FISHERIES & AQUATIC LIFE (2022) 30: 95 - 103
Archives of Polish Fisheries
DOI 10.2478/aopf-2022-0009

RESEARCH ARTICLE

Morphometric and meristic characters of cultured and wild carp, *Cyprinus carpio* L., populations (southern Iraq)

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Received – 17 February 2022/Accepted – 02 June 2022. Published online: 30 June 2022; ©Inland Fisheries Institute in Olsztyn, Poland Citation:
Jawad, L. A., Abed, J. M., Ibáñez, A. L., Al-Faisal, A. (2022). Morphometric and meristic characters of cultured and wild carp, *Cyprinus carpio* L., populations (southern Iraq). Fisheries & Aquatic Life 30, 95-103.

Abstract. This study aimed to evaluate morphological differences between cultured and wild common carp, *Cyprinus carpio* L. Wild specimens were collected from fishers operating in the waters of the Shatt al-Arab River, Basrah, Iraq, while cultured specimens were obtained from the Aquaculture Unit of the Marine Science Centre, University of Basrah, Basrah, Iraq. Significant changes were detected in all eight morphometric and three meristic characters measured and counted. Boxplots by habitat and variable showed high divergence between the populations. The meristic counts were also higher in the cultured population, and, ultimately, the two populations diverged.

Keywords: morphometric, meristic, escapees, body shape variation, Cyprinidae

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Introduction

The common carp, *Cyprinus carpio* L., is a species that has been successfully introduced in countries around the world and is used both as an ornamental species and in aquaculture (Li and Moyle 1993, Lever 1996, Lever 1996, FAO 2002). Carp production reaches biomasses as high as 3,144 kg ha^{-1} and densities of up to 1,000 fish ha^{-1} (Harris and Gehrke 1997). Additionally, this species is known to have adverse effects on both aquatic environments and biota since it can eliminate aquatic plants (Fletcher et al. 1985, Roberts et al. 1995) and increase water turbidity while feeding (Fletcher et al. 1985, King et al. 1997, Robertson et al. 1997), which, consequently, reduces photosynthetic production and visibility.

Over 100 countries globally have considered including this species in their aquaculture plans since it contributes up to 10% (over 3 million metric tons) to global annual freshwater aquaculture production (FAO 2007, Bostock et al. 2010). The common carp is also a noteworthy ornamental fish species. One well-known variety of carp is Koi, which is the most widespread outdoor ornamental fish thanks to its characteristic colors and scale patterns.

The common carp was introduced to Iraq in from 1960 to 1972 (Jawad 2003). Soon after, it became a threat to the native freshwater fish species of Iraq such as *Mesopotamichthys sharpeyi* (Günther), *Luciobarbus xanthopterus* Heckel, and *Arabibarbus grypus* (Heckel) when its numbers increased greatly in marsh areas. By the early 1980s, common carp had eradicated many native fish species that had previously been abundant in the freshwater regions of Iraq, including the three species mentioned above (Jawad 2003, 2012).

Research on cultured fish species clearly indicates there are significant differences in groups of characters between these fish and the same species in the wild. Differences are noted in some morphological characters that respond to changes in environmental factors in aquaculture facilities (e.g., Swain et al. 1991, Fleming et al. 1994, Fleming and Einum 1997, Olla et al. 1994). All cultured species live in environments that lack predators and in which densities are high and growth is rapid, and these environmental conditions can change the morphological, behavioral, and life history development of fishes.

Cultured and wild stocks of any fish species might develop morphological differences genetically. Such factors include the non-indigenous sources of cultured stocks, which are, thus, likely to differ genetically from wild populations (e.g., Youngson et al. 1991), cultured populations are occasionally created using just a few fish and have small genetically-effective population sizes that can cause random genetic changes (e.g., Allendorf and Phelps 1980, Ryman and Ståhl 1980), and, finally, human-engineered breeding forms and culture environments generate intentional and unintentional selection that can result in domestication over a few generations (reviewed in Fleming 1995).

Morphometric analysis is the oldest technique used to identify fish stocks or populations. Technological advances have made this method effective and easy to apply especially when differentiating between hatchery cultured and wild fishes (Cadrin 2000, Anumudu and Mojekwu 2015). The morphometric and meristic characters of fishes can diverge among stocks mainly because of the mixed influences of genetics, environmental factors, and development stages (Wimberger 1992, Cadrin 2000). It is imperative to maintain population variations in aquaculture and fisheries. In fisheries management, correctly identifying fish is necessary to manage hatchery escapees (Šegvić-Bubić et al. 2014). Morphological characters are used to categorize wild and cultured populations in many fish species (Arechavala-Lopez et al. 2012, Nakaya et al. 2013, Patiyal et al. 2014, Jawad et al. 2020).

