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Combining nursery closed-system and pond grow-out common carp (Cyprinus carpio) production is a profitable business in Hungary

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ABSTRACT

Extensive, large-scale long-term pond fish production has several challenges and high economic risks, such as continuous bird predation. Moreover, common carp (*Cyprinus carpio*) production costs are relatively high using this production strategy. To reduce risks and improve production safety and efficiency, European common carp farmers are challenged to shorten the classic 3-year production cycle. This study aimed to comprehensively analyze the main farm parameters, production efficiency, cost and revenue of a production strategy based on combining hatchery/nursery closed-system, a second phase of the nursery in ponds and a final phase of pond grow-out of common carp. A deterministic economic model was used. Combined production has a lower fish loss by bird predation, a shorter production cycle, a better feed conversion ratio than conventional pond fish production, and a similar yield at a cost of approximately 2.02 USD/kg. This value are higher than those assumed in the conventional extensive 3-year common carp, completely pond-based production strategy. However, the current assets turnover ratio is much lower in the latter case. The yearly average net revenue can increase by implementing a more intensive combined production strategy. The combined strategy can improve security and predictability of production while reducing the pond area used for grow-out of extensive common carp farm.

1. Introduction

In Europe, the common carp (*Cyprinus carpio*) is the most important species of fish in extensive or semi-intensive polyculture farming (Bostock et al., 2010). Feed practice is based on fishmeal-independent cereals. Common carp (*C. carpio*) production occurs mainly in freshwater ponds since the past century until now (Kestemont, 1995; EUMOFA, 2021) because of its good adaptability to the environment and wide range of use as food (Soltani et al., 2010; Manjappa et al., 2011; Rahman, 2015). Common carp production is mainly characteristic of Central and Eastern European countries (Czech Republic, Poland, Hungary, Germany, and Romania) (FAO, 2022), but its significance is high in Asia (Woynárovich et al., 2019). Common carp production in the EU-27 is considered to be small on a global scale (81.2 thousand tonnes), accounting for only 1.86 % of global common carp production in 2020 (FAO, 2022). Hungary is one of the largest common carp producers in the EU, with a production of approximately 17.4 thousand tonnes (2019), and the constant development of the extensive fish farming aquaculture sector is largely based on common carp (Specziár and Erős, 2020). These farms also produce other co-products other than common carp, such as, bighead carp (*Hypophthalmichthys nobilis*) /silver carp (/*Hypophthalmichthys molitrix*) grass carp (*Ctenopharyngodon idella*), wels catfish (*Silurus glanis*), pikeperch (*Sander lucioperca*), and common bream (*Abramis brama*).

Common carp production in Hungary and Europe is based on the conventional 3-year farming system, in which the fish reaches its market size in the autumn of the third year. The market-sized common carp weighs approximately 2.5–3 kg. Moreover, market-sized common carp can be produced in 2 years using feed, primarily in small-scale systems. In conventional production, larvae are produced by artificial propagation and reared to juveniles in extensive ponds during the first and second years. In the third year, they are moved to other extensive ponds to reach market size. In the combined fish farming technology, larvae are produced off-season by artificial propagation and reared in intensive

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closed recirculating systems; then, in the second year, they are moved to semi-intensive ponds to reach the market size. Therefore, market-sized common carp (2.6–3.0 kg/fish) can be obtained in two growing seasons by producing a minimum of 500–600 g of 1-year-old common carp in the first season. This requires a lower stocking rate of fry and more intensive feeding compared to conventional pond carp production. Artificial propagation involves human-controlled breeding, while off-season production allows for larvae production year-round by manipulating environmental conditions. The advantage of this production strategy is that market-sized fish can be sold relatively quickly, even in the second term by the end of the summer (Egyed et al., 2012).

Extensive fish ponds account for the largest part of common carp production in Hungary and the EU, and therefore, an increase in yield can be achieved by a more efficient use of the biological potential of ponds, by reducing feed costs and losses, and by more intensive production. Challanges in the fish market, stagnation of common carp consumption, relative decline in competitiveness, and several other factors suggest that the efficiency of production should be examined. Another common concern is the relatively low profitability of extensive pond fish production, and an increasing number of aquaculture enterprises are facing persistent labor shortages (Szűcs et al., 2017; Bondad-Reantaso et al., 2020). Production risks and the extent of yield loss are extremely high in extensive fish pond systems. The continuous presence of fish-eating birds, primarily the great cormorant (*Phalacrocorax carbo*) and secondarily the pygmy cormorant (*Microcarbo pygmeus*) can lead to the almost complete disappearance of fry from the pond. Therefore, classical fry production is nearly unfeasible. Increasing competitiveness is a key factor in the success of modern aquaculture (Asche, 2008; Kumar and Engle, 2016). Factors that have an economic impact on the safety of production, the cost of production, and the profitability of farming should be identified. Increasing productivity leads to lower production costs and higher profit.

Combining intensive and extensive systems by nursing larvae, fries and juveniles in intensive closed systems improves the survival of released fry, shortens the production cycle, frees up pond space for fry rearing, consequently increasing yields. Recirculating aquaculture systems (RAS) have several advantages, such as saving water, continuous monitoring, relatively low environmental impact, and, perhaps most importantly, no weather exposure and no reduction in yield due to fish loss (Váradi, 2001; Martins et al., 2010; Calone et al., 2019; Ahmed and Turchini, 2021). In this production strategy, the production phase of fry is separated from the ponds, namely, in a closed RAS, which is increasingly favored in the development of aquaculture in Europe (Martins et al., 2010; Espinal and Matuli, 2019). This production strategy results in higher and more predictable yields. Another solution is the use of the "pond recirculating systems," where effluent from small-scale intensive ponds is purified in a larger-scale extensive pond, providing the necessary organic matter input for fish production in the extensive pond. The purified water can then be recycled back into intensive ponds (NAS, 2020).

Thus, this study aimed to perform a comprehensive analysis of the production parameters, cost and income ratios, and efficiency of a production strategy by combining a nursery closed-system and pond-rearing common carp production. This combined production strategy involves off-season artificial common carp propagation followed by closed-system nursery and pond-rearing. The study sets up a deterministic economic model and its comprehensive sensitivity analysis. Main research questions were as follows: (1) What is the technological specificity of this fish production strategy? (2) How do the unit cost and competitiveness of the market-sized common carp, produced by combining nursery closed-system and pond grow-out common carp production, vary? Furthermore, which economic factors have the greatest impact on these economic indicators? (3) What effect does the change in the most important production parameters (feed conversion ratio, average weight at the time of sale) have on various economic indicators?

Table 1
Production data of the combined production strategy. Values were determined from a experiment for the first two phases and from three commercial common carp farms, operating under similar principles and natural conditions in Hungary for the last phase.

