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Modifications in aquaculture technology for increasing fishpond's primary productivity in temperate climatic conditions

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Abstract: Aquaculture plays a great role in producing foodstuffs, sustaining inland capture fisheries and providing employment. The key to future development in pond aquaculture is diversification of production technology, intensity, and function connected to increasing the environmental value of pond areas. New production systems involve a combination of intensive and extensive pond culture, increasing productivity and improving nutrient utilisation and fish species diversification. The most important principle of these systems is the possibility to use the wastes from intensive aquaculture as the input for extensive, environment-friendly fish production. These systems were proven to be profitable and sustainable in tropical and subtropical areas. However, for temperate climatic conditions, such data are scarce. For this reason, we decided to discuss modifications that, in our opinion, can be applied in an extensive part of the integrated intensive-extensive system in temperate climatic conditions in order to increase the overall productivity of the pond aquaculture.

Keywords: integrated intensive-extensive aquaculture; carbon-nitrogen ratio, periphyton, pond aeration, polyculture fish farming

INTRODUCTION

The rapid depletion of natural resources of marine and freshwater fish and increased demand for aquaculture products is the main reason why, over the past 30 years, it has become the fastest-growing food production sector in the world. The recent fast development of aquaculture has been mainly oriented toward food security and income generation. Therefore, fish culture has become much more intensified, which has drawbacks such as increased environmental impact due to large amounts of waste-water discharge [Saremi *et al.* 2013].

Water quality and availability are becoming one of Central European aquaculture's main limiting factors [Všetičková *et al.* 2012; Wezel *et al.* 2013]. Freshwater resources are under the sway of such factors as water demand driven socio-economic activities and climate-governed seasonality in the water supply. What is more, the recent rapid progress in climate change hinder efforts to control these factors. According to a report published by the European Environmental Agency in 2019 [EEA 2019] water shortage affects around 15–25% of total European territory. Over half of southern Europe constantly lives under water deficiency conditions, particularly during the summer. Basins and rivers in the Czech Republic, Germany, Poland, Denmark and the United Kingdom are all at risk of water scarcity. The main contributory factors to this risk are food production, agriculture, tourism, the use of water for cooling in energy generation and overall high exploitation of public water supplies. Concerning the availability and type of water supply, freshwater fish farming can be divided into three basic types: a) recirculating systems, b) flow-through systems, and c) pond systems.

In the **recirculating systems,** the unutilised nutrients are mechanically and biologically turned into mineral forms and integrated into bacterial biomass or released into the atmosphere as nitrogen or carbon dioxide. The main purpose of this is to eliminate the excessive amounts of nutrients with biofilters to provide good-quality water for fish. However, water filtration in recirculating systems requires mechanical devices that generate high energy costs. Over 60% of biogenic elements are removed from the system during filtration, thus wasted.

The **flow-through systems** are prevalent in Central Europe for the production of carp species and especially for the production of carnivorous fish (trout, catfish). These systems require a constant supply of clean water, and very often, postproduction wastewaters are not properly treated or not treated at all before being removed from the system. In this case, biogenic elements are introduced into the environment, contributing to eutrophication processes.

Pond aquaculture is in opposition to the above-mentioned systems. In ponds the unutilised nutrients are reused by primary producers and passed on through all levels of the pond trophic web. As a result, a considerable share of biogenic elements is returned into natural fish feed. Therefore, fish ponds are able to accumulate and utilise effectively high amounts of nutrients. Thanks to this advantage, pond culture still has the potential to be an important part of European freshwater aquaculture.

The key to future development in pond aquaculture is diversification in terms of the production technology, the level of production intensity, and the function related to increasing the environmental value of pond areas. The last example is particularly essential when discussing innovative systems that combine different types of production aimed at increasing productivity while reducing the environmental impact. The most important principle of these systems is the possibility to use agricultural wastes as the input for environmentally friendly fish production in ponds. Therefore integration of new, innovative solutions into traditional pond aquaculture aimed at higher productivity, improved nutrient utilisation and fish species diversification will make it economically viable while remaining environmentally friendly.

