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RESEARCH ARTICLE

Integrated cage-pond carp farming for increased aquaculture production

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Abstract. The study investigated the potential for increasing carp (*Cyprinus carpio* L.) production in temperate climates without expanding farming area and simultaneously reducing wastewater discharge in intensive fish production using an in-pond cage system. An earthen pond with a stocking density of 209.3 kg per ha^{-1} and four cages stocked with 8.12 kg m^{-2} (A1 and A2) and 2.61 kg m^{-2} (B1 and B2) were monitored. The gross yield from the cages was 27.09 kg m^{-2} (A1), 24.3 kg m^{-2} (A2), 10.09 kg m^{-2} (B1), and 9.73 kg m^{-2} (B2). The fish in the pond had the highest specific growth rate (SGR) at 0.98%, and the feed conversion ratio (FCR) was above 3 for all the cages. The cages provided a high enough nutrient load to enable a net fish production of about 450 kg ha^{-1} in the pond. Ineffective feed utilization affected the production performance in the cages. Thanks to the high yield obtained in the pond, the overall return on the investment was 16%, which rendered production profitable.

Keywords: aquaculture technology, extensive aquaculture, feed conversion ratio, integrated aquaculture, intensive aquaculture

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Introduction

European Union aquaculture is considered to be one of the most important segments of food production in terms of quantity and employment (Framian 2009, Bostock et al. 2016). Extensive, pond-based aquaculture, which is typical for Central Europe, is among the most sensitive sectors to globalized market changes. Fish farming in this area focuses on common carp (*Cyprinus carpio* L.), although the production of this species has decreased over the past decade (FAO 2017), and this can be attributed to various factors such as disease (e.g., koi herpes virus), wild bird predation, and the replacement of traditional products with imported seafood or other competitively-priced fish products. Most carp farms are managed extensively, which hinders competitiveness with intensive pond technologies (Framian 2009, Adamek et al. 2012).

Nevertheless, it must be remembered that extensive fish farming of species like carp, pike (*Esox lucius* L.), or tench (*Tinca tinca* (L.)) can still be of great importance thanks to consumers' preferences for traditional products and sustainability in local markets. Additionally, increased demand for "bio-carp" has been noted recently in some areas. This means that carp production should focus on extensive or semi-intensive, environmentally-friendly technologies that could broadly increase consumer demand for this species. Therefore, carp farmers must look for effective strategies to support their economic conditions.

One way is to integrate intensive fish production with traditional extensive aquaculture. Integrated aquaculture systems are considered to be the way to achieve sustainable small-scale fish production. There are various types of integrated fish farming systems with different levels of technological complexity (Phong et al. 2011). Integrated cage-pond aquaculture is potentially one of the most important methods for poor rural communities and/or farmers that have at their disposal small land areas. In integrated cage-pond culture, fish in cages are fed artificial diets while fish in the pond utilize natural food, which is enhanced by the waste produced by cage farming. Nutrient recycling in fishponds is a way to improve feed utilization (Bosma and Verdegem 2011). Various combinations of species can be used for cage and pond culture. Yi et al. (2001) and Sangma et al. (2017) described integrated farming of walking catfish (*Clarias batrachus* (L.)) and tilapia (*Oreochromis niloticus* (L.)), while Mandal et al. (2014) experimented with the combination of African catfish (*Clarias gariepinus* (Burchell) and Nile tilapia (*O. niloticus*) in cages and carp in earthen ponds. Asaduzzman et al. (2006) also conducted an experiment in which carp ponds were used for rearing climbing perch (*Anabas testudineus* (Bloch)). Yi and Lin (2001) describe the practice of fish monoculture with tilapia (*O. niloticus*) in both ponds and cages. An undoubted advantage of cage aquaculture is the ease of stocking, harvesting, and feeding. Likewise, facilitated stock monitoring can be done without disturbing the fish excessively, which is helpful when preventing or treating diseases.

