Scientific Papers. Series D. Animal Science. Vol. LXVII, No. 2, 2024
ISSN 2285-5750; ISSN CD-ROM 2285-5769; ISSN Online 2393-2260; ISSN-L 2285-5750

INTEGRATING FRESHWATER SWAN MUSSEL *Anodonta cygnea* IN POLYCULTURE WITH FISH: ESTABLISHING A CONTROLLED ZONE WITHIN THE LOWER SECTION OF A FISH CAGE FARM

Mariana Cristina ARCADE[1, 2], Mioara COSTACHE[2], Marinela GANCEA[2], Daniela RADU[2], Mihail COSTACHE[2], Carmen Georgeta NICOLAE[1]

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania
[2]Fish Culture Research and Development Station of Nucet, 549 Principala Street, 137335, Nucet, Dambovita County, Romania

Corresponding author email: arcademarianacristina@gmail.com

Abstract

Integrated multi-trophic aquaculture (IMTA) presents opportunities for transforming diverse aquaculture-generated waste into revenue streams through the growth of species of economic and biological value. In fresh water, swan mussel Anodonta cygnea (Linnaeus, 1758) exhibit the capacity to purify aquaculture effluent by extracting nutrients contained within it. Also, it represents a value food source for fish, like Black carp, and human consumption. The study aimed to propose an IMTA strategy for freshwater cage fish farming. The feed provided to caged fish is not entirely consumed, serving as the foundation of the food chain for other organisms like swan mussels. To enhance feed efficiency for the fish, which settles at the bottom of the culture ponds where floating fish cages are located, individual net compartments are installed to accommodate the swan mussels. This association yields positive effects across all levels of the food chain by reducing losses and generating a living raw material that falls within the dietary range of other species. Also, through the feeding process, swan mussels filter the water and prevent the undesirable phenomena of decomposition of organic matter and decrease in oxygen concentration, which occur with increasing water temperature. This experiment applies the concept of IMTA by the simultaneous activity of fish and swan mussel farming, which results in minimizing economic losses, maximizing profit and environment protection by cleaning the water.

Key words: *aquaculture, bivalve, cage culture, IMTA, wastes valorisation.*

INTRODUCTION

Romania holds 25% of the total area under fish farming in the European Union, although in 1988, Romania produced 55.000 tons of fish for consumption in fish farming alone, now Romania's domestic production is about 12.500 tonnes of fish in fish farming, 3.500 tons in inland commercial fishing and 8.000 tons in the Black Sea fishery of which 7.500 tons are veined rapa whelk *Rapana venosa* (Valenciennes, 1846), and only 500 tons of fish. In last years, Romania imports over 100,000 tons of fish and fishery products, mainly frozen and in various forms (https://www.fao.org/fishery/en/facp/rou?lang=en). Of this, 15,000 tons are from species also produced domestically in fish farms, including common carp *Cyprinus carpio* (Linnaeus, 1758), Prussian carp *Carassius gibelio* (Bloch, 1782), and Rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792) (Neculita & Moga, 2015).

The method of fish farming applied in Romania (Costache et al., 2021a), and in general in Central and Eastern Europe, is the traditional method, in land-based fish farms (Radu et al., 2018; Costache et al., 2021b). However, recent concerns about controlled fish farming have arisen across all regions of the country.

The notable benefits that aquaculture provides to society include: maintaining wetlands and specific microclimates, generating habitats for water-loving plant and animal species, shelters, breeding and nesting sites for birds frequenting areas in the immediate vicinity of water bodies, providing a suitable feeding environment for birds, hydrological regulation of groundwater near aquaculture areas, maintaining local biodiversity (Hanif, 2022), especially in protected areas of the country, and preserving cultural values. Stocking fish farms to maximize resource utilization, including accumulation lakes and any water source that can sustain growing activity, can reduce algal blooms, maintain optimal water chemistry and significantly reduce waste (Costache et al., 2021a; Azhar & Memiş, 2023; Nissar et al., 2023). The predominant fish farming activities in our country include freshwater fish polyculture rearing, both in classical rearing systems and in recirculating systems, floating cages and pens, concrete tanks and controlled systems.