This unique quality of fish ponds has become the basis for the development of integrated aquaculture. This process initially originated in Asia, where different agricultural wastes were traditionally used as a source of fertilisers for fish ponds [Chang 1987; Edwards 1993; NACA 1989]. Different types of such integrated systems have become popular around the world and one of them combines the advantages of intensive and extensive aquaculture. The concept is built upon water circulation between intensive and extensive system units. Wastewater from the intensive fish production part is transported to the extensive unit, which is usually a fish pond. There, through the biological and biochemical processes, nutrients are retained in fish biomass, accumulated in pond sediments or changed into a gaseous state and released into the atmosphere. When the intensive unit of the system is properly designed in terms of fish biomass and feeding intensity, then the extensive unit is able to efficiently process delivered nutrients and supply good quality water back to the intensive part. Furthermore, literature data suggest that there are ways to further enhance nutrient retention ability, which leads to ecologically more sustainable production systems.

Fisheries and aquaculture products play an important role in the European food supply. Facing the deficiency in captured fish supplies, aquaculture benefits from the increasing market demand for fish and fish products. In central Europe, freshwater fish production is based on pond farming, with common carp (*Cyprinus carpio* L.) being the most common species produced. Czech Republic and Poland are the leading EU producers of common carp, each producing about one-quarter of the EU total. On the global level, this species is the third most farmed finfish [Eurostat 2019]. However, the majority of ponds are exploited in a traditional way, based on low production intensity. Unfortunately, a recent increased competition from relatively cheap imports from other regions is the reason why extensive pond farming has become unprofitable. The key to progress in aquaculture in Central and Eastern Europe is diversification at the level of functions, technologies, production intensification, and fish species produced. Additionally, one of the main challenges facing the fishpond economy in the coming years is the need to improve the ecological and economic efficiency of traditional fisheries production technology. That could be achieved by applying modern concepts and new technological solutions at the technical and biological levels.

Modified intensification techniques such as the integrated intensive-extensive aquaculture systems are increasingly used in Asia and countries of the tropical climate zones and have been a significant economic growth source of the sector [Asaduzzaman 2008; Crab 2007]. Some solutions, such as combining pond fish farming with other agricultural activities like plants cultivation or application of organic manure in fish ponds, have long been a tradition and applied commercially for decades in Europe. Others, including integration of aquaponics and fish production in recirculated systems or integrated multitrophic aquaculture (IMTA), need adjustments in European climatic conditions. Unfortunately, there has been almost no industry uptake of the aforementioned concepts. In contrast, scientific evidence suggests that this recycling of nutrients is possible in modern European aquaculture, where the waste nutrients from finfish aquaculture are used as energy and nutrients for organisms such as algae, shellfish and seaweeds [Giangrande *et al.* 2020; Kleitou *et al.* 2018].

For temperate climatic conditions, such data are scarce and therefore, the present paper intends to focus on the analysis and summary of the data concerning the extensive (pond) part of the integrated aquaculture system. As semi-natural ecosystems, many fishpond parameters such as fish stock, nutrients load, or water level are under human control. Therefore, the management practice can significantly influence pond production and the environment. Specifically, we are considering modifications that can be applied in temperate climatic conditions to increase the overall productivity of the integrated aquaculture system.

The present paper is compiled to fill in the gap concerning the possible way of increasing extensive pond productivity. It provides researchers, fishpond owners and operators with basic knowledge and ideas on selecting research directions and production techniques and technologies adaptable to their specific conditions. This short review summarises the basic principles and mechanisms of natural food-based aquaculture and explores the potential of pond modifications that have been or could feasibly be applied in central European climatic conditions.

MATERIALS AND METHODS

For the purpose of this article a detailed literature survey was performed. The literature data was selected and compiled to obtain the following structure. First, the principles of integrated intensive-extensive aquaculture systems used in central Europe are briefly reviewed. Then, how polyculture enhances nutrients recycling is described, followed by a walkthrough microbial and photosynthetic intensification techniques.

RESULTS AND DISCUSSION

INTEGRATED INTENSIVE-EXTENSIVE AQUACULTURE SYSTEMS

The basic principle of integrated fish production is the use of extensive fish ponds to treat wastewater produced by intensive aquaculture. Fish in the intensive part are stocked in high density and fed artificial diets, while fish in the extensive part rely solely on natural feed. Regarding technological conditions, we can distinguish three basic types of integrated aquaculture: cages in a pond and fish tanks combined with a pond [Asaduzzaman *et al.* 2006; Fullner *et al.* 2007; Pilarczyk *et al.* 2016; Yi, Lin 2001] or consolidation in one production chain the large traditional fishponds with smaller wintering ponds [Gal *et al.* 2003].