Description	Phase 1	Phase 2	Phase 3
	Hatchery and nursery I in a recirculating aquaculture system (RAS)	*Nursery II (intensive rearing in monoculture small ponds)*	*Grow-out (Market-sized fish production for human consumption in semi-intensive polyculture ponds)*
Phase length (*days*)	60	210	approx. 365
Used up area	0.7 m^3	0.6 ha	4 ha
Average water depth (*cm*)	-	110	130
Proportion of species by stocked (*common carp:silver carp: grass carp:wels catfish*)	-	-	80:15:3:2
Month of stocking	February	April	November
Average weight (*g*) of common carp at the time of stocking	0.01	1.2	760
Stocking density	7143 fish/m^3	6 kg/ha	345 kg/ha
Fish moratlity (*%*)	0	41	10/5/5/2*
Month of harvest	April	October	October
Average weight of common carp at harvest (*g*)	1.2	760	3600
Gross yield of common carp (*kg/area*)	3.60	1390.36	5734.70
Feed conversion ratio (FCR) (*kg/kg*)	0.57	1.27	3.45
Organic manure use (*t/ha*)	-	-	10.0
Natural yield (*kg/kg*)	-	0.84	2.09
Pond FCR (*kg/kg*)	-	2.11	5.23

Source: Own editing and farm-level data (2021)
* Two-year-old common carp (P2), two-year-old silver carp (B2), two-year-old grass carp (A2), two-year-old wels catfish (H2)

2. Materials and methods

2.1. Data acquirement

An experiment carried out in Hungary provided the primary data required for this study. Data were collected on the extensive and intensive technology of a combined (nursery closed-system and pond-based rearing) common carp-rearing experiment in Hajdú-Bihar County. The off-season artificial propagation was performed in the Fish Biology Laboratory of the Faculty of Agricultural and Food Sciences and Environmental Management of the University of Debrecen in February 2019, followed by pond-based rearing in an extensive pond farm in Hajdú-Bihar County in 2019–2021. Result of the experiment has led to sectoral improvements combining recirculation and pond fish farming, which allows for a safer and more efficient way of common carp production and a shorter production cycle (Kozłowski et al., 2014; Flickinger et al., 2020; Campanati et al., 2021; Thomas et al., 2021).

Based on the experiment, the production strategy has three distinct stages (Table 1). In phase 1, larvae and fryes rearing are performed in a closed RAS. Phase 2 is an intensive monoculture of juveniles in small ponds. The production cycle is completed with the grow-out in semi-intensive polyculture ponds to market-sized fish (phase 3), which takes 1 year.

The fish stock was derived from artificial, off-season propagation (phase 1). Preparation of males and females for mate was based on the manipulation of water temperature and photoperiod, as described by Kucharczyk et al. (2008). The mate was carried out in February. After the hatching of larvae and adsorption of the yolk sac, larvae were transferred into plastic circular tanks with a water volume of 350 L each. In the first phase of the rearing, fish stock was kept under controlled conditions, in a closed water recirculation system, provided with mechanical and aerated biofilter as well as an ultraviolet lamp. During the first week, larvae were fed *ad libitum* with live feed (*Artemia nauplii*); then, there were 2 days of co-feeding with commercial diet, and thus, they fed on commercially available dry feeds were used (BioMar Inicio Plus G; 0.5; 0.8, BioMar Group, Aarhus, Denmark). Oxygen saturation was maintained above 80 % by aeration stones, and the temperature was controlled at 22.0°C ± 0.1°C. The photoperiod was 12 h light and 12 h dark. Water temperature and dissolved oxygen were checked daily with a HACH HQ30d portable meter (HACH CO., Loveland, CO, USA). NO_2^-, NO_3-, and NH_4+ concentrations were measured using the HACH Lange DR/3900 spectrophotometer (HACH CO., Loveland, CO, USA). The duration of the hatchery plus nursery I phase was 8.5 weeks (60 days). At the end of phase 1, the average individual body weight of common carp and their biomass density was 1.2 g and 4.5 kg/m^3, respectively. After the body weight measurement, 3000 fish were transferred to phase 2, into pond conditions.

Since the larvae were hatched in February, the fish were released into the pond farm before the normal stocking period (April), considering the weather and plankton biomass, following intensive rearing. The flexibility of the technology lies precisely in the fact that if the external conditions (e.g., water temperature) are suitable, the reproduction can be forward to allow earlier stocking. Phase 2 began in April when the fry was stoked into fish ponds. Common carp can be sold following the autumn harvest or further fattened in the pond after the wintering period. In the experiment, stocking into the pond farm took place on April 10, into a 6000 m^2 pond (3000 fry/pond) at a water temperature of 16.7°C. The pond was prepared and fertilized before stocking to ensure adequate plankton production, which helps in nutrient enrichment, enhances plankton production, provides natural food for the cultured organism, and results in substantial fish growth and production (Sayeed et al., 2008). In the second phase, the survival rate was close to 59 %, and the growth was homogenoius, as approximately 85 % of the fish were of nearly the same size. Fish were mainly fed on plankton and benthos until mid-June, after which they were gradually switched to common carp compound feed (*Aqua Garant Classic 2–4 mm; Aqua Garant Vital Swim 4 mm*). At this stage, increasing the size of the fish and achieving faster growth were of top priority; thus, they were provided high protein feed, with a yield of approximately 1 kg of fry being obtained using 1 kg of feed. To ensure economical production and to meet market demands (min. 2.5 kg common carp), all fish harvested in phase 2 were reared in a grow-out pond for 1 more year.

Phase 3 was performed in a 4-ha round-dam pond with a 1.3-m average depth, gravity-controlled water inlet. Common carp was the main product. Fish with aproximately 760 g were stocked at the highest population density (80 %, 364 pcs/ha), followed by grass carp (15 %, 52 pcs/ha, 1 kg/pcs), silver carp (3 %, 16 pcs/ha, 0.6 kg/pcs), and catfish (2 %, 10 pcs/ha, 0.7 kg/pcs) totalling 345 kg/ha. After one year common carp reached an average weight of 3.6 kg by the end of the autumn harvest. The weight gain was aproximately 2.8 kg/fish. The gross yield of nearly 5750 kg/ha can be obtained.

Data was collected using detailed farm records in different production phases, covering culture conditions (e.g., water volume, water use, water exchange/replacement, energy use, labor requirements, and water temperature) and production parameters (phase duration, stocking density, individual body weight at the population, survival, mortality, reclassification, individual body weight at harvest, test catches, number of feeding days, and feeds used and their quantity). Average of the obtained data of pond farms was used as a basis for model calculation of the pond farm. Based on the production data, derived indicators for each production phase and the whole technology were defined: mortality per phase (%); total mortality (%); average weight at depopulation or harvest (kg/fish); gross yield (kg/ha or kg/m^3); weight gain ratio (kg/kg); feed conversion ratio (FCR) (kg/kg); and stocking density (fish/m^3, fish/ha).

Financial data included input and output prices of production and average cost items (Table 2). All obtained financial data expressed in Hungarian Forint (HUF) were converted into USD according to the average exchange rate (1 USD = 330 HUF) during the present study in 2021. The calculation does not derive the cost and revenue from analytical records and accounting data but assigns prices to the inputs used based on technological and production data. This is because the producers could not provide precise data on the costs of the items to be purchased but could provide precise data on the manual and mechanical work performed throughout the year. Furthermore, the specific output, materials used, and their quantities (expressed in physical units) from various farm registers were made available to us. Yield data was obtained from production enterprises, whereas sales price data was obtained from producer and trader enterprises and also from secondary sources (IAE 2021a,b, HCSO, 2021). Input and output prices reflected the average price level in 2021.

As a supplement to the primary analysis, we meticulously searched international and Hungarian literature related to the study topic, which we processed analytically after systematization. This information was collected from sectoral literature, articles, and international (FAO–*Food and Agricultural Organization of the United Nations*; EUROSTAT–*Statistical Office of the European Communities*) and Hungarian statistical databases

Table 2
Basic financial data of the model, input, and output prices. (1 USD = 330 HUF).