Freshwater cage aquaculture is very common in Asian countries such as Indonesia, the Philippines, Vietnam, and China (Lin and Yi 2001). In Europe this type of production is practiced in Russia and Turkey in sturgeon farming (Cardia and Lovatelli 2007, Tacon and Halwart 2007) and in Bulgaria (Hadjinikolova et al. 2010), where in addition to sturgeon, carp are produced in cages. Common carp and rainbow trout (*Oncorhynchus mykiss* (Walbaum)) dominate cage farming in Serbia and Montenegro (Marković and Poleksić 2008, Martinovska et al. 2017). Aquaculture integration systems have also been reported in Hungary for intensive African catfish production (Gal et al. 2010, Gal et al. 2013, Popp et al. 2018) and in Poland for intensive sturgeon rearing (Pilarczyk et al. 2016, Kolek et al. 2019). Some intensive carp cage farming studies were also conducted in the German Democratic Republic, Hungary, and the Soviet Union about forty years ago (Muller 1979). Recent changes in global climatic conditions and difficulties with water availability make it necessary to increase the share of such production systems in aquaculture in Central Europe. Intensive cage farming has been practiced with various fish species at the Institute of Ichthyobiology and Aquaculture of the Polish Academy of Science in Golysz. This article describes the results of monitoring conducted during cage carp farming.

The following presents the results of producing common carp farmed in an integrated system composed of cages at two different stocking densities and a carp pond. The main goal of monitoring was to provide insight into whether carp cage production can be economically reasonable in an integrated intensive-extensive system. We also estimated whether the productivity of traditionally managed carp ponds could be increased with the simultaneous intensive production of this species.

Materials and Methods

This comparative study was conducted to evaluate the differences in the growth performance of fish in cages and a pond. The aquaculture site was located in southern Poland and was characterized by temperate climate conditions. The monitoring was carried out for 23 weeks from May to October 2019. An earthen pond with a 0.2 ha surface area and an average depth of 0.7 m was used for this experiment.

Four rectangular mesh net cages, 4.2 cubic meters each, were installed in the pond for in-cage pond aquaculture. To ensure water flow through the cages they were placed across the pond and had no contact with the bottom. The pond and cages were stocked with common carp of the same age and with an average body weight of 0.29 ± 0.03 kg. The fish in the pond were stocked at a density of 209.3 kg per ha^{-1}, while in the cages two stocking densities in two replicates were applied: 8.12 kg m^{-2} (A1 and A2, high density) and 2.61 kg m^{-2} (B1 and B2, low density). The fish in the pond relied on natural food sources, while those in the cages were fed daily using a demand feeder. For 16 weeks, a self-formulated, locally prepared feed that contained 30% protein was applied. Then for two weeks, this feed was supplemented with Aller Bronze (Aller Aqua) containing 45% protein. For the last three weeks of the rearing season, the fish were fed self-formulated feed containing 16% protein. The self-formulated feed contained wheat, distillery dried corn still, post-extraction soybean meal, hemoglobin, post-extraction sunflower meal, soybean oil, fish meal, minerals (including 7% phosphorus) and amino acids (15% lysine and 6.9% methionine). Feed ratios were adjusted within a range of 1.2–2.2 % body weight according to Steffens (1986). To speed up fish growth, the amount of protein in the feed was kept high and increased when it became apparent that the fish were eager to eat the feed. The protein content was reduced to only 16% at the end of the rearing period because fast growth was no longer so important, while the lower amount of protein in the feed had a positive effect on the taste of the fish meat.

The fish in the pond and cages were measured and weighed at the beginning of the experiment and during harvesting. Individual body mass and length of 30 randomly selected fish per treatment were measured. The values of the specific growth rate (SGR), feed conversion ratio (FCR), and net yields were calculated as follows:

SGR = [ln (final weight) – ln (initial weight) x 100] / Number of experiment days;

FCR = feed applied (dry weight) / live weight gain;

Gross yield of fish (kg m^{-3} or ha^{-1}): harvested fish weight (kg) / volume;

Weight gain: harvested fish weight (kg) – initial fish stock biomass (kg);

Net yield (kg m^{-3} or ha^{-1}): harvested fish weight (kg) – initial fish stock biomass (kg) / volume (cage, pond).