In the first approach, fish in high density are reared in cages in the open pond. Wastes and uneaten feed are removed from the cages by water flow and incorporated into the pond trophic web [Yi, 1999; Yi, Lin 2001]. The volume of fish stocking in the cages and feeding must be properly adjusted otherwise, excessive feeding may lead to the accumulation of suspended solids and nutrient-rich wastes in the cage surrounding. This can negatively affect overall water conditions [Sipauba-Taveres *et al.* 2016]. Also, the size of cages is limited depending on the aeration efficiency and the rate of water flow and therefore, paddle aerators are often used. They help to infuse the water with oxygen and force the water movement. The cage-pond integration is a technically uncomplicated solution. Thus, its incorporation into traditional fish farming does not involve high investment costs.

Much more technically complex is the combination of fish tanks with extensive ponds. The intensive unit and pond (the extensive units) are separated in this type of production. Subsequently, there is a need for electric pumps or some other solution that will force the movement of the wastewater from the fish tanks into the pond and the treated water back from the pond. In addition, due to high stocking density, the water in the intensive fish tanks requires constant aeration. Despite these technical impediments, combined intensive fish tanks and extensive ponds production system allows for better control of technological parameters such as the water flow, aeration or fish handling and catching.

The third integrated fish production system combines two different types of ponds. The intensive fish production takes place in small earthen ponds (frequently these are wintering ponds), and the effluents are pumped out or collected in a drainage canal, to be pumped from there or gravitationally discharged into a much bigger extensive pond. Treated water from the extensive pond must be pumped back into intensive ponds.

From the production angle, the major advantage of all of the above-mentioned types of intensive – extensive aquaculture is the possibility to produce valuable predatory fish or species, which in traditional fish ponds is difficult. In the intensive unit, a farmer can easily control weight gain, water parameters and the feeding regime. The extensive pond is usually stocked with traditionally raised species in much lower densities to engage the wastewater treatment. Subsequently, delivered nutrients can be recycled within the fishpond and recovered in fish production [Avnimelech *et al.* 1986; Yadav *et al.* 2007; Yi, Lin 2001]. This allows the farmers to broaden the range of produced fish species. Furthermore, this kind of production does not claim more land; therefore, the "ecological footprint" measured by quantifying the amount of ha needed to produce 1 kg of fish [Kautsky *et al.* 1997; Folke *et al.* 1998] can be reduced. Obviously, that increases economic sustainability [Roth *et al.* 2000] and decreases water usage, which results in decreased wastewater pollution.

POLYCULTURE

Traditional fish ponds are complex environments comprised of several niches for species from diverse levels of the food web [Sipauba-Tavares *et al.* 2011]. Four main biotopes can be distinguished in all fish ponds: the water surface, the water column, the pond bottom, and the periphyton. This quality can be fully utilised in temperate climatic conditions by using a wide range of fish species with different feeding habits and requirements. Therefore, polyculture practices are recommended as a management system. This system is based on at least two, but preferably more species (or size categories of the same species) characterised by complementary feeding niches. They inhabit the same pond to utilise a maximum range of available food and water resources, allowing to increase the fish production per unit area of a water body. This solution has also been shown to improve the environmental conditions of the pond [Azim, Little 2006; Rahman *et al.* 2008; Shoko *et al.* 2014]. The combination of species should be balanced in order to maximise synergistic and minimise antagonistic fish-fish and fish-environment interactions.

The pond water surface can be periodically abundant in aquatic or terrestrial insects; however, it is a rather limited source of fish food. The phytoplankton and zooplankton that inhabit the water column cover a large share of natural fish food, especially for the advanced fry of all cyprinids, pike or pikeperch [Rahamn *et al.* 1992; Woynarovich *et al.* 2010]. Biological control of phytoplankton scum using herbivores (plankton feeding fishes such as silver carp) helps to reduce the blue-green algae. Excessive growth of blue-green algae causes shallow thermal stratification, lesser availability of soluble phosphate in the top layer and prevents the penetration of light for photosynthesis. Frequently this leads to detrimental anoxic conditions in the deep areas [Bhatnagar, Devi 2013]. Furthermore, according to van Dam *et al.* [2002], fish yields from extensive and semi-intensive ponds could be up to ten times higher if primary production is harvested directly by herbivorous fish.

Another significant role as a food source is the bacterioplankton since other planktonic organisms feed on it, and the colonies of these organisms are, in turn, consumed by fish. Thereby an extra trophic level takes part in converting plankton into fish biomass. Many fish species are unable to harvest phytoplankton directly from the water column; thus, a large part of the phytoplankton contributes to nutrients for the bottom sediments [van Dam *et al.* 2002]. Bottom sediments are explored by fish like black carp, common carp or sturgeon in search of detritus, bacteria or ciliate that live and develop there. Water weeds attached to the pond bottom are consumed by grass carp. Also, catfish is a bottom feeder with a varied diet composed of insect larvae, clams, fish, plants, snails and crayfish.