Name of phases	Description	Unit of measure	Value
Phase 1	Cost of breeding material (larval)	USD/pcs	0.01
	Feed prices		
	Artemia/Brine Shrimp	USD/kg	14.24
	Inicio Plus G (63/11)	USD/kg	8.18
	Inicio Plus 0,5 (58/15)	USD/kg	4.79
	Inicio Plus 0,8 (56/18)	USD/kg	4.12
	Electricity cost	USD/kWh	0.11
	Water cost	USD/m^3	0.74
	Other costs*	USD/m^3	4.33
	Wage (worker)	USD/hour	4.55
	Depreciation and maintenance	USD/m^3	41.86
	General expenses	USD/m^3	8.01
Phase 2	Feed prices		
	Aqua Garant Classic 4 mm	USD/kg	0.95
	Aqua Garant Vital Swim 4 mm	USD/kg	1.08
	Aqua Garant Classic 2 mm	USD/kg	1.03
	Other costs*	USD/ha	303.03
	Wage (worker)	USD/hour	4.55
	Depreciation and maintenance	USD/ha	90.91
	General expenses	USD/ha	260.10
Phase 3	Cost of breeding material (by-catch)	USD/kg	0.32
	Feed prices		
	Feed wheat	USD/tonne	151.52
	Feed corn	USD/tonne	121.21
	Organic manure	USD/tonne	3.79
	Fuel price	USD/L	1.15
	Other costs*	USD/ha	213.64
	Wage (worker)	USD/hour	4.55
	Depreciation and maintenance	USD/ha	151.52
	General expenses	USD/ha	143.94
	Sales price of market-sized common carp	USD/kg	2.05

Source: Own editing and farm-level data (2021)
* Other costs include fuel consumption and servicing of the machines used in the activity, use of animal health and other external services as well as consumables (rubber gloves, fishing nets, plankton nets, etc.).

Table 3
Mathematical correlations of deterministic model calculation.

Description	Correlation
Sold live weight (market-sized fish) (*kg*)	Live weight sold from a given area (kg/m^3, kg/ha) × area used (m^3, ha)
Yield (*kg*)	Amount of live weight harvested from the area (kg) – the amount of live weight released into the area (kg)
Biomass at harvesting (kg)	Quantity harvested in a given area (number of fish) × individual body weight at the time of harvest (kg/fish)
Sales revenue (*USD*)	Market-sized fish (kg) × sales price of market-sized fish (USD/kg)
Gross revenue (*USD*)	Sales revenue (USD) + subsidy (USD)
Total variable costs (*USD*)	$\Sigma_{i=1}^{6} \quad k_i$
Cost of larvae or juveniles (k_1)	Average price of larvae (USD/fish) × stocking density (number of fish/m^3, number of fish/ha) × area used (m^3, ha)
Energy cost (k_2)	Energy cost used (USD/m^3, USD/ha) × area used (m^3, ha)
Water cost (k_3)	Cost of water used (USD/m^3) × area used (m^3)
Feed cost (k_4)	Amount of feed applied to the area (kg/m^3, kg/ha) × area used (m^3, ha) × feed price (USD/kg)
Organic manure cost (k_5)	Amount of organic fertilizer applied to the area (t/ha) × area used (ha) × price of organic manure (USD/kg)
Other cost (k_6)	Value of other material costs (USD/m^3, USD/ha) × area used (m^3, ha)
Total fixed cost (*USD*)	k_7+k_8+k_9
Labor costs (k_7)	Labor input (number of hours worked) × hourly rate (USD/working hour)
Depreciation and maintenance (k_8)	Depreciation and cost of maintenance (USD/m^3, USD/ha) × area used (m^3, ha)
General expenses (k_9)	General expenses (USD/m^3, USD/ha) × area used (m^3, ha)
Specific gross yield of common carp (*kg/area*)	Amount of live weight harvested from the area (kg) / area used (m^3, ha)
Feed conversion ratio (FCR) (*kg/kg*)	Amount of feed applied to the area (kg) / total yield in a given area (kg)
Organic manure use (*t/ha*)	Amount of organic fertilizer applied to the area (t) / area used (m^3, ha)
Natural yield (*kg/kg*)	Amount of natural food present in the area (kg) / amount of biomass harvested from a given area (kg)
Pond FCR (*kg/kg*)	(amount of feed applied to the area (kg) + amount of organic fertilizer applied to the area (kg)) / amount of biomass harvested from the area (kg)

Source: Own editing

(HCSO–*Hungarian Central Statistical Office*; IAE–*Institute of Agricultural Economics*) to explore causal relationships.

2.2. Economic analyses

A deterministic model (Table 3) calculation was performed to determine the costs and revenue of the activity based on the obtained data. Simulation modeling is the most appropriate method for demonstrating farm-level production (Piedrahita, 1984, 1988). The model contains a complete enterprise budget developed based on standard budgeting techniques (Engle, 2010; Engle et al., 2017; Dantas et al., 2022). Variable costs were the acquisition of larvae or juveniles, commercial feed, electric power, water, and other costs, such as the fuel consumption and servicing of the machines used in the activity, the use of animal health and other external services, and purchase of consumables (rubber gloves, fishing nets, plankton nets, etc.). Fixed costs were labor, maintenance of equipment and facilities, depreciation, and other general expenses. Depreciation was calculated by the linear method. Opportunity costs were not computed. The total production cost is the sum of the total variable cost and total fixed cost. Sales revenues were obtained by multiplying the production quantity by the sales price. Gross revenue is the sum of sales revenue and subsidy. The net revenue is obtained by the difference between gross revenue and total production cost.

Table 4
Costs of the three different phases in combined common carp production strategy (unit: USD).

Description	Phase 1	Phase 2	Phase 3
Larvae or juveniles	45.45	-	514.27
Energy	32.29	-	60.61
Water	1.66	-	-
Feed	18.30	1830.58	2345.45
Organic manure	0.00	-	151.52
Other	6.06	181.82	854.55
Total variable cost	**103.77**	**2012.40**	**3926.39**
Labor	45.45	690.91	3318.18
Depreciation and maintenance	58.60	54.55	606.06
General expenses	11.21	156.06	575.76
Total fixed cost	**115.27**	**901.52**	**4500.00**
Total production cost	**219.04**	**2913.91**	**8426.39**

Source: Own data collection and calculation (2021)

Supplementing the basic model, sensitivity analyses were performed to determine the impact of changes in various parameters (e.g., amount of feed and its purchase price, wage, output, and sales price) on the profitability of the activity (Szűcs et al., 2002). Within the sensitivity analyses, scenario analyses were performed on variables that most significantly affected the production efficiency and profitability. We also examined the effect of changes in sales price, feed price, and the most important production parameters (FCR, average weight at the time of sale) on various economic indicators using cross-table analysis. For the necessary model calculation, the sales price of the common carp and average weight at the time of sale were identified as independent variables. In the cross-table, sales and feed prices have been determined based on the extremes of fluctuations experienced over the last 5 years. The average feed price was defined as the weighted arithmetic average of the feed price and quantity determined in the different stages of the activity.

3. Results and discussion

Extensive pond farms have a low intensity of production, and therefore, relatively low water efficiency. These farms use one of the scarcest resources, freshwater, inefficiently (Hishamunda and Ridler, 2002; Harvey et al., 2007; Sustainaqua, 2009). This poses a global issue, as the market demand (demand for animal products) (Subasinghe et al., 2009; FAO, 2017) is increasing and aquaculture sustainability (social, economic, and environmental) is becoming an increasingly important issue in developing and developed countries (Stead, 2005; Bueno, 2008; Krause et al., 2015).

In fish production, producers primarily aim to maintain the stability and profitability of the activity, improve feed conversion ratio or energy efficiency, and efficienlty use water, which in most cases will reduce the costs. However, ancillary investments related to the treatment of run-off water, while enhancing environmental sustainability, also increase the cost price and thus reduce economic efficiency. In the global fish market, unit cost and sales price are important competitive factors. The relatively stable sales price of aquaculture and fisheries products on the market is increasingly driving production technology toward intensification to maximize the profit/ha. Sustainability requires production to be performed most efficiently. Moreover, the use of a production strategy by combining a hatchery/nursery closed-system and pond-rearing common carp production offers a good opportunity to increase production efficiency, allowing fish farmers to produce market-sized common carp more safely and in a shorter rearing period (Karnai and Szűcs, 2018).

