EXPERIMENTAL RESEARCH ON INTENSIVE AQUACULTURE SYSTEMS ESTABLISHED IN CLOSED PONDS

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Abstract. The global need for food is increasing every year, yet aquaculture production in most countries has stagnated or increased relatively slowly in the last decade. The primary goal is to increase annual production using sustainable aquaculture, delivering many social, economic, and environmental long - term benefits. Closed fish-farming systems are attractive solutions for intensive production, because they can provide favorable development conditions and allow a strong input and output control, avoiding damaging the ecosystems and wild populations. The current study includes a series of experimental investigations related to intensive growth of cyprinids in polyculture system, employing various renewable energy sources in order to provide the daily energy requirement. The research was carried in a high-capacity impermeable concrete pond, covered with a presocratic PVC membrane, equipped with an automatic system for regulating oxygen and food. The energy independence of the fish pool is ensured by a hybrid photovoltaic-wind turbine-diesel system, which helps the optimal growth of fish by maintaining a high-quality of water. Water quality characteristics must be accurate and reliable evaluated in order to ensure a successful and sustainable aquaculture business, using environmentally friendly methods. Without a comprehensive understanding of growth circumstances, fish health may suffer, and incorrect feeding practices may be employed, resulting in unsatisfactory output levels, high input costs, water contamination, and even diseases. The composition of the water from the fishing pond (dissolved oxygen, pH, turbidity, EC, salts, dissolved solids, nitrates, and so on) had been determined weekly during the tests carried out over a one-year growth cycle. At the same time, the health and development of the fish material were being monitored. Our aim was to analyze different nutrition recipes in order to increase productivity in intensive aquaculture systems. The proposed diet showed very good results, especially for the growth of Cyprinus carpio Linnaeus. Due to the pond covering system, which better preserves the interior heat and provides a more pronounced thermal inertia, all fish species have seen constant growth, even throughout the colder months.

Keywords: aquaculture, intensive polishing, indoor system, aquatic plants, energy independence.

Introduction

Aquaculture refers to all forms of aquatic organism growth or cultivation, using various techniques to increase production beyond the natural capacity of the environment. It is always recommended that all the natural capacity of the environment to be protected, and that production to focus especially on fish farming [1].

All over the world, aquaculture is developing rapidly due to the influence of two important factors: the increasing demand for seafood and the low reserves of fish in the world's oceans. Farmers involved in aquaculture must be equally concerned about environmental security, economic viability, and socially acceptable development, which are the principles of sustainability in their current and future development. About 75 percent of the most valuable marine resources are either exploited to or above the limit [2]. At the same time, world fish consumption has risen from 45 million tons in 1973 to more than 160 million tons in 2020, and the FAO estimates that an additional 40 million tons of seafood will be needed by 2030, just to maintain the current level of consumption [3]. In order to sustain this growing demand over the long term, sustainable alternatives to classical technologies need to be developed.

The limited availability of natural resources and the rising energy costs emphasize the need to make aquaculture more sustainable [4]. Even though the aquaculture sector is moving toward this objective, there is still a long way to go. Compared to other animal production systems, aquaculture is under special pressure since it uses many natural resources such as fresh water, wetlands, or coastal areas. However, in terms of sustainability production methods can be the most reasonable basis for description. Although there are many overlaps and transitions between freshwater fish production systems, the following basic methods can be distinguished: farm fishing in ponds, growing systems on flowing waters, recirculating aquaculture systems, floating pond cultures.

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The production of freshwater fish in anthropic fish ponds is often considered to be the oldest farming activity in Europe. Fish ponds were built in areas where water supplies were available and the soil was not suitable for agriculture. The total European production on farms with fish ponds is about 755 000 tons. Almost half of this production consists of cyprinids, such as common carp (*Cyprinus Carpio Linnaeus*), silver carp (*Hipophtalmichtys molitrix*) and *Aristichthys nobilis*. The main producing countries are the Russian Federation, Poland, the Czech Republic, Germany, Ukraine and Hungary. Typical fish ponds are basins where fish live in a climate similar to the natural, much of the food growing inside the pond due to sunlight and available nutrients. In order to achieve higher yields, today's farming practices involve introduction of organic fertilizers and extra feeder (usually granular).