Periphyton consists of bacteria, algae, moss and animals of different sizes that live on the surface of objects submerged in the water. When provided sufficient area for development, it may also comprise a considerable quantity of food for fish like tilapia [Reboucas *et al.* 2012] or typically omnivorous fish like common carp [van Dam *et al.* 2002].

Results of studies conducted in Hungary [Gal *et al.* 2009] suggest that polyculture fish stock comprising 40–50% of common carp should be used. This species has a larger impact on pond productivity than most other benthivorous fish [Rahman, Verdegem 2007]. Parkos III *et al.* [2003] showed that phytoplankton biomass and total phosphorus availability is larger in the presence of common carp than in the presence of channel catfish *Ictalurus punctatus*. In studies carried out by Wahab *et al.* [2002], polyculture with common carp gave 60% higher yield in rohu (*Labeo rohita*) production than with mirgal (*Cirrhinus cirrhosis*). The individual body mass of carp should be adjusted to ensure that they can effectively re-suspend the bottom sediment to increase nitrogen and phosphorus transport from sediment to the water column, and thus the flow of biochemical compounds in the pond. Other species introduced to the pond should be filter feeders such as bighead carp (*Hypophthalmichthys nobilis*), silver carp (*Hypophthalmichthys molitrix*) and grass carp (*Ctenopharyngodon idella*). Also, there is a niche for species or appropriate age range for fish that feed on periphyton.

Predator fish added to a polyculture system may increase the average weight of prey species. The best results are obtained when the size of predator fish is adjusted to consume preferably small or slow-growing prey. This prevents the prey from growing large enough to compete for food with larger fish of its species [Shresta *et al.* 2018] In a relatively small pond, it is not likely to achieve predator/prey balance similar to natural conditions. But in the practice of small scale aquaculture, it has been shown that predator fish, when stocked at rates of 5 to 20 fish per 100 m^2 of pond surface area, are able to completely control the reproduction of the prey species.

One of the basic concepts of intensive-extensive fish production is to attain complete utilisation of nutrients in one production system by producing organisms from different levels of the ecosystem's trophic network. Accumulation of the scientific knowledge and practical know-how caused further development of the traditional polyculture into the Integrated Multi-Trophic Aquaculture (IMTA) concept. Similarly to polyculture, the term Multi-trophic refers to the inclusion of different species from different trophic or nutritional levels in the same aquaculture system [Chopin 2006; Chopin, Robinson 2004]. But in the last case, the term *integrated* refers to the more intensive cultivation of the different species, frequently in monoculture but not necessarily right at the same location, connected by nutrient and energy transfer through water. These systems are used to recycle waste nutrients from higher trophic-level species into the production of lower trophic-level crops of commercial value. The IMTA concept is based on the reduction of the environmental impacts directly through the uptake of dissolved nutrients by primary producers (e.g. macroalgae) and of particulate nutrients by suspension feeders (e.g. mussels), and through removing the nutrients from the location. Thus, IMTA increases the efficiency of converting nutrients into total biomass in the system [Crab *et al.* 2007]. Many examples of IMTA systems could be found in marine as well as in freshwater aquaculture, especially in the countries of southern Asia.

For instance, Kibria and Haque [2018] applicated IMTA technology in freshwater earthen ponds. The system included ponds stocked with a typical for Bangladesh mix of carp species (catla (*Catla catla*), silver carp (*Hypophthalmichthys molitrix*), rohu (*Labeo rohita*), and mrigal (*Cirrhinus mrigala*)) combined with freshwater snails (organic waste extractive) and aquatic plants (inorganic waste extractive). In addition, carp ponds contained cages stocked with stinging catfish (*Heteropneustes fossilis*) fed by snails. The same study demonstrated that the application of IMTA principles considerably increased pond productivity but allowed the water quality parameters to be kept within balanced levels. Although, it should be noted that the study showed results in quite warm conditions compared to Europe, where the typical summer water temperature is within 28–32°C.

