Phenotypic performance of the synthetic population of common carp reared in different culture systems based on its environmental carrying capacity

[1]Didik Ariyanto, [1]Yogi Himawan, [2]Flandrianto S. Palimirmo, [1]Suharyanto Suharyanto, [1]Listio Dharmawantho

[1] Research Center for Fisheries, National Research and Innovation Regency, Bogor, Cibinong, Bogor, West Java, Indonesia; [2] Research Center for Conservation of Marine and Inland Water Resources, National Research and Innovation Regency, Bogor, Cibinong, Bogor, West Java, Indonesia. Corresponding author: D. Ariyanto, didik29ariyanto@gmail.com

Abstract. The synthetic population has empirically succeeded in increasing the phenotypic performance of cultured fish. This study aimed to evaluate the phenotypic performance of the synthetic populations of Indonesian common carp in three different culture systems, which have different environmental carrying capacity: stagnant water ponds, running ponds, and floating net cages, for 90 days. For the comparison, Mustika, Mantap, and Marwana carp populations, obtained from a selection breeding program, were used. The results showed that the synthetic population of common carp has better performance than other populations in all culture sites. The common carp culture was better conducted in floating net cages than in running ponds and stagnant water ponds. In the floating net cage, the growth rate, body weight, harvested yield, and feed conversion ratio of the synthetic population were significantly better than others, while the survival rate was not significantly different. There is no interaction between genetics and the environment (G x E) on the phenotypic performance of the synthetic population.
Key Words: environment, genetic, G×E interaction, phenotypic performance, synthetic population.

Introduction. The genetic quality of cultured common carp (*Cyprinus carpio*) in Indonesia has experienced significant quality degradation for more than two decades (Ariyanto et al 2019a). The formation of superior carp in Indonesia has been carried out and has produced several varieties with different superior characteristics. Mantap carp, a population obtained from a selection breeding program, which started at 2010, was released as a new variety by the government in 2015. The superiority of this population is the high resistance of the carp to *Aeromonas hydrophila* infection (MMAF 2015). In 2016, three populations of superior common carp, which resulted from three others breeding programs, were released as new varieties, namely Jayasakti carp, Mustika carp, and Marwana carp. Jayasakti carp is a fast-growing common carp (MMAF 2016a), Mustika carp is a disease-resistant common carp, especially to Koi Herpesvirus (MMAF 2016b), and Marwana carp is a common carp that is not only fast in growth but also high resistance to disease (MMAF 2016c). Apart from Marwana carp, all these superior common carp were obtained through a selection breeding program from one common carp strain: Jayasakti and Mantap carp from the Majalaya carp and Mustika carp from the Rajadanu carp. Genetically, this type of selection has the potential to reduce the genetic diversity of the selected population in the future.

In order to improve the genetic quality of common carp, one of the steps that can be taken is to form a synthetic population. A synthetic population is a population that is deliberately formed because nature does not allow it to occur naturally. This population is formed by combining (blending) several populations of common carp as genetic resources. Ariyanto et al (2021) reported the formation of a synthetic population or carp consisting of five main strains of carp in Indonesia, namely Majalaya, Rajadanu, Wildan, Sutisna, and Sinyonya strains. The formation of this synthetic population aims to increase the genetic diversity of the Indonesian common carp population. This synthetic population is used to form a base population (F0) as the main material for selection programs. The formation of synthetic populations as selection material has been widely carried out not only for freshwater fish, including the selection of common carp (*C. carpio*) (Nielsen et al 2010), tilapia (*Oreochromis niloticus*) (Eknath et al 2007; Bentsen et al 2017), and catfish (*Clarias geriepinus*) (Iswanto et al 2016), but also for marine fish, namely Atlantic salmon (*Salmo salar*) (Gunnes & Gjedrem 1978) and rainbow trout (*Oncorhynchus mykiss*) (Gjedrem et al 1987).

In general, synthetic populations have different genotype from their founder populations. These genotypic differences are thought to have an impact on phenotypic performance even if the populations are cultured in the same environment. It is because the genetic characteristic will determine the phenotypic expression. However, apart from being determined by genetic characteristics, phenotypic performance is also influenced by environmental conditions. The presence of interactions between genetics and the environment (G×E) can also affect the phenotypic performance of the reared population (Tave 1993; Gjedrem 2005; Sae-Lim et al 2016).