Fish production in anthropic fish ponds can be either "extensive" or "semi-intensive" (with additional feeding) in most countries, where semi-static freshwater systems play an important role in agriculture.

Chemicals and medication are not usually used in fish ponds; therefore, the most important environmental issue is the use of organic fertilizers that can cause contamination of natural waters. The use of organic fertilizers is regulated nationally. Extensive fishing ponds are usually surrounded by belts of reeds and natural vegetation, providing important habitat for flora and fauna. Landscaping can play an important role in rural tourism. Many fishing farms have been transformed into multifunctional systems, where various services are offered for relaxation, maintaining biodiversity and improving water management [5].

In fishing ponds, carp polyculture has been chased to be used for a certain amount of added nutrients or may be used for trophic regulation of ponds. Common carp regularly feed on the bottom of the pond on sediments, therefore nutrients and organic matter are being spread in the water body, intensifying primary production and increasing the food supply for other species [6-9]. Silver carp tolerate higher densities and can consume much of the phytoplankton and zooplankton. It has been observed that silver carp can filter food debris from intensive farm discharges. In a eutrophic/hypertrophic basin, aquatic plant species grow either by deliberate or spontaneous sowing and can cover the entire surface of small basins, preventing the primary production of beneficial algae.

The introduction of common carp juveniles can prevent overgrowth of zooplankton. However, there are many elements that need to be considered, given that the size of the fish and the relationship between the species are particularly important [10-12]. For example, a one-year-old fish should grow more intensive than a large fish, however, the 2-year-old common carp is able to spread sediment more efficiently. In order to achieve an optimal ecosystem, aquatic plants play an important role from a structural and functional point of view for aquatic ecosystems. They act as a source of food and shelter for fish and aquatic invertebrates. Aquatic plants have the ability to change water quality by regulating oxygen balance, nutrient cycle, and the accumulation of heavy metals [13-15]. Nile salad and water hyacinth grow the fastest, if they are provided with two conditions: water with an organic load between 20-10 000 mg per liter and temperatures between 5 ºC and 39 ºC for water and 45 ºC for air temperature. Within these limits, the two plants produce 5-8 tons of plant mass per hectare daily, for 150 days a year, in natural conditions and 365 days a year, in the greenhouse environment. They are able to reduce by 40% the organic load of water and by 20-30% nitrogen and phosphorus. At the same time, they absorb a great amount of carbon dioxide from the atmosphere and, produce the oxygen necessary for fish development. If they do not come from water polluted with toxic substances, the aquatic plants can be used in animal feed (as a supplement to green mass, silage or as a protein extract mixed with compound feed), for food juices and pigments [16; 17].

The experiments carried out in this study aimed at the design, construction and testing of a new fish pond, where different technologies of polyculture growth systems were tested. We considered a diet consisting of grains and protein sources and evaluated the fish growth over a year period.

Materials and methods

In order to test and develop optimal technologies for aquaculture sector, within INMA Bucharest institute has been designed and constructed an experimental pilot station for growing fishing material indoors. The intensive fishing pond designed for polyculture (ICP), designed by INMA is a construction made of reinforced concrete with a thickness of 300 mm, its width is 14.4 m, the length is 57 m, while the depth is 4.6 m. Waterproofing of reinforced concrete has been ensured by applying a binder specific to fish ponds that does not affect the proper growth and development of fish species and aquatic plants. In order to achieve a rapid growth of the fish material (maintaining a relatively constant temperature), the pool was covered with a pressurized balloon having a width of 17 m, a length of 62 m, presenting a maximum height of 6 meters at the center. The feeding system is composed of 3 automatic feeders, equiped with an auger and pelletized feed disperser, having the diameter adjustable between 2-10 mm. The aeration system of the basin is composed by means 2 Aerators Osaga ORV, while the air diffusion system in the water is made using a HDPE pipe pipe, PE80, D 63 mm, PN 10. This HDPE pipe has been installed at a height of 1 m from the bottom of the basin using collar devices, the total length being 130 liniar meters, and every 100 mm were made 2 holes with a diameter of 1 mm each. The design and construction of the ICP fishing pond and its dimensions can be seen in Figure 1.