An example of the IMTA application in a more temperate climate has been provided by Jaeger and Aubin [2018]. The experiment was performed in France from March to November and aimed at evaluating the influence of a planted lagoon on water quality in a freshwater pond system. The IMTA system in this study comprised a pond stocked with a polyculture of common carp (*Cyprinus carpio*), roach (*Rutilus rutilus*) and tench (*Tinca tinca*), which were supplied with formulated feed. The polyculture pond was connected with the lagoon (neighbouring pond) planted with macrophytes to filter the water. A water pump circulated water from the lagoon to the polyculture pond. This IMTA system was compared with "extensive" (unfed) and "semi-intensive" fishpond systems without a planted lagoon. The authors tested the hypothesis that combining a planted lagoon with an intensive pond decreases the latter's environmental impacts and maintains or increases its fish productivity. The study demonstrated that the IMTA system had better water quality throughout the rearing season and also seemed to have less variable nutrient dynamics and physicochemical parameters (pH, $\%O_2$) than that in extensive or semi-intensive ponds.

AERATION SYSTEMS

The concentration of oxygen dissolved (*DO*) in water depends on temperature, salinity and barometric pressure. As water salinity and/or temperature increase, *DO* concentration decreases. The concentration of *DO* also differs between day and night time. During daylight hours, plants in ponds may produce oxygen fast enough to increase the *DO* concentration above saturation. Like in case of fish and other pond organisms, plant respiration leads to a decline in *DO* concentration at night. Therefore, during warm months *DO* concentrations are often below saturation. In production ponds, dissolved oxygen may decrease to level of 5–10 $mg \cdot dm^{-3}$ at night, and at sunrise may be less than 2 $mg \cdot dm^{-3}$ [Boyd 1990]. Obviously, under the condition of low *DO* concentration, it is necessary to aerate the water to force the movement of oxygen between the atmosphere and the water surface to prevent stress and mortality of fish.

Aeration performed by water turbulence promotes mass convection of water and oxygen into deeper places within the water body. At the same time, aeration minimises the stratification of chemical substances and thermoclines by bringing cooler oxygen-poor water to the pond's surface, where it is infused with oxygen. In this way, warmer oxygen-rich water reaches the pond's bottom. The organic and mineral matter accumulates in the sediments as the pond ages. When bottom sediments get more oxygen through aeration, it can be utilised by aerobic bacteria, known to be more efficient in breaking down organic matter compared to anaerobic microorganisms.

Aeration efficiency is the key element and depends on the design features that determine both cost-effectiveness and performance. Paddlewheel aerators and propeller-aspirator-pumps are probably the most widely used [Nugroho *et al.* 2021]. Also, pump sprayers, vertical pumps, and diffused-air systems are in use. Boyd and Martinsen [1984] performed comparison tests of propeller-aspirator pumps, spray-type surfaces and diffused-air system aerators. According to their salt-mixing experiments, the propeller-aspirator pump performed more efficiently than the other two. Results suggest that the first type of aerator might be suited better for mixing the entire volume of water in the pond. Qayyum *et al.* [2005] showed that fish production in ponds aerated with vertical pump diffusers was averagely 80% higher than in non-aerated ponds. Also, total ammonia nitrogen was lower in aerated ponds (averagely 30 $\mu g \cdot dm^{-3}$ in May and 39 $\mu g \cdot dm^{-3}$ in June) than in ponds with no aeration (averagely 73 $\mu g \cdot dm^{-3}$ and 80 $\mu g \cdot dm^{-3}$ in May and June, respectively). Relatively simple solutions, as mentioned above, were proven to be useful, however, the problem of energy supply seems to be the main drawback of electrically powered equipment. For a location away from the electrical power grid, the cost of supplying power is one of the main practical limitations. In countries where solar radiation is sufficiently high, solar aeration systems can play a vital role in improving the water quality by removing dissolved gases [Chowdhury *et al.* 2018; Prasetyaningsari *et al.* 2013].

In some cases, using a photovoltaic system need battery backup of properly adjusted capacity because the need for aeration also emerges on cloudy days or during the night period when the concentration of *DO* concentration is low [Prasetyaningsari *et al.* 2013]. Recently Atia *et al.* [2012a, b] presented the aeration of water controlled by a "PEM fuel cell powered air diffused aeration system", which opens a prospective for renewable energy in pond aquaculture. The proposed aeration system does not require a connection to the electrical power grid and may be used in any location. According to the authors, fuel cells are of the most promising technologies for delivering clean and efficient power for many applications. A resurgence of interest in fuel cells has occurred with increased urgency in reducing pollution and greenhouse gas emissions. Fuel cells are very useful as a power source in remote locations due to their high reliability and no moving parts. Recently artificial intelligence techniques are becoming useful as alternate approaches to conventional techniques or as components of integrated systems.