The geographical condition of carp culture area in Indonesia is widely variable. Therefore, different cultivation systems were developed based on each region. The three main models of common carp cultivation in Indonesia are stagnant water ponds, running water ponds, and floating net cages (Khairuman et al 2008). A stagnant water pond is widely used in relatively flat areas, and the system's water source usually comes from rivers, tertiary irrigation, or rain (Supriatna 2013). A running water pond is often found in locations with a certain height and a high slope, and the water source of this system is usually the high flow river (Jayalaksana et al 2016). The third cultivation system is a floating net cage, mostly conducted in open waters, such as lakes and reservoirs. This cultivation system utilizes a large volume of water at the location (Nugroho 2012). With these different environments and water sources, the carrying capacity of each environment for cultivation is also different. The stagnant water pond has a relatively lower carrying capacity compared to the other two culture systems. Meanwhile, the carrying capacity of cultivation system for running water ponds and floating net cages is relatively the same, depending on several factors such as river flow, water pollution load, and others. It's well known that phenotypic performance is influenced by genetic factors, environmental factors, and the interaction between the two. Linhart et al (2002) and Ariyanto et al (2019b) reported that environmental factors have a very large influence on the phenotypic performance of common carp, compared to both genetical factors and the interaction of the two. Therefore, an analysis of the environmental and geographical conditions and various cultivation systems is required to evaluate the performance, including the adaptability and stability of a new genotype of carp. This is necessary for deciding whether a population, with a specific genotype, has a broad adaptation capacity, so that it can be cultivated in all locations or has a narrow adaptation capacity, that is specific to a location. One of the adaptability analysis methods that has been widely used in agricultural cultivation is the Eberhart & Russell's (1966) method. This method was carried out by analyzing the regression coefficient (β_i) of several genotypes reared at various locations. The magnitude of the regression coefficient value is used as a measure of genotype adaptability; that is, if the value of β_i is not equal to 1, a variety interacts with its environment; if $\beta_i>1$, a variety that interacts with a favourable environment is defined. Conversely, if $\beta_i<1$, it is a genotype that can still adapt to an unfavourable environment. The variety is considered stable if the value of β_i is 1.

This study aimed to evaluate the phenotypical performance of the synthetic population, carrying the new genotype of carp, in three culture systems with different environmental carrying capacity. This performance was compared to several superior carp populations that have been cultured by farmers. In addition, the study also evaluates the genetic (G) and environmental (E) influences, as well as the alleged presence of interactions between genetic and environmental (G×E) factors on the phenotypic performance of common carp.

Material and Method

The tested fish. The main population of carp used is the F2 of the synthetic population, which is a blended population between five common carp strains (Ariyanto et al 2021). Mantap carp, Mustika carp, and Marwana carp were used as the comparison populations. The Mantap carp was obtained from the Development Center for Freshwater Aquaculture, Sukabumi, Mustika carp were obtained from the Research Institute for Fish Breeding, Sukamandi, and Marwana carp were obtained from the Institute for Freshwater Fish Development, Wanayasa. All tested fish were two months old and measured between 12.0-15.0 g fish^{-1}.

Locations and culture systems. The study was conducted from March to July 2023 at three locations with different cultural systems. The first is a stagnant water pond in Sukamandi (-6.372420907391551, 107.62376526906118), the second is a running water pond in Tanjungsiang (-6.694494838821707, 107.73770398563076), and the last is a floating net cage in Cirata reservoir (-6.734971767914624, 107.28056399225723) (Figure 1).

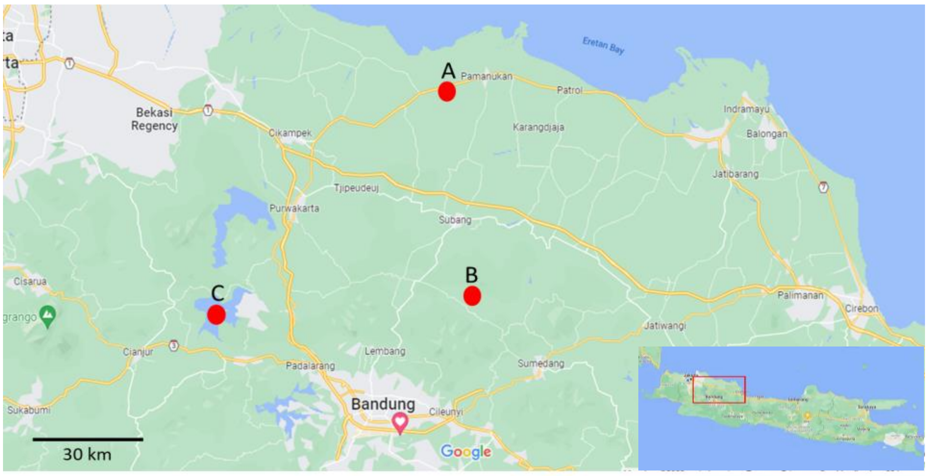

Figure 1. Site locations for phenotypic performance test for four populations of *Cyprinus carpio*. A. Stagnant water pond in Sukamandi; B. Running water pond in Tanjungsiang; C. Floating net cage in Cirata reservoir.