3.1. Inputs and production costs in combined production strategy

After examining the different production phases separately, a significant difference in production cost and cost structure was noted. In

Table 5
Production costs for the whole production technology in combined common carp production strategy.

Description	Value (*USD*)	Value per one kg market-sized common carp (*USD/kg*)	Distribution (*%*)
Larvae or juveniles	559.72	0.10	4.84
Energy	92.90	0.02	0.80
Water	1.66	0.00	0.01
Feed	4194.33	0.73	36.29
Organic manure	151.52	0.03	1.31
Other	1042.42	0.18	9.02
Total variable costs	**6042.55**	**1.05**	**52.27**
Labor	4054.55	0.71	35.08
Depreciation and maintenance	719.21	0.13	6.22
General expenses	743.03	0.13	6.43
Total fixed cost	**5516.79**	**0.96**	**47.73**
Total production cost	**11,559.34**	**2.02**	**100.00**

Source: Own data collection and calculation (2021)

phase 1, a total production cost of 219.04 USD is realized in the closed system of the hatchery/nursery (Table 4). The rate of total variable cost is 47.4 %, with the main components being the cost of purchased breeding material (43.8 %) and electricity (31.1 %). Feeding costs varied across production phases depending on the age and size of the fry and fish. Feed accounted for only 17.6 % of the total variable cost in phase 1. There was a relatively low feed consumption from relatively more expensive live food (*Artemia sp.*) and inert fry food. The use of this higher-quality feed led to relatively rapid growth. Higher consumption was observed for larger-sized special starter feeds. Artemia and BioMar Inicio Plus G were used in small quantities for acclimatization to artificial feed, and the quantities of BioMar Inicio Plus 0.5 and 0.8 are larger. The total fixed cost accounted for 52.6 % of the total production cost in phase 1. Depreciation and maintenance have a higher rate than labor costs. Feeding the same amount of fry took a shorter time in intensive technology than in conventional pond fish production, due to both the spatial concentration and the method of feed delivery to the fish. Consequently, the unit cost per kilogram of fry, averaging 1.2 g, was 60.84 USD/kg.

In the post-rearing phase (phase 2), the offspring reared in an intensive recirculating system were stocked into monoculture under intensive feeding conditions. The total variable cost of this phase represented 69.1 %, of which feed costs were 91 %. The feed used amounted to 1.8 tonnes, with a price of 1.02 USD/kg. Pond fish production also relied on natural food sources (planktonic organisms, benthic invertebrates, etc.). In the experiment, after stocking the juveniles into the nursery II pond in April, the fish predominantly consumed natural food until June, after which they switched to the provided mixture. Labor cost constitutes the main component of the total fixed cost, accounting to 23.7 % of the total production cost. This includes both feeding and fishing-related work costs. A total of 152 work hours were recorded during the operation of the small common carp pond. The fixed cost rate was significantly lower in pond farms compared to intensive recirculating systems.

The final phase, market-sized common carp grow-out, was carried out on a total area of 4 ha, with a total production cost of 8426.39 USD. The value/ha was 2106.60 USD. The harvested common carp yield reached approximately 5.7 tonnes. The total variable cost of this phase represents 46.6 % of the total production cost. The main component of the total variable cost is the feed (59.7 %). A total of 5 tonnes/ha of forage (wheat, barley) was used in this production phase, consistent with Egyed et al.'s (2012) findings. The breeding material costs include the acquisition cost of other fish species used in polyculture. Labor costs contribute to 39.4 % of the total production cost, including approximately 730 work hours for the total area.

Table 6
Cost and revenue in combined common carp production strategy.

Description	Value (*USD*)	Value per one kg market-sized common carp (*USD/kg*)	Value per 1-ha pond (*USD/ha*)
Sales revenue	13,030.80	2.27	3257.70
Subsidy	147.88	0.03	36.97
Gross revenue	13,178.68	2.30	3294.67
Total production cost	11,559.34	2.02	2889.82
Net revenue	1619.34	0.28	404.85

Source: Own data collection and calculation (2021)

Table 7
Financial efficiency in combined common carp production strategy.

Description	Value	Unit
Return on sales (net revenue / sales revenue × 100)	12.43	%
Net revenue-to-cost ratio (net revenue / total production cost × 100)	14.01	%
Sales revenue per one hour worked	14.61	USD/hour
Gross revenue per one hour worked	14.77	USD/hour
Net revenue per one hour worked	1.82	USD/hour
Unit cost of 1.2-g juveniles (after phase 1)	60.84	USD/kg
Unit cost of 760-g common carp (after phase 2)	2.25	USD/kg
Unit cost of market-sized common carp (after phase 3)	2.02	USD/kg

Source: Own data collection and calculation (2021)

Aggregated production cost of the three production phases (Table 5) amounted to 11,559.34 USD for the modeled farm size. This equates to 2889.82 USD for a 1-ha fish pond and 2.02 USD for 1-kg market-sized common carp. The largest cost components are feed (36.29 %) and labor (35.08 %).

3.2. *Profitability in combined common carp production strategy*

Specificity of the technology lies in the fact that it is a common carp-centered production process. During the first two phases, no other fish species are reared, but during the grow-out of market-sized fish, other fish are also released as by-products. These by-products are also sold and should be considered when calculating sales revenue. There are no sales between phases as the fish have been fully restocked or transported. Sales revenue is specifically derived from the sale of market-sized fish based on the price at the pond in the autumn of the second year. A total fish yield of 6.3 tonnes can be achieved for the entire pond area, with common carp accounting for 90.3 % of the yield. Therefore, the largest share of sales (90.70 %) comes from the sale of market-sized common carp, amounting to 11,730.07 USD. The sale of other fish species amounts to approximately 10 % of the total sales revenue (Table 6). In our study, the yield average was higher than that in Central Europe (from 500 to 1500 kg/ha in common carp farming) due to combined production. This is a good research direction, as the need for efficient use of land and water resources should be highlighted (Gyalog et al., 2017).

Hungarian farmers receive a subsidy amounting to 36.97 USD/ha. This subsidy is an environmental compensation aid, which can only be accessed for pond fish production. This aid increases the farm's revenue by 1.1 %. The gross revenue of the modeled fish farm is 13,030.80 USD per year, with a value of 3294.67 USD/ha. Based on the gross revenue and total production cost, a net revenue of 1619.34 USD can be realized for the entire pond area. This equals a net revenue of 404.85 USD per 1-ha fish pond. Comparing the gross revenue of 1-kg market-sized common carp (2.30 USD/kg) to the unit cost (2.02 USD/kg), a net revenue of 0.28 USD is realized for each kilogram harvested and sold common carp. This result is similar to that calculated by Stoycheska et al. (2017) for

Table 8
Estimated unit cost (USD/kg) in the combined common carp production strategy as a function of yield and average feed price.