Pond water samples for water quality monitoring were collected between 08:00 and 09:00 with a horizontal tube sampler from three locations in the pond and pooled before analysis. The basic water parameters such as temperature, dissolved oxygen, and pH were measured twice weekly in the field with a MultiLine P3 with OxiCal–SL and SenTIx 41 electrodes (WTW, Germany). The ammonia nitrogen level was measured once weekly (modified Clesceri et al. 1998).

To evaluate the productivity of the integrated system, net production results were compared with data collected in the same production season and in previous years from traditional fish farming on the farm where the study was conducted. The stocking density was 116 kg ha^{-1} during the production season described. The ponds on this farm are manured yearly, and the fish are fed wheat grain at 1–1.5% approximate body weight.

The investment return was calculated by subtracting the direct costs of production, such as the costs of fish for stocking and feed from the profits obtained from the fish sold. Because the costs of workforces differ among fish farms, they were not included in the calculations.

A one-way analysis of variance (ANOVA) was used to compare the total growth gain of fish between the treatments. The statistical analyses were performed using MedCalc Statistical Software version 18.11 (MedCalc Software bvba, Ostend, Belgium).

Results and discussion

Water parameters

The average temperature during the experimental period was 19.45 ± 4.25°C. The highest temperatures, over 25°C, were noted in June and the lowest, below 15°C, were at the beginning and the end of the rearing season. The average seasonal level of dissolved oxygen was 6.43 ± 1.54 mg O_2 L^{-1}. Values of 4–5 mg O_2 L^{-1} were noted during periods of high water temperatures, but they never decreased below levels that could threaten fish health. The average seasonal pH level was 7.12 ± 0.22, and it never exceeded the level that could be harmful to the fish. The average amount of ammonia nitrogen in the water was low at 0.21 ± 0.12 mg NH_4 L^{-1} and only once exceeded 0.5 mg L^{-1}.

Growth and yield parameters

The growth and production performance of the carp are presented in Table 1. The average initial weight of the fish was 0.29 ± 0.03 kg per individual. The overall production result obtained for the pond was 651.75 kg ha^{-1} (0.065 kg m^{-2}). The gross yields calculated for the cages were as follows: cage A1 – 27.09 kg m^{-2}; cage A2 – 24.3 kg m^{-2}; cage B1 – 10.09 kg m^{-2}; cage B2 – 9.73 kg m^{-2}. The average final individual weight of the pond fish was 1.302 ± 0.2 kg, which was significantly higher than that of the fish from all the cages. The fish from cage A1 weighed an average of 1.11 ± 0.25 kg per individual, while from cages B1 and B2 they weighed 1.23 ± 0.23 and 0.96 ± 0.16 kg per individual, respectively. The mean individual weight of the fish from cage A2 was significantly lower (0.78 ± 0.16 kg, $P < 0.05$) compared to the results from the other cages. The longest body length was recorded for the fish from the pond (at an average of 42.47 ± 1.98 cm) and the lowest length values were noted in the fish from cage B12 (33.69 ± 1.82 cm). The differences in the average individual weights and lengths of the fish and net yield are presented in Table 1.

The net yield results from the pond and the cages (Table 1) indicated that the net production in cages was nearly 400 (A cages) and over 150 (B cages) higher than that in the pond. However, the data should be analyzed based on weight gain from the area used for rearing. This is because the purpose of integrated intensive-extensive production is to use the available surface area to increase fish production, while simultaneously using the rearing pond for the disposal of waste from this type of production. Therefore, it is obvious that the area of cages used for fish rearing cannot cover the entire surface area of the pond. In this paper, production in this system is discussed in terms of the surface area of the entire pond, because the pond surface area is what is available for cage production.