Among the most active preoccupations, worldwide, are increasing aquaculture production with minimal damaging effect on the environment and supplying quality products, with the most reasonable effort involved (FAO, 2020; Arcade et al., 2023). Fishery in our country, as a zootechnical specialization, has focused mainly on the development of technical-scientific methodologies of fish breeding and rearing, creating fish breeds with high productive genetic characteristics (Costache et al., 2018). The trend of increasing productivity per unit area has become more prevalent with the passage of time and the foundation of developed practices (Ahmed et al., 2019; Heydari et al., 2023). The major problem in developing a technology adapted to the new requirements is dimensioning the populations and selecting the most suitable classes of aquatic organisms so that the specific technological consumptions are minimal and the growth rate is upward by introducing extractive, bio-remedial species such as algae, crustaceans etc. into the culture (Ranjbar et al., 2021).

In order to be able to isolate a fish population and grow it in a controlled, more efficient method, it is practiced to use floating fish cages, placed on the surface of a water body (Bucur et al., 2016; Araujo et al., 2022). World-wide, this practice is predominantly applied in open waters (inland and marine). The use of controlled areas such as floating cages has many advantages such as: the possibility of isolating populations by age and species, the possibility of administering feed manually, semi-automatically and automatically, the easy handling of fish material and the reduction of stress during harvesting. In addition to all these advantages, there is also the efficiency of production costs, the possibility of introducing several species of fish, which are not normally compatible in common growing, and the interconnection of several branches of animal husbandry in the fish growing process (Bardach et al., 1972).

Currently, intensive fish culture in cages (with floating nets) is widespread internationally and is indicated as one of the main methods of intensive fish production in the Tropics (Liao et al., 2004; Sangirova et al., 2020). Over the last decade, intensive cage aquaculture in countries such as Brazil, China, for example, has expanding rapidly at an alarming rate, generating substantial additional profits and increasing production and hence export of fish for global consumption. The impact on the aquatic environment created by externalised waste (fish faeces, uneaten feed, bacterial biomass created, destabilisation of the aquatic environment used) from fish farms, especially caged fish farms, is a growing concern worldwide. Increasing the intensity of cage fish farming can lead to harmful effects such as eutrophication and negative effects on water quality. There are several papers that actively seek to show the effect of cage fish farming on the quality of the environment and water (Ntengwe & Edema, 2008; Azevedo et al., 2011; Schenone et al., 2011).

In Romania, fish farming in cages is mainly carried out in small fish farms (earth ponds), but also in water reservoirs. It is essential to control the physical, chemical and biological parameters of water in fish farming technologies. These parameters can greatly affect the survival and growth of fish as well as the development of secondary species such as aquatic plants and crustaceans (Lachi et al., 2008). In addition to the water quality parameters listed above, microorganisms play an important role in the natural cycling of chemical elements inside a water body (Koroleff, 1976). They have a very important function in aquatic ecosystems as they actively participate in the chemical cycling of nutrients. They are also a natural food source for animals, contribute to disease control and can also influence various water quality parameters such as dissolved oxygen, pH and organic matter, ratio of priority elements such as nitrogen, phosphorus, magnesium, fluoride, iodine, ammonia (Moriarty, 1997). The aquaculture in cages can also induce other effects on aquatic ecosystems, including pronounced destabilization of natural habitats (Song et al., 2023) and changes in the structure and dynamics of local organisms, but also trophic changes (Agostinho et al., 2008; Dias et al., 2012; Klinger & Naylor, 2012; Wang et al., 2012). The success of cage aquaculture depends on the physical, chemical and biological characteristics of the water source, the constructive characteristics of the aquatic life ecosystem in which aquaculture is practised, and good nutritional management of the targeted species (Ridler et al., 2007). All these variables in the ponds and the lakes populated with fish are interdependent and require continuous monitoring to avoid the contamination and/or the deterioration of the aquatic habitat. The introduction of bivalve molluscs into freshwater ponds, has led to remediation of the effects of environmental pollution and provided multiple benefits (Khan, 2019; Poznańska-Kakareko et al., 2021).

MATERIALS AND METHODS

The experiment was carried out at SCDP Nucet, in experimental pond number 3 (BE3). In terms of construction techniques, this pond is a classical construction, with water inflow and outflow system, the bottom is composed of alternating layers of soil and other specific sub-strates, and the embankment are simple rein-forced concrete constructions. The design cha-racteristics are presented in Figures 1, and 2.