Phenotypic performance evaluation. The phenotypic performance evaluation of carp used a factorial experimental design with two-factors and three replications. The first factor is the population of carp, and the second factor is the culture system with a different environmental carrying capacity. The stagnant water pond used is an earthen pond 200 m^2 in size with a water depth of 50–60 cm, while the running water pond used is a concrete pond measuring 50 m^2 with a water depth of 2.5 m. The measure of the floating net cage system used is 50 m^2 with a water depth of 3–4 m. The stocking densities used in stagnant water ponds, running water ponds, and floating net cages were 10, 50, and 100 fish m^{-2}, respectively. The density of stocked fish in this study was applied based on the optimal carrying capacity of each culture system, estimated before (Jayalaksana et al 2016; Rahmani et al 2011). During the three-month period, all fish were fed commercial pellets with a crude protein content of 28%, at satiation. Sampling of the average individual weight of each population is carried out every month. At the end of the study, the total amount of feed used was calculated, and individual biometric analyses of each population included body weight and survival. Weighing the total harvested yield is carried out to analyze the productivity of cultivation per unit area.

Statistical analysis. The superiority of the carp population that was tested in a certain environment for each character was determined through the F test using the Excel 2010 program. The influence of genetics, environment, and the estimation of genetic-environment interactions were carried out by analysis of variance on the combined data of specific growth rate characters in all locations. The specific growth rate character was chosen for this analysis because it is the main character that will further influence other characters, such as final weight, harvest yield, and feed conversion ratio. Prior to the combined analysis of variance, the homogeneity of error variation was tested for three locations using the Bartlett test, with the Excel 2010 software.

Stability analysis was carried out on the specific growth rate characteristics of each carp population in all cultivation locations. The concept of the stability of a population, according to Eberhart & Russell (1966), is the relative comparison between populations in a set of tests under different environmental conditions. The cultivation environment index in this study was analysed based on the value of the average specific growth rate of a set of populations tested in each environment minus the average specific growth rate of all populations tested in all environments. The stability analysis was calculated manually using Excel 2010, following the Eberhart & Russell's (1966) statistical model:

$$Y_{ij} = \mu + ß_i I_j + \delta_{ij}$$

Where:

Y_{ij} - mean of i^{th} population in j^{th} environment;

μ - mean of all the populations over all the environments;

$ß_i$ - the regression coefficient of the i^{th} variety on the environmental index which measures the response of the population to varying environments;

I_j - the environmental index which is defined as the deviation of the mean of all the populations at a given location from the overall mean;

δ_{ij} - the deviation from regression of the i^{th} population at j^{th} environment.

During the testing period, the water quality of the rearing media was observed using a water quality checker (WQC), including the transparency, water temperature, dissolved oxygen, and pH. The analysis of ammonia and nitrite levels was carried out in the laboratory. Observation of the water quality of the maintenance media was carried out every 2 weeks.

Results. The location and quality of the common carp-rearing media, including transparency, water temperature, pH, dissolved oxygen, ammonia, and nitrite at each location, are presented in Table 1.

Table 1

Altitude and water quality of *Cyprinus carpio* rearing media for three months period

Water parameter quality	*Location of the test*		
	Stagnant water pond in Sukamandi	*Running water pond in Tanjungsiang*	*Floating net cage in Cirata reservoir*
Altitude (m ASL)	11.0–12.0	75.0–80.0	220.0–230.0
Transparency (cm)	10.2–12.6	40.3–60.6	35.8–58.8
Temperature (°C)	28.5–32.2	25.2–28.5	24.0–28.0
Dissolved oxygen (mg L^{-1})	1.0–2.2	4.8–7.8	3.5–8.2
pH	6.8–9.2	6.8–8.0	6.5–8.5
Ammonia (mg L^{-1})	0.5–1.2	0.0–0.3	0.0–0.6
Nitrite (mg L^{-1})	0.4–1.9	0.0–0.6	0.0–0.8