Since morphometric and meristic characters are vital for effectively monitoring fisheries and for optimal resource exploitation, the aim of this study was to assess the morphological and meristic characters of *C. carpio* caught in different habitats (cultured and wild) in Iraq. This will assist in developing further breeding and conservation policies for this fish and in improving productivity.

Materials and Methods

Five hundred and fifty six samples of cultured (249 specimens) and wild (307 specimens) *C. carpio* were obtained from two locations. The cultured samples were obtained from the aquaculture facility of the Marine Science Centre, University of Basrah, Basrah, Iraq in 2013. The facility covers an area of 1,500 m^2 and specializes in fish farming and conducts activities including common carp fry production, semi-intensive and intensive on-growing, and marketing. The carp were propagated using hormonal feed that contained 1.5 g of the hormone 17α-2-methyltestosterone in 20 kg of food. Common carp specimens were reared in tanks within recirculating aquaculture systems. The nursery area was equipped with aeration devices. Wild specimens of *C. carpio* were obtained from fishers operating in the Shatt al-Arab River in the vicinity of Qarmat Ali north of Basrah in November 2013. Identification, morphometric measurements, and meristic counts of *C. carpio* were taken in the laboratory as soon as the fish specimens arrived. All morphometric measurements were taken on the left side of the fish to ensure uniformity using a Vernier Caliper adjusted to the nearest 0.01 mm. A total of eight morphometric and three meristic characters were measured and counted, as

Table 1
Mean ± SD, minimum and maximum values of morphometric (length in mm) and meristic variables in cultured and wild specimens of *C. carpio*. Z and *p* values of the Mann-Whitney test

	Cultured		Wild		Mann-Whitney	
Variable	Mean ± SD	Min- Max	Mean ± SD	Min- Max	Z	p
Total length	171.2 ± 45.80	120.2–290.3	189.3 ± 26.46	170.0–280.6	-6.859	< 0.01
Caudal peduncle length	17.9 ± 0.84	16.8–19.9	14.68 ± 0.57	14.0–15.9	-20.345	< 0.01
Caudal peduncle depth	18.85 ± 2.29	15.7–21.7	13.94 ± 0.29	13.5–14.3	-20.356	< 0.01
Eye diameter	7.95 ± 0.98	6.2–9.4	4.71 ± 0.30	4.2–5.3	-20.394	< 0.01
Predorsal fin length	50.68 ± 1.58	48.2–52.9	44.70 ± 0.95	44.0–46.8	-20.439	< 0.01
Postdorsal fin length	15.78 ± 0.81	14.8–17.2	13.04 ± 0.62	12.0–13.8	-20.342	< 0.01
Head length	31.88 ± 0.85	30.1–33.2	27.90 ± 0.81	26.3–29.3	-20.326	< 0.01
Snout length	12.97 ± 0.68	11.7–14.0	9.48 ± 0.43	9.0–10.7	-20.553	< 0.01
Number of gill rakers	21.82 ± 0.65	21–23	19.50 ± 0.50	19–20	-20.950	< 0.01
Number of dorsal fin rays	19.28 ± 0.45	19–20	17.51 ±0.50	17–18	-21.156	< 0.01
Number of pectoral fin rays	16.40 ± 0.49	16–17	14.51 ± 0.50	14–15	-21.033	< 0.01

follows: total length; head length; eye diameter; snout length; predorsal fin length; postdorsal fin length; caudal peduncle length; caudal peduncle depth; number of dorsal fin rays; number of pectoral fin rays; and number of gill rakers on the first gill arch. The fin rays of the dorsal and pectoral fins were counted using hand-held magnifying lenses. Boxplots were created to display the dataset based on a four-number summary: minimum; maximum; sample mean; standard error. The manuscript includes datasets by habitat (cultured or wild) and by each variable (total length, predorsal fin length, etc.), and by habitat and variable; these serve to compare and determine the distribution of each variable. Table 1 presents mean ± SD minimum and maximum values of morphometric and meristic variables for the fish from cultured and wild habitats. Comparisons were done with the Mann-Whitney U test since normality was not achieved in any case. This test is the nonparametric equivalent of the t-test and is used when the normality assumption is violated.