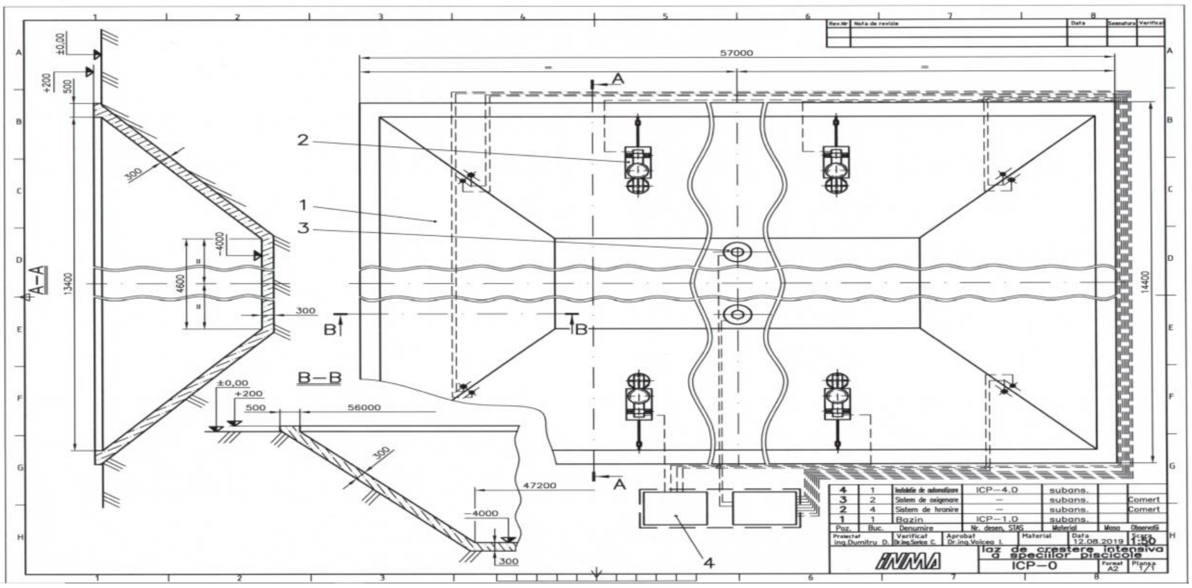

Fig.1. **Technological system of intensive fish farming in polyculture system (ICP), [9]**

In Figure 2 (a) the roof of the pool can be seen, made of a pressurized balloon, having the role of maintaining as constant as possible the parameters of fish growth. Figure 2 (b) and (c) show the addition of the 5 species of fish in the pond, as well as the pipeline used to maintain the oxygen in the water to the optimal values.

a) b) c)

Fig. 2. **Depicting the characteristics of the technological system of intensive fish farming in a polyculture system: (a) pressurized balloon cover; (b) addition of the 5 species of fish in the pond, as well as the pipeline used to aerate the water; (c) cluster of fish within the pond in a polyculture system**

Figure 3 shows the aquatic two plant families used in the polyculture system (water lilies and Nile lettuce), in order to purify the water from the basin, to partially produce the dissolved oxygen necessary for the development of the fish, and to provide shelter.

Fig. 3. **Aquatic plants (water lilies and Nile lettuce), used for oxygenation, shelter and creation of the proper ecosystem features for fish farming in a polyculture system**

The automated monitoring and control system for ICP consists of: the water quality monitoring system for fishing basins (ponds) designed for a polyculture system, the nutrition monitoring and control subsystem (feeding system), the 5 fish species, and the aeration subsystem. All these 3 component subsystems are monitored and controlled via a PLC (programmable logic controller). The pond water monitoring is performed with the use of a specific temperature and pH sensors – Sensorex 8000 series, with a monitoring system for oxygen determination and control – Aqua Control one with Dryden probe. The calibration and validation is performed with a mobile probe multiparameter HANNA - HI9829. All information received from the component subsystems is displayed on an operating terminal or directly on the devices own terminals.

In order to experiment intensive fish farming system grown in polyculture, the pool was populated with a quantity of 500 kg of fish from the Cyprinidae Family (45% Cyprinus carpio Linnaeus, 15% Hypophthalmichthys molitrix Val. (Blood), 15% Aristichthys nobilis Rich, 15% Ctenopharyngodon idella Val. and the remaining 10% was Carassius auratus gibelio.