ORGANIC CARBON SUPPLEMENTATION

A considerable proportion of protein-rich feed becomes a major source of ammonium when the pond is a part of an integrated intensive-extensive system. For this reason, minimising the impact of toxic inorganic nitrogenous species (NH_4^+ and NO_2^-) becomes the basic issue that requires a systemic solution.

Unlike carbon dioxide, nitrogenous metabolites cannot be released into the air by diffusion or with the help of artificial aeration. Various approaches based on nitrification enhancement of the ammonium and nitrites to the inert nitrate species have been tested. These involve biofilters such as immobile surfaces serving as substrates to the nitrifying bacteria [Brahmchari *et al.* 2018; Suantika *et al.* 2016]. The problem with biofiltration is the high costs and the fact that a large mass of feed residues must be treated and digested. More recently, biofloc aquaculture has gained an interest in highly intensive systems [Boyd 2018; Gou *et al.* 2019]. This technology is based on bacterial floc suspension that needs constant aerobic conditions to proceed with decomposition. If densely developed, these microorganisms function as a bioreactor that effectively controls water quality. The strategy is based on the enhancement of ammonium assimilation into microbial proteins by providing additional carbonaceous materials to the system. Biofloc technology can also be applied in traditional fish ponds. An important benefit of this method is the possibility of microbial protein as a source of feed protein for growing fish.

The C/N ratio has been identified as the key environmental factor that determines the products of nitrate reduction [Kraft *et al.* 2014]. The control of inorganic nitrogen accumulation hinges upon the utilisation of carbohydrates (sugar, starch, cellulose), accompanied by the immobilisation of inorganic nitrogen, which bacteria use for building up proteins. The ability to adjust the C/N ratio and thus bacterial processes is an attractive controlling tool for intensive aquaculture. However, nitrogen removal pathways could be different depending on substrate utilisation. When organic carbon is unavailable, the system is primarily autotrophic, using inorganic carbon from the alkalinity as a substrate. If sufficient supplemental organic carbon is added, then heterotrophic bacteria utilise it along with nitrogen. As indicated in US Environmental Protection Agency [US EPA 1993] maximum growth rate of heterotrophs is significantly higher than nitrifiers (5 day^{-1} and 1 day^{-1}, respectively). Because the energetics for the heterotrophic bacteria are more favorable than for autotrophic bacteria, it is assumed that heterotrophic bacteria first assimilate available nitrogen using carbohydrates. Then, the remaining nitrogen is utilised by autotrophic bacteria with the use of inorganic carbon. Several studies focused on estimating the most effective C/N ratio in lab-scale and indoor culture trial systems. The majority of them demonstrated that the addition of carbohydrates helps to reduce inorganic nitrogen and increase microbial biomass [Avnimelech 1999; Chen *et al.* 2017; Panigrahi *et al.* 2018; Torres-Beristain *et al.* 2005].

For instance, Chen *et al.* [2017] studied the effect and extent of the impact of different C/N ratios on the nitrate removal efficiency in ponds sediments. Their results showed that the nitrate removal efficiency increases along with increasing the C/N ratio. Based on this, the authors recommended a C/N ratio of 8 for nitrate removal from the pond sediments. This proportion was shown to allow for denitrification without nitrite accumulation. Avnimelech [1999], in a laboratory experiment, utilised the suspension of sediment from a commercial tilapia pond. He demonstrated that the addition of glucose at a concentration 20 times higher than that of total ammonia nitrogen helped reduce almost all ammonium within about 2 h. Furthermore, the process was not accompanied by the concomitant production of nitrite or nitrate. In another experiment on a dense shrimp culture, the author showed that the addition of glucose and cassava meal led to a significant reduction in the accumulation rate of ammonium in the tanks. Also nitrates and nitrites were reduced.

PANIGRAHI *et al.* [2018] evaluated various ratios of carbon and nitrogen level in the culture of Pacific white shrimp (*Litopenaeus vannamei*, Boone, 1931). The experiment included a control tank, maintained autotrophically without adding any carbon source and treatment groups in which molasses were added in C/N ratios of 5, 10, 15 and 20. They highlighted that growth, physicochemical and microbiological parameters were higher in the treatment tanks compared to the control. Also, the higher C/N ratio treatment positively influenced the immunological parameters of the cultured shrimps. ASADUZZAMAN *et al.* [2010a] conducted a trial to examine the effect of three C/N rations: 10/1, 15/1 and 20/1, on natural food communities in freshwater prawn culture ponds. In addition to the artificial feed, tapioca starch was applied as a carbohydrate source. They observed that carbohydrate addition helped lower total ammonia nitrogen an NO_3-N and increased the biovolume of phytoplankton, crustaceans, and rotifers. Also, the biomass of heterotrophic bacteria was raised. Results suggest that under the C/N ratio of 20/1, the stocking density of prawn could be raised and/or periphyton grazing fish introduced to utilise the increased quantity of plankton, periphyton and microbial biofloc communities.