m ASL = meters Above Sea Level

The culture test is located at different altitudes, from 11 m ASL in Sukamandi to 220 m ASL in Cirata Reservoir. The altitude of the different locations directly affects the agro climate of the cultivation environment. The stagnant water pond in Sukamandi has an environmental temperature that tends to be warm, so the water temperature is also relatively higher. The higher cultivation locations in Tanjungsiang and Cirata Reservoir have lower water temperatures. The lowest water temperature in Cirata Reservoir, the highest location, during the study reached 24°C. The relatively low temperature is thought to influence the performance of cultured common carp. In addition to temperature, the parameters that are significantly different are the culture medium's brightness, ammonia, and nitrite level. The low brightness in stagnant water ponds is thought to be caused by the carp's habit of grinding the pond bottom and embankments in search of natural life food, such as worms and other benthic animals. The relatively high levels of ammonia and nitrite are also due to a large amount of feed waste and fish metabolism residues that do not decompose and settle to the bottom of the pond.

Phenotypic performance. The results of rearing four carp populations in three different culture systems are presented in Table 2. An analysis of variance on the phenotypic performance of carp at each location showed significantly different results ($P<0.05$).

Table 2

The phenotypic performance (mean±standard deviation) of the synthetic population of *Cyprinus carpio* and three comparison populations reared in three different culture systems for three months

Parameters	*Common carp population*	*Stagnant water pond*	*Running water pond*	*Floating net cage*
Specific growth rate (% day^{-1})	Synthetic population	2.2±0.3^{a}	3.2±0.0^{a}	3.4±0.0^{a}
	Mustika	1.7±0.1^{b}	3.0±0.0^{b}	3.0±0.0^{c}
	Marwana	1.5±0.1^{c}	2.9±0.1^{b}	3.0±0.0^{c}
	Mantap	1.9±0.1^{ab}	3.0±0.2^{ab}	3.2±0.0^{b}
Body weight (g)	Synthetic population	77.9±12.8^{a}	186.0±12.2^{a}	238.2±15.0^{a}
	Mustika	60.0±4.7^{b}	165.0±13.2^{ab}	193.0±4.1^{b}
	Marwana	42.7±5.3^{c}	149.7±8.4^{b}	162.9±15.2^{c}
	Mantap	46.0±2.0^{c}	160.0±20.0^{ab}	144.6±25.8^{c}
Survival rate (%)	Synthetic population	66.3±22.4^{a}	80.8±5.1^{a}	66.2±6.9^{a}
	Mustika	83.0±6.1^{a}	85.8±6.3^{a}	59.6±2.0^{a}
	Marwana	82.2±1.6^{a}	81.3±7.1^{a}	63.8±5.4^{a}
	Mantap	70.9±13.3^{a}	85.6±7.1^{a}	71.5±4.4^{a}
Harvested yield (kg)	Synthetic population	10.0±2.5^{a}	150.5±16.2^{a}	776.8±69.7^{a}
	Mustika	9.9±0.2^{ab}	142.1±21.2^{a}	561.9±30.2^{b}
	Marwana	7.0±0.9^{b}	122.1±17.0^{a}	517.9±46.6^{b}
	Mantap	6.5±1.4^{b}	137.0±20.4^{a}	523.6±22.8^{b}
Food conversion ratio	Synthetic population	3.8±1.4^{a}	2.0±0.1^{a}	1.3±0.2^{b}
	Mustika	3.5±0.1^{a}	1.8±0.2^{a}	1.8±0.1^{a}
	Marwana	4.4±0.8^{a}	1.9±0.3^{a}	1.9±0.2^{a}
	Mantap	3.7±0.8^{a}	1.8±0.3^{a}	1.9±0.1^{a}

Different superscripts in the same column and at the same parameters show significant differences.

Table 2 showed that synthetic populations in three culture systems performed better than Mustika carp, Marwana carp, and Mantap carp. Especially in the floating net cage system, the characteristics of growth rate, body weight, harvested yield, and feed conversion ratio of synthetic populations were significantly better than those of other varieties, while the survival rate was not significantly different.

Interaction of genotype × environment. The results of the analysis of variance to evaluate the influence of the carp population (G), the location or cultivation system applied (E), and the possibility of an interaction between the population and the environment (G×E) on the specific growth rate characters are presented in Table 3.

Table 3 shows that different populations have significantly different specific growth rates. The culture system or location also has a significantly different effect on the specific growth rate of carp. However, there is no significant interaction between the population (genotype) and the system or location (environment) where the carp are cultivated.

