The influence of IMTA pond production systems on the cyprinid species, weight-length relationship and distribution

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Abstract. The main aim of this research was to evaluate the influence of the integrated multi-trophic aquaculture (IMTA) concept on the distribution and the weight-length relationship of four cyprinid species, common in Romanian aquaculture sector, by conducting a comparative study between an IMTA pond production systems and a classical pond polyculture system. Two fishponds were used for our study, with an area of 0.45 ha each. In the first pond (PCP) common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idella*), bighead carp (*Hypophthalmichthys nobilis*) and silver carp (*Hypophthalmichthys molitrix*) were reared in polyculture system. The second pond (IMTA) was divided by a net into two sections, as follows: first one, with an area of 0.15 ha considered as common carp monoculture pond section (CP) and the second one, with an area of 0.30 ha considered as cyprinids polyculture pond section (PP) for: *C. carpio*, *C. idella*, *H. nobilis* and *H. molitrix*. The experimental study had lasted 83 days, from 15 June to 5 September 2016. The allometric exponent "b" indicates a superior condition status in case of *C. carpio* reared by using IMTA technique, comparing with the specimens reared in in polyculture system. However, the rest of cyprinids species had revealed a superior condition status by applying polyculture production technology, comparing with IMTA. The Fulton's condition coefficient (K) registered the highest values in case of *C. carpio*, fact confirmed both in IMTA (K = 2.89 g cm^{-3} - CP and K = 3.39 g cm^{-3} - PP) and polyculture ponds (K = 3.19 g cm^{-3}). The IMTA pond production technique and its technology can represent a solution for improving fish condition, production efficiency and production management.

Key Words: allometric exponent, cyprinids, Fulton's condition coefficient, integrated multi-trophic aquaculture, polyculture.

Introduction. Common carp (*Cyprinus carpio*) is one of the most cultivated freshwater fish worldwide due to its considerable economic value (Stankovic et al 2011). In Romania, the distribution of total aquaculture production by species is represented by 87% of cyprinids (Virlanuta et al 2015).

Cypriniculture is the branch of aquaculture dealing with the growth of fish species from the Cyprinidae family, first represented by *C. carpio*, followed by the prussian carp (*Carassius auratus gibelio*) - among the autochthonous species - as well as by the acclimatized Asian cyprinids (*Hypophthalmichthys nobilis*, *Hypophthalmichthys molitrix*, *Ctenopharyngodon idella*) (Dumitru & Ciornea 2010). As known, *C. carpio* is a precocious species, characterized by a rapid growing rhythm, by a high capitalization of the additional food it gets, and also by its relatively high resistance to parasitic diseases (Dumitru & Ciornea 2010).

Most of the time *C. carpio* is grown in polyculture with other species. The need for the application fish in polyculture system is based on the concept of total utilization of all the living space and the trophic basin potentials, with the purpose to ensure the maximum level of fish production per unit of water surface (Bllaca & Sapho 2014). According to Billard & Jacqueline (1986), the purpose of the introduction of Chinese cyprinid herbivorous and plankton eaters in polyculture along with *C. carpio*, is the increase of production through the use of phytoplankton, zooplankton and macrophytes. Interactions between fish and other species that serve as food have special importance for the polyculture systems (Milstein et al 2008; Kumar at al 2005). Those species that have different habits of nutrition can positively affect the availability of natural food, e.g. by liberating nutrients deposited in the bottom of the basin, or negatively, by consuming various components of the food reserve (Milsten & Svirsky 1996; Pearl & Tucker 2007). The displacement of sediment from *C. carpio* increases the availability of the natural food enriching the nutrient flux that passes through the food chain (Hepher et al 1989; Milsten & Svirsky 1996). It should be recognized that for several reasons mainly related to trophic flexibility and the opportunistic nature of feeding of the omnivore and phytophagous species, in many cases it is difficult to predict the interconnection between the structure of the polyculture system and the production generated from this cultivation practice (Schroeder 1980; Sandhu Jaswindher & Toor 1983; Billard & Jacqueline 1986). The selection of fish species is of paramount importance to ensure the success of the production, both in terms of quantity and quality (Ur-Rehman et al 2016). Population densities and species that combine a polyculture vary from one country to another depending on the cultivation practices, as well as on the environmental conditions and practices of the market needs (Singh 1997). Considering the problem in terms of natural food consumption claimed that the level of efficient use of food depends on the combination of the species that would constitute a polyculture and their relative densities (Kumar et al 2005).

As opposed to polyculture system, the integrated multi-trophic aquaculture (IMTA) is both conceptually a simple idea and also highly appealing to regulators: the waste products from one food production process (in this case, carps production) is acquired and assimilated by other organisms and converted into valuable products (Petrea et al 2017). This process both eliminates waste and increases the productivity of the food production system (Troell et al 2003; Neori et al 2004; Chopin et al 2004).

In fisheries biology, the length-weight relationships (LWR) of fishes are important in order to estimate of the average weight of the individual of a given length group by establishing a mathematical relation between them (Mir et al 2012).

Besides providing a mathematical relationship between length and weight of fish, it solves various problems concerned with the life history of fishes such as means of interconversion, yields information on the general wellbeing of the fish, variations in growth, size at first maturity, gonad development and breeding season (Thomas et al 2003). LWR parameters (a and b) are useful in fisheries science in many ways: to estimate weight of individual fish from its length, to calculate condition indices, to compare life history and morphology of populations belonging to different regions (Petrakis & Stergiou 1995) and to study ontogenetic allometric changes (Teixeira de Mello et al 2006).

In aquaculture, the condition factor (Fulton coefficient) is used in order to compare the "condition", "fatness" or well-being of fish. It is based on the hypothesis that a better physiological condition is reflected by a heavier fish of a particular length. For monitoring of feeding intensity, age, and growth rates in fish the condition factor is considered a useful index. It can be used as an index to assess the status of the aquatic ecosystem in which fish live, and it is strongly influenced by both biotic and abiotic environmental conditions. Condition factor also gives information when comparing two populations living in certain feeding, density, climate, and other conditions when determining the period of gonad maturation, and when following up the degree of feeding activity of a species to verify whether it is making good use of its feeding source (Bagenal & Tesch 1978; Oni et al 1983; Anene 2005; Kumolu-Johnson & Ndimele 2010; Abowei 2010).

The efficient use of the natural food resources, the stimulation of their development through the organic and mineral fertilization and the complementary and limited use of the concentrated foods aims precisely to increase the efficiency and maximize the utilization of trophic opportunities at the pond level, by using IMTA production techniques (Bllaca & Spaho 2014).

The main aim of this research was to evaluate the influence of IMTA concept on the distribution and the weight-length relationship of four cyprinid species, very common in Romanian aquaculture sector, by conducting a comparative study between an IMTA pond production system and a classical pond polyculture system.

Material and Method

Description of the study sites. This study was conducted in a private fish farm, which is situated in the Larga Jijia village, 24 km north-west from Iasi city, Romania. The location of the farm is described in the work published by Petrea et al (2017).

Experimental design. In this research were used two ponds with an area of 0.45 ha each. The experimental design is presented in Figure 1.