		Yield (kg/ha)									
		1200	1250	1300	1350	1400	1450	1500	1550	1600	1 650
Average feed price *(USD/kg)*	**0.182**	2.28	2.19	2.11	2.03	1.96	1.89	1.83	1.77	1.71	1.66
	0.188	2.31	2.22	2.13	2.05	1.98	1.91	1.85	1.79	1.73	1.68
	0.194	2.33	2.24	2.15	2.07	2.00	1.93	1.87	1.81	1.75	1.70
	0.200	2.36	2.26	2.18	2.10	2.02	1.95	1.89	1.83	1.77	1.72
	0.206	2.38	2.29	2.20	2.12	2.04	1.97	1.91	1.85	1.79	1.73
	0.212	2.41	2.31	2.22	2.14	2.06	1.99	1.93	1.86	1.81	1.75
	0.218	2.43	2.34	2.25	2.16	2.09	2.01	1.95	1.88	1.82	1.77
	0.224	2.46	2.36	2.27	2.18	2.11	2.03	1.97	1.90	1.84	1.79
	0.230	2.48	2.38	2.29	2.21	2.13	2.05	1.99	1.92	1.86	1.81
	0.236	2.51	2.41	2.32	2.23	2.15	2.08	2.01	1.94	1.88	1.82

Source: Own data collection and calculation (2021)

Macedonia and Serbia in cage fish farming but differs slightly from the calculation by Sándor et al. (2021) for Hungary.

The return on sales is 12.43 %, indicating that a net value of 12.3 USD can be generated with a sales revenue of 100 USD over the complete production cycle. The net revenue-to-cost ratio is 14.01 % (Table 7). It is crucial to evaluate the labor efficiency, which includes the labor requirements for both the closed recirculating system, intensive cage management, and pond farming. Overall, nearly 900 work hours are required to harvest nearly 1600 market-sized common carp. In the combined common carp production strategy, employees generate 14.61 USD in sales revenue per work hour, 14.77 USD in gross revenue, and 1.82 USD in net revenue. The unit cost of a 1.2-g offspring was 60.84 USD/kg at the end of phase 1. During phase 2, common carp can reach 760 g with a unit cost of 2.25 USD/kg. Overall, the cost of a 3600-g market-sized common carp was 2.02 USD.

A previous Hungarian study (Karnai and Szűcs, 2020) investigated conventional extensive 3-year common carp production in a polyculture pond. Results of this study revealed a total production cost of 2557.58 USD/ha over 3 years, equivalent to an average annual cost of 852.53 USD/ha. Our results indicate that a total production cost of 2889.92 USD/ha accumulates over two years in combined common carp production. Consequently, the more intensive production strategy incurs 13 % higher production cost over the entire production period, exceeding the average annual cost of conventional production by 69 % for one year. Common carp sales revenue constituted 78 % of the total sales revenue (1993.94 USD/ha), with a gross revenue of 3103.03 USD/ha over 3 years in the conventional extensive 3-year production strategy (Karnai and Szűcs, 2020). Therefore, an average gross revenue of 1034.34 USD/ha can be calculated for one year. According to our results, the average gross revenue amounts to 1647.34 USD/ha for one year in the combined common carp production strategy, exceeding the value realized in the extensive production strategy by 59 %. The previous study (Karnai and Szűcs, 2020) reported a net revenue of 545.46 USD/ha over 3 years, equivalent to an average value of 181.82 USD/ha for one year in the conventional extensive production strategy. Based on our findings, a yearly average net revenue of 202.43 USD/ha can be realized in the combined common carp production strategy, which is 11 % higher than in the conventional strategy. Market-sized common carp can be produced at a cost of 1.72 USD/kg in the conventional 3-year common carp production strategy (Karnai and Szűcs, 2020). Our results indicate that a unit cost of 2.02 USD/kg can be calculated in the combined common carp production strategy, exceeding the value of conventional production by 0.30 USD/kg (17 %). Overall, our findings suggest that the production cost required in the intensive production strategy is higher than the cost assumed in the extensive production strategy. However, the yearly average net revenue can be increased by using a more intensive common carp production strategy, while also reducing production risks by shortening the production cycle by one year.

3.3. Sensitivity analysis of financial results

Cross-table analyses were performed to investigate the net revenue and unit cost of the combined common carp production strategy under different combinations of the key variables (yield, FCR, feed price, and sales price) (*ceteris paribus*, i.e. maintained all other variables constant). Average feed price was defined as a sum of multiples based on the quantity and unit price of feed fed during the whole production period. It can be concluded that an increase in yield/ha at a given feed price reduces the unit cost of market-sized common carp but to a decreasing extent, in line with the principle of diminishing returns (Table 8). At the most favorable average feed price and the highest yield, the unit cost is about 1.66 USD/kg, which is about 0.60 USD/kg lower than at low yield levels. For a given yield, unit cost decreases for increasing feed prices, but the lower yield is associated with a higher increase in unit cost. There is a difference of 0.85 USD/kg in unit cost between the worst case (minimum yield / maximum feed price) and the best case (maximum yield / minimum feed price).

Table 9
Estimated unit cost (USD/kg) in the combined common carp production strategy as a function of yield and feed conversion ratio.

		Yield (kg/ha)									
		1200	1250	1300	1350	1400	1450	1500	1550	1600	1650
$FCR_{combined}$ *(kg/kg)*	**3.15**	2.33	2.24	2.15	2.07	2.00	1.93	1.87	1.81	1.75	1.70
	3.20	2.35	2.25	2.17	2.09	2.01	1.94	1.88	1.82	1.76	1.71
	3.25	2.36	2.26	2.18	2.10	2.02	1.95	1.89	1.83	1.77	1.72
	3.30	2.37	2.28	2.19	2.11	2.03	1.96	1.90	1.84	1.78	1.72
	3.35	2.38	2.29	2.20	2.12	2.04	1.97	1.91	1.85	1.79	1.73
	3.40	2.40	2.30	2.21	2.13	2.05	1.98	1.92	1.86	1.80	1.74
	3.45	2.41	2.31	2.22	2.14	2.07	1.99	1.93	1.87	1.81	1.75
	3.50	2.42	2.33	2.24	2.15	2.08	2.00	1.94	1.88	1.82	1.76
	3.55	2.44	2.34	2.25	2.16	2.09	2.02	1.95	1.89	1.83	1.77
	3.60	2.45	2.35	2.26	2.18	2.10	2.03	1.96	1.90	1.84	1.78

Source: Own data collection and calculation (2021)

Table 10
Estimated unit cost (USD/kg) in the combined common carp production strategy as a function of average feed price and feed conversion ratio.

		Average feed price *(USD/kg)*									
		0.182	**0.188**	**0.194**	**0.200**	**0.206**	**0.212**	**0.218**	**0.224**	**0.230**	**0.236**
FCR$_{combined}$ *(kg/kg)*	**3.15**	1.86	1.88	1.90	1.92	1.93	1.95	1.97	1.99	2.01	2.03
	3.20	1.87	1.89	1.91	1.93	1.94	1.96	1.98	2.00	2.02	2.04
	3.25	1.88	1.90	1.92	1.94	1.95	1.97	1.99	2.01	2.03	2.05
	3.30	1.89	1.91	1.93	1.95	1.97	1.99	2.01	2.03	2.05	2.07
	3.35	1.89	1.91	1.93	1.96	1.98	2.00	2.02	2.04	2.06	2.08
	3.40	1.90	1.92	1.94	1.97	1.99	2.01	2.03	2.05	2.07	2.09
	3.45	1.91	1.93	1.95	1.98	2.00	2.02	2.04	2.06	2.08	2.10
	3.50	1.92	1.94	1.96	1.99	2.01	2.03	2.05	2.07	2.09	2.11
	3.55	1.93	1.95	1.97	2.00	2.02	2.04	2.06	2.08	2.10	2.12
	3.60	1.94	1.96	1.98	2.01	2.03	2.05	2.07	2.09	2.11	2.14

Source: Own data collection and calculation (2021)

Table 11
Estimated net revenue (USD/kg) in the combined common carp production strategy as a function of average feed price and feed conversion ratio.