Figure 1. Experimental pond 3 (B.E.3) (Original)

To minimise the effect of rearing fish in floating cages, a new population was introduced into the food chain of the rearing culture system. This species is popularly referred to as the swan mussel and is a freshwater bivalve mollusc, swan mussel *Anodonta cygnea* (Linnaeus, 1758), and it was introduced to try to remedy the environmental problems and to make the resulting production more efficient (Whitmarsh et al., 2006).

Figure 2. B.E.3 pond - Defining construction element (Original)

The swan mussel *A. cygnea* was introduced because of its ability to biofilter fish effluent water and is also a marker of environmental quality. These aquatic organisms were strategically placed in cages, made of a metal structure to prevent them from floating, and hermetically locked with a fishing net with a mesh diameter of 2 cm (Figure 3).

Figure 3. *A. cygnea* - biometric data recording, before stocking in freshwater pond (Original)

The swan mussels were carefully attached to the construction of the floating cages to allow for movement in tandem with the waves and current on the water.
Stocking fish formulas have been established so that the combination of different species can be complementary and not in competition for feeding. The freshwater swan mussels introduced were taken from another fish pond owned by SCDP Nucet. They entered the pond from their wild habitat (Ilfov stream - this is also the source of water supply to the experimental site studied). The estimated age of the swan mussels, following specific analysis to determine this indicator, it was predominantly in the range of 8-10 years. The size of the swan mussels was variable in the range 8-15 cm long and a variable total weight (shell + body) of 100-170 g.

Data recording

To monitor the physico-chemical parameters of the water, a HANNA JI9829-11042 portable oxygen analyser was used, equipped with special sensors to determine pH, water and air temperature, dissolved oxygen, conductivity and saturation. It is manufactured in Romania and is equipped with sensors for measuring the mentioned parameters, which are calibrated monthly according to the protocol requested by the device.

Laboratory analysis

Chemical analysis of water is carried out by standard methods for determining Ca/Mg ratio, alkalinity, nitrite, nitrate, phosphate, chloride, ammonium, organic matter, pH, total hardness. Finally, the data obtained are transcribed into water analysis reports and these water samples are analysed in the SCDP Nucet laboratory.

Construction characteristics of fish cages and mussel cages

Floating fish cages are technological platforms equipped with anchoring systems (bivalve cages are made of light metal to make it difficult to move the fish cages without holding them in place) consisting of multiple isolated fish rearing modules mounted on a system of floats sized to support the entire construction. The anchoring cages are sized according to the weight of the aggregate, wind force and wave pressure in the pond.
The growth modules have the same dimensions (6 m long and 6 m wide, with a total height of 2 m in the water and 80 cm above water level) and are four by four, in total the system installed in the experimental pond (BE3) contains 8 panels which are separated by a wooden pontoon. Each module is covered with polyester fishing nets with a mesh size of 10 mm and a twine thickness of 2.5 mm, the nets are not constructed with knots and have been pre-treated with a substance to make them more slippery so as not to harm the fish. The floating body is made of HDPE and is interconnected by heating and gluing. Structurally the nets have the following specifications (Figure 4.):

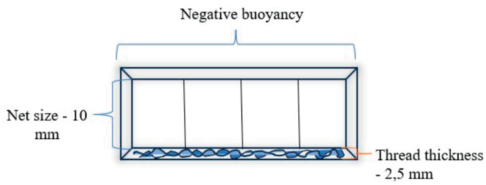

Figure 4. Construction characteristics of floating live-nets and swan mussels cages (Original)

Another important characteristic of net manufacture is that it shouldn't allow fish fins to catch in it or damage it, and nets must be non-toxic and able to tolerate a large temperature variation.
Metal cages have a dual purpose, both to isolate freshwater swan mussels and to serve as an anchor, also preventing the cages from moving over large areas. In terms of dimensions, they are designed to be 70 cm long, 50 cm wide and 30 cm high, resulting in a cage volume of 0.105 m^3. The nets used to cover them are of the same construction as those used in the floating system.

Norms for stocking fish ponds with different fish species

An effective method of stocking floating cages is polyculture, which will minimise antagonistic relationships and maximise the synergies of relationships in the pond. In this way, there will be an increase in the availability of food resources for reared species and a successive improvement in the environmental conditions.