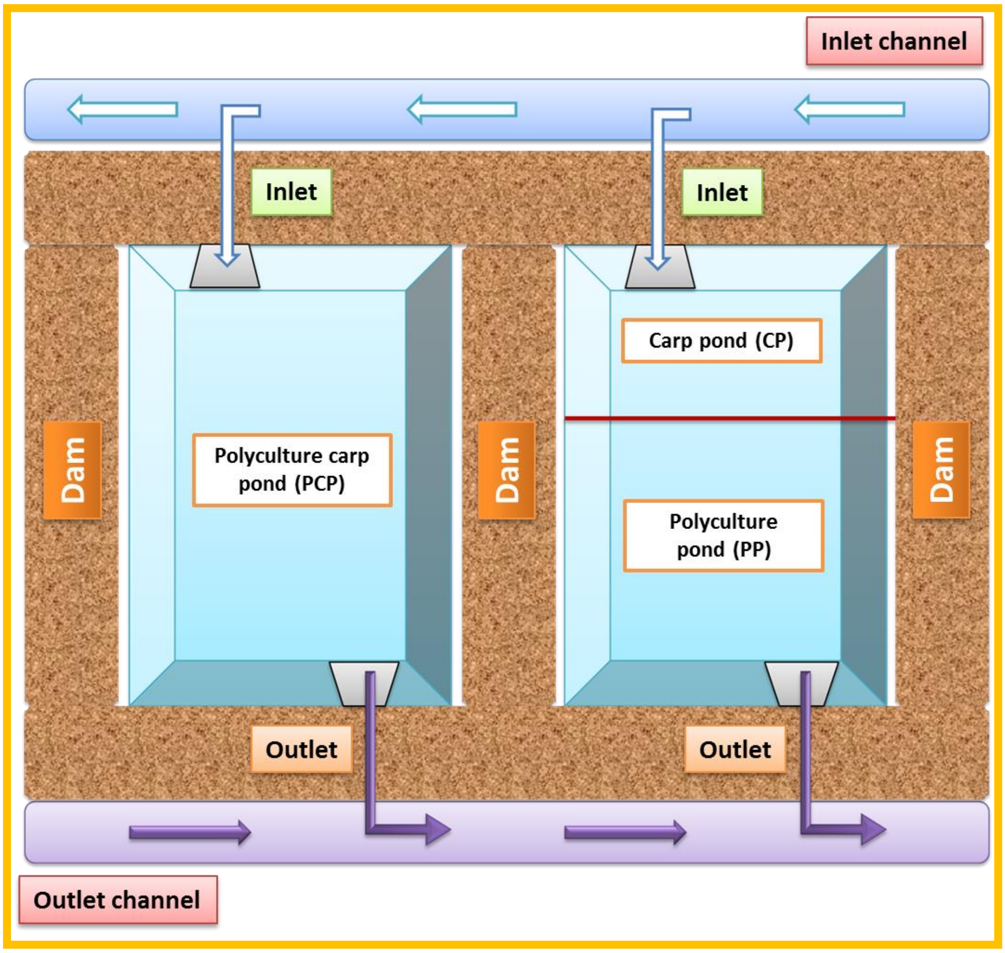

Figure 1. Experimental design of the research.

The first pond (PCP) was used for rearing in polyculture system: 2,500 *C. carpio* specimens (63.0±7.80 g fish^{-1}, 12.7±0.40 cm fish^{-1} respectively) with 100 *C. idella* specimens (200.4±20.01 g fish^{-1}, 17.2±0.99 cm fish^{-1} respectively), 40 *H. nobilis* specimens (1937.0±191.48 g fish^{-1}, 35.5±1.70 cm fish^{-1} respectively) and 40 *H. molitrix* specimens (2006.3±213.80 g fish^{-1}, 37.9±1.40 cm fish^{-1}).

The second pond was divided by using a net (Figure 2), as follows: first part with an area of 0.15 ha CP (monoculture pond section for *C. carpio*) and the second part with an area of 0.30 ha PP (polyculture pond section). The CP pond was populated with 2,000 *C. carpio* specimens (61.2±11.60 g fish^{-1}, 12.5±0.90 cm fish^{-1} respectively). The PP pond section was populated with: 500 *C. carpio* specimens (60.0±10.45 g fish^{-1}, 12.3±0.7 cm fish^{-1} respectively), 100 *C. idella* specimens (199.4±20.00 g fish^{-1}, 17.1±1.00 cm fish^{-1} respectively), 40 *H. nobilis* specimens (1824.1±182.59 g fish^{-1}, 34.7±1.20 cm fish^{-1}

respectively) and 40 *H. molitrix* specimens (2044.0±289.80 g fish^{-1}, 38.7±1.80 cm fish^{-1} respectively).

Figure 2. The pond divided by using a net (CP and PP).

The research was conducted for 83 days from 15 June to 5 September 2016. During this experimental period were made three intermediary biometric and biomass measurements (intermediary 1 – after 22 days, intermediary 2 – after 42 days and intermediary 3 – after 52 days), except measurements from the stocking date and the harvesting date. The fish biometric measurements were made by using ImageJ image processing program, designed for scientific multidimensional images.

During entire period of our research, feed was manually administered, twice/day, only in PCP and CP, for five days/week. The administered feed had a crude protein content of 28% and was represented by a mix of cereals and flour protein. The quantity of administered feed was adjusted after each control fishing. Throughout the entire experimental period there were used two daily feeding ratios: 3% of biomass weight (BW) and 1.5% BW (Petrea et al 2017).

Length-weight relationship (LWR). The length-weight relationship (LWR) between total length (TL) in centimeters and body weight (W) in grams was determined from the transformed collected data. The parameters: *a* and *b* were estimated by linear regression equation given by LeCren (1951), Jones (2002) and Koutrakis & Tsikliras (2003). This equation is sometimes also referred as the length-weight key (Biswas 1993):

$$W = a\, L^{b}$$

$$\log W = \log a + b \log L,$$

Where:

a = coefficient related to body form,

b = exponent.

The coefficient of correlation (r) was calculated following standard statistical procedure given by Snedecor & Cochran 1967.

Fulton's condition coefficient (K) was calculated for all fish species from the ponds (PCP, CP and PP) as the ratio between individual weight and total length of the fish:

$$K = 100 \times (W / TL^{3}),$$

Where:

W – individual fish weight (g),

TL – individual fish total length (cm).

Statistical analysis. The results of fish distribution, weight-length relationship and condition factor (K), of the experimental research were statistically analyzed using descriptive statistics and ANOVA test. We used Microsoft Excel 2010 and IBM SPSS Statistics 20.0. Programs. The results were presented as minimum, maximum and mean ± standard deviation.

Results and Discussion

A. PCP experimental variant

In a pond production system, the technological performance of fish biomass is correlated with multiple factors related to the rearing environment and the nutritional demands, therefore, conducting to the optimization of feed conversion ratio. However, the success of a fish farm is conditioned both by the total fish biomass values, recorded at the end of the production cycle, and homogeneity degree of fish stocks in terms of individual length and biomass.

At the beginning of the experimental period, no significant differences ($p>0.05$) were observed between the experimental variants in terms of fish individual length and weight. Therefore, the homogeneity of fish experimental biomass was statistically verified (Levene Test, $p>0.05$).

1. Cyprinus carpio

Regarding the distribution of *C. carpio* individual length values, it can be stated that, at the beginning of the experimental period, the values are close to the median, while, as the experiment evolves, the values are spread within a larger range around the median, fact that indicates a small decrease of fish population homogeneity degree throughout the experimental period (Figure 3). It can be observed that the highest individual length value was recorded in case of Int.1 (Figure 3). This situation can be explained by the number of fish catch at Int. 1 control harvesting, which was the lowest, compared with the other control harvestings (Int.2, Int.3).

The evolution of common carp individual weight had an upward tendency, a symmetric distribution of values around the median, being observed in case on Int.2 (Figure 4).

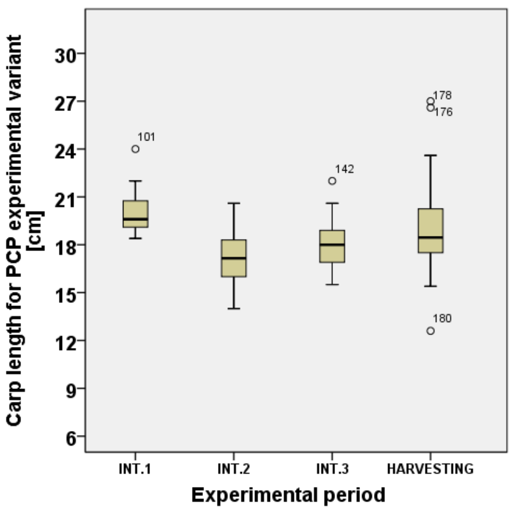

Figure 3. The distribution of *Cyprinus carpio* individual length values throughout the experimental period.

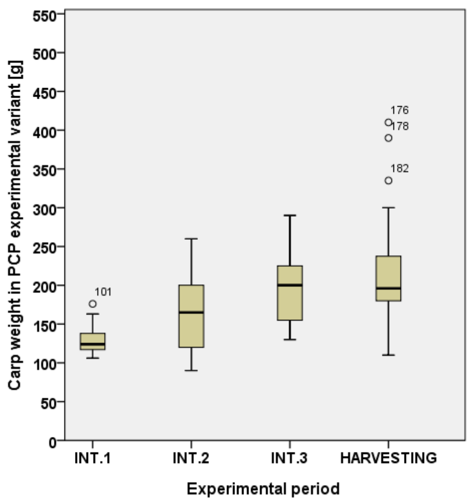

Figure 4. The distribution of *Cyprinus carpio* individual weight values throughout the experimental period.

The correlation between the evolution of *C. carpio* individual length (Figure 3) and individual weight (Figure 4) shows a more prominent growth in length rather than weight, at least till the first control harvesting (Int.1) (Figure 3 & 4).

The relative robustness of the population of fish can be detected from a length-weight regression. Therefore, it can be observed that allometric exponent "b" has its values under three units, fact that indicates a growth in length rather than weight (Figure 5).