		Average feed price *(USD/kg)*									
		0.182	**0.188**	**0.194**	**0.200**	**0.206**	**0.212**	**0.218**	**0.224**	**0.230**	**0.236**
FCR$_{combined}$ *(kg/kg)*	**3.15**	0.44	0.42	0.40	0.38	0.36	0.34	0.33	0.31	0.29	0.27
	3.20	0.43	0.41	0.39	0.37	0.35	0.33	0.31	0.30	0.28	0.26
	3.25	0.42	0.40	0.38	0.36	0.34	0.32	0.30	0.28	0.26	0.24
	3.30	0.41	0.39	0.37	0.35	0.33	0.31	0.29	0.27	0.25	0.23
	3.35	0.40	0.38	0.36	0.34	0.32	0.30	0.28	0.26	0.24	0.22
	3.40	0.39	0.37	0.35	0.33	0.31	0.29	0.27	0.25	0.23	0.21
	3.45	0.39	0.36	0.34	0.32	0.30	0.28	0.26	0.24	0.22	0.20
	3.50	0.38	0.36	0.33	0.31	0.29	0.27	0.25	0.23	0.21	0.19
	3.55	0.37	0.35	0.32	0.30	0.28	0.26	0.24	0.22	0.20	0.17
	3.60	0.36	0.34	0.31	0.29	0.27	0.25	0.23	0.21	0.18	0.16

Source: Own data collection and calculation (2021)

Table 12
Estimated net revenue (USD/kg) in the combined common carp production strategy as a function of sales price and average feed price.

		Average sales price *(USD/kg)*									
		1.621	**1.697**	**1.773**	**1.848**	**1.924**	**2.000**	**2.076**	**2.152**	**2.227**	**2.303**
Average feed price (*USD/kg*)	**0.182**	−0.04	0.04	0.11	0.19	0.26	0.34	0.42	0.49	0.57	0.64
	0.188	−0.06	0.02	0.09	0.17	0.24	0.32	0.40	0.47	0.55	0.62
	0.194	−0.08	0.00	0.07	0.15	0.22	0.30	0.37	0.45	0.53	0.60
	0.200	−0.10	−0.03	0.05	0.13	0.20	0.28	0.35	0.43	0.50	0.58
	0.206	−0.12	−0.05	0.03	0.11	0.18	0.26	0.33	0.41	0.48	0.56
	0.212	−0.14	−0.07	0.01	0.08	0.16	0.24	0.31	0.39	0.46	0.54
	0.218	−0.16	−0.09	−0.01	0.06	0.14	0.21	0.29	0.37	0.44	0.52
	0.224	−0.18	−0.11	−0.03	0.04	0.12	0.19	0.27	0.35	0.42	0.50
	0.230	−0.21	−0.13	−0.05	0.02	0.10	0.17	0.25	0.32	0.40	0.48
	0.236	−0.23	−0.15	−0.08	0.00	0.08	0.15	0.23	0.30	0.38	0.46

Source own data collection and calculation (2021)

Changes in FCR and yield strongly influence the magnitude of the unit cost of market-sized common carp. It can be observed that for a given FCR, an increase in the yield/ha decreases the unit cost, but to a decreasing extent. Similarly, for a given yield level, the same increase in the unit cost is observed for a given FCR change, but the increase in specific feed use for higher yield results in a comparatively smaller increase in cost per kilogram. A difference of 0.75 USD/kg in unit cost is observed between the extremes of the different production parameters (Table 9).

We demonstrate that changes in the average feed price and FCR significantly increase the unit cost and decrease the net revenue. The difference in unit cost and net revenue between the two extremes is close to 0.28 USD/kg (Tables 10 and 11). At the lowest examined feed price, there is an increase of 0.08 USD/kg in unit cost between the two extremes of the FCR. It is imperative to note that, for a given FCR, an increase in feed price of 0.003 USD/kg results in a higher unit cost of 0.010–0.011 USD/kg. Similarly, for a given average feed price, an increase of 0.5 kg/kg in FCR increases the unit cost by 0.009–0.012 USD/kg. The FCR and average feed price required to achieve a specific net revenue of zero in a given technological environment were examined. This suggests that, for an average feed price of 0.21 USD/kg, the activity is no longer feasible at 4.8 kg/kg FCR (this is outside the values of the independent variables in the table).

After examining the relationship between the sales price of market-sized common carp and the average feed price (Table 12), we concluded that for a given sales price, the critical feed price *(ceteris paribus)* is 0.29 USD/kg, at which point the net revenue is zero. In the same scenario, each increase of 0.003 USD/kg in the average feed price reduces the net revenue per kg by 0.01 USD. It is important to note that, at a feed price of 0.21 USD/kg, activity operates at a loss if the sales price falls below 1.76 USD/kg.

Average weight of common carp sold and the specific feed used have a significant impact on net revenue evolution. For a given FCR, an increase in average weight increases net revenue but at a decreasing rate, and for a given average weight, increasing feed use decreases net revenue by the same amount. Between the two extremes, a change in net

Table 13
Estimated net revenue (USD/kg) in the combined common carp production strategy as a function of average weight at harvest and feed conversion ratio.

		Market-sized common carp average weight *(kg/fish)*									
		2.6	**2.8**	**3.0**	**3.2**	**3.4**	**3.6**	**3.8**	**4.0**	**4.2**	**4.4**
FCR$_{combined}$ *(kg/kg)*	**3.15**	−0.05	0.05	0.14	0.21	0.28	0.34	0.40	0.45	0.49	0.53
	3.20	−0.06	0.04	0.13	0.20	0.27	0.33	0.39	0.44	0.48	0.52
	3.25	−0.07	0.03	0.12	0.19	0.26	0.32	0.38	0.43	0.47	0.51
	3.30	−0.09	0.02	0.11	0.18	0.25	0.31	0.37	0.42	0.46	0.50
	3.35	−0.10	0.01	0.09	0.17	0.24	0.30	0.36	0.40	0.45	0.49
	3.40	−0.11	0.00	0.08	0.16	0.23	0.29	0.34	0.39	0.44	0.48
	3.45	−0.12	−0.01	0.07	0.15	0.22	0.28	0.33	0.38	0.43	0.47
	3.50	−0.13	−0.03	0.06	0.14	0.21	0.27	0.32	0.37	0.42	0.46
	3.55	−0.14	−0.04	0.05	0.13	0.20	0.26	0.31	0.36	0.41	0.45
	3.60	−0.15	−0.05	0.04	0.12	0.19	0.25	0.30	0.35	0.40	0.44

Source: Own data collection and calculation (2021)

revenue of approximately 0.68 USD/kg is observed. The weight at the modeled harvest (3.6 kg) no longer yields a net revenue at an FCR of 4.77 kg/kg, and the FCR of 3.45 kg/kg at an average weight of 2.8 kg/fish shows a break-even point (Table 13).

4. Conclusions

Combined production strategy involves off-season artificial common carp reproduction, followed by intensive monoculture hatchery/nursery rearing in RAS and semi-intensive pond-rearing. By adopting this intensive production strategy, farmers can produce market-sized common carp in 2 years instead of 3 years using the conventional method. A total production cost of 2889.92 USD/ha accumulates over two years in combined common carp production. Feed is the most significant cost item in the combined common carp production strategy, primarily due to the intensive use of feed in the first two phases of production. Labor cost represents the second main component of the total production cost over the two years. The more intensive technology requires higher-value fixed assets (buildings, equipment, and machinery) mainly in the first phase of production, which increases depreciation and maintenance costs. The fish yield for the 1-ha pond area in polyculture amounts to 1.75 tonnes, with common carp contributing to 90.3 % of the total yield. Consequently, a unit cost of 2.02 USD/kg can be calculated in the combined common carp production strategy. Overall, a net revenue of 404.85 USD per 1-ha fish pond and 0.28 USD per 1-kg market-sized common carp can be realized over 2 years. Changes in yield, FCR, sales price, and feed price significantly affect common carp unit cost and net revenue evolution. Increasing yields/ha reduces the unit cost at a constantly decreasing rate.

