a higher price for better quality products (Ceder 2020) and these factors are valid elsewhere [1]. Thus, SAVRY aims to address the four mentioned core aspects in order to clear the way for the development and application of AP in Finland in the long run. Not only the knowledge of potential end-consumers on AP itself but also the awareness on, for instance, food safety, sustainability, and animal welfare must improve, especially for products that are imported to Finland from outside the EU.

Credit: https://www.wmg.com/who-we-are.

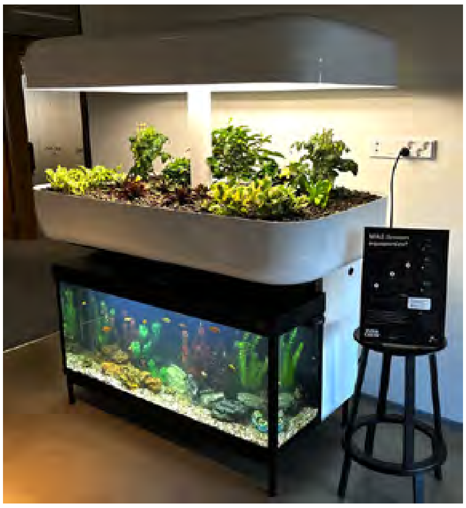


Figure 3:
This is a decorative AP-system, which was marketed by a Helsinki-based company and displayed in care homes, a school, a library, and shopping malls in multiple parts of Finland.

The Finnish Aquaponics Society

The networking activities within the scope of this study led to the foundation of a new non-profit NGO, the Finnish Aquaponics Society (Suomen Akvaponinen Viljely ry, SAVRY). SAVRY currently consists of seven members with a diverse collective expertise and has been a registered association since early September 2021. The motivation of SAVRY is to improve the communication, organisation, research, and education (referred to henceforth as the four core aspects) on this topic in Finland.

SAVRY

FINNISH AQUAPONICS SOCIETY

Improving the four core aspects, is required to allow the commercialization of AP in the long run. The main goals of SAVRY are to provide a platform to connect researchers and entrepreneurs working on AP and related fields, raise the public awareness about the advantages of AP for food production, and to develop ideas as well as innovative solutions to overcome obstacles, especially minding the challenges for this alternative food production method in the Northern hemisphere. Details on this organisation can be obtained from the corresponding website [8] and of course from the author of this article.

Promising trends for the future

In order to establish the base for successful and sustainable AP-farms the following factors are of special importance: legislation; consumer behaviour; promising choice of farmed species; innovative solutions regarding water treatment; extended product range; and the development of strategies to ensure profitability.

Currently, there is no specific legislation for foodstuffs produced using AP and a subsidy structure for Finnish fish farmers does not exist. The fish products on Finnish markets today are dominated by relatively cheap Atlantic salmon (*Salmo salar)* originating from Norway and this species is regarded as everyday food for Finns. However, there seems to be a common trend in Finland, showing that several carp-like species *(cyprinids)* have become more popular as food fish. Market research conducted by a supermarket chain in 2017, revealed that Finns eat a greater variety of fish than before

One of the major advantages of AP, is that the treatment of the nutrient-rich effluent ("wastewater") from the fish unit of the facility is achieved by a natural approach using a biofilter (microbiome) and phototrophic organisms (plants and algae). The efficiency of this bioremediation decides on the amount of water that can be recycled to the fish rearing unit. As algae are more efficient in the uptake of nutrients, producing these phototrophs (especially microalgae) instead of or in combination with plants in one system represents a highly promising approach (referred to henceforth as algaeponics) for AP farms. This will not only reduce the water use (and thus, costs) but also extend the product range (and thus, enhance the profitability) of the facility.

The profitability of AP farms in Nordic countries and elsewhere can be improved in several ways: reducing the operating costs; minimising production losses; expanding the product range; following a zero-waste approach; consumer-inspired product development; direct sales of different products; the collaboration of multiple farms; and joining forces of already existing producers, currently focusing on different food stuffs that can be combined in AP-systems.