The average mass of the introduced fish material was 0.350 kg per specimen for *Cyprinus carpio L.*, 0.150-0.200 kg per specimen for all Asian species, while for *Ctenopharyngodon idella Val*. and *Carassius auratus gibelio* 0.150 kg per specimen. In order to ensure an energy independence of the ICP system, the pond was provided with a power supply from renewable energy sources, namely photovoltaic panels and a wind turbine. The renewable hybrid system consists of 16 photovoltaic panels Model: SH-310S6-20 with a maximum total power of approx. 5 kW and a 0.6 kW Idella Flyboy wind turbine.

The pool is equipped with a monitoring system equiped with specific sensors (pH, temperasture, dissolved oxygen, dissolved solids) that stores information in the form of databases. Considering the size of the pool, there are 3 sensors of each type (at both ends and center), and the recorded values are recorded as the arithmetic mean of the 3 values. A measurement is made every 15 minutes, and in case of exceeding critical values an alarm is triggered. The data processing was performed at the end of the month, by associating the water quality indicators with the indicators of feeding and growth of the fish mass in the basin.

Results and discussion

In order to demonstrate the efficiency of the fish farming system in a covered aquaculture pond for the entire period of the experiment, water samples were taken to detect any disturbances that may occur with potentially harmful effects on the fish. In the following figures we have depicted the graphical representation of the variation of the water parameters during the experiment, where the 23 points represent an average of the variation in a month of the experiment. Under the ICP pond characteristics, a range of indicators including pH (Figure 4), water temperature (Figure 5), dissolved oxygen (Figure 6) and total dissolved solids (Figure 7) were examined in the polyculture regime.

Following the analysis of the 4 graphs, it can be seen that the variation of the factor temperature, pH, dissolved oxygen and totally soluble dissolved in the water of the ICP basin for growing in polyculture of fish species is generally suitable for optimal development. It can be deduced that the system reduces stress and pressure exerted by the air temperature can become harmful for aquaculture activity. The loss of oxygen from the water is due to the processes of respiration of various organisms and as a result of the diffusion of water into the air. The respiration of plankton registers values of 5-15 $mg \cdot l^{-1}$, the respiration of fish 2-6 $mg \cdot l^{-1}$, the respiration of benthic organisms 1-3 $mg \cdot l^{-1}$, and the water-air diffusion 1-5 mg·l^{-1}. In order to ensure good development of the Asian species, the water was sown with plants in order to favor, on the one hand, the development of the phytoplankton and, on the other hand, of the zooplankton. In order to ensure an additional source of food for the species of common carp, aquatic plants have been introduced such as Nile lettuce and water hyacinth, which showed properties of biological water purification. The water with sediments found at the bottom of the pool, along with the manure and debris left over from the pelletized feed, have been passed daily through a mechanical drum filter, followed by a mechanical sponge-filters. Although the installation is also provided with UV-C filters their use was limited since they largely destroy beneficial microorganisms.