Results

The total length of the specimens from the culture habitat was much smaller than that of those from the wild; however, the rest of the morphometric and meristic characters were smaller for the latter with the exception of eye diameter, which was larger in cultivated fish (Table 1). Accordingly, the boxplot by habitat in Figs. 1 and 2, shows that, with the exception of total length (Fig. 1), all the characters, whether morphometric or meristic, did not overlap (Figs. 1 and 2), which indicated that any variable can be used to discriminate between the fish from the two habitats. Therefore, significant differences between habitats were detected in all morphometric and meristic characters ($p < 0.01$) (Table 1). The boxplot by habitat in Fig. 1 indicates that, with the exception of total length, none of the morphometric or meristic characters overlapped (Table 1), which meant that any of them can be used to discriminate between the two habitats, locations, and areas. Therefore, significant differences in the fish from the two habitats were detected for all morphometric and meristic characters ($p < 0.01$) (Table 1). The values of all the parameters investigated were higher in the cultured population than in the wild one, with the exception of total length. Annual variation in water temperature, pH, dissolved oxygen, and salinity were, respectively, 21.0–23.0°C, 7–8, 4–6 mg O_2 dm^{-1}, and 2–4 parts per million.

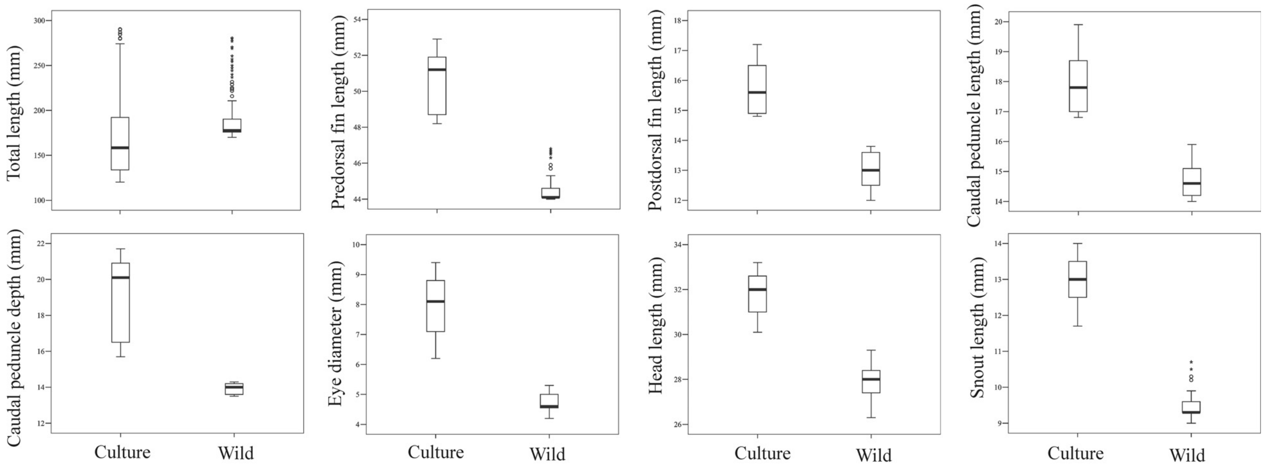

Figure 1. Boxplot, Mean ± standard error for cultured and wild specimens of *C. carpio* of total length (mm) and seven morphometric variables (mm): predorsal fin length; postdorsal fin length; caudal peduncle length; caudal peduncle depth; eye diameter; head length; snout length.