The further development and optimisation of the mentioned factors is required to clear the way for AP in countries where this approach is currently not commercially used. Lessons learned from AP-farmers in other countries can (at least partially) be transferred to the needs in, e.g., Finland. In addition, this article proposes strategies specifically suitable for the commercialisation of AP in Finland. Promising approaches for AP in general were also mentioned by other authors.

Legislation

According to the Finnish Food Authority, there is no specific national legislation for foodstuffs produced using AP in Finland at the moment (personal communication, 2021). Most likely because it is currently not necessary, since AP is not used to produce food. The EU-legislation is valid for, e.g., the food industry in Finland. However, the EU-rules to produce certified organic products should be revised. Currently, for example, a hydroponically produced lettuce cannot be certified organic because it was not grown in soil [e.g., 9]. The advantage that plants could be grown without the use of pesticides and artificial fertilisers with AP, improving the health of humans, farmed animals, and natural environments seems to be neglected.

Based on a more recent publication, plants from AP farms could be certified organic if produced under certain conditions [10] but this needs to be adopted by the EU-commission and specified in the corresponding legislation. According to the EU-commission [7], plants that grow naturally in water can be marketed as organic when produced hydro- and aquaponically. Unfortunately, there are no fully aquatic plants that could feed the world. On the other hand, algae from indoor facilities can be certified organic when sticking to the corresponding EU-legislation, since they naturally grow in water [11]. Fortunately, the EU legislation has changed since 2017 and according to a recent document prepared by the EU-commission ("Frequently asked questions on organic rules"), it is now possible to market fish produced with AP as organic, considering specific conditions [12].

The advantages of AP compared to other food production methods and the current research on this topic should be considered for adjusting and extending the corresponding EU-legislation (especially for plant production). Currently, the EU rules do not seem to cover all aspects and varieties of AP and thus, a recheck of the legislation was requested (February / March 2023). Certification as organic is no precondition to ensure healthy and safe food but it could increase the popularity of AP farming and the trust of the consumer in the corresponding products. This will benefit the intensification of the food production using this method and thus, the improvement of the sustainability in the aquaculture sector, simultaneously. Minding the environmental threats caused by, for example, sea-ranching, it is likely that permissions for this grow out method will be reduced in the future. Thus, the development and implementation of a subsidy structure for Finnish fish farmers is advisable.

Consumer behaviour in Finland and recommendations for fish species in AP farms

Nowadays, *S. salar* (produced by sea-ranching in Norway) is the predominant species found at Finnish markets. In fact, oven-baked salmon was identified as the most popular everyday dish for Finns in 2018 [13]. For example, the arctic char (*Salvelinus alpinus)* is a highly promising species for land-based indoor fish farms in Finland. S. alpinus features optimal growth rates at 12 to 14 °C and it can be kept in high densities, since this resembles its natural behaviour [14]. Like *S. salar*, this species is native to Finland, which has several advantages: 1) Finnish fish consumers are used to it; 2) For instance, eggs to produce fingerlings for stocking a farm do not have to be imported; 3) There is no risk of introducing an alien (potentially invasive) species to natural waters.

Cold-water adapted fish (e.g., *S. salar, S. alpinus*, and *Coregonus lavaretus*) are generally interesting for Nordic countries due to the heating costs for land-based fish farms and the fact that plenty of native species exist. The rainbow trout (*O. mykiss*) is not native to Europe but known to be an AP-proof species [e.g., 14] and a very popular food fish in Finland. In general, trout can still do well at 3.3 °C but grow best at 13–17 °C [15] and are thus promising species for Nordic countries as well.