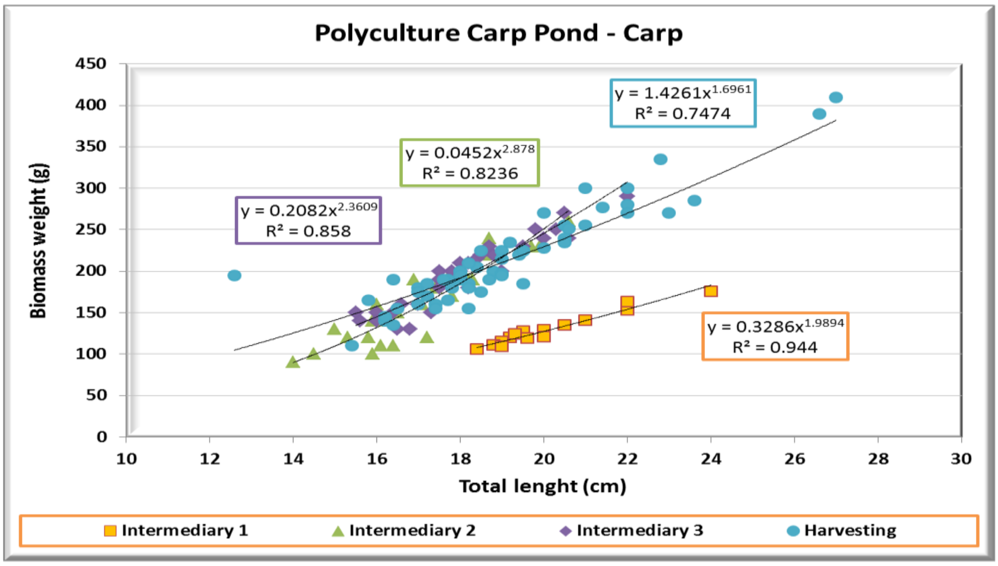

Figure 5. Power regression of *Cyprinus carpio* biomass individual length-weight during the experimental period.

The superior values of allometric factor obtained in Int.1 (b = 2.36) and Int.2 (b = 2.87), compared with Int.3 (b = 1.69) and final harvesting (b = 1.98), indicates a superior condition status of *C. carpio* in the first half of the experimental period (Figure 5).

Based on the interpretation made by Ricker (1975), the negative allometric values of intercept "b" show that the cultivation environment or specific elements of technology implemented do not fully responded to the physiological requirements of the two populations of *C. carpio*.

2. *Hypophthalmichthys molitrix*

Concerning *H. molitrix* individual length distribution, it can be observed that the values widespread degrees around the median, from Int. 2 and Int. 3, is lower compared with final harvesting (Figure 6). This indicates a significant decrease in homogeneity of *H. molitrix* population, throughout the experimental period.

For Int.1 harvesting there were no values registered, because the amount of silver carp caught was less than the minimum limit that permits us to obtain a fair statistically result. However, it must be pointed out the low values of silver carp total length from final harvesting, compared with the Int.3 control harvesting (Figure 6). This may be due to the fact that, at control harvesting there is the possibility that the catches to be part of a certain range of values, included in the entire silver carp population total length range of variation.

The evolution of silver carp individual weight had an upward tendency, until Int.3-final harvesting period, where a significant decrease has been observed (Figure 7). This could be related to the decrease of temperature and also to the phytoplankton downward dynamic. Also, at final harvesting a wider spread of *H. molitrix* individual weight values, around the median, can be observed, fact that can indicate a homogeneity degree decrease of fish population, throughout the experimental period (Figure 7).

It can be observed that allometric exponent "b" has its values under three units in case of Int.2 and final harvesting, fact that indicates a growth in length rather than weight (Figure 8). In case of Int.3, the exponent is higher than three units, which indicates a growth in weight, rather than length. The superior values of allometric factor obtained at Int.3 (b = 5.22) compared with Int.2 (b = 2.25) and final harvesting (b =

2.95), can indicate a superior condition status of *H. molitrix* at Int.3, rather than the rest of the experimental period (Figure 8).

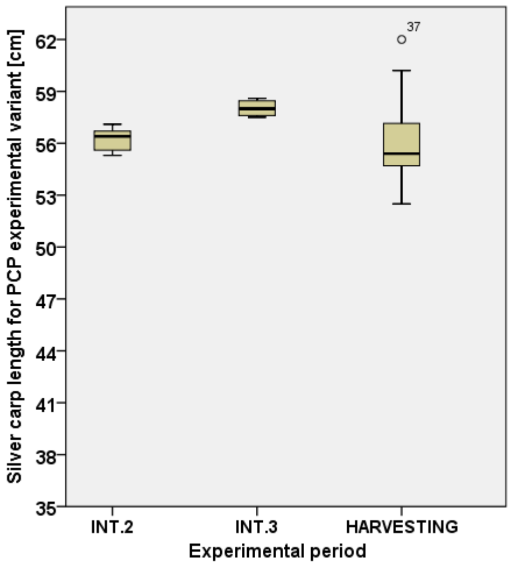

Figure 6. The distribution of *Hypophthalmichthys molitrix* individual length values throughout the experimental period.

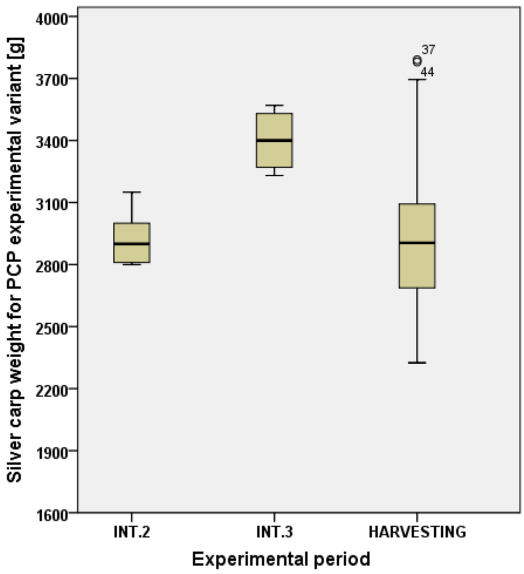

Figure 7. The distribution of *Hypophthalmichthys molitrix* individual weight values throughout the experimental period.

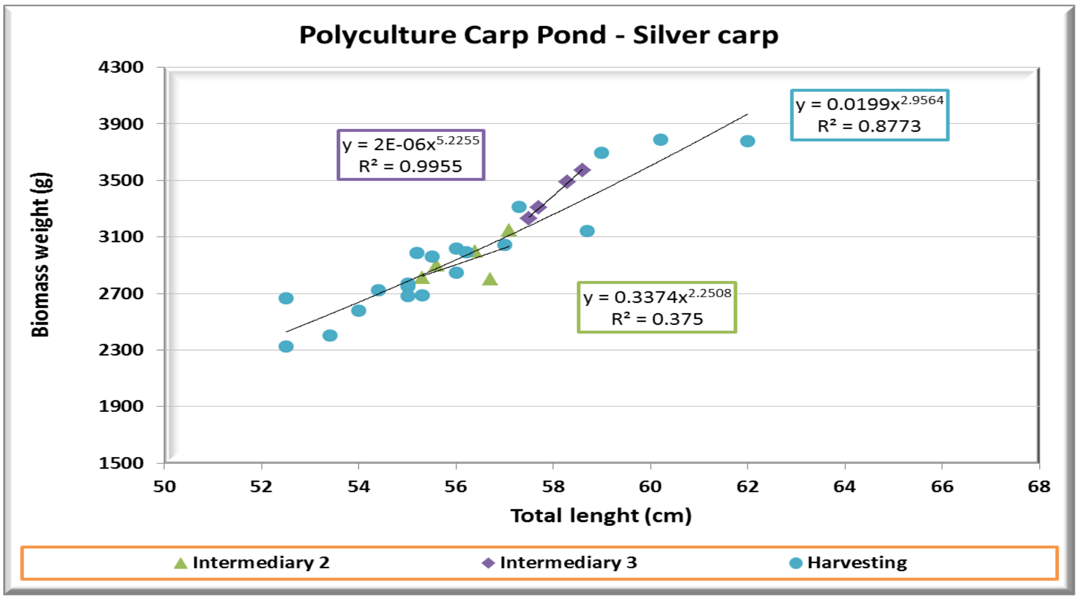

Figure 8. Power regression of *Hypophthalmichthys molitrix* biomass individual length-weight during the experimental period.

However, the low number of catches at Int.3, correlated with the possibility that all recorded catches at this control harvesting can be part of the same range of variation in terms of both total length and individual weight, can be considered also as explanations of this phenomenon.

3. *Hypophthalmichthys nobilis*

The evolution of *H. nobilis* individual length had an upward tendency, until Int.2, followed by a linear constant tendency (Figure 9).

Regarding *H. nobilis* individual weight distribution, it can be said that at the beginning of the experimental period, the values are symmetrical in relation with the median (Figure 10). Also, it can be observed that in case of Int.3 was recorded the highest individual weight value (Figure 10). However, it must be pointed out the decrease in weight of *H. nobilis*, from the Int.3 until the final harvesting (Figure 10), a similar evolution with the one of *H. molitrix*.