Table 3
Analysis of variance to examine the effect of population (G), environment (E) and interaction (G×E) on the specific growth rate of *Cyprinus carpio*

Source of variation	*Sum of square*	*Degrees of freedom*	*Mean square*	*F-value*	*P-value*	*F crit*
Population (G)	0.987	3	0.329	11.772*	6.14E-05	3.009
Environment (E)	12.751	2	6.376	228.060*	2.43E-16	3.403
Interaction (G×E)	0.183	6	0.031	1.089^{ns}	0.396782	2.508
Error	0.671	24	0.028			
Total	14.592	35				

* Significant different, ns: not significant different, F crit: critical significant differences based on F table

Analysis of stability. The results of the environmental index analysis in this study are presented in Table 4. Table 4 showed that floating net cages have the highest environmental index, while stagnant water ponds have the lowest environmental index.

Table 4
The environmental index of each location where the four populations of *Cyprinus carpio* were cultured

Type of common carp culture	*Environmental index*
Stagnant water ponds	-0.84
Running water ponds	0.35
Floating net cages	0.49

The environmental index of these three culture systems is in line with their own carrying capacity. Various environmental conditions have an impact on the growth rate of a carp population. The better the environmental quality, the higher the environmental index. This has an impact on increasing the specific growth rate of carp in the environment. This is in accordance with the results of the analysis of the effects of population (G), culture system (E), and the interaction between the two factors, where the environment of the culture system greatly affects the specific growth rate of carp.

The analysis of the stability of each population, especially on the specific growth rates, was presented in Table 5. Table 5 showed that the regression coefficient ($ß_i$) values for the four populations of common carp were significantly different from 1.0, and the deviation of the regression (Sd_i^2) value was not equal to 0. This indicates that all populations of carp in this study did not have good stability when cultivated in different environments of the culture system. The results of this analysis indicate that each population of common carp has different responses to changes in environmental conditions. This response is in accordance with the previous analysis results: the influence of the environment is significantly high on the phenotypic performance, especially on the specific growth rate character.

Table 5
Stability parameters for specific growth rates of each population of *Cyprinus carpio* cultured in three different locations

Populations	$ß_i$	Sd_i^2
Synthetic population	0.08*	0.41^{ns}
Mustika carp	0.09*	0.56^{ns}
Marwana carp	0.08*	0.42^{ns}
Mantap carp	0.09*	0.69^{ns}

*: significantly different from 1.0, ns: not significantly different from 0

Discussion. The environmental carrying capacity for fish culture is defined as the maximum number of fish of a specific species that can be farmed safely in the water body under consideration. The oxygen content of water is a well-known issue that may limit the maximum number to more than the given area. Fish rely on dissolved oxygen, which must not dip below a particular range (Legović et al 2008). Determining carrying capacity in aquaculture is very important because it will affect the performance of the fish being farmed. Different locations and culture systems will have different levels of carrying capacity. Therefore, the number of fish cultivated or the level of fish density in each cultivation system is also different. Density that is appropriate to the characteristics of each cultivation environment makes the carrying capacity optimal for that environment.

This study considered the optimum carrying capacity of each location so that different levels of fish density are not a differentiating factor. In floating net cages, the specific growth rate of synthetic populations was significantly better than that of other populations. This higher growth rate resulted in the synthetic population's individual weight at the end of the study being better than that of other populations. The higher average weight of individuals, supported by the survival rate, which was not significantly different between populations, had an impact on the harvested yield of synthetic populations (significantly better than others). Likewise, the use of relatively the same amount of feed in all populations indicates that the synthetic population has good feed efficiency. This is supported by the feed conversion ratio, which is significantly lower than in other populations. In this study, the first-generation synthetic population of carp had a good phenotypic performance, which was able to compensate for the phenotypic performance of the superior varieties.

The superiority of the synthetic populations compared to other populations is thought to be due to their better genetic quality, as indicated by the high level of genetic diversity and heterozygosity (Ariyanto et al 2021). Genetic diversity in a population will have an impact on the phenotypic performance of that population (Overturf et al 2003; Johnson et al 2016). Overturf et al (2003) explained that fish populations with better levels of genetic diversity have higher specific growth rates and lower feed efficiency. In this study, the high genetic diversity of the synthetic population reported by Ariyanto et al (2021) allegedly caused the specific growth rate of the population to be significantly faster than other populations tested. This has an impact on the final weight of the individual and the harvested yield of the synthetic population, which is higher than in other populations, especially in the floating net cages. In this culture system, the feed efficiency of the synthetic population was also higher than that of other populations, as indicated by the lower FCR value of this population than others.