Research on consumer behaviour conducted by a supermarket chain (K-market, 2017) revealed that carp-like species (cyprinids) gained popularity by Finns and that more fish species are consumed than before. For example, bream (*Abramis brama*) has been very well received by customers [16]. Additionally, roach (*Rutilus rutilus*) is a common sight in the shelves of Finnish supermarkets nowadays (product name: "Järki Särki"; [17]). This development and the fact that climatic changes will favour the production of other species than salmonids in the future, should be considered by fish farmers. Ideally, they will produce popular and forward-looking fish species to meet the demand and thus, increase the chances of running a viable business. The largest carp-like species found in European waters is the common carp (*Cyprinus carpio*). This species grows fast (under certain conditions), which benefits its production as a food fish. *C. carpio* could be used to develop similar recipes for products as mentioned above [16, 17]. Furthermore, a female carp can produce up to 300,000 eggs per kg per year [18], which could be interesting to produce affordable and more sustainable "caviar" [19]. *C. carpio* is not native to Finnish waters but it was introduced already a long time ago. In fact, the cultivation and introduction of this species in Europe dates back to the mediaeval times [20]. In addition, C. carpio is the fourth most-produced fish species on a global scale and its production is especially popular in Europe and Asia [21]. Thus, new carp farmers can benefit from the extensive available knowledge on carp production. Beside *C. carpi*o, also tilapia species and barramundi (*Lates calcarifer*) are considered as robust fish species and are suitable for AP systems [e.g., 14]. The latter two are tropical species and the common carp tolerates comparably lower temperatures [14], which is beneficial for cultivation in the Northern hemisphere. When farming non-native species, measures avoiding escapes of the fish to natural waters must be taken to protect native aquatic ecosystems.

Algaeponics – Bioremediation of wastewater and interesting products

Microorganisms can be used to reduce the nutrient concentrations in different kinds of wastewater [e.g., 22]. The following will focus on microalgae, since the indoor cultivation of macroalgae (seaweed) is currently less developed.

There are vast possibilities to use algae and many species are already part of the food industry (including aquaculture) and medical research, amongst others. The genera *Chlorella, Arthrospira, Haematococcus,* and *Dunaliella* have anti-tumor, anti-viral, and anti-inflammatory properties for humans [23]. Furthermore, microalgae grow 5 to 10 times faster than traditional food crops [24] and certain species produce valuable compounds, vital for higher trophy levels, such as humans and fish [23, 25]. The use of algae-derived food supplements, containing compounds that humans usually take up by eating fish (e.g., omega-3 fatty acids and carotenoids), will aid in counteracting the exploitation of the sea and thus, contribute to the conservation of natural ecosystems.

Algaeponics is a new variety of AP and a highly exciting field to explore as well as a sustainable way to grow algae for different purposes when done under certain conditions. The combination of fish and algae has great potential for the whole salinity gradient of fish farming (fresh, brackish, and marine). Regarding the use of microalgae for wastewater treatment in aquaculture, human nutrition, and aquafeed, e.g., *Haematococcus pluvialis* (freshwater green algae) is especially interesting. This species is known to produce nature's strongest antioxidant astaxanthin [26], which is not only healthy for, e.g., humans and fish but also a carotenoid pigment colouring fish flesh (e.g., salmon) red in a natural way. *H. pluvialis* can be cultivated using the nutrient-rich effluent water from RAS facilities, which in turn reduces the nutrient concentrations in this type of wastewater [27]. It is possible to use filtered and unfiltered RAS effluent water to grow *H. pluvialis* and other microalgae species [28]. Due to these findings [27, 28], this species is also suitable for algaeponics. In aquaculture, the microalgae biomass can be used as feed in larvae culture (e.g., fish and crustaceans), which is one of the most critical production steps (keyword: "green water"; [e.g., 29]). Another option is to accumulate the microalgae in zooplankton species [30] and subsequently feed the latter to carnivorous and omnivorous fish larvae [e.g., 25]. Microalgae and zooplankton can be used to produce valuable foodstuffs, such as fish, oysters, and prawns [25].

The production of plankton biomass is therefore highly relevant for the aquaculture industry and thus, also for AP. The (EU-)legislation on using, for instance, microalgae as food and feed must be considered [23] and might have to be developed and / or specified for innovative production methods such as algae cultivation using RAS effluent water and AP systems. In general, novel products must be tested regarding public health, hygiene, and safety [31].