Stocking fish formula of a 70 m^3 cage volume, with majority cyprinids, is presented in Table 1.

Table 1. Population formula for a 70 m3 floating cage in a super-intensive rearing system

Species and age	Floating cage volume (m3)	No. of units	%	Average weight of unit (g/ex)	Quantity (kg)
Carp (1-1+ age)	70	150	30	120	18
Silver carp		80	16	70	5.6
Bighead carp		80	16	70	5.6
Grass carp		80	16	70	5.6
Predatory fish		110	22	50	5.5
Total	70	500	100	Total quantity = 40.3 kg	

The average size of the introduced swan mussels is ~15.5 cm average total shell length, ~7 cm average body height and a weight of 211 g total mass + residual water (internal + external) (Figure 5).

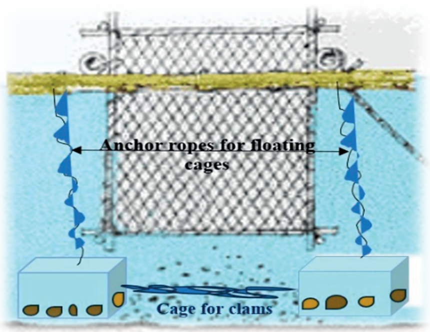

Figure 5. Scheme for anchoring cages to grow swan mussels under floating fish cages (Processed)

Based on these approximate sizes, their distribution over the surface of a cage, in the hypothetical case of occupying the entire surface of the cage base, the estimated number of individuals is 28 swan mussels of identical size (ideal case); however, the total number of swan mussels introduced was 30 ex./cage.
The total number of anchored cages was six cages, distributed in pairs of three cages, tied on the outside of the cage at equal and parallel distances.
Stocking formula of the metal cages with swan mussels, is presented in Table 2.

Table 2. Formula of popular creep cage for swan mussels (*A. cygnea*)

Species *A. cygnea*	**Cage volume (m^3)**	**No. of units**	**Average weight of unit (g)**	**Average quantity (kg)**
Total cage 1	0.105	30	211	6.300
Total cage 2	0.105	30	206	6.180
Total cage 3	0.105	30	219	6.570
Total cage 4	0.105	30	198	5.940
Total cage 5	0.105	30	201	6.030
Total cage 6	0.105	30	209	6.270

In order to keep the swan mussel cages under the floating fish cages and to avoid distancing them, the two pairs were linked in series and in parallel to follow its exact trajectory. The length of the mooring ropes is designed to minimise the contact between the cage and the surface layer of the pond bottom, so that the system created can cover as short a distance as possible, but it can cross variable areas of the pond so that the process runs smoothly. If it is not possible to migrate the whole assembly, then oxygenation problems and destabilisation of the vital processes of the aquatic life being monitored may appear.

RESULTS AND DISCUSSIONS

The selection of the appropriate aquatic habitat for the development of all the organisms under investigation, was carried out according to several criteria, such as: to present a classical construction in order to improve its natural productivity; the dike delimiting the freshwater pond should be made of cement in order to avoid the risk of blocking the floating cages in the ground; its depth should be suitable for the proper execution of the experiment; it should have a water inflow and outflow installation.
The purpose of the experiment was to introduce swan mussels into a freshwater pond used for polyculture of carp, Asian cyprinids and predators, to demonstrate the benefits of integrating them into the system.
The bivalves were placed in specially designed cages, positioned parallel to the floating fish cages. The rationale for their introduction was to recycle nutrients deposited, on the bottom of the freshwater pond, and to maintain the balance of the ecosystem where the floating cages crossed the water body. The stocking formula were set to be super-intensive in the

area of the fish cages and to allow sufficient space for mussel growth.
Water samples were taken from the fish cages before the bivalves were introduced, and after the swan mussels were placed in the specially created spaces. The parameters which were monitored, oxygen and organic matter, underwent variable changes. Throughout the experiment, fish were fed with pelleted feed.
There are a wide range of advantages of integrated fish farming (rearing fish in pens and cages), but there may also be negative precursors of this intensive fish farming, as shown in Table 3.