Microbial flocs can be an effective potential food source for cultured fish. AVNIMELECH and KOCHBA [2009] evaluated the contribution of microbial protein to the nutrition of tilapia. They added starch to enhance the assimilation of ammonium into microbial biomass. According to the researchers, microbes contributed close to 50% of the fish protein requirement. ASADUZZAMAN *et al.* [2010b] tested the effect of high-cost tapioca starch and low-cost maize flour on the ecology, production and economical performances of freshwater prawn ponds. Prawn juveniles were stocked either with Nile tilapia or rohu carp or both species mixed in 50% + 50% ratio to serve as bioturbation sources. In conclusion, they stated that the combination of fish species had a significant effect on pond ecology. Tested carbohydrate sources that increased the C/N ratio from 10 to 20 had no significant effect on water quality parameters, natural food abundance, or prawn and finfish production.

Another study by SILVA *et al.* [2017] aimed to improve tilapia production and was conducted with three carbon sources (sugar, molasses and cassava starch) which were arranged in two setups of carbon to nitrogen ratios (10:1 and 20:1). They concluded that under the C/N ratios of 10:1 and 20:1, the best carbon source for microbial floc formation were molasses and sugar. However, the growth performance of Nile tilapia did not differ between treatments. Therefore, the authors concluded that these three carbon sources may be an option for reducing production costs in regions where these products are available.

FUGIMURA *et al.* [2015] compared the effects of brewery residues, as a source of organic carbon, alongside sugarcane molasses and cassava flour on the performance of juvenile southern white shrimp (*Litopenaeus schmitti*). The results showed that the nutritional composition of biofloc was different depending on the carbon source and that the best growth performance of *L. schmitti* was recorded for brewery residues.

Although the concept of C/N ratio manipulation has been broadly investigated and gained popularity in southern Asia and the middle east, the knowledge base concerning its applicability in temperate climate conditions of Europe is still undeveloped.

SUPPORTING OF PERIPHYTON DEVELOPMENT

In the traditional pond aquaculture, several feeding approaches are usually applied: (1) fish feeds can be supplied into the pond; (2) fish can utilise organic matter which is produced by autotrophic primary producers such as algae; (3) fish feed on organic matter that is decomposed by bacteria, protozoa and other heterotrophic invertebrates. In integrated intensive-extensive systems, each of these three pathways is interconnected. Stable isotope studies [VAN DAM *et al.* 2002] show that a large share of microbial production in ponds relies on algal detritus. This is one of the main advantages of an extensive fish culture where non or minimum feed is needed. Fish production though, entirely relies on the pond ecosystem's biological productivity and solar energy [BOSMA, VERDEGEM 2011]. The main energy and nutrient source for stocked fish is phytoplankton, which production can be stimulated by fertilisation. In integrated intensive-extensive systems, phytoplankton indirectly relies on the amount of nutrients coming from the intensive unit [GAL *et al.* 2010; 2011]. Although most herbivorous fish in traditional polyculture ponds can feed directly on suspended algae, the quantity ingested in this way is usually not sufficient to fully meet their energy requirements [HASAN *et al.* 2012; JHA *et al.* 2018]. For most cultured fish species, benthic algae, algal detritus or plant fodder are more easily accessible. Fish yields from extensive and semi-intensive ponds could be up to ten times higher when primary producers are harvested directly by herbivorous fish [VAN DAM *et al.* 2002]. Most such algae require hard substrates for attachment [DIOS *et al.* 2014; SIGNOR *et al.* 2015; TORTOLERO *et al.* 2016], which is usually absent in well-managed, traditionally exploited ponds.

In the integrated systems, high nutrient load is typically introduced to the pond from the intensive unit. The latter creates perfect conditions for phytoplankton blooms, limiting light penetration to the pond bottom. This lack of light limits the benthic algae development. Periphyton mats may be efficient biofilters as they can reduce ammonia levels in water [AZIM, LITTLE 2006]. Therefore, artificial substrates as periphyton growth providers have been the subject of many investigations. Most of them were carried out in tropical and subtropical environments and proved successful in raising pond productivity. The obtained data point toward a strong influence of substrate type both on periphyton productivity and composition, which convert directly into fish yield [KESHAVANATH *et al.* 2001; MILSTEIN *et al.* 2003]. Modifications of fish ponds to culture periphyton can bring substantial and satisfying benefits more easily and with little management.