Improving the profitability of AP farms

The operating costs might be a challenge, especially for AP in the Northern hemisphere. Therefore, the use of waste heat from existing industries as well as renewable energy sources should be used whenever possible. In addition, minimising production losses (e.g., by considering species-specific requirements for setting up the farm, *etc*.), expanding the product range (e.g., secondary products), following a zero-waste approach, consumer-inspired product development, direct sales (on-site and / or on farmer's markets) of different products such as fresh, smoked and / or marinated fish, roe-based products as well as herbs that go well with fish (e.g., dill [*Anethum graveolens*] and coriander [*Coriandrum sativum*]), and the collaboration of multiple (small) facilities are ways to improve the profitability of future aqua farms.

A zero-waste approach can be realised by, for example, using the sludge (organic waste from, e.g., fish) from RAS (and thus also AP) as fertiliser for plant growth [32]. The principle of "vermi-aquaponics" can be considered to digest the sludge using worms, which can be used to feed fish in AP-systems [33] and marketed as fishing bait (secondary products). Additionally, the collaboration of already existing food producers applying modern and proven technologies (e.g., RAS farmers and glasshouse growers) will benefit the commercialisation of AP in the long-term. In fact, a significant part of the vegetable production (tomatoes and cucumbers) in Finland is already done in greenhouses using hydroponics nowadays [34].

Regarding the need for sustainable solutions, methods such as AP [35], integrated multi-trophic aquaculture (IMTA) as well as fully recirculating aquaculture systems (FRAS) are a favourable choice for modern fish producers. However, an improved sustainability and food safety can only be achieved if the feed for farmed aquatic organisms meets certain requirements. The corresponding raw materials must be produced in a sustainable and safe way and, e.g., natural solutions instead of unnecessary chemical additives (e.g., conservatives and antioxidants) should be considered. There are immense options for different combinations of aquatic animals, plants, and algae as well as products using the ecosystem approach of AP. However, the different species of choice must tolerate the same ranges of, for example, temperature, pH-value, and salinity [e.g., 14].

The accumulation of off flavours such as geosmin in fish flesh produced with AP can be lower compared to RAS [6] but also avoided in RAS, depending on the design and the management of the facility (Bert Wecker, personal communication, 2021). Also, the accumulation of environmental pollutants in the fish is far less or even not relevant for this production method (depending on the water source and farm management) compared to commercial fisheries. These facts should be included in the process of raising consumer awareness, developing marketing strategies for modern aqua farms, and create a meaningful AP-specific legislation for food production.

Concluding comments

How can the four core aspects be improved to clear the way for AP?

> By organising ourselves, meaning the people (researchers, entrepreneurs, *etc.) interested in AP; learning from each other's experiences and ideas; teaming up for funding proposals, projects, publications, and food production; and by supporting research-to-business (and vice versa) approaches.*

What could be the role of SAVRY and its collaborators in the future?

> SAVRY and its collaborators could expand the AP network and bringing like-minded people together; organise / participate in conferences and organise educational events; raise the public awareness of the AP principle and its advantages; conduct consumer surveys to create a basis (e.g., product development and marketing strategies) for profitable but sustainable aqua farms; and collaborate with governmental institutions to, for example, develop a subsidy structure for Finnish fish producers, define a specific national food legislation for AP products, and put this method on the road map for the development of the aquaculture sector.

The presented findings and strategies are not only valid to improve the sustainability of the aquaculture industry in Finland. Nordic countries in general are facing the same challenges and obstacles to develop and commercialise AP to increase the regional food production and thus, enhance their self-sufficiency. Furthermore, the consideration of the relevant legislation, consumer behaviour, choice of farmed species, innovations related to the bioremediation of the used water, extending the product range as well as enhancing the profitability of future aqua farms is important for people aiming to produce food using AP for a living, independent of the location.

Finally: Thanks to all those that provided information on their activities related to the field of AP, which contributed to the presented results and the foundation of SAVRY.