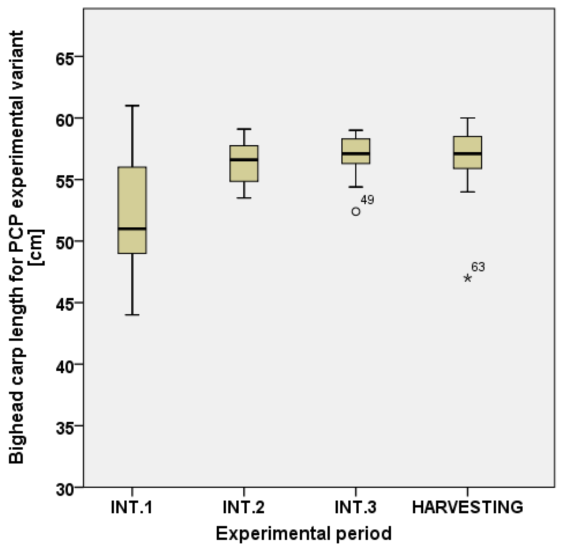

Figure 9. The distribution of *Hypophthalmichthys nobilis* individual length values throughout the experimental period.

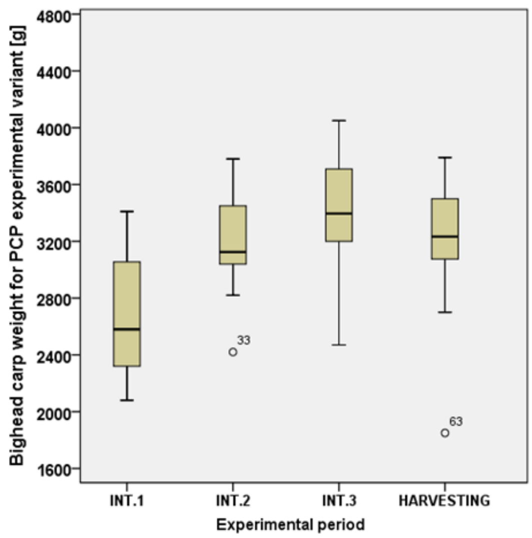

Figure 10. The distribution of *Hypophthalmichthys nobilis* individual weight values throughout the experimental period.

The allometric exponent "b" has its values under three units in case of Int.1 and final harvesting, fact that indicates a growth in length rather than weight (Figure 11). The higher values of allometric factor obtained at the Int.2 (b = 3.17) and Int.3 (b = 3.55) compared with Int.1 (b = 1.65) and final harvesting (b = 2.56), can indicate a superior condition status of *H. nobilis*, in the middle part of the experimental period (Figure 11).

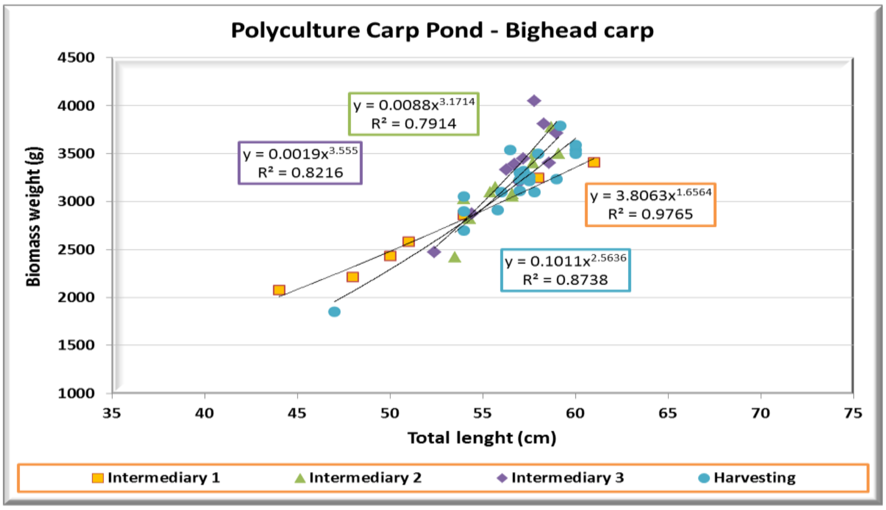

Figure 11. Power regression of *Hypophthalmichthys nobilis* biomass individual length-weight during the experimental period.

4. *Ctenopharyngodon idella*

Concerning *C. idella* individual length distribution, it can be observed that in case of Int.1 and Int.3 the values are relatively symmetrical in relation with the median, comparing with Int. 2 control harvesting and also, with final harvesting (Figure 12). The most significant widespread of total length values, around the median, is recorded at final harvesting (Figure 12). A highly upward tendency regarding the individual length is reported in initial-Int.1 experimental period, followed by a small upward linear tendency until the final harvesting (Figure 12).

The evolution of *C. idella* individual weight had an upward tendency until Int.3 control harvesting, followed by a small decrease until the final harvesting (Figure 13). Also, it must be pointed out that at final harvesting, the values widespread range, around the median, is considerable higher than the rest of the experimental period. This shows a high heterogeneity of *C. idella* population, at harvesting, in terms of individual weight (Figure 13).

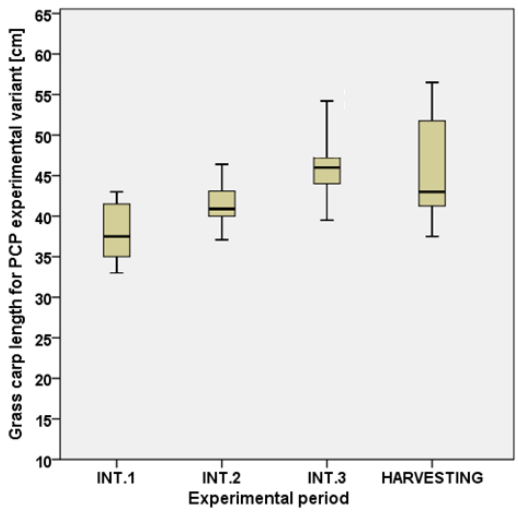

Figure 12. The distribution of *Ctenopharyngodon idella* individual length values throughout the experimental period.

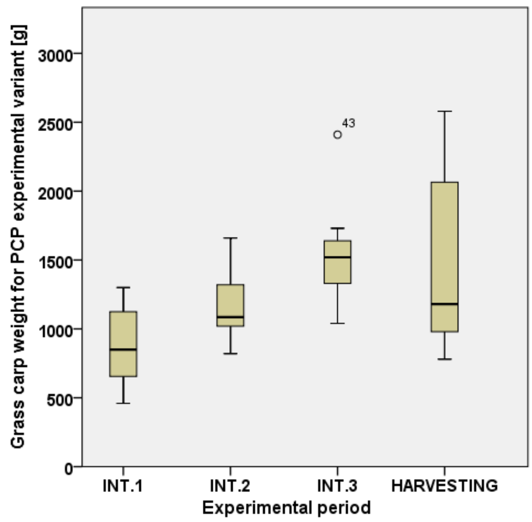

Figure 13. The distribution of *Ctenopharyngodon idella* individual weight values throughout the experimental period.

The allometric exponent "b" has its values under three units, in case of Int.3 and final harvesting, fact that indicates a growth in length rather than weight (Figure 14). The higher values of allometric factor obtained at the Int.1 (b = 3.53) and Int.2 (b = 3.02) compared with Int.3 (b = 2.19) and final harvesting (b = 2.73), indicates a superior condition status of *C. idella* in the middle part of the experimental period (Figure 14).

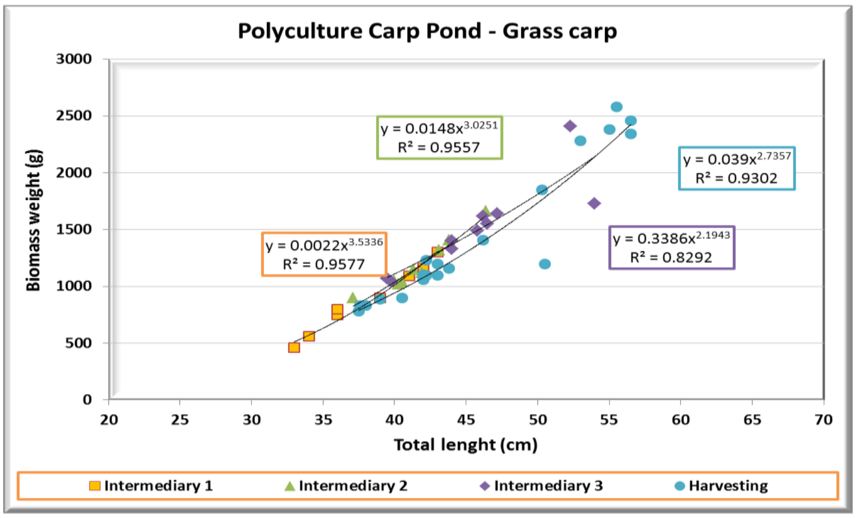

Figure 14. Power regression of *Ctenopharyngodon idella* biomass individual length-weight during the experimental period.