Our findings suggest that production costs associated with the intensive production strategy are higher than those assumed in the conventional extensive 3-year common carp production strategy. However, annual average net revenue can be increased by implementing a more intensive combined common carp production strategy based on off-season artificial common carp propagation. Multiple revenues are realized by shortening the production period by one year, which increases the assets turnover ratio and improves farms' liquidity.

Futhermore, this study aims to promote sustainable and economically viable practices in the aquaculture sector by addressing the specific needs of investors and farmers. Considering the broader concept of sustainability, future studies could analyze the long-term environmental and social benefits of combined fish production strategies alongside their long-term economic feasibility. Integrating environmental and social impact variables could provide a more holistic perspective on evaluating combined fish production strategies, aligning with sustainability goals.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Data availability

Data will be made available on request.

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References

Ahmed, N., Turchini, G.M., 2021. Recirculating aquaculture systems (RAS): environmental solution and climate change adaptation. J. Clean. Prod. 297, 126604 https://doi.org/10.1016/j.jclepro.2021.126604.

Asche, F., 2008. Farming the sea. Mar. Resour. Econ. 23 (4), 527–547. https://doi.org/10.1086/mre.23.4.42629678.

Bondad-Reantaso, M.G., Mackinnon, B., Hao, B., Huang, J., Tang-Nelson, K., Surachetpong, W., Alday-Sanz, V., Salman, M., Brun, E., Karunasagar, I., Hanson, L., Sumption, K., Barange, M., Lovatelli, A., Sunarto, A., Fejzic, N., Subasinghe, R., Mathiesen, Á.M., Shariff, M., 2020. Viewpoint: SARS-CoV-2 (the cause of COVID-19 in humans) is not known to infect aquatic food animals nor contaminate their products. Asian Fish. Sci. 33, 74–78. https://doi.org/10.33997/j.afs.2020.33.1.009.

Bostock, J., Mcandrew, B., Richards, R., Jauncey, K., Telfer, T., Lorenzen, K., Little, D., Ross, L., Handisyde, N., Gatward, I., Corner, R., 2010. Aquaculture: global status and trends. Philos. T. Roy. Soc. B. 365 (1554), 2897–2912. https://doi.org/10.1098/rstb.2010.0170.

Bueno, P.B., 2008. Social risks in aquaculture. In: Bondad-Reantaso, M.G., Arthur, J.R., Subasinghe, R.P. (Eds.), Understanding and Applying Risk Analysis in Aquaculture. FAO Fisheries and Aquaculture Technical Paper. FAO, Rome, Italy, pp. 209–228.

Calone, R., Pennisi, G., Morgenstern, R., Sanye-Mengual, E., Lorleberg, W., Dapprich, P., Winkler, P., Orsini, F., Gianquinto, G., 2019. Improving water management in European catfish recirculating aquaculture systems through catfish-lettuce aquaponics. Sci. Total Environ. 687, 759–767. https://doi.org/10.1016/j.scitotenv.2019.06.167.

Campanati, C., Willer, D., Schubert, J., Aldridge, D.C., Campanati, C., Willer, D., Schubert, J., Aldridge, D.C., 2021. Sustainable intensification of aquaculture through nutrient recycling and circular economies: more fish, less waste, blue growth. Rev. Fish. Sci. Aquacult. 30 (2), 143–169. https://doi.org/10.1080/23308249.2021.1897520.

Dantas, D.P., Flickinger, D.L., Costa, G.A., Moraes-Valenti, P., Valenti, W.C., 2022. Economic effects of production scale, use of agricultural greenhouses, and integration of tropical aquaculture species when farming in a subtropical climate. Aquacult. Int. 30 (1), 1–33. https://doi.org/10.1007/s10499-021-00822-2.

Egyed, I., Körmendi, S., Urbányi, B., Fodor, F., Mészáros, E., Hegyi, Á., Katics, M., 2012. A ponty tápos etetése a Czikkhalas Kft. telephelyén. Hal. ászatfejlesztéS. 34, 28–33. URL: hakinapok.haki.hu/tartalom/HF34/HF_34_28_33_Egyed.pdf (Accessed 1 Oktober 2020).

Engle C.R., 2010. Aquaculture economics and financing: management and analysis. Wiley-Blackwell Scientific, Ames, Iowa, USA.

Engle, C.R., McNevin, A., Racine, P., Boyd, C.E., Paungkaew, D., Viriyatum, R., Tinh, H. Q., Minh, H.N., 2017. Economics of sustainable intensification of aquaculture: evidence from shrimp farms in Vietnam and Thailand. J. World Aquac. Soc. 48, 227–239. https://doi.org/10.1111/jwas.12423.

Espinal, C.A., Matuli, D., 2019. Recirculating aquaculture technologies. In: Goddek, S., Joyce, A., Kotzen, B., Burnell, G.M. (Eds.), Aquaponics Food Production Systems. Springer, Cham, pp. 35–76. https://doi.org/10.1007/978-3-030-15943-6.