References

1. Palm HW, Knaus U, Appelbaum S et al (2018) Towards commercial aquaponics: a review of systems, designs, scales and nomenclature. Aquaculture International 26(3):813–842. https://doi.org/10.1007/s10499-018-0249-z

2. Díaz PA, Álvarez G, Varela D et al (2019) Impacts of harmful algal blooms on the aquaculture industry: Chile as a case study. Perspectives in Phycology (PiP) 6(1–2):39–50. https://doi.org/10.1127/pip/2019/0081

3. Cubillo AM, Ferreira JG, Lencart-Silva J et al (2021) Direct effects of climate change on productivity of European aquaculture. Aquaculture International 29:1561–1590. https://doi.org/10.1007/s10499-021-00694-6

4. https://www.agtira.com/about-us/. Accessed 27 February 2023

5. https://www.rewe.de/nachhaltigkeit/nachhaltig-einkaufen/green-farming/. Accessed 27 February 2023

6. Atique F, Lindholm-Lehto P, Pirhonen J (2022) Is Aquaponics Beneficial in Terms of Fish and Plant Growth and Water Quality in Comparison to Separate Recirculating Aquaculture and Hydroponic Systems? Water 14(9):1447. https://doi.org/10.3390/w14091447

7. https://agriculture.ec.europa.eu/farming/organic-farming/organic-production-and-products_en#rulesonwineaquacultureandhydroponics. Accessed 27 February 2023

8. https://savry.org. Accessed 27 February 2023

9. Miličić V, Thorarinsdottir R, Santos MD et al (2017) Commercial aquaponics approaching the European market: to consumers' perceptions of aquaponics products in Europe. Water 9(2):80. https://doi.org/10.3390/w9020080

10. Fruscella L, Kotzen B, Milliken S (2021) Organic aquaponics in the European Union: towards sustainable farming practices in the framework of the new EU regulation. Reviews in Aquaculture 13(3):1661–1682. https://doi.org/10.1111/raq.12539

11. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02018R0848-20220101&from=EN. Accessed 27 February 2023

12. https://agriculture.ec.europa.eu/system/files/2022-09/organic-rules-faqs_en.pdf. Accessed 27 February 2023

13. https://www.kesko.fi/en/media/news-and-releases/news/2018/we-examined-what-finns-really-eat-everyday-meals-revolve-around-nine-dishes/. Accessed 25 March 2023

14. Lennard W (2017) Commercial Aquaponic Systems– Integrating recirculating fish culture with hydroponic plant production. Produced and published in Australia, ISBN 978-1-64204-837-7

15. https://farmingaquaponics.com/best-fish-for-cold-water-aquaponics/. Accessed 25 March 2023

16. https://www.marketscreener.com/quote/stock/KESKO-OYJ-1412478/news/Kesko-Oyj-Finns-eat-a-greater-variety-of-fish-than-before-24651753/. Accessed 25 March 2023

17. https://www.k-ruoka.fi/kauppa/tuotehaku/sailykkeet-keitot-ja-ateria-ainekset/sailykkeet/kala--ja-ayriaissailykkeet. Accessed 25 March 2023

18. Linhart O, Kudo S, Billard R et al (1995) Morphology, composition and fertilization of carp eggs: a review. Aquaculture 129(1–4):75–93.

19. Binsi PK, Nayak N, Sarkar PC et al (2019) Conversion of carp roe mass to caviar substitutes: Stabilization with oregano extract. LWT 108:446–55.

20. Hoffman RC (1995) Environmental change and the culture of common carp in medieval Europe. Guelph Ichthyology Reviews 3:57–85.

21. FAO (2020) The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome. https://doi.org/10.4060/ca9229en

22. Mohsenpour SF, Hennige S, Willoughby N et al (2021) Integrating micro-algae into wastewater treatment: A review. Science of the Total Environment 752:142168. https://doi.org/10.1016/j.scitotenv.2020.142168

23. Hayes M, Skomedal H, Skjånes K et al (2017) Microalgal proteins for feed, food and health. In: Gonzalez-Fernandez C, Muñoz R (eds) Microalgae-Based Biofuels and Bioproducts: From Feedstock Cultivation to End-products. Woodhead Publishing: Duxford, UK, pp 347–368. ISBN 978-0-08-101027-3. https://doi.org/10.1016/B978-0-08-101023-5.00015-7