Table 3. Advantages and disadvantages of integrated multi-trophic cultures in floating cages

Advantages	Disadvantages	Remediation possibilities
The organic waste derived from the diet, rich in macroergic substances, can be used as feed by the fish in the ponds where they are mounted;	This type of integrated fish farming system, based on a high-protein diet, involves feeding a species with a high economic value to make this type of production profitable;	Introducing a fish species with high economic value and obtaining adjacent aquatic crops that can generate profit;
As a consequence of the decomposition of the resulting residues, it has the potential to be recovered by the next food chain in freshwater ponds;	With integrated fish farming, due to the high concentration of accumulated residues, eutrophication of waters can occur;	Introducing into aquaculture a species of living organisms capable of constantly maintaining the trophic and chemical balance of the ecosystem;
Integrated fish rearing in floating cages leads, to a much higher growth of fish material compared to conventional systems and, on the other part, the whole system can be controlled more easily;	For the application of such a rearing process, the need to know the relationships between living organisms and their habitat involves many variables;	Develop perfectly balanced stocking formula rules in terms of species synergy and sustainable exploitation of natural resources;
Stimulates the development of natural feed, thanks to the waste released into the environment from cages and pens.	The possibility to accumulate excessive waste and disturb chemical balances in the water source.	Maintain as stable as possible the chemical equilibrium of the water and the development of active biomass in ponds, where this type of construction is installed.

After the introduction of swan mussels *A. cygnea*, it was observed an increased efficiency, in terms of the consumption of supplementary feed administered, due to the fact that another consumer class with a different feeding behaviour was introduced into the system. Due to the fact that the anchoring system of the cages allowed the "sweeping" of the bottom of the cage, the possibility for swan mussels to feed has been favoured, because these bivalves are sedentary and swim very short distances in their habitat.
By analysing the water and soil samples taken in the SCDP Nucet's own laboratory, it was possible to determine the concentration of organic solids. Due to the displacement of sediments deposited on the bottom of the pond (the water in the pond has an organic substance, containing organic nitrogen or sulphur compounds, humic acid or humates, etc.) there is an improvement of this fish water quality parameter by constant replenishment of the Benthic zone found at the bottom of the pond (Table 4.).
Each lot of water samples analysed (3 samples were collected from the same key points, cage 1, cage 3 and cage 6), it was collected at 14-day intervals, starting with lot 1, which represents time zero for both experimental variants (without swan mussels - variant 1 and with swan mussels - variant 2).
In Table 4, Lot 1 coincides with time zero (T0). Time zero (T0) represents the time when sampling started, day 1, but also day 91 (the first day after the introduction of swan mussels into the specially designed cages). Lot 2 corresponds to the next two weeks (day 14) and so on for a period of 6 months. The six months coincide with the warm growing season for fish.
In the water samples collected from the bottom of the floating cages (20 cm depth), the level of organic matter ($KMnO_4$ – oxidability, expressed in mg/l) averaged 49 mg/l $KMnO_4$ for all batches of samples collected before the introduction of swan mussels into the mussel cages. The same parameter underwent variable changes, with the introduction of freshwater swan mussels into the system, reaching a lower value of 34 mg/l $KMnO_4$.

Table 4. Data obtained by physical-chemical analysis of water samples from floating fish cages

Sample lot/ Characteristics	Oxidability $KMnO_4$ (mg/l)		Dissolved oxygen (mg/l)	
	Without *A. cygnea* - variant 1 (day 1)	With *A. cygnea* - variant 2 (day 91)	Without *A. cygnea* - variant 1 (day 1)	With *A. cygnea* - variant 2 (day 91)
Lot 1/ Feed administration	48	38	5.8	6.1
Lot 2/ Feed administration	50	36	5.4	6.2
Lot 3/ Feed administration	50	36	5.2	5.8
Lot 4/ Feed administration	47	32	6.1	6.5
Lot 5/ Feed administration	49	32	6.6	6.9
Lot 6/ Feed administration	50	31	6.9	7.1

The standard value of this parameter in fish farming waters is in the optimal range 20 - 60 mg/l. The average difference in $KMnO_4$ between the two sets (without swan mussels and with swan mussels) is 14.83 mg/l, lower than the baseline (Figure 6).