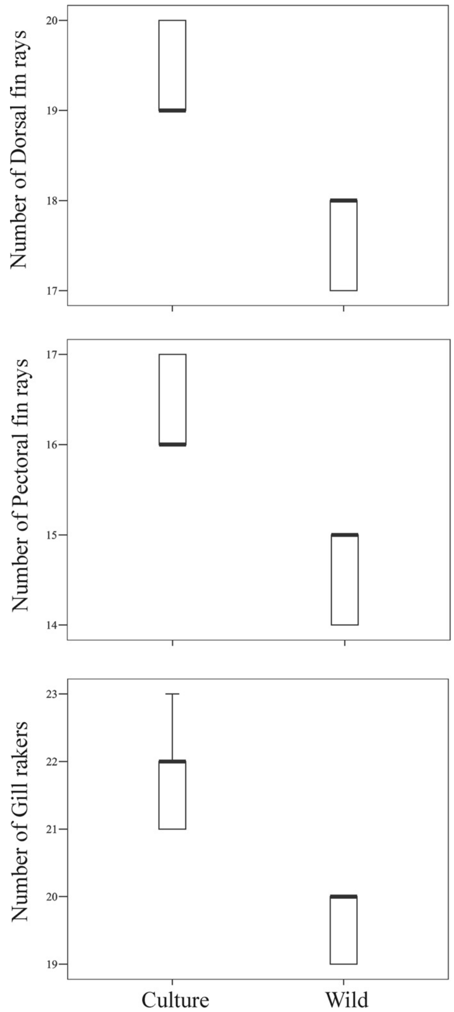

Figure 2. Boxplot, Mean ± standard error for three meristic variables (numbers of dorsal and pectoral fin rays and numbers of gill rakers) in cultured and wild specimens of *C. carpio*.

Discussion

Research on the morphology of fish has proved that both genetic and environmental factors influence the morphology of fishes, which are considered to be the animals that are most affected by these factors because they inhabit water (Currens et al. 1989, Wainwright et al. 1991). Conversely, some factors other than environment and genetics, such as diet, have been shown to change the external characters of crucian carp, *Carassius carassius* (L.) or to heighten defenses against predators, while good food conditions have been observed to lead to a deep body shape in this species (Brönmark and Pettersson 1994).

The two types of specimens of *C. carpio* examined in the present study were collected from the wild and the other group was reared in tanks at an aquaculture facility. Specimens from the second group spent their whole lives in the tanks and were completely different from the specimens from the first group that lived in the wild. The differences in the habitats influenced variations in some morphological characters of the two groups of stocks; this might indicate that these variations could stem from environmental factors or differences in genetic makeup or both.

Nonetheless, variation between wild and cultured populations were mostly the result of environmental differences. Other studies verified the major role environment plays in morphological differentiation among populations of genetically homogenous fish (Ryman et al. 1984, Kinsey et al. 1994).

In a preliminary study, Jawad (2021) examined some meristic characters of the common carp, *C. carpio*, from southern Iraq. In this study, the variation of five meristic characters were investigated in populations of *C. carpio* from natural and farmed environments. The farmed specimens had fewer scales on their lateral lines, caudal fin rays, and vertebrae. Conversely, they had more dorsal and anal fin rays. These results concur with those of the present study.

Several morphological characters (i.e., body color, size, and shape), behavioral aspects, and immunological (differences in major histocompatibility complex), biochemical (isoenzymes), and molecular (simple sequence-length polymorphism) (Sharp et al. 2002) features have been used to identify different cultured stocks. However, in contrast to other approaches, morphological analysis offers large amounts of data in a short time without requiring high levels of skill or costs. With the use of boxplots by areas/habitats vs. variables applied in the present study, the full separation of the wild and cultured populations with significant differences in morphometric measures (except total length) was observed. This result confirms that this method is a useful tool for differentiating between populations of *C. carpio*. In addition, the eight characters regarding body shape used in the present analysis played key roles in morphological differentiation.

The results of the current study showed that all eight body proportions were larger in the cultured population than in the wild stock. These differences between the populations might have been connected to different habitat settings, such as water temperature, water turbidity, food availability, and water depth and flow. For example, the large eye diameter in the specimens of the cultured population could have originated from differences in turbidity between the rearing facilities and the wild habitats (Matthews and Robison 1988). Presumably, this was a vital habitat favorite, which was specified by Aleev (1969) to be linked with the position of eyes in the head. These morphological disparities could have originated from the selective breeding programs used in aquaculture, genetic drift following founding generations, or the different origin of fish used in broodstocks (Karaiskou et al. 2009). Likewise, the values of the meristic characters were higher in the cultured population than in the wild one, which made it possible to discriminate between the two populations. Furthermore, the modes of meristic values between the two populations were not equal or close, which indicated there were intraspecific variations.

The results of the present study regarding the comparison between wild and cultured *C. carpio* meristic counts revealed some variations between the two stocks. In the wild population, the range of variation in meristic characters such the number of dorsal, pectoral, and anal fin rays was higher than that in the cultured population. Matsuoka (1987) and Boglione et al. (2003) reported similar results. The dissimilarities in meristic characters are thought to be influenced by both environmental and genetic factors (Foote et al. 1999); nonetheless, in specific cases, some authors (Davidson et al. 1985, Hedgecock et al. 1989, Shepherd 1991, Kinsey et al. 1994) linked these discrepancies chiefly to environmental impacts and phenotypic plasticity (Lindsey 1981, Stearns 1989, West-Eberhard 1989, Swain and Foote 1999).