Several previous studies have revealed that the phenotypic performance of carp is strongly influenced by the environment in which this species is cultivated. The genotype of cultured carp also had a significant effect on its phenotypic performance. However, the interaction between genotype factors and the environment did not significantly affect the phenotypic performance of common carp (Wang & Li 2007; Ariyanto et al 2019b). This is supported by Purdom (1993), Tave (1993), and Linhart et al (2002), who stated that the influence of the environment is the main factor that affects the phenotypic performance of common carp. The results of this research follow these early studies, where the use of different genotypes of population, as well as their cultivation systems, have a significant effect on the phenotypic performance of common carp. In this research, the effect of genotype interaction with the environment (G×E) on the phenotypic performance of common carp was not significant. The insignificant G×E value in terms of specific growth rates indicates that common carp have stable performance and a good ability to adapt to a wide range of environmental conditions (Ariyanto et al 2019b).

The stability of the tested genotype was based on the regression response of the specific growth rate of the population to its environmental index. Based on this, the adaptability and stability of a genotype are determined by the value of the regression coefficient (β_i) and the deviation of the regression (Sd_i^2). In this analysis, a population is said to be stable if it has a regression coefficient that is not significantly different from 1.0 and the deviation of the regression is equal to 0. The results of the stability analysis of the specific growth rate of carp in this study are presented in Table 5.

The Eberhart and Russell's model is an adaptability and stability analysis that is often used by breeders to observe the stability of phenotypic performance (Djaelani et al 2001). The value of the regression coefficient (β_i) is used as the level of adaptability of a population. The value of *b* is not equal to 1, which means that a population interacts with its environment. A value of β_i>1 is defined as a population that interacts with a favourable environment, while a value of β_i<1 means that the population can still adapt to a less favourable environment. A population is considered adapted and stable if the value of β_i is 1. Based on the theory of Eberhart and Russell, all populations of common carp in this study have a value of β_i<1. Genotypes with a value of β_i<1 are not responsive to environmental changes but can adapt well to a less favourable environment. This means that all carp populations tested can be sought to improve their performance, for example, with technological inputs, such as fertilizer application to the water or additional water flow or waterwheels in stagnant water ponds to increase dissolved oxygen content (Boyd & Pillai 1985). Ideally, the best population is one that can adapt widely because it can be cultivated in a variety of different environments. Genotypes with a value of β_i=1, followed by an average phenotypic performance that is higher than the general average, adapt well to all environments.

Based on stability observations, breeders can sort out varieties based on the needs of a location, or the amount of input issued by carp farmers. The decision of breeders to accept or reject populations with a value of β_i>1 (high response to environmental changes) or β_i<1 (low response to environmental changes) must, of course, consider the context of the composition of the carp farming system in Indonesia. For example, most carp cultivators have low inputs, so a genotype with a value of β_i<1 is very suitable. On the other hand, if the carp cultivator has sufficient funds (high investment) with the application of high technology, the genotype that has a value of β_i>1 is more suitable. For a stable population, with a value of β_i=1, it can culture anywhere because this genotype in a less favourable environment still has good performance, and in a favourable environment, it displays an even higher phenotypic performance (Kusmana 2005).

Allard & Bradshaw (1964) reported two influence levels that promote the stability of a genotype: supporting individuals and populations, respectively. Populations with heterogeneous genetic compositions generally have a greater support capacity than those with homogeneous genetic compositions. This means that populations with heterogeneous genetic composition adapt better than populations with homogeneous genetic composition at different locations. The high level of heterozygosity of the synthetic population is thought to cause the population to have a better level of adaptability and stability than the comparison populations.

The results of this study provide convenience for breeders and farmers to choose the type of carp and the location of cultivation to be used. Of the four populations of common carp, the synthetic population is the type of common carp with the fastest specific growth rate, resulting in the best final individual weight in all cultivation systems or locations used. Of the three culture systems applied, the floating net cage is the one that supports the performance of common carp. Common carp culture using floating net cages produces a fast growth rate, resulting in greater individual weight for each type of carp compared to other cultivation systems. A heavier final individual weight, supported by survival values that were not significantly different, would produce the greatest harvest yield. Based on the results of this study, the synthetic population carp cultured in floating net cages is the common carp cultivation that provides the largest and most profitable yields for farmers.