5. Invasive fish species

At the Int.3 and final harvesting, a significant *C. auratus gibelio* biomass was caught. This was due to the large diameters of screen holes, that permitted the small *C. auratus gibelio* fingerlings to enter into the PCP pond. In order to determine the relative robustness of *C. auratus gibelio* population, a length-weight regression was made (Figure 15). Therefore, the allometric exponent "b" has its values under three units, in case of both Int.3 control harvesting and final harvesting, fact that indicates a growth in length rather than weight (Figure 15). However, an improvement of the *C. auratus gibelio* condition status can be observed at final harvesting (b = 2.96), compared with the Int.3 control harvesting moment (b = 2.66).

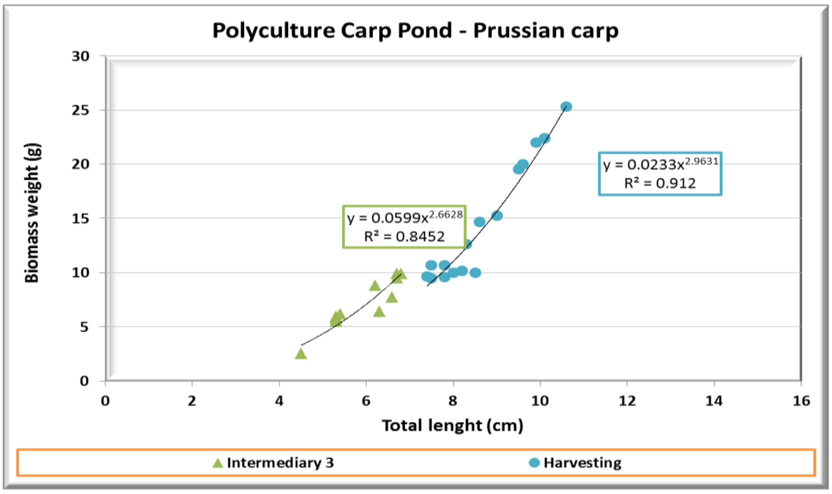

Figure 15. Power regression of *Carassius auratus gibelio* biomass individual length-weight during the experimental period.

Fulton's condition coefficient (K)

Another correlation which marks the relationship between the length and the weight of the fish samples is the condition factor. Moreover, the condition factor is at the same time a measurement which shows the fact whether the fish is fed enough (Geldiay & Balık 1988; Mert et al 2008).

The highest values of K are recorded at *C. carpio*, followed by *C. auratus gibelio* and *H. nobilis* (Table 1), while the lowest values are registered in case of *C. idella* (Table 1). This can be due to the fact that *C. carpio* has dominated the competition for feed, during the production cycle, comparing with the other fish species. However, *C. auratus gibelio* seems to be a significant feed competitor for *C. carpio*. The lowest K values recorded for *C. idella* may reveal low natural food availability at the PCP pond level.

Table 1

Condition coefficient (K) for species from polyculture carp pond (PCP)

Species	*Condition coefficient (K) (g cm^{-3})*			
	INT.1	*INT.2*	*INT.3*	*Harvesting*
Cyprinus carpio	1.59±0.12	3.22±0.38	3.30±0.32	3.19±0.95
Hypophthalmichthys molitrix	-	1.65±0.05	1.74±0.03	1.68±0.08
Hypophthalmichthys nobilis	1.90±0.26	1.77±0.09	1.83±0.11	1.74±0.10
Ctenopharigodon idella	1.54±0.12	1.62±0.07	1.57±0.16	1.43±0.13
Carassius auratus gibelio	-	-	3.34±0.48	2.87±1.63

B. CP-PP experimental variant

1. Common Carp – CP

At Int.1 control harvesting was recorded a symmetrical distribution of carp individual length values, around the median, fact that emphasizes a significant homogeneity of the biological material (Figure 16). However, the results obtained in case of Int.3, which suggest a high heterogeneity (Figure 16) of the *C. carpio* population, are probably due to low number of fish caught at the control harvesting, fact that leads to inconclusive statistically result regarding this experimental stage. Also, it must be highlighted the general symmetrical and homogenous distribution of *C. carpio* population individual length values, at the end of the experimental period (Figure 16). This fact can be explained by the rearing technology applied. Rearing *C. carpio* in monoculture, at high stocking densities, in small ponds (CP – 0.15 ha) leads to a more significant homogenous distribution of *C. carpio* population individual length values, compare with PCP, where common carp was reared in polyculture conditions, on a larger area pond (PCP – 0.45 ha).

The evolution of *C. carpio* individual weight had a linear upward tendency, asymmetric distribution of values around the median being observed in case on Int.3, fact caused by the same reasons mentioned above (Figure 17).

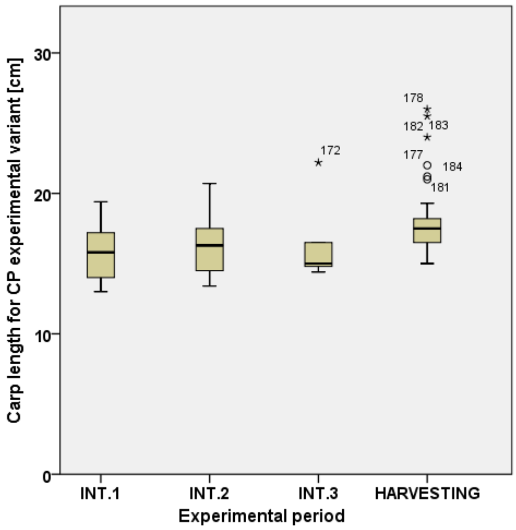

Figure 16. The distribution of *Cyprinus carpio* individual length values throughout the experimental period.

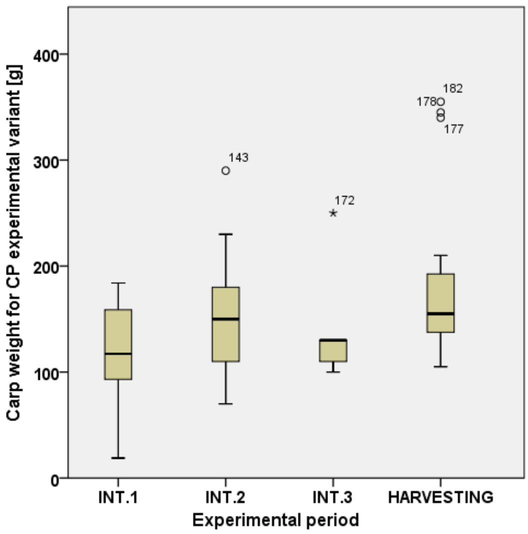

Figure 17. The distribution of *Cyprinus carpio* individual weight values throughout the experimental period.

It can be observed that allometric exponent "b" has its values under three units fact that indicates a growth in length rather than weight (Figure 18). The higher values of allometric factor obtained at the Int.1 (b = 2.59) and Int.2 (b = 2.73), compared with Int.3 (b = 1.94) and final harvesting (b = 1.94), indicates a superior condition status of *C. carpio* in the first half of the experimental period (Figure 18).

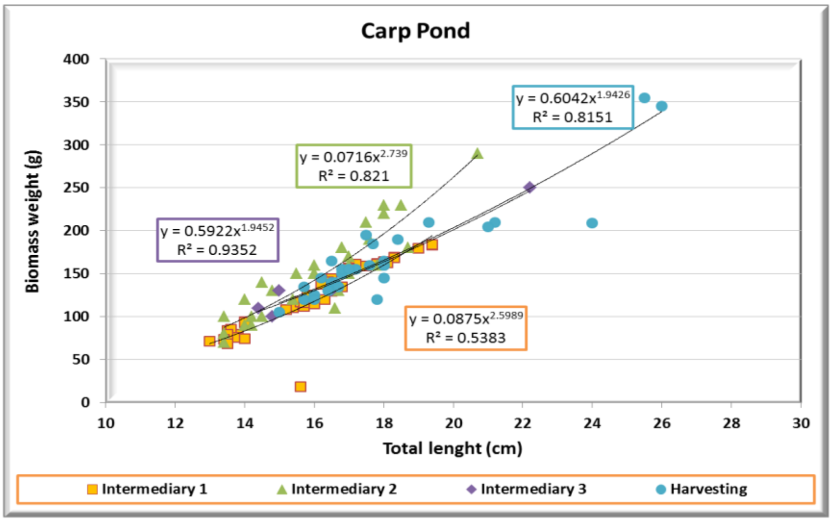

Figure 18. Power regression of *Cyprinus carpio* biomass individual length-weight during the experimental period.