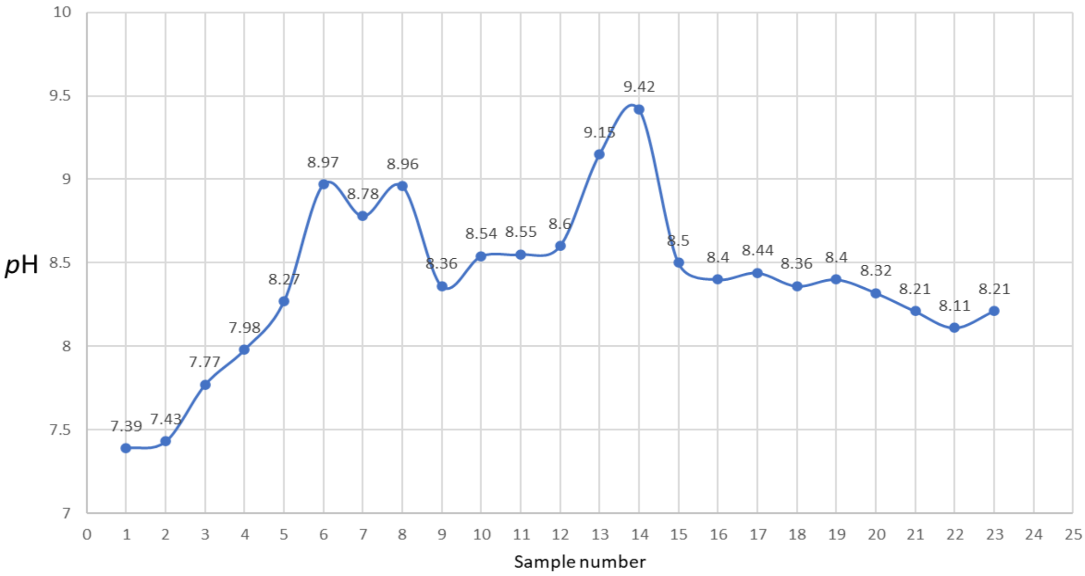

Fig. 4. **Variation of pH values in the ICP basin**

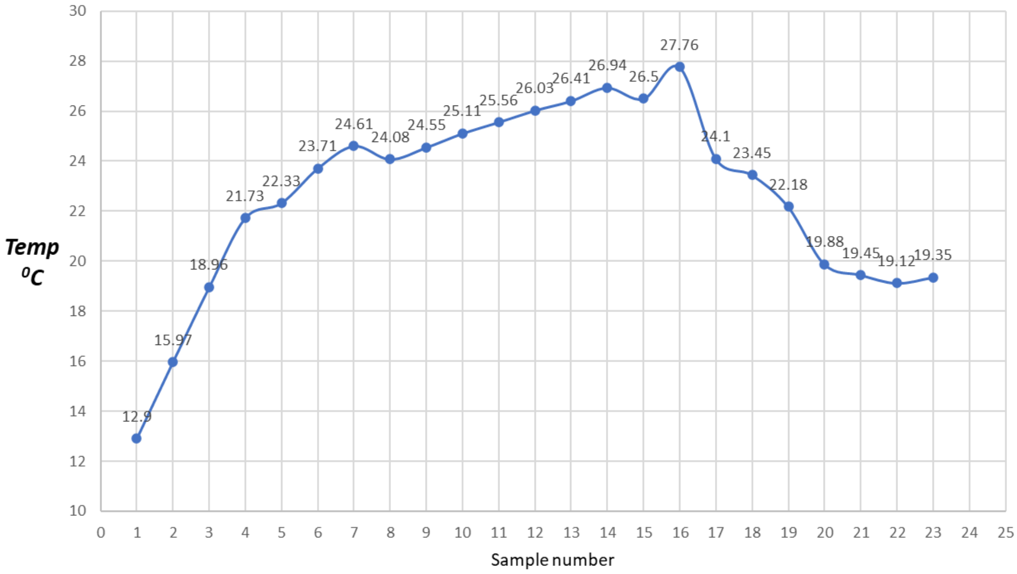

Fig. 5. **Variation of temperature values in the ICP basin**

The minimum water-soluble oxygen requirement for most fish is low and the lower lethal threshold is sometimes below 1 mg·l^{-1}, as follows: *Carrassius gibelio*, 0.1-2.0 mg·l^{-1} O_2; *Cyprinus carpio linnaeus*, 0.2-0.8 mg·l^{-1} O_2; *Ctenopharyngodon idella*, 0.2-0.6 mg·l^{-1} O_2; *Hypophthalmichthys molitrix*, 0.3-1.1 mg·l^{-1} O_2. Research has shown that at low levels of 0-0.3 mg·l^{-1}, some fish can survive if the duration of exposure to these small values is short. Survival is possible and growth is weak between 1.0-5.1 mg·l^{-1} O_2, while between 1.0 and 5.0 mg·l^{-1}, (permanent exposure), there is also an increased susceptibility to disease and a higher level of food conversion. Normal growth conditions are achieved when oxygen exceeds 5 mg·l^{-1}; between 3-3.5 mg the carp refuses food and moves to the area with higher O_2 (next to the aeration equipment).

