ACROSS
Journal of Interdisciplinary Cross-Border Studies
Vol 10, No.5, 2026

Environment

Comparative Hematological Profiles of Migratory and Non-migratory Fish Species from the Lower Danube River

Angelica DOCAN[1], Iulia GRECU[1]*, Lorena DEDIU[1], Mirela CREȚU[2]

[1] Faculty of Food Science and Engineering, University of "Dunărea de Jos" Galați, Romania

[2] Department of Life Sciences, Cross-border Faculty, University of "Dunărea de Jos" Galați, Romania

***Corresponding author:** iulia.grecu@ugal.ro

Abstract

Hematological parameters are widely recognized as reliable indicators of fish health and physiological adaptation to environmental conditions. The present study aimed to characterize the hematological profile of six economically important fish species from the lower Danube River, representing different ecological strategies: *Alosa immaculata, Alosa tanaica, Aspius aspius, Silurus glanis, Cyprinus carpio*, and *Abramis brama*. Blood samples were obtained through caudal vein puncture, and erythrocyte count (RBC), hemoglobin concentration (Hb), hematocrit (Ht), and erythrocyte indices (MCV, MCH, and MCHC) were determined using standard fish hematology methods.

Significant interspecific differences were observed in the erythrocyte-related parameters. The migratory species *A. immaculata* and *A. tanaica* exhibited the highest erythrocyte counts, hemoglobin concentrations, and hematocrit values, indicating an enhanced oxygen transport capacity associated with the elevated metabolic demands of anadromous migration. In contrast, erythrocyte indices showed comparatively limited interspecific variation, suggesting that the increased oxygen-carrying capacity of migratory species is achieved primarily through an increase in erythrocyte number rather than substantial changes in erythrocyte morphology. The presence of immature erythrocytes in peripheral blood smears of *A. tanaica* further suggests enhanced erythropoietic activity during migration.

The results provide baseline hematological reference values for economically important fish species from the lower Danube River and contribute to a better understanding of species-specific physiological adaptations. These data may support fish health assessment, ecological monitoring, aquaculture practices, and sustainable fisheries management.

Keywords: blood parameters, environmental factors, clupeids, cyprinids, silurides

Introduction

Lotic ecosystems are characterized by continuous water flow and pronounced spatial and temporal variability in physicochemical parameters, including temperature, dissolved oxygen, salinity, and nutrient availability. These environmental fluctuations directly influence the physiology of aquatic organisms, requiring fish to continuously adjust their metabolic and homeostatic processes to maintain normal biological functions.

Understanding these physiological responses is essential for assessing the health of natural fish populations and for supporting the sustainable management and conservation of fishery resources.

Among the physiological indicators used to evaluate fish health, hematological parameters are recognized as reliable and sensitive biomarkers because they rapidly reflect both the internal physiological status of the organism and its response to environmental conditions. Blood composition provides valuable information on oxygen transport capacity, metabolic activity, immune competence, and stress responses, making hematological analyses an effective approach for assessing fish health and physiological adaptation.

Although hematological investigations have long been established as routine diagnostic tools in terrestrial animals, their application in fish biology has expanded considerably in recent years. Hematological indices are increasingly used as early indicators of physiological disturbances associated with anemia, infectious diseases, nutritional deficiencies, and environmental stress (Fazio, 2015; Witeska, 2022). Moreover, variations in hematological parameters have proven useful for evaluating the effects of habitat quality (Jeamah et al., 2023; Malathi et al., 2021), nutrition (Ahmed et al., 2023), stress (Fazio et al., 2015; Sagar et al., 2024), infectious diseases (Seibel et al., 2021; Siddiqui et al., 2020), temperature fluctuations (Missinhoun et al., 2023; Saenphet, 2025), and exposure to environmental contaminants (Kim et al., 2021; Witeska et al., 2023). Consequently, hematological analyses have become valuable tools for monitoring fish health and evaluating the physiological consequences of environmental change in both natural ecosystems and aquaculture.

Despite the growing body of research on fish hematology, baseline hematological data remain limited for many species inhabiting the lower Danube River. This lack of reference values restricts the interpretation of physiological status under natural conditions and limits the application of hematological biomarkers in ecological monitoring and fisheries management. The available information is particularly scarce for anadromous species of the genus *Alosa*, for which most published studies have focused on taxonomy, distribution, population dynamics, or fisheries, while hematological investigations remain limited. Considering that anadromous migration involves profound physiological adjustments associated with transitions between mesohaline and freshwater environments, increased swimming activity, and changes in feeding behavior, expanding the hematological knowledge of these species is of ecological and conservation interest.

Therefore, the aim of the present study was to characterize the hematological profile of several economically and ecologically important fish species from the Danube River, representing different ecological strategies, including both migratory and non-migratory species. Attention was paid to *Alosa tanaica*, whose hematological characteristics have been only scarcely documented despite their ecological importance. The present study provides baseline hematological data for populations inhabiting the lower Danube River, contributing to a better understanding of species-specific physiological adaptations and establishing reference values that may support fish health assessment, ecological monitoring, aquaculture practices, and sustainable fisheries management.

Materials and methods

Materials

Fish sampling was conducted in the Danube River within the Galați town area as part of an ichthyofaunal monitoring program. Specimens were collected using drift gillnets with different mesh sizes to ensure the capture of fish of various sizes. The economically important species included in the study were *Alosa immaculata, Alosa tanaica, Aspius aspius, Silurus glanis, Cyprinus carpio,* and *Abramis brama*.