2. *Common carp – PP*

The distribution of *C. carpio* individual length values, resulted from Int.2 control harvesting, was symmetrical around the median, fact that reveals a considerable homogeneity degree of the biological material (Figure 19). At the end of the experiment, the values had higher widespread degree around the median, fact that suggests a considerable heterogeneity degree of the *C. carpio* biomass in terms of individual length (Figure 19). Comparing with *C. carpio* from CP, the specimens from PP reveals a higher heterogeneity degree throughout the experimental period. This fact could be explained by the lack of feed administration on PP pond area. Therefore, the only source of feed for the biological material in PP pond is generated by the nutrients that came from CP pond, where two feeding rates were applied, as described in the material and methods section. The evolution of *C. carpio* individual weight had an upward tendency, manifested especially at the end of the experimental period (Figure 20).

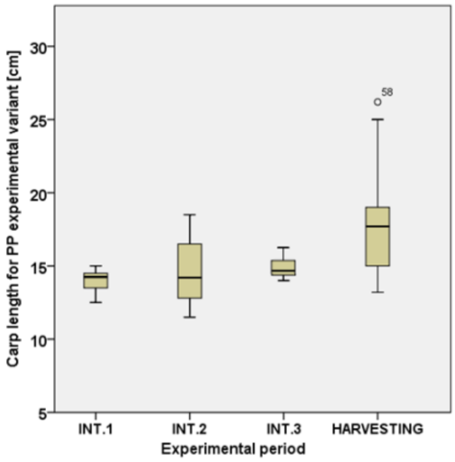

Figure 19. The distribution of *Cyprinus carpio* individual length values throughout the experimental period.

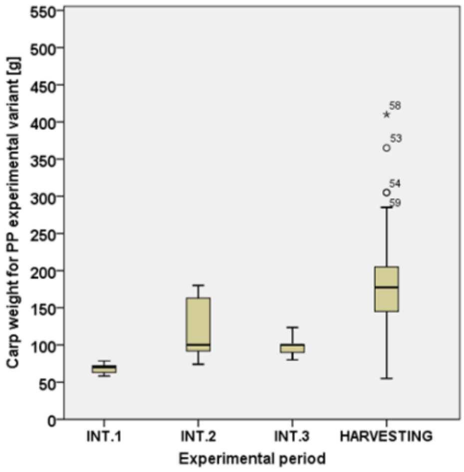

Figure 20. The distribution of *Cyprinus carpio* individual weight values throughout the experimental period.

The allometric exponent "b" has its values under three units during all experimental period, except Int.3 (Figure 21). The superior value of allometric factor obtained at the Int.3 (b = 3.03) compared with initial (b = 1.85), Int.1 (b = 1.60) and Int.2 (b = 1.88), indicates a superior condition status of *C. carpio* at the end of the experimental period

(Figure 21). Therefore, it can be concluded that, during the experimental period, except Int.3 control harvesting, the *C. carpio* – PP registered a growth in length, rather than weight.

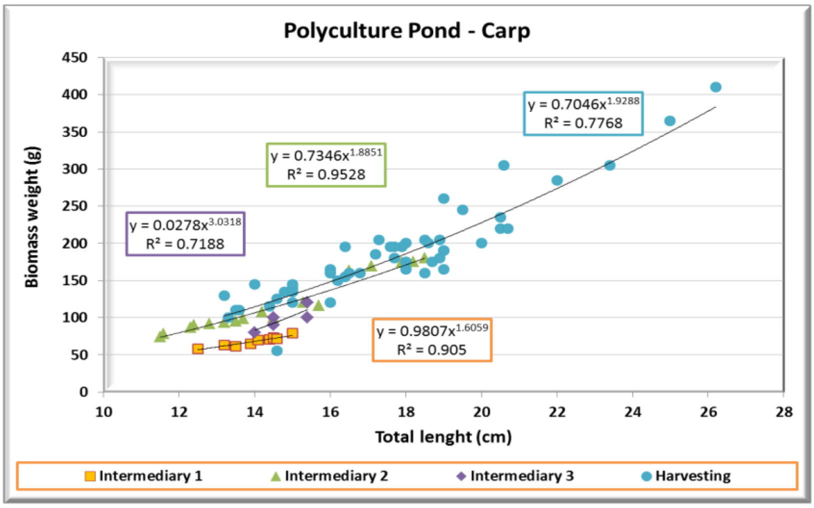

Figure 21. Power regression of *Cyprinus carpio* biomass individual length-weight during the experimental period.

3. *Hypophthalmichthys molitrix* – PP

The number of *H. molitrix* caught during the experimental period was lower, fact that justifies the absence of biometrical and biomass measurements, others than the final harvesting ones (Figure 22 & 23).

The distribution of individual weight and length values, at the final harvesting, reveals a higher homogeneity of *H. molitrix* biomass in term of individual weight, comparing with individual length (Figure 22 & 23)

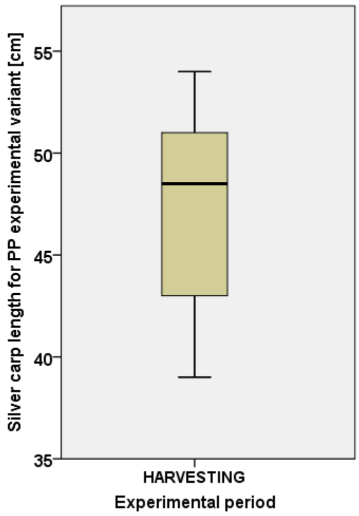

Figure 22. The distribution of *Hypophthalmichthys molitrix* individual length values throughout the experimental period.

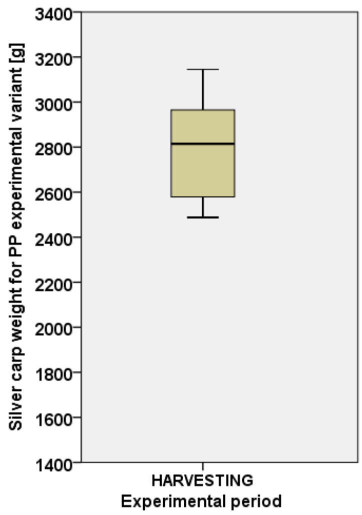

Figure 23. The distribution of *Hypophthalmichthys molitrix* individual weight values throughout the experimental period.

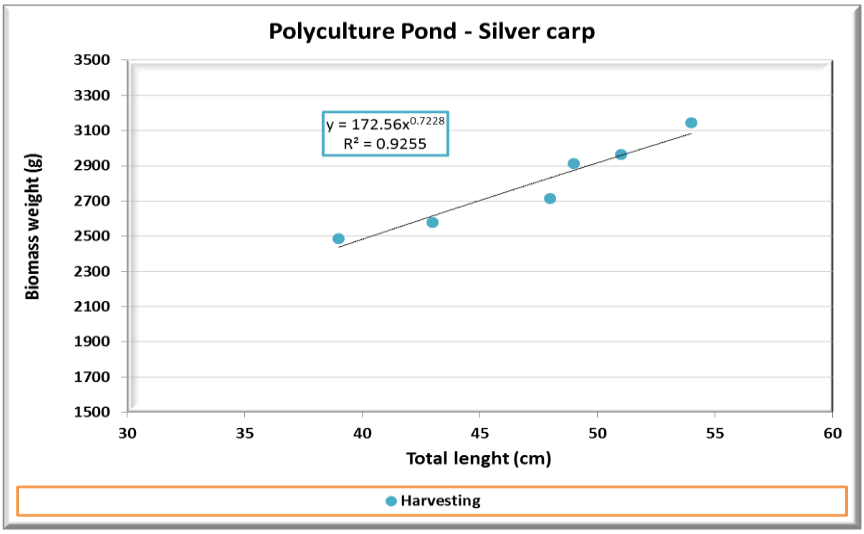

Figure 24. Power regression of *Hypophthalmichthys molitrix* biomass individual length-weight during the experimental period.

The allometric exponent "b" has its values under three units in case of final harvesting, fact that indicates the accentuated growth in length rather than weight (Figure 24).

4. *Hypophthalmichthys nobilis* - PP

The evolution of *H. nobilis* individual length had an intense upward tendency, until Int.3, followed by a nearly constant tendency until the end of the experiment (Figure 25). The evolution of *H. nobilis* individual weight had a linear intense upward tendency, until Int.3, followed by a small downward tendency until the final harvesting (Figure 25).

The distribution of individual *H. molitrix* weight and length values, recorded at final harvesting, suggests a relatively good homogeneity degree of this population, in PP pond section (Figure 26). The number of *H. nobilis* caught during Int.1 control harvesting was lower, fact that justifies the absence of biometrical and biomass measurements in this experimental stage (Figure 25 & 26).