In total, the fish in the pond gained 89.75 kg (448.75 kg ha^{-1}) over 23 weeks, which was lower than that in the densely stocked cages A1 (113.84 kg) and A2 (97.08 kg) but higher than in cages B1 and B2 with low stocking densities and in which total weight gain was 44.93 and 42.74 kg, respectively. No fish mortality was noted in the cages, while in the pond the mortality rate was 29% and stemmed primarily from attacks by birds of prey, mainly cormorants.

On the farm where the study was conducted, the average yield of market-sized carp farmed in traditional extensive ponds in the rearing season studied

Table 1
Initial weight and growth performance of carp in the pond and cages.

Parameters	Pond	A1	A2	B1	B2
Total initial weight (kg)	40.60	48.72	48.72	15.66	15.66
Average individual initial weight (kg)	0.29±0.03	0.29±0.03	0.29±0.03	0.29±0.03	0.29±0.03
Total final weight (kg)	130.35	162.56	145.80	60.59	58.40
Total weight gain (kg)	89.75	113.84	97.08	44.93	42.74
Final average individual weight (kg)	1.30±0.2	1.11±0.25	0.78±0.16	1.12±0.23	0.96±0.16
Final average individual length (cm)	42.47±1.98	38.48±2.14	36.11±2.12	33.69±1.82	36.7±1.83
Net yield (kg m^{-2} $cage^{-1}$)	0.045	18.97	16.18	7.48	7.12

was 570 kg ha^{-1}, and net production was about 450 kg ha^{-1}, which was higher than the average 400 kg ha^{-1} obtained in previous years.

The yield obtained from the pond-cage system demonstrated its high natural productivity. Traditional carp farming permits obtaining 150–300 kg of fish per ha^{-1} per year (Kestemont 1995). Applying fertilizers can help increase yearly fish production up to 500–800 kg ha^{-1} (Yadava and Garg 1992, Kaur and Ansal 2010, Adamek et al. 2012). The study results showed that intensive fish production in cages provided a high enough nutrient load to allow for a net fish production in the pond of 448.75 kg ha^{-1}. This was similar to the results obtained in the same rearing season on the farm with traditional farming in which fertilization and supplemental feed were applied. More frequent applications of fertilizer to ponds can increase fish growth performance (Bhakta et al. 2004). Our results concur with the finding that the productivity of extensive ponds can be enhanced purely by integrating them with intensive production without additional fertilization or supplemental feeding (Jha et al. 2018). In carp monoculture, pond yield is usually below 1,000 kg ha^{-1}. Obtaining higher yields of up to 1,500 kg ha^{-1} is possible when ponds are well managed with additional feeding (Kestemont 1995). If such a high yield is expected, the feed must be rich in protein (Woynarovich et al. 2010). The intensive and extensive integrated farming presented in this article permitted obtaining a gross yield of 2,788.5 kg ha^{-1} and a net yield of 1,941.7 kg ha^{-1}, which, on this farm, was nearly four times higher than that of traditional carp production. These yields are in the range of results expected for semi-intensive fish production in which combinations of fertilization and feeding are applied (Woynarovich et al. 2010). The average individual fish weight (1.3 ± 0.2 kg) was close to what was expected for extensive polyculture ponds (Woynarovich et al. 2010).

From an economic point of view, cage stocking density should be as high as possible. However, this is constrained by environmental factors and social relations in crowded fish stocks. The number of fish per cage should be adjusted to the water flow to provide enough oxygen for the fish. Carp are able to utilize about 60% of the oxygen dissolved in water. The water flow in a pond without additional aeration is low, therefore the stocking density in variant A was reduced to half of the number recommended by Steffens (1986), but it was still a reasonably high density for the stagnant waters of the relatively small pond. The number of fish in the B cages was decreased to evaluate the influence of stocking density on production outcomes. As the growth parameters and water quality results show, the environmental conditions in the A cages were not negatively affected by their high stocking densities.