Methods

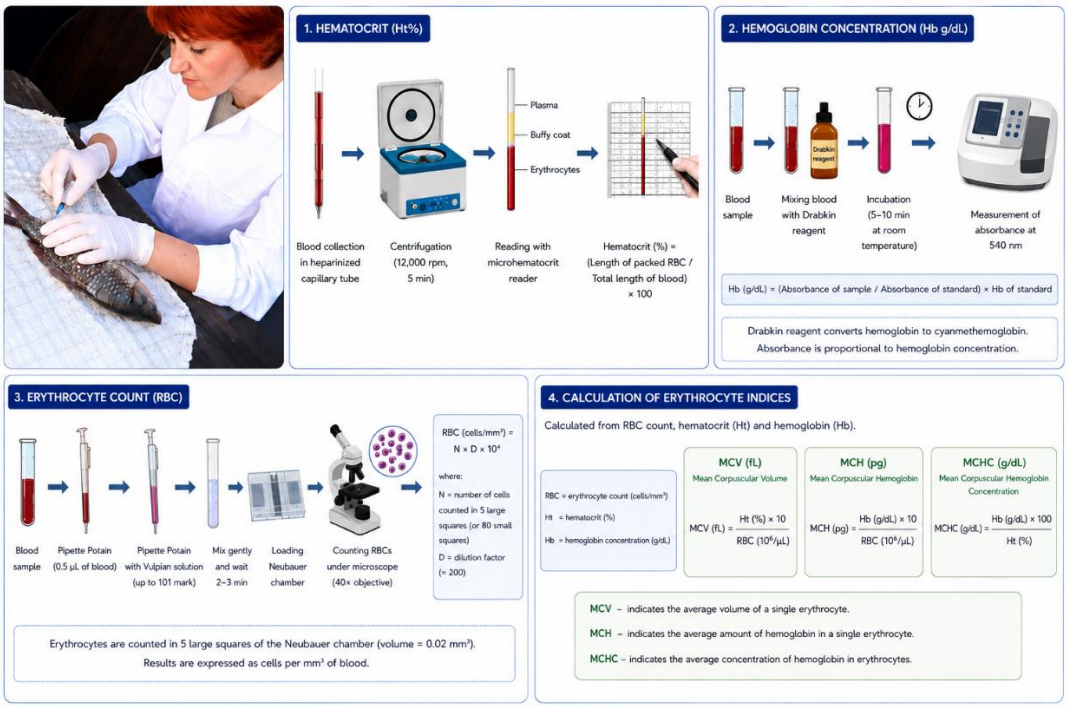


Figure 1. Workflow illustrates the hematological analyses performed on fish blood samples (source: illustration generated using ChatGPT (OpenAI) based on the author's description).

Blood samples were collected from the caudal vein using heparinized syringes and immediately transferred into Eppendorf tubes. Throughout the sampling procedure, the tubes were kept on ice and subsequently transported to the laboratory for hematological analyses. Hematological determinations were performed according to the standard methods for fish described by Svobodova et al. (2012). Erythrocytes count (RBC, $\times 10^6$ cells/µL) was determined with a Neubauer hemocytometer after dilution of the blood with Vulpian solution using a Potain glass pipette for erythrocytes. Hematocrit (Ht, %) was measured by the microhematocrit method. Briefly, 30 µL of heparinized whole blood was distributed into microhematocrit capillary tubes and centrifuged at 12,000 rpm for 5 min using a Hettich Haematokrit 210 centrifuge and the values were read with the microcentrifuge nomogram. Hemoglobin concentration (Hb, g/dL) was quantified by the cyanmethemoglobin method using Drabkin's reagent, with absorbance measured at 540 nm using a Specord 210 UV–VIS spectrophotometer. Erythrocyte indices: (i) mean corpuscular hemoglobin (MCH, pg); (ii) mean corpuscular volume (MCV, fL); (iii) mean corpuscular hemoglobin concentration

(MCHC, g/dL) - were calculated according to the equations described by Svobodova et al. (2012).

The results were statistically processed using the following programs: Microsoft Excel (Office 2007) for Windows and SPSS Statistics 17.0 for Windows. Normality of distribution was assessed with the Kolmogorov-Smirnov test, and homogeneity of variance was verified using Levene's test. Differences between variables were evaluated using the parametric t-test ($p < 0.05$).

Results and discussion

Although hematological analyses are widely recognized as valuable tools for evaluating fish health and physiological status, baseline hematological reference values remain unavailable or limited for many species (Kori-Siakpere et al., 2005, Witeska 2022). Establishing such reference data is essential for interpreting physiological responses and for distinguishing normal adaptive variation from pathological changes. Recent studies on economically and ecologically important fish species have further emphasized the importance of species-specific hematological reference values for monitoring the health of both wild and cultured populations (Tavares-Dias & Moraes, 2007; Witeska et al., 2016; Seibel et al., 2021; Huijie et al., 2023).

The erythrocytes count obtained for the studied fish species revealed clear interspecific differences (Figure 1). The migratory species (*Alosa immaculata* and *Alosa tanaica*) exhibited the highest red blood cell (RBC) counts, suggesting an increased oxygen-carrying capacity and enhanced erythropoietic activity associated with the elevated metabolic demands of anadromous migration. These findings are further supported by the presence of immature erythrocytes observed in peripheral blood smears, particularly in *A. tanaica*. In contrast, the non-migratory species (*Aspius aspius*, *Silurus glanis*, *Cyprinus carpio* (Tripathi et al., 2004), and *Abramis brama* (Hayatbakhsh et al., 2014) exhibited erythrocyte counts within the ranges previously reported in the literature, reflecting species-specific metabolic requirements and oxygen transport capacity. The observed interspecific differences are consistent with physiological adaptations related to locomotor activity, feeding ecology, and lifestyle (Witeska, 2013; Witeska, 2023).