The fish feeding in the aquaculture pond is higher in captivity conditions. It was performed every few hours, with the food ratio divided into two: a morning meal and one meal at the end of the day. The total amount of feed administered was calculated according to the following formula (1):

$$H = [N * (G - g) - (S * P)] * K, \quad (1)$$

where H – total quantity of feed, in kg;
N – total number of fish to be fed;
G – average weight of the fish, planned to be reached, kg;
S – pond area, ha;
P – natural productivity of the pond (where applicable);
K – degree of feed conversion.

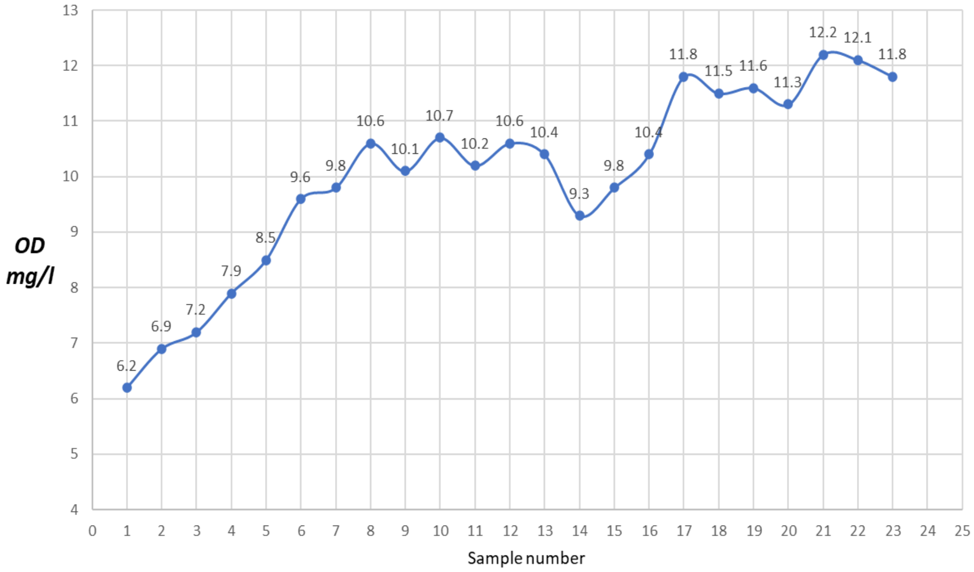

Fig. 6. **Variation of dissolved oxygen values in the ICP basin**

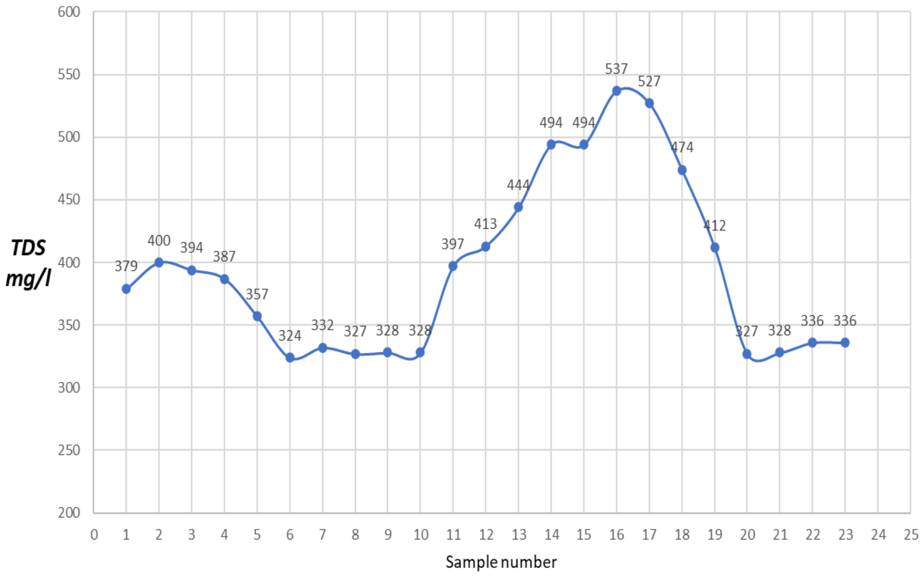

Fig. 7. **Variation of totally dissolved solids values in the ICP basin**

The feed administered in the basin is of the pelletized type, it is also made within the project and is based on cereal material: sunflower, corn, wheat, soybean and additives (fishmeal; vitaminized calcium; black dye gum arabica; fried hemp; yeast extract; starch; vitamin C; sweet corn syrup; krill flour; starch; seaweed extract; spirulina; buoyancy extract).