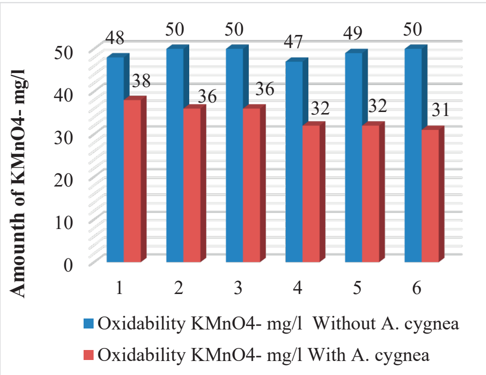

Figure 6. Variation of $KMnO_4$ (mg/l)

The average dissolved oxygen, measured with the HANNA JI9829-11042 portable oxygen meter for all samples before the introduction of swan mussels, was 6 mg/l, and after the addition of swan mussels, the total average changed to 6.43 mg/l. Dissolved oxygen in water increased from an average value of 6 mg/l to 0.43 mg/l (Figure 7).

With the introduction of the bivalve cages, by conducting regular (every 3 days) checks on uneaten food, it was possible to observe a notable reduction in the amount of waste reaching the bottom of the tank, which means that their introduction increases the consumption of additional feed that was distributed to the fish. Periods when more uneaten food was observed after feeding control coincided with changes in wind intensity and increases in daily water temperature. Wind intensity increased the speed with which the cages moved, so that the area covered by the cages was greater than during normal periods. As the contact surface between the cages and the pond bottom has varied, the time spent by the swan mussels for physiological processes (breathing, feeding, excretion) has fluctuated and decreased as well.

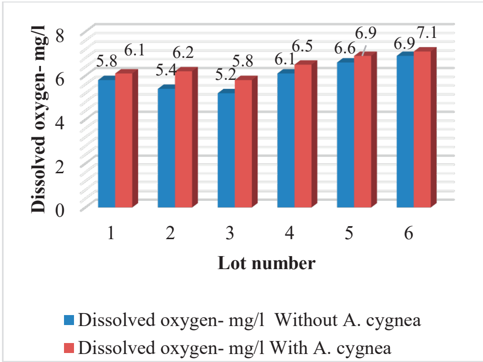

Figure 7. Dissolved Oxygen variation (mg/l)

CONCLUSIONS

The practice of stocking fish and molluscs in cages, as described above, stimulates the application of integrated multi-trophic aquaculture in the current context of circular economy principles. In Romania, the exploitation of freshwater swan mussels is a new chapter, the full benefits of this culture are not yet known and it does not enjoy appropriate attention in terms of popularity. Their introduction at S.C.D.P-Nucet was not intentional, as they ended up in the source water's rearing ponds, together with wild fish that passed through the filters installed on the Ilfov stream. The development considerably of swan mussel *A. cygnea* in freshwater pond was observed during the growing season (April - September). Encouraging results were obtained after biometric measurements, which showed an increasing variation in the total weight of the biomass studied, as well as an increase in total length and girth. Used as biofilters, this edible swan mussel has a valuable performance, is easy to handle and does not require a large investment.

ACKNOWLEDGEMENTS

This research work was carried out with the support of the Faculty of Animal Productions Engineering and Management, University of Agronomic Sciences and Veterinary Medicine of Bucharest, and is part of the elaboration of the doctoral thesis.

REFERENCES

Agostinho, A.A., Pelicice, F. M. & Gomes, L. C. (2008). Dams and the fish fauna of the Neotropical region: impacts and management related to diversity and fisheries. *Brazilian Journal of Biology*, *68*(4), 1119-1132.

Ahmed, N., Thompson, S., & Glaser, M. (2019). Global aquaculture productivity, environmental sustainability, and climate change adaptability. *Environmental management*, *63*, 159-172.

Araujo, G. S., Silva, J. W. A. D., Cotas, J., & Pereira, L. (2022). Fish Farming Techniques: Current Situation and Trends. *Journal of Marine Science and Engineering*, *10*(11), 1598.

Arcade, M. C., Costache, M., Bahaciu, G. V., Dragomir, N., & Nicolae, C. G. (2023). IMTA key concept for developing a strategy to increase aquaculture production and improve environmental sustainability. *Scientific Papers. Series D. Animal Science*, *LXVI* (1), 525-531.

Azevedo, P. A., Podemski, C. L., Hesslein, R. H., Kasian, S. E. M., Findlay, D. L. & Bureau, D. P. (2011). Estimation of waste outputs by a rainbow trout cage farm using a nutritional approach and monitoring of lake water quality. *Aquaculture*, *311*(1-4), 175-186.