EUMOFA, 2021. Freshwater Aquaculture in the EU. ISBN 978-92-76-28899-2. European Market Observatory for fisheries and aquaculture. https://doi.org/10.2771/62316.
FAO, 2017. Regional review on status and trends in aquaculture development in Asia-Pacific – 2015. FAO, Rome, Italy.
FAO, 2022. Fishery and Aquaculture Statistics. Global aquaculture and capture production 1950-2020 (FishstatJ), in: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 2022. URL: ⟨www.fao.org/fishery/statistics/software/fishstatj/en⟩.
Flickinger, D.L., Dantas, D.P., Proença, D.C., David, F.S., Valenti, W.C., 2020. Phosphorus in the culture of the Amazon river prawn (Macrobrachium amazonicum) and tambaqui (Colossoma macropomum) farmed in monoculture and in integrated multitrophic systems. J. World Aquac. Soc. 51, 1002–1023. https://doi.org/10.1111/jwas.12655.
Gyalog, G., Oláh, J., Békefi, E., Lukácsik, M., Popp, J., 2017. Constraining factors in Hungarian carp farming: an econometric perspective. Sustainability 9 (11), 2111. https://doi.org/10.3390/su9112111.
Harvey, B., Soto, D., Carolsfeld, J., Beveridge, M., Bartley, D.M., 2007. Planning for Aquaculture Diversification: The Importance of Climate Change and Other Drivers. FAO Technical Workshop, 23-25 June 2016, FAO, Rome. FAO Fisheries and Aquaculture Proceedings No. 47. Rome, Italy.
HCSO, 2021. Summary Tables (STADAT). Hungarian Central Statistical Office, Budapest. URL: ⟨https://www.ksh.hu/stadat_eng⟩.
Hishamunda, N., Ridler, N.B., 2002. Macro policies to promote sustainable commercial aquaculture. Aquacult. Int. 10, 491–505. https://doi.org/10.1023/A:1023985430206.
IAE, 2021a. Weekly/monthly prices and quantities for the main agro-food products. Institute of Agricultural Economics Market Price Information System, Budapest. URL: ⟨https://www.aki.gov.hu/piaci-arinformacios-rendszer/#pair⟩.
IAE, 2021b. Fish Prices Data Query Interface. Institute of Agricultural Economics Market Price Information System, Budapest. URL: ⟨https://www.aki.gov.hu/en/fish-prices-data-query-interface/⟩.
Karnai, L., Szűcs, I., 2018. Outlooks and perspectives of the Common Carp production. Ann. Pol. Ass. Agric. Agribus. Econ. 20 (1), 64–72. https://doi.org/10.5604/01.3001.0011.7230.
Karnai, L., Szűcs, I., 2020. Profitability analysis of fish production in an extensive pond fish system: a hungarian case study. Ann. Pol. Ass. Agric. Agribus. Econ. 22 (2), 60–69. https://doi.org/10.5604/01.3001.0014.1387.
Kestemont, P., 1995. Different systems of carp production and their impacts on the environment. Aquaculture 129 (1-4), 347–372. https://doi.org/10.1016/0044-8486(94)00292-V.
Kozłowski, M., Szczepkowski, M., Wunderlich, K., Szczepkowska, B., Piotrowska, I., 2014. Polyculture of juvenile pikeperch (Sander lucioperca (L.)) and sterlet (Acipenser ruthenus L.) in a recirculating system. Arch. Pol. Fish. 22 (4), 237–242. https://doi.org/10.2478/aopf-2014-0024.
Krause, G., Brugere, C., Diedrich, A., Ebeling, M.W., Ferse, S.C., Mikkelsen, E., Agúndez, J.A.P., Stead, S.M., Stybel, N., Troell, M., 2015. A revolution without people? Closing the people-policy gap in aquaculture development. Aquaculture 447, 44–55. https://doi.org/10.1016/j.aquaculture.2015.02.009.
Kucharczyk, D., Targońska, K., Hliwa, P., Gomułka, P., Kwiatkowski, M., Krejszeff, S., Perkowski, J., 2008. Reproductive parameters of common carp (Cyprinus carpio L) spawners during natural season and out-of-season spawning. Reprod. Biol. 8 (3), 285–289. https://doi.org/10.1016/S1642-431X(12)60018-7.
Kumar, G., Engle, C.R., 2016. Technological advances that led to growth of shrimp, Salmon, and Tilapia farming. Rev. Fish. Sci. Aquacult. 24 (2), 136–152. https://doi.org/10.1080/23308249.2015.1112357.
Manjappa, K., Keshavanath, P., Gangadhara, B., 2011. Influence of sardine oil supplemented fish meal free diets on common carp (Cyprinus carpio) growth, carcass composition and digestive enzyme activity. J. Fish. Aquat. Sci. 6 (6), 604–613. https://doi.org/10.3923/jfas.2011.604.613.
Martins, C.I.M., Eding, E.H., Verdegem, M.C.J., Heinsbroek, L.T.N., Schneider, O., Blancheton, J.P., d'Orbcastel, E.R., Verreth, J.A.J., 2010. New developments in recirculating aquaculture systems in Europe: a perspective on environmental sustainability. Aquacult. Eng. 43 (3), 83–93. https://doi.org/10.1016/j.aquaeng.2010.09.002.
NAS, 2020. Nemzeti Akvakultúra Stratégia (Multiannual National Strategy Plan on Aquaculture of Hungary). A 2014-2020-as időszak Európai Tengerügyi és Halászati Alap szerinti Magyar Halgazdálkodási Operatív Program kötelező kísérő dokumentuma. Magyarország Kormánya, 1–66. URL: ⟨https://halaszat.kormany.hu/download/d/f5/f0000/2015_03_30_NAS_4%201_program%25C3%25ADr%25C3%25B3i%20verzi%25C3%25B3_v%25C3%25A9lem%25C3%25A9nyez%25C3%25A9sre.pdf⟩.
Piedrahita, R.H., 1984. Development of a computer model of the aquaculture pond ecosystem. Ph.D. Thesis. University of California, Davis, CA.
Piedrahita, R.H., 1988. Introduction to computer modelling of aquaculture pond ecosystems. Aquacult. Res. 19 (1), 1–12. https://doi.org/10.1111/j.1365-2109.1988.tb00328.x.
Rahman, M.M., 2015. Role of common carp (Cyprinus carpio) in aquaculture production systems. Front. Life Sci. 8 (4), 399–410. https://doi.org/10.1080/21553769.2015.1045629.
Sándor, Z.J., Révész, N., Varga, D., Tóth, F., Ardó, L., Gyalog, G., 2021. Nutritional and Economic Benefits of Using DDGS (Distiller' Dried Grains Soluble) as Feed Ingredient in Common Carp Semi-Intensive Pond Culture. Aquacult. Rep. 21, 100819 https://doi.org/10.1016/j.aqrep.2021.100819.
Sayeed, M., Alam, M., Sultana, S., Ali, M., Azad, M., Islam, M., 2008. Effect of inorganic fertilizer on the fish growth and production in polyculture system of Bangladesh. Univ. J. Zool. Rajshahi. Univ. 26, 77–80. https://doi.org/10.3329/ujzru.v26i0.705.
Soltani, M., Sheikhzadeh, N., Ebrahimzadeh-Mousavi, H.A., Zargar, A., 2010. Effects of Zataria multiflora essential oil on innate immune responses of common carp (Cyprinus carpio). J. Fish. Aquat. Sci. 5 (3), 191–199. https://doi.org/10.3923/jfas.2010.191.199.
Specziár, A., Erős, T., 2020. Development of a fish-based index for the assessment of the ecological status of Lake Balaton in the absence of present day reference condition. Knowl. Manag. Aquat. Ecosyst. 421, 11. https://doi.org/10.1051/kmae/2020002.
Stead, S.M., 2005. A comparative analysis of two forms of stakeholder participation in European aquaculture governance: self-regulation and integrated coastal zone management. In: Gray, T.S. (Ed.), Participation in Fisheries Governance, 4. Springer, Dordrecht, the Netherland, pp. 179–192.
Stoycheska, A.M., Stamenkovska, I.J., Marković, T., Kokot, Ž., 2017. Profitability of carp production on Macedonia and Serbia. Biotechnol. Anim. Husb. 33 (1), 103–113. https://doi.org/10.2298/BAH1701103M.
Subasinghe, R., Soto, D., Jia, J., 2009. Global aquaculture and its role in sustainable development. Rev. Aquacult. 1, 2–9. https://doi.org/10.1111/j.1753-5131.2008.01002.x.
Sustainaqua, 2009. A handbook for Sustainable aquaculture, EU FP6 project, Integrated approach for a sustainable and healthy freshwater aquaculture. Project N: COLL-CT-2006-030384. URL: ⟨https://haki.naik.hu/sites/default/files/uploads/201809/sustainaqua_handbook_hu.pdf⟩ (Accessed 30 September 2020).
Szűcs, I. (Ed.), Stündl, L., Nábrádi, A., 2002. A halászati ágazat gazdasági szervezési és piaci kérdései. Mezőgazdasági Szaktudás Kiadó, Budapest.
Szűcs, I. (Ed.), Stündl, L., Karnai, L., Szőllősi, L., 2017. Az akvakultúra helyzete és lehetőségei, a magyar halgazdálkodási operatív program (MAHOP) hatása az ágazat fejlődésére. OTP Bank Nyrt Agrár Kollégiuma, Debrecen.
Thomas, M., Pasquet, A., Aubin, J., Nahon, S., Lecocq, T., 2021. When more is more: taking advantage of species diversity to move towards sustainable aquaculture. Biol. Rev. 96 (2), 767–784. https://doi.org/10.1111/brv.12677.
Váradi, L., 2001. Erőforrás kímélő haltermelő rendszerek fejlesztése, különös tekintettel az integrációra. Doktori PhD értekezés, Debrecen.
Woynárovich, A., Kovács, É., Péteri, A., 2019. A takarmányozás gyakorlati szempontjai a tógazdasági haltermelésben. Duna-Mix Kft, Budapest.