Conclusions. Synthetic populations have better phenotypic performance than other populations of common carp tested in this study. Based on the optimum carrying capacity of each culture system, the cultivation of synthetic population carp that is carried out in floating net cages produces the fastest growth, the largest harvested yield, and the highest profit for farmers. There is no G×E interaction in the common carp culture. Although not conducted in floating net cages, common carp cultivation using the synthetic population will produce the best-harvested yield compared to other populations.

Acknowledgements. The authors are thankful to The Indonesian Ministry of Marine Affairs and Fisheries, especially to The Research Institute for Fish Breeding, The Agency for Marine Affairs and Fisheries Research, and Human Resources Development, for funding this research.

Conflict of interest. The authors declare no conflict of interest.

References

Allard R. W., Bradshaw A. D., 1964 Implication of genotype environmental interaction in applied plant breeding. Crop Sciences, pp. 503-507.

Ariyanto D., Himawan Y., Palimirmo F. S., Suharyanto, 2019a [The inbreeding level of five strains of Indonesian common carp (*Cyprinus carpio*)]. Proceeding of the 15th Nasional Symposium for Fisheries and Marine Sciences Research. Gadjah Mada University, Yogyakarta, pp. 23-27. [In Indonesian].

Ariyanto D., Himawan Y., Syahputra K., Palimirmo F. S., Suharyanto, 2019b [Improving the growth of Mustika carp trough selection]. Jurnal Riset Akuakultur 14(2):71-76. [In Indonesian].

Ariyanto D., Carman O., Soelistyowati D. T., Zairin Jr. M., Syukur M., Himawan Y., Palimirmo F. S., 2021 [Formed the synthetic population for genetic improvement of common carp]. Jurnal Riset Akuakultur 16(2):93-98. [In Indonesian].

Bentsen H. B., Gjerde B., Eknath A. E., Vera M. S. P., Velasco R. R., Danting J. C., Dionisio E. E., Longalong F. M., Reyes R. A., Abella T. A., Tayamen M. M., Ponzoni R. W., 2017 Genetic improvement of farmed tilapias: Response to five generations of selection for increased body weight at harvest in *Oreochromis niloticus* and the further impact of the project. Aquaculture 468(1):206-217.

Boyd C. E., Pillai V. K., 1985 Water quality management in aquaculture. CMFRI Special, pp. 1-44.

Eberhart S. T., Russell W., 1966 Stability parameters for comparing varieties 1. Crop Science 6(1):36-40.

Eknath A. E., Bentsen H. B., Ponzoni R. W., Rye M., Nguyen N. H., Thodesen J., Gjerde B., 2007 Genetic improvement of farmed tilapias: Composition and genetic parameters of a synthetic base population of *Oreochromis niloticus* for selective breeding. Aquaculture 273:1–14.

Gjedrem T., Refstie T., Gjerde B., 1987 A review of quantitative genetic research in salmonids at AKVAFORSK. Proceeding of 2nd International Conference on Quantitative Genetics, pp. 527-535.

Gunnes K., Gjedrem T., 1978 Selection experiments with salmon. IV. Growth of Atlantic salmon during two years in the sea. Aquaculture 15:19-23.

Iswanto B., Imron, Marnis H., Suprapto R., 2016 Response to selection for body weight in the third generation of mass selection of the African catfish (*Clarias gariepinus*) at Research Institute for Fish Breeding Sukamandi. Indonesian Aquaculture Journal 11(1):15-21.

Jayalaksana M. R., Handaka A. A., Subhan U., 2016 [Business and production of common carp culture conducted in running water ponds]. Jurnal Perikanan Kelautan 7(1):84-92. [In Indonesian].

Johnson D. W., Freiwald J., Bernardi G., 2016 Genetic diversity affects the strength of population in a marine fish. Ecology 97(3):627-639.

Khairuman, Sudenda D., Gunadi B., 2008 [Intensive culture for common carp]. PT Agromedia Pustaka, Jakarta, 100 p. [In Indonesian].

Kusmana, 2005 [Stability test for harvest yield of seven genotypes of potato at high land regions of Java]. Jurnal Hortikultura 15(4):254-259. [In Indonesian].

Legović T., Palerud R., Christensen G., White P., Regpala R., 2008 A model to estimate aquaculture carrying capacity in three areas of the Philippines. Science Diliman 20(2):31-40.