The food was distributed according to the type of feeding for each species, for pelagic species are used mainly dehydrated foods that float for a while, then sink. The granules sink faster and are therefore intended especially for benthic species. These foods have not been over-distributed, as they degrade very easily, with the final effect of altering water quality. For the biometric study 10 fish for each species were measured, at the end of each week during the experiment. The biometric study consisted of measuring the total length (*L*), standard length (*Sl*), maximum body height (*H*) and body mass (*G*), as can be seen in Figure 8. The composition of the fodder administered to the fish raised in the polyculture system from the experimental pond is shown in Figure 9.

Fig. 8. **Weekly assessment of the fish health in the pool, as well as evolution of their mass using the sample fishing**

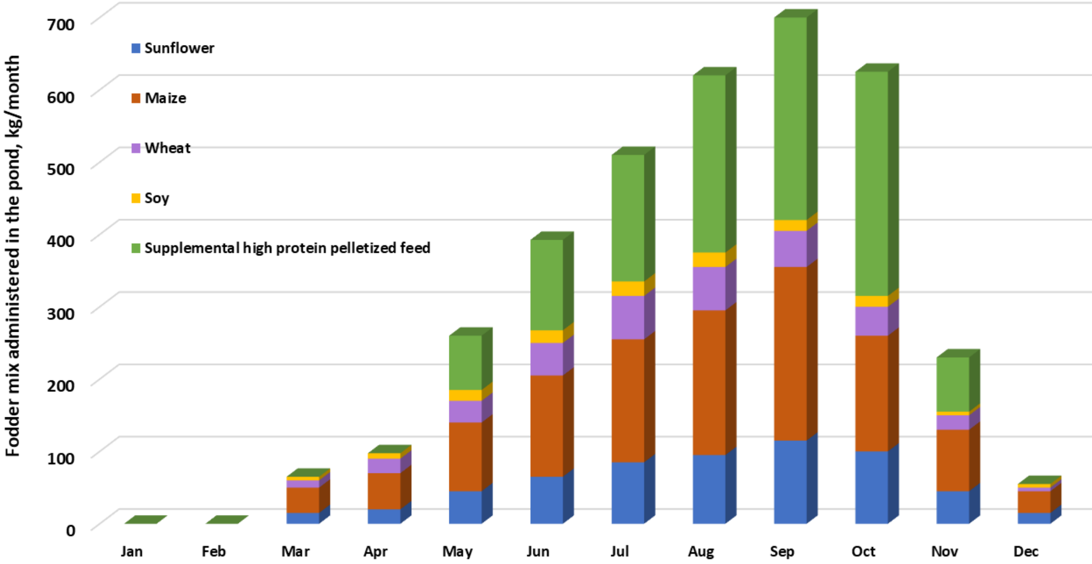

Fig. 9. **Composition of the fodder administered to the fish raised in the polyculture system in the ICP basin**

Depending on the food and the feeding schedule, the feeding efficiency can be quantified over a year. We chose to analyze the feeding efficiency according to the increase of the fish mass in the pool. Therefore, Figure 10 depicts the mass of the 5 species of fish raised in the polyculture regime, in the ICP basin.

The sample fishing shows a very good increase in weight of the common carp (*Cyprinus carpio linnaeus*) and *Carrassius gibelio* species (in the first year, there is a body increase between 155-185% due mainly to the low-protein diet achieved by administering extruded feed), a good growth for *Ctenopharyngodon idella* (a body growth between 100 -137%) due to the plants introduced into the aquaculture basin, respectively for the species of “Asian carps”, when the average in the first year of the experimentation was around 105%. One of the promoters of this growth was the fact that the basin was inoculated with phytoplankton and zooplankton. Regarding the mortality rate, has been found that in the first year of the experiment, it is insignificant, being rated to values below 2.5%.