This question has been broadly explored in tropical and subtropical climatic conditions [HAQUE *et al.* 2016; JHA *et al.* 2018; KUMAR *et al.* 2019; MILSTEIN *et al.* 2003]. GAL *et al.* [2010; 2012] recently provided quite convincing data for temperate climatic zones. Their experiment was carried out in extensive ponds stocked with common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*), which contained cages as intensive units stocked with African catfish (*Clarias gariepinus*). They tested three different setups for periphyton development by creating additional areas made of the plastic substrate, which equalled 0, 100 and 200% of the pond surface area. The study demonstrated that nutrient retention efficiency improves by facilitating periphyton development. The best results were noted where the periphyton area comprised 100% of the pond surface. It was concluded that additional substrate for periphyton growth increases the ratio of protein utilisation by 40% compared to traditional ponds.

Kosaros *et al*. [2010] presented different approaches focusing on periphyton quantity and quality in three different setups. The first one comprised two combined intensive-extensive fishponds, stocked with common carp and African catfish (*Clarias gariepinus*) in the extensive unit. A second treatment included three traditional polyculture fishpond stocked with common carp, hybrids of silver carp and bighead carp (*Hypophthalmichthys molitrix* V. × *Aristichthys nobilis* R.), grass carp (*Ctenopharyngodon idella*) and European catfish (*Silurus glanis*). The last variation consisted of two wetland-type pond systems constructed for experimental wastewater treatment. The study showed that water conditions in the intensive-extensive system were comparable to water in a traditional extensive fishpond. The authors concluded that periphyton grown on artificial substrates notably improves fish yield and water quality in aquaculture systems.

CONCLUSIONS

This short review outlines the range of production technologies that have been well developed for traditional fish farming. According to studies, C/N ratio manipulation may double protein input, while the right proportions of species polyculture double the production. The addition of a substrate for periphyton has been shown to raise production as much as 2–3 fold. The simplicity of the described methods allows their simultaneous application in order to meet the most optimal benefits and costs. Considering the increasing progress of climate change in Europe and the growing problems with water supply, we are convinced that traditional pond aquaculture needs transformative change. Furthermore, these changes must be environmentally friendly and cost-effective.

There is no doubt that described here, modified management of the ponds can affect many other aspects of pond utilisation. It allows concentrating and intensifying fish production on a smaller area inside the farms. Latter enables maintaining the remaining ponds with their current nature of production. In such a system, the more intensive part of the farm provides the dominant part of the production, expressed both in the fish biomass and the production value. At the same time, such a concept might allow reducing the intensity of production in the rest of the ponds, even to an extensive level, which allows for preservation or even improve the natural values of carp ponds.

Furthermore, the technologies described herein allow existing pond complexes to be protected as valuable landscape elements and refuges for the biodiversity of plants and birds. This way, besides sustaining habitats for natural wildlife, fish farmers have more opportunities for creating multifunctional fish farms for recreational use. Such action can be an essential argument in the possible valuation of costs or values of organic pond farms.

The solution can also have eco-hydrological implications. Concerning water management, an important feature of the described modifications is that water is used not only as a medium for the movement of matter but also as an active component of the ecosystem, providing a significant contribution to biomass growth. Biochemical (matter cycle) and biological (primary production) processes are inherent and indispensable elements of pond fishery production. The importance of these processes decreases with the increase of production intensification; however, they always influence the environmental conditions in the pond. We highlight that modifications described in our review can enhance such processes. Particularly bearing in mind that pond water is released to the environment after the end of the production cycle. Therefore, the more efficient the biochemical processes are in the ponds, the less post-production matter is discharged outside the fish farm.

However, examples of experiments that consider long-term production cycles are still lacking. We believe that there is an urgent need for multi-seasonal pilot studies that take into account the impact of seasonal temperature changes on the profitability of fish production in integrated systems. Their adjustment to central European climatic conditions will likely aid the more efficient use of land and water in an environmentally friendly and sustainable way. To achieve this ambitious goal, a compilation of detailed guidelines for implementing innovative production systems and their dissemination among fish producers is crucial to the further development of European freshwater aquaculture.

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