Linhart O., Gela D., Rodina M., Slechtov V., Slechta V., 2002 Top-crossing with paternal inheritance testing of common carp (*Cyprinus carpio* L.) progeny under two altitude conditions. Aquaculture 204:481-491.
Nielsen H. M., Ødegård J., Olesen I., Gjerde B,. Ardo L., Jeney G., Jeney Z., 2010 Genetic analysis of common carp (*Cyprinus carpio*) strains. I: Genetic parameters and heterosis for growth traits and survival. Aquaculture 304(1-4):14-21.
Nugroho E., 2012 [The production of common carp from floating net cages in Djuanda reservoir, Jatiluhur]. Media Akuakultur 7(1):11-13. [In Indonesian].
Overturf K., Castens M. T., LaPatra L., Rexroad III C., Hardy R. W., 2003 Comparison of growth performance, immunological response and genetic diversity of five strains of rainbow trout (*Oncorhynchus mykiss*). Aquaculture 217(1-4):93-106.
Purdom C. E., 1993 Genetics and fish breeding. Fish and Fisheries Series 8. Chapman & Hall, London, UK, 277 p.
Rahmani U., Syaukat Y., Fauzi A., Hidayat A., 2011 Internalization of environmental costs in floating net cage fish cultivation in Cirata Reservoir. Indonesian Journal of Agricultural Economics 2(2):157-168.
Sae-Lim P., Gjerde B., Nielsen H. M., Mulder H., 2016 A review of genotype-by-environment interaction and micro-environmental sensitivity in aquaculture species. Review in Aquaculture 8(4):369-393.
Supriatna Y., 2013 [Common carp culture in stagnant water ponds]. PT Agromedia Pustaka, Jakarta, 78 p. [In Indonesian].
Tave D., 1993 Genetic for fish hatchery managers. AVI. Publishing Company Inc., Connecticut, 418 p.
Wang C., Li S., 2007 Genetic effects and genotype × environment interactions for growth-related traits in common carp, *Cyprinus carpio* L. Aquaculture 272:267-272.
*** MMAF, Ministry of Marine Affairs and Fisheries, 2015 [Government Certificate No. 24/KEPMEN-KP/2015. Mantap carp, the resistant common carp to *Aeromonas hydrophila*]. MMAF, Jakarta, Indonesia. [In Indonesian].
*** MMAF, Ministry of Marine Affairs and Fisheries, 2016a [Government Certificate No. 25/KEPMEN-KP/2016. Jayasakti carp, the fast growth of common carp]. MMAF, Jakarta, Indonesia. [In Indonesian].
*** MMAF, Ministry of Marine Affairs and Fisheries, 2016b [Government Certificate No. 26/KEPMEN-KP/2016. Mustika carp, the resistant common carp to Koi Herpes Virus (KHV)]. MMAF, Jakarta, Indonesia. [In Indonesian].
*** MMAF, Ministry of Marine Affairs and Fisheries, 2016c [Government Certificate No. 27/KEPMEN-KP/2016. Marwana carp, the fast growth, and disease-resistant common carp]. MMAF, Jakarta, Indonesia. [In Indonesian].

Received: 04 July 2024. Accepted: 03 October 2024. Published online: 19 October 2024.
Authors:
Didik Ariyanto, Research Center for Fisheries, National Research and Innovation Regency, Jl. Raya Jakarta, Bogor Km. 46, Cibinong, Bogor, West Java, Indonesia, e-mail: didik29ariyanto@gmail.com
Yogi Himawan, Research Center for Fisheries, National Research and Innovation Regency, Jl. Raya Jakarta, Bogor Km. 46, Cibinong, Bogor, West Java, Indonesia, e-mail: yogi011@brin.go.id
Flandrianto Sih Palimirmo, Research Center for Conservation of Marine and Inland Water Resources. National Research and Innovation Regency, Jl. Raya Jakarta, Bogor Km. 46, Cibinong, Bogor, West Java, Indonesia, e-mail: fspalimirmo@gmail.com
Suharyanto Suharyanto, Research Center for Fisheries, National Research and Innovation Regency, Jl. Raya Jakarta–Bogor Km. 46, Cibinong, Bogor, West Java, Indonesia, e-mail: suhar.yanto83@ymail.com
Listio Dharmawantho, Research Center for Fisheries, National Research and Innovation Regency, Jl. Raya Jakarta, Bogor Km. 46, Cibinong, Bogor, West Java, Indonesia, e-mail: dharmawanthol@gmail.com

How to cite this article:
Ariyanto D., Himawan Y., Palimirmo F. S., Suharyanto S., Dharmawantho L., 2024 Phenotypic performance of the synthetic population of common carp reared in different culture systems based on its environmental carrying capacity. AACL Bioflux 17(5):2129-2138.