24. Zullaikah S, Utomo AT, Yasmin M et al (2019) Ecofuel conversion technology of inedible lipid feedstocks to renewable fuel. In: Azad K (ed) Advances in Eco-Fuels for a Sustainable Environment. Woodhead Publishing: Duxford, UK, pp 237–276. https://doi.org/10.1016/B978-0-08-102728-8.00009-7

25. Bauer L, Ranglová K, Masojídek J et al (2021) Digestate as Sustainable Nutrient Source for Microalgae—Challenges and Prospects. Applied Sciences 11(3):1056. https://doi.org/10.3390/app11031056

26. https://www.algatech.com/why-whole-food-sourced-from-microalgae-is-big-deal-david-foreman-the-herbal-pharmacist-explains/. Accessed 25 March 2023

27. Stevčić Č, Pulkkinen K, Pirhonen J (2019) Screening of microalgae and LED grow light spectra for effective removal of dissolved nutrients from cold-water recirculating aquaculture system (RAS) wastewater. Algal Research 44:101681.
https://doi.org/10.1016/j.algal.2019.101681

28.Calderini ML, Stevčić Č, Taipale S et al (2021) Filtration of Nordic recirculating aquaculture system wastewater: Effects on microalgal growth, nutrient removal, and nutritional value. Algal Research 60:102486. https://doi.org/10.1016/j.algal.2021.102486

29. Neori A (2011) "Green water" microalgae: the leading sector in world aquaculture. Journal of Applied Phycology 23:143–149.

30. Stevčić Č, Pulkkinen K, Pirhonen J (2020) Efficiency of Daphnia magna in removal of green microalgae cultivated in Nordic recirculating aquaculture system wastewater. Algal Research 52:102108. https://doi.org/10.1016/j.algal.2020.102108

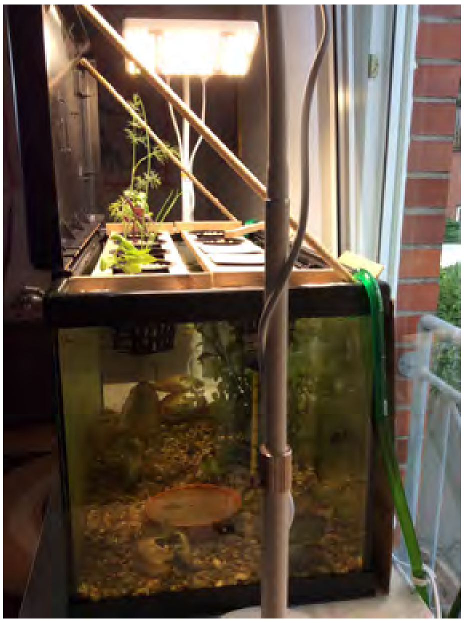
31. Koutra E, Economou CN, Tsafrakidou P et al (2018) Bio-Based Products from Microalgae Cultivated in Digestates. Trends in Biotechnology 36:819–833.

32. Yogev U, Vogler M, Nir O et al (2020) Phosphorous recovery from a novel recirculating aquaculture system followed by its sustainable reuse as a fertilizer. Science of The Total Environment 722:137949. https://doi.org/10.1016/j.scitotenv.2020.137949

33. Kotzen B, Emerenciano MGC, Moheimani N et al (2019). Aquaponics: Alternative types and approaches. In: Goddek S, Joyce A, Kotzen B, Burnell GM (eds) Aquaponics food production systems: Combined aquaculture and hydroponic production technologies for the future. Springer Open, pp 301–330. ISBN 978-3-030-15943-6 (eBook). https://doi.org/10.1007/978-3-030-15943-6

34. https://www.goodnewsfinland.com/en/articles/feature/2018/finnish-innovation-makes-veggie-growth-greener/. Accessed 26 March 2023

35. Kloas W, Groß R, Baganz D et al (2015) A new concept for aquaponic systems to improve sustainability, increase productivity, and reduce environmental impacts. Journal of Aquaculture Research & Development 7(2):179–192. https://doi.org/10.3354/aei00146



An AP-system with ornamental fish and edible plants in the author's living room.