Of the three experimental treatments, the pond fish had the highest specific growth rate (SGR) at 0.98%. The SGR values calculated for the caged fish were 0.87 in cage A1, 0.64 – A2, 0.88 – B1, and 0.78 – B2. The feed conversion ratio (FCR) was high in all the cages. The least favorable values were noted in cage A2 (4.32) while the others were similar at 3.69 – A1, 3.32 – B1, and 3.49 – B2. We could not measure FCR for the pond since no feed was supplied to it. During the season, 1,138 kg of feed was utilized. The amount of feed used in variants A1 and A2 was 420 kg each, while in variants B1 and B2 it was 149 kg per cage.

Feed cost was the major expenditure at 62% of total production costs, which was in the range of the average expenditure for typical cage farming (Datta et al. 2014, Martinovska et al. 2017). On the same farm, feeding costs usually contribute to over 50% of total costs. Cereal grains are commonly used as feed in carp farming; however, because of the better digestibility of processed feeds, compound pellets have gained popularity in production intensification in many EU countries (Gyalog et al. 2011, Marković et al. 2016). Considering just the cage yield, 4 kg of feed was required to produce 1 kg of fish, which was twice as much as the average used by other carp cage farms (Martinovska et al. 2017).

The lower FCR indicates that the feed is converted into biomass more efficiently. In the production system investigated, FCR values for all the cages were within the upper limit of FCR of feeds expected for table fish (2–3.5; Woynarovich et al. 2010), and these were high and unprofitable (Woynarovich et al. 2010). The feeders were systematically inspected to check if the fish consumed all the feed. In cages A1 and A2, the feeders were always empty, but in cages B1 and B2 small amounts of feed were usually left, which was a sign that the fish had reached satiation. It was likely that the fish in densely stocked cages (A1 and A2) consumed feed more aggressively thus spilling it out of the feeder and wasting it. This could be why the FCR values were higher in the A cages than in those with the lower stocking density. The growth simulation was based on the optimal utilization of the feed in relation to the temperature of the water (Steffens 1986). Even though the protein content of the feed was kept within the range recommended for carp, its caloric value was lower than that of commercial feed. When there is intense competition for feed, fish appetites are stimulated, so they tend to consume more feed; therefore, fish in densely stocked cages gain more weight than do other fish. Considering the high FCR values for the cages, and similar net yield in the pond compared to the A variants and even higher yield than in the B cages, it must be emphasized that feed quality played a major role in production efficiency. The FCR values obtained together with the SGR values suggest that the production performance in cages was affected by ineffective feed utilization. Considering the net yields and costs of each cage treatment separately, the production in the A cages was not advantageous while the cost return for the B cages was 7.6%, which, compared to the results of others (Martinovska et al. 2017), leaves room for improvement. Thanks to the high yield in the pond, the overall return on the investment was 16%, which made production profitable.

Conclusion

Integrated aquaculture systems are often utilized for the simultaneous production of several species. Introducing new species is challenging for some traditional carp farmers as they must meet species-specific environmental needs. An experiment involving more replicates should be performed in the future in order to prove the scientific value of these results; however, this production model can provide farmers insight into its benefits and disadvantages while demonstrating possibilities for meeting market demand for the eco-friendly intensive cage production of table-sized fish. The main conclusion is that the profitability of extensive pond aquaculture can be increased without additional financial burden or complicated technological requirements. However, we concluded that carp production in cages in the system presented in this article can be reasonable only if the aim is to accelerate the production cycle. In order to ensure profitability, intensive cage production should be based on higher market value species than carp. Properly executed and managed cage-pond farming can guarantee environmentally-friendly production chains and become more competitive against imported species from other parts of the world.

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Author contributions. L.K.: investigation, data curation, writing - original draft, methodology, conceptualization, project administration; M.I.: investigation, methodology, data acquisition, conceptualization.

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