Azhar, M. H., & Memiș, D. (2023). Application of the IMTA (Integrated Multi-Trophic Aquaculture) System in Freshwater, Brackish and Marine Aquaculture. *Aquatic Sciences and Engineering*, *38*(2), 106-121.

Bardach, J. E., Ryther, J. H., & McLarney, W. O. (1972). *Aquaculture: The Farming and Husbandry of Freshwater and Marine Organisms*. Hoboken, USA: John Wiley & Sons, Inc. Publishing House.

Bucur, C., Costache, M., Radu, D., Marica, N., Costache, M., & Nicolae, C. G. (2016). Fish rearing experiment in a combined intensive-extensive system (I.E.S.) for complex recovery of the fishery potential from water basins. *Agriculture and Agricultural Science Procedia, 10,* 238-243.

Costache, M., Costache, M., Radu, D., Marica, N., & Dobrota, G. (2018). Research Regarding The influence of different types of hormones on reproductive performances of European catfish (*Silurus glanis* L.). *International Multidisciplinary Scientific Geoconference: Sgem*, *18*(6.2), 529-534.

Costache, M., Costache, M., Marica, N., Radu, D., & Nicolae, C. G. (2021a). Growth technologies for the complex exploitation of aquatic basins from the traditional fish farms. *Scientific Papers. Series D. Animal Science*, *LXIV*(2), 423-430.

Costache, M., Cristea, D. S., Petrea, S. M., Neculita, M., Turek Rahoveanu, M. M., Simionov, I.-A., Mogodan, A., Sarpe, A., & Turek Rahoveanu, A. (2021b). Integrating aquaponics production systems into the Romanian green procurement network. *Land Use Policy*, *108*, 105531. DOI: https://doi.org/10.1016/j.landusepol.2021.105531.

Dias, J. D., Simões, N. R. & Bonecker, C. C. (2012). Zooplankton community resilience and aquatic environmental stability on aquaculture practices: a study using net cages. *Brazilian Journal of Biology*, *72*(1), 1-11.

Fishery and Aquaculture Country Profiles (n.d.) FAO, Fisheries and Aquaculture. Retrieved from https://www.fao.org/fishery/en/facp/rou?lang=en.

Food and Agriculture Organization of the United Nations FAO (n.d.) (2020). *FAO Yearbook. Fishery and Aquaculture Statistics 2018 / FAO annuaire. Statistiques des pêches et de l'aquaculture 2018 / FAO anuario. Estadísticas de pesca y acuicultura 2018.* Retrieved June 28, 2023 from https://www.fao.org/fishery/en/publications/269665

Hanif, M. (2022). Development of the Integrated multi-trophic aquaculture (IMTA) System in the World; Article Review. *Journal of Aquaculture Science*, *7*(2), 29-38.

Heydari, S., Pourashouri, P., Shabanpour, B., Shamsabadi, F. T., & Arabi, M. S. (2023). Evaluation of Freshwater Mussel (*Anodonta cygnea*) Protein Hydrolysates in Terms of Antibacterial Activity and Functional Properties. *Waste and Biomass Valorization*, 1-12.

Khan, M. I. (2019). *Freshwater Mussel (Anodonta Cygnea) as a Bioindicator for Monitoring of Pollution Status in River Kabul, Pakistan* (Doctoral dissertation, University of Peshawar, Peshawar). Retrieved March, 2, 2023 from http://142.54.178.187:9060/xmlui/handle/123456789/5179.

Klinger, D., & Naylor, R. (2012). Searching for solutions in aquaculture: charting a sustainable course. *Annual Review of Environment Resources*, *37*, 247-276.

Koroleff, F. (1976). Determination of nutrients. In E. Grashof, & E. Kremling, E. (Eds.), *Methods of seawater analysis* (pp. 117-181). New York, USA: Verlag Chemie Wenhein. DOI: https://doi.org/10.14934/chikyukagaku.39.173.

Lachi, G. B. & Sipaúba-Tavares, L. H. (2008). Qualidade da água e composição fitoplanctônica de um viveiro de piscicultura utilizado para fins de pesca esportiva e irrigação. *Boletim de Instituto de Pesca*, *34*, 29-38.