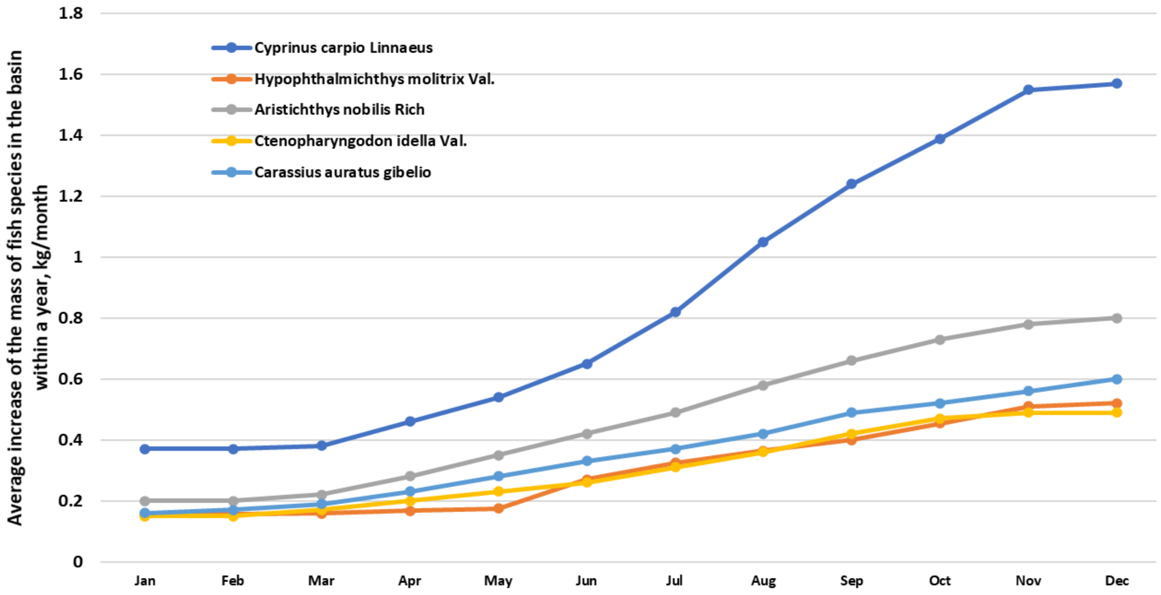

Fig. 10. **Growth curves of fish mass raised in the ICP basin in the polyculture system, over the course of a year (5 species)**

Conclusions

1. The study involved testing the polyculture-intensive growth regime, in a new basin designed and executed for the implementation of advanced research on fish development. The first experiment aimed at testing the diet of fish raised in the polyculture system. The results showed the growth rates of the main species of interest (common carp) of around 1 200 kg per specimen, while for the Asian species an average weight of 0.600 kg per specimen, the *Ctenopharyngodon idella* had an average body weight of 0.500 kg per piece and the *Carrassius gibelio* a size of 650 kg per specimen.
2. During the experiment, the power supply system of the hybrid pilot station managed to sustain the energy of the equipment, however, in the autumn-winter period when the level of solar radiation was lower a diesel generator was used for back-up. It is worth mentioning that we also had a context in which during this period the wind power was higher in the Bucharest-Ilfov area than usual.
3. The amounts and rate of feeding have been shown to be effective in raising species in polyculture. However, other feeder combinations will be tested to see if they perform better than in this experiment.
4. The parameters monitored in the pool were maintained at acceptable values, except for dissolved oxygen. Dissolved oxygen during summer, due to the heating of the water (especially on the surface), showed values below the maximum allowed rates, therefore the water aeration was supplemented with an additional submersible equipment operating as an artesian well.

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Author contributions

Conceptualization, I.V. and F.N.; methodology, I.V., F.N., G.N. R.O., C.I.M, and V.N.A.; software, V.N.A.; validation, I.V. and F.N.; investigation, I.V., F.N., G.N. R.O.; writing – original draft preparation, I.V. and F.N.; writing – review and editing, I.V., F.N., G.N. R.O., C.I.M, and V.N.A.; visualization, I.V. and F.N.; project administration, I.V. and F.N.; funding acquisition, I.V. and F.N. All authors have read and agreed to the published version of the manuscript.

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