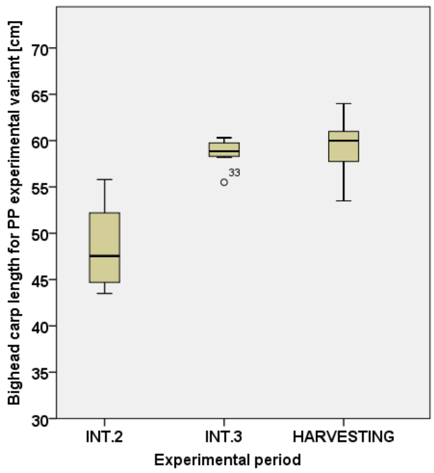

Figure 25. The distribution of *Hypophthalmichthys nobilis* individual length values throughout the experimental period.

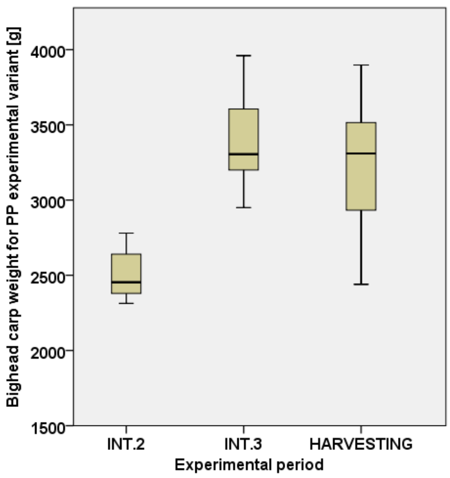

Figure 26. The distribution of *Hypophthalmichthys nobilis* individual weight values throughout the experimental period.

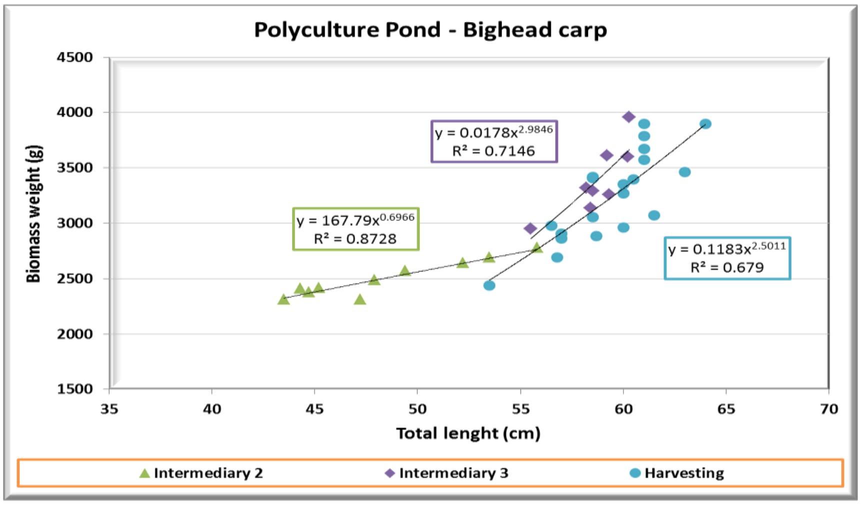

Figure 27. Power regression of *Hypophthalmichthys nobilis* biomass individual length-weight during the experimental period.

The allometric exponent "b" has its values under three units during the entire experimental period, fact that indicates a growth in length rather than weight (Figure 27). The superior values of allometric factor obtained at Int.3 (b = 2.98) and final harvesting (b = 2.50), compared with Int.2 (b = 0.69), indicates a superior condition status of *H. nobilis* in the second half of the experimental period (Figure 27).

5. *Ctenopharyngodon idella* - PP

Concerning *C. idella* individual length distribution, it can be observed that at the end of the experiment, the values are widespread in the upper part of the median (Figure 28). A highly upward linear tendency regarding the individual length is registered during the entire experimental period (Figure 28).

The evolution of *C. idella* individual weight had registered a highly upward tendency during Int.3 - final harvesting experimental periods (Figure 29). Also, it must be pointed out that at the final harvesting, the values were widespread in the upper part of the median, compared with the rest of the experimental period, were a relatively symmetrical distribution of the values, around the median, was observed (Figure 29).

The number of *C. idella* caught during Int.3 control harvesting was lower, fact that justifies the absence of biometrical and biomass measurements for this experimental stage (Figure 28 & 29).

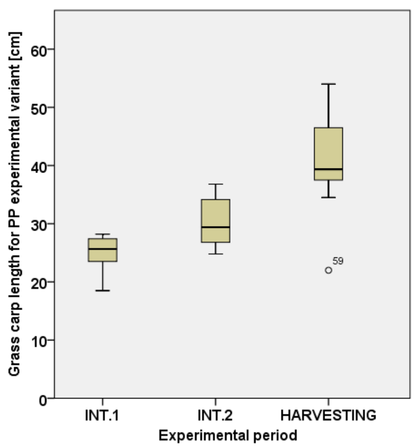

Figure 28. The distribution of *Ctenopharyngodon idella* individual length values throughout the experimental period.

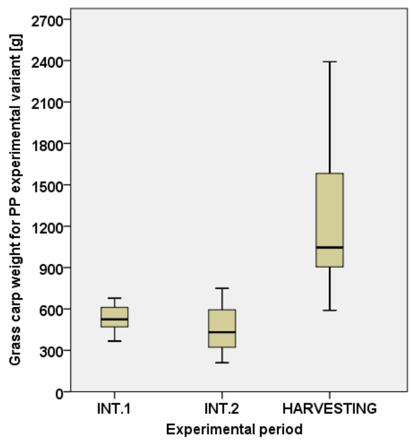

Figure 29. The distribution of *Ctenopharyngodon idella* individual weight values throughout the experimental period.

The allometric exponent "b" has its values under three units during the entire experimental period, fact that indicates a growth in length, rather than weight (Figure 30). The superior values of allometric factor obtained at the Int.2 (b = 2.9), compared with Int.1 (b = 1.27) and final harvesting (b = 1.78), indicates a superior condition status of *C. idella* in the middle part of the experimental period (Figure 30).

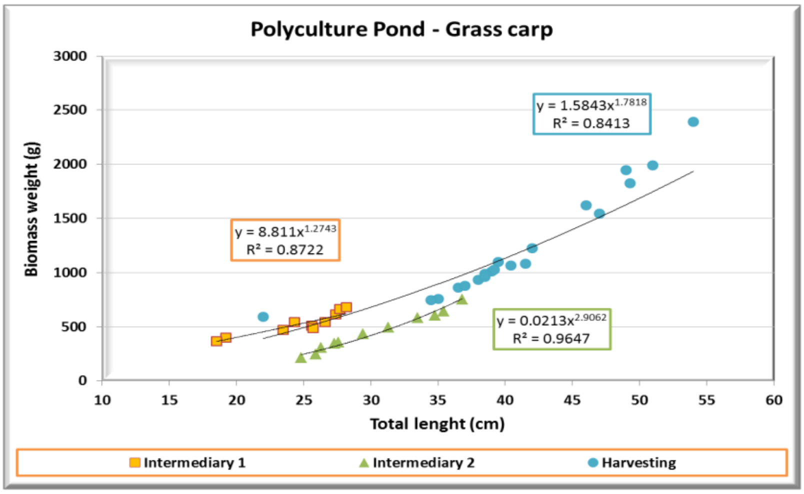

Figure 30. Power regression of *Ctenopharyngodon idella* biomass individual length-weight during the experimental period.

6. *Invasive fish species CP-PP*

As it happened also in case of PCP, at the Int.3 and final harvesting, significant *C. auratus gibelio* and common rudd biomass were caught. This was due to the large diameters of screen holes that permitted the small *C. auratus gibelio* and common rudd fingerlings to enter the CP-PP pond.

The *C. auratus gibelio* allometric exponent "b" has its values under three units in case of Int.3 - CP pond section (b = 2.48), while in case of Int. 3 – PP pond section, the values are over 3 units (b = 3.022) (Figure 31 & 32). In case of final harvesting, positive allometric values are recorded in case of CP pond section (b = 3.12), while negative allometric values are recorded in case of PP pond section (b = 2.99) (Figure 31 & 32). However, since both Int.3 and final harvesting values of allometric factor from PP pond section are close to 3, it can be stated that the growth of *C. auratus gibelio* in PP is nearly isometric, fact which indicates a superior condition status of *C. auratus gibelio* from this pond section, compare with the CP pond section.

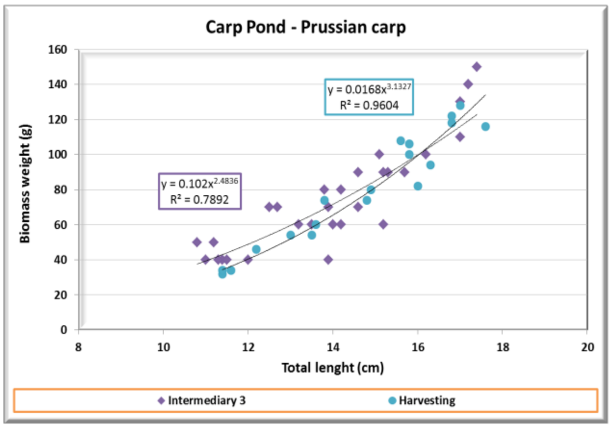

Figure 31. Power regression of *Carassius auratus gibelio* biomass individual length-weight during the experimental period, for CP.

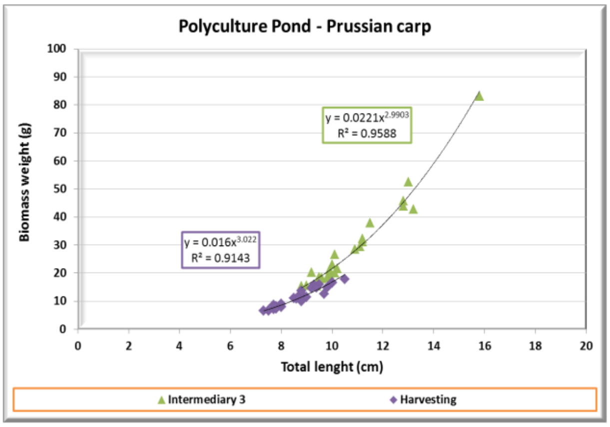

Figure 32. Power regression of *Carassius auratus gibelio* biomass individual length-weight during the experimental period, for PP.

The differences between *C. auratus gibelio* average individual biomass harvested at CP and the biomass harvested at PP can be explained by the fact that this species entered into the pond (CP-PP) through the inlet channel screen, but the mesh used to divide the pond into CP and PP allowed only the small dimension specimens to migrate from CP to PP. The specimens that remained at CP have competed with *C. carpio* for feed, since CP was the only area of CP-PP pond where feed was administrated.

Regarding the common rudd biomass, significant catches were recorded only in PP case, both at Int.3 control harvesting and at the final harvesting.

The allometric exponent "b" has its values under three units at Int. 3 control harvesting (b = 2.41), while at final harvesting, a positive allometric value is recorded (b = 3.92), fact which indicates a superior condition status of common rudd at the end of the experimental period (Figure 33).

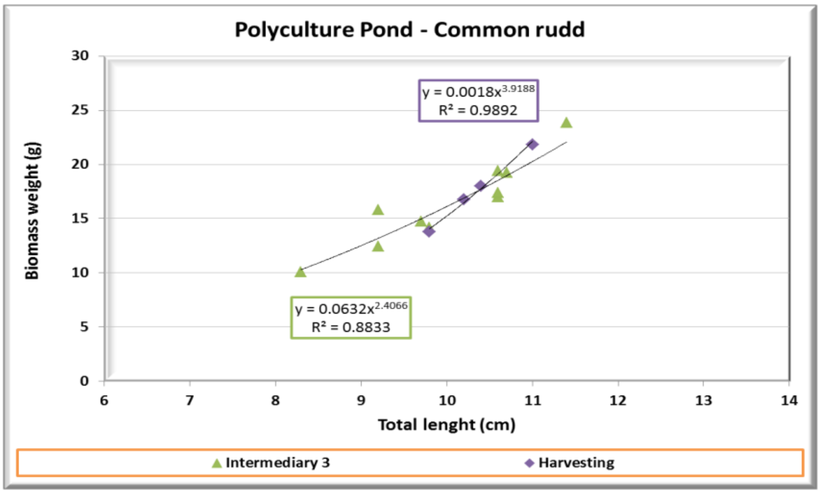

Figure 33. Power regression of common rudd biomass individual length-weight during the experimental period.

Fulton's condition coefficient (K)

In order to increase the awareness related to the results of this present study, a literature review that imply the values of Fulton's condition factor (K), for cyprinids of various individual biomass, is presented in Table 2.

The highest values of K are registered at *C. carpio* from PP (3.80±0.68 g cm^{-3}) at Int.2 control harvesting, followed by *C. idella* (3.67±1.00 g cm^{-3}) at Int.1 control harvesting and *H. molitrix* at final harvesting (Table 3), while the lowest values are recorded *H. nobilis* and *C. auratus gibelio* from PP at the final harvesting (Table 3). This can be due to the fact that *C. carpio* has dominated the competition for feed in PP, during the production cycle, comparing with the other fish species that targeted the same trophic niche.

The higher value of K, for *C. carpio*, registered in case of PP final harvesting, comparing with CP final harvesting, can be due to high stocking density that was applied in the first pond section (CP), comparing with the second pond section.

Also, it can be observed that *C. auratus gibelio* has a higher value of the Fulton's condition coefficient in the first pond section (CP), comparing with the second pond section. This can be due to the fact that in CP pond section feed was administrated during the entire experimental period, comparing with PP pond section, where no feed regime was applied. Thus, *C. auratus gibelio* can be considered a significant competitor for *C. carpio* feeding niche, at least in CP pond sector.

Therefore, it can be observed that approximately the same values of Fulton's condition factor (K) with those registered in present study, were reported by Mert & Bulut (2014) for *C. carpio*, Dumitru & Ciornea (2010) and Naeem & Salam (2010) for *H.*

nobilis, Naz et al (2013) and Hayer et al (2014) for *H. molitrix* and Naz et al (2013) and Hernández et al (2014) for *C. idella*.

Table 2

A literature review of Fulton's condition coefficient (K) values for *Cyprinus carpio*, *Hypophthalmichthys nobilis*, *Hypophthalmichthys molitrix*, *Ctenopharyngodon idella* and *Carassius auratus gibelio*

No.	*Fish specie*	*Weight (g)*	*K (g cm^{-3})*	*Reference*
1.	*C. carpio*	896	2.17	Hernández et al (2014)
2.	*C. carpio*	108.3 – 2280	1.23 – 2.37	Dirican & Çilek (2012)
3.	*C. carpio*	51 – 896	1.06 – 3.39	Mert & Bulut (2014)
4.	*C. carpio*	200 – 1589	1.49 – 1.61	Sahtout et al (2017)
5.	*C. carpio*	379 – 637	2.6	Dumitru & Ciornea (2010)
6.	*C. carpio*	1593	2.05	Hernández et al (2014)
7.	*C. auratus gibelio*	156 – 290	1.7	Dumitru & Ciornea (2010)
8.	*A. nobilis*	449	1.15	Hernández et al (2014)
9.	*A. nobilis*	772	1.18	Hernández et al (2014)
10.	*A. nobilis*	6.86 – 1766	0.728 – 1.756	Naeem & Salam (2010)
11.	*A. nobilis*	640 – 950	2.8	Dumitru & Ciornea (2010)
12.	*A. nobilis*	-	0.58 – 2.04	Nuevo et al (2004)
13.	*H. molitrix*	430	1.06	Hernández et al (2014)
14.	*H. molitrix*	658	1.14	Hernández et al (2014)
15.	*H. molitrix*	6150	0.5 – 1.7	Hayer et al (2014)
16.	*H. molitrix*	2.16	2.53	Naz et al (2013)
17.	*C. idella*	334 – 1173	1.38 – 3.13	Chitrakar & Parajuli (2017)
18.	*C. idella*	200	1.07	Hernández et al (2014)
19.	*C. idella*	478	1.31	Hernández et al (2014)
20.	*C. idella*	1.89	2.94	Naz et al (2013)

Table 3

Condition coefficient (K) for species from carp pond (CP) and polyculture pond (PP)

Species	*Condition coefficient (K); (g cm^{-3})*				
	Pond	*INT. 1*	*INT. 2*	*INT 3*	*Harvesting*
C. carpio	CP	2.96±0.44	3.71±0.22	3.16±0.52	2.89±0.49
	PP	2.48±0.19	3.80±0.68	3.03±0.20	3.39±0.78
H. molitrix	PP	-	-	-	2.77±0.69
H. nobilis	PP	-	2.27±0.40	1.67±0.07	1.55±0.11
C. idella	PP	3.67±1.00	1.55±0.11	-	1.85±0.83
C. auratus gibelio	CP	-	-	2.67±0.51	2.40±0.22
	PP	-	-	2.17±0.20	1.68±0.16

Outside the fact that it marks the length - weight relationship of the fish samples, according to Geldiay & Balık (1988) and Mert et al (2008), the condition factor shows, also, the fact whether the fish is fed enough or not.

Conclusions. In conclusion, the weight-length relationship and distribution and the condition factor values, presented in this research, provides useful information in terms cyprinids pond production technique and technology and fish population dynamics during a production cycle.

The data presented in this study provides an improved understanding of the production management and the evaluation of the cyprinids, both in IMTA pond systems and classical polyculture pond systems. The IMTA pond production technique and technology can represent a solution for improving fish condition, production efficiency and production management. However, future studies are recommended to be made, in order to find better cyprinids population structures, as well as technical solutions, which are meant to improve the sustainability of IMTA pond systems.

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