Liao, I. C., Huang, T. S., Tsai, W. S., Hsueh, C. M., Chang, S. L. & Leaño, E. M. (2004). Cobia Culture in Taiwan: Current Status and Problems. *Aquaculture*, *237*, 155-165.

Moriarty, D. J. W. (1997). The role of micro-organisms in aquaculture ponds. *Aquaculture*, *151*, 333-349.

Neculita, M., & Moga, L. M. (2015). Analysis of Romanian fisheries and aquaculture in regional context. *The USV Annals of Economics and Public Administration*, *15*(1 (21)), 127-132.

Nissar, S., Bakhtiyar, Y., Arafat, M. Y., Andrabi, S., Mir, Z. A., Khan, N. A., & Langer, S. (2023). The evolution of integrated multi-trophic aquaculture in context of its design and components paving way to valorization via optimization and diversification. *Aquaculture*, *565*, 739074. DOI: https://doi.org/10.1016/j.aquaculture.2022.739074.

Ntengwe, F. W., & Edema, M. O. (2008). Physico-chemical and microbiological characteristics of water for fish production using small ponds. *Physics and chemistry of the Earth, Parts A/B/C*, *33*(8-13), 701-707.

Ouattara, N. I., Teugels, G. G., N'Douba, V., & Philippart, J. C. (2003). Aquaculture potential of the black-chinned tilapia, *Sarotherodon melanotheron*. Comparative study of the effect of stoking density on growth performance of landlocked and natural populations under cage culture conditions in lake (Lake Ayamé) (Côte d'Ivoire). *Aquaculture Research*, *34*(13). https://hdl.handle.net/2268/241481.

Poznańska-Kakareko, M., Wiśniewski, K., Szarmach, D., Witkowska, A., Kakareko, T., & Kobak, J. (2021). Importance of substratum quality for potential competitive niche overlap between native and invasive unionid mussels in Europe. *Science of the Total Environment*, *799*, 149345. DOI: https://doi.org/10.1016/j.scitotenv.2021.149345.

Radu, D., Costache, M., Costache, M., Marica, N., & Dobrota, N. (2018). Research on reproductive performance of carp breeds (*Cyprinus carpio* L.) Frasinet, Ineu and Ropsa. *International Multidisciplinary Scientific GeoConference: SGEM, 18(6.2)*, 513-520.

Ranjbar, R., Shariati, F. P., Tavakoli, O., & Ehteshami, F. (2021). Fabrication of a new reactor design to apply freshwater mussel Anodonta cygnea for biological removal of water pollution. *Aquaculture*, *544*, 737077. DOI: 10.1016/j.aquaculture.2021.737077.

Ridler, N., Wowchuk, M., Robinson, B., Barrington, K., Chopin, T., Robinson, S., Page, F., Reid, G., Szemerda, M., Sewuster, J., & Boyne-Travis, S. (2007). Integrated multi-trophic aquaculture (IMTA): a potential strategic choice for farmers. *Aquaculture Economics & Management*, *11*, 99-110.

Sangirova, U., Khafizova, Z., Yunusov, I., Rakhmankulova, B., & Kholiyorov, U. (2020). The benefits of development cage fish farming. *E3S Web of Conferences*, *217*, 09006. EDP Sciences. DOI: https://doi.org/10.1051/e3sconf/202021709006.

Schenone, N. F., Vackova, L. & Cirelli, A. F. (2011). Fish-farming water quality and environmental concerns in Argentina: a regional approach. *Aquaculture International*, *19*, 855-863.

Song, Y., Li, M., Fang, Y., Liu, X., Yao, H., Fan, C., Tan, Z. & Chen, J. (2023). Effect of cage culture on sedimentary heavy metal and water nutrient pollution: Case study in Sansha Bay, China. *Science of The Total Environment*, *899*, 165635. DOI: https://doi.org/10.1016/j.scitotenv.2023.165635.

Wang, X., Olsen, L. M., Reitan, K. I., & Olsen, Y. (2012). Discharge of nutrient wastes from salmon farms: environmental effects, and potential for integrated multi-trophic aquaculture. *Aquaculture Environment Interactions, 2*, 267-283.

Whitmarsh, D.J., Cottier-Cook, E. J., & Black, K. D. (2006). Searching for sustainability in aquaculture: An investigation into the economic prospects for an integrated salmon-mussel production system. *Marine Policy, 30*(3), 293-298.