The morphological characters of the cultured specimens of *C. carpio* diverged from the ancestral form as indicated by the wild population, with the body becoming more robust with higher numbers of fin rays. These changes in body robustness differ from results obtained by studies on sea-ranched salmon, where the reverse trend relative to wild fish was observed and was thought to be primarily environmental in origin (Taylor 1986, Swain et al. 1991, Fleming et al. 1994). The different rearing systems could be responsible for this. In contrast to the wild population of *C. carpio*, the cultured fish were reared throughout their lives and never came into contact with the natural environment. Furthermore, they were exposed to stable artificial selection for rapid growth based on body weight (Gjedrem et al. 1988), which might have been linked with a positive reaction in body depth (Gjerde and Schaeffer 1989).

Differences in fin morphology of cultured *C. carpio* were also reported by other researchers (Taylor 1986, Swain et al. 1991, Fleming et al. 1994). Uninterrupted selection for swimming training combined with artificial selection could have resulted in high levels of fin nipping (Abbott and Dill 1985) and erosion (Bosakowski and Wagner 1994).

Increased food requirements might have had a direct effect on changing the external characters of the cultured population of *C. carpio*. Since there is no predation in cultured environments (Johnsson et al. 1996, Einum and Fleming 1997), the relaxation of selection against predator-susceptible phenotypes in culture facilities could have shifted the focus to food competition. The cause of these variations in anti-predation behavior could have been amplified through growth hormone production and thus appetite (Johnsson et al. 1996).

Growth performance in common carp in the aquaculture facilities was better than that in the wild (Metcalfe et al. 1988), which was disturbed by the state (lipid or weight) and/or rate of changes in growth rates at this time (Thorpe 1986, Økland et al. 1993). Such fast growth rates are genetic in cultured specimens (Thorpe 1986). Our results showed that the cultured *C. carpio* exhibited changes in fitness other than those of the wild population that resulted from domestication and were linked to intentional and unintentional selection. Since much of this change appeared to be an adaptive response to the culture habitat, it can be of significance for programs attempting to develop aquaculture production (Doyle et al. 1991). This change, however, poses a threat to wild populations when these fish escape and then compete and breed with wild *C. carpio*. When farmed specimens escape into rivers this not only increases competition for resources, but it also results in the mixing of different genetic characters into wild populations. Many of these characters are expected to be detrimental in local environments because of the non-indigenous origins of farmed stocks (Einum and Fleming 1997) and the changes that have occurred during culturing. Whereas natural selection might be able to eliminate wild populations of such unwanted qualities, this is severely delayed by the introgression of farmed stocks year after year.

The results of the current study discriminating between cultured and wild populations of *C. carpio* based on morphometric and meristic characters are reflected in the findings of Barriga-Sosa et al. (2004) and Narváez et al. (2005), who reported morphological differences among wild and reared populations of *Oreochromis niloticus*. These researchers attributed such differences to food, environmental conditions, and habitat type (wild and cultured). Nevertheless, in the present study, all meristic characters were significantly different between populations, which contradicted the research by Solomon et al. (2015) on *Clarias gariepinus* (Burchell).

Fishes generally demonstrate greater variance in morphological characters both within the same and different species and among populations than do any other vertebrates. This reflects changes in feeding environments, prey types, food availability, and other abiotic aspects (Allendorf 1988, Thompson 1991, Wimberger 1992).

Additional studies on the functional importance of the morphological differences found in the current study on *C. carpio* could assist in elucidating the impact of morphological disparity on the survival of hatchery specimens in the wild. The use of a joint approach, such as morphometric, genetic, and other biological indicators (e.g., scale and otolith growth patterns, fatty acids and trace elements), should be applied for more thorough assessments of the influence of escaped cultured fish on natural populations, fisheries landings, or to evaluate stocking programs. This will not only expand biological and ecological knowledge of the species considerably, it will also aid in the development of policies for natural stock conservation and in improving aquaculture sustainability.

Author contributions. L.A.J. study concept, experiment design, manuscript preparation; J.M.A. and A.A.F. collecting fish and data; A.L.I. data analysis, drawing figure 1, writing part of the materials and methods and results sections.

Conflicts of interest. The authors declare they have no conflicts of interest.

Sources of funding. This research did not receive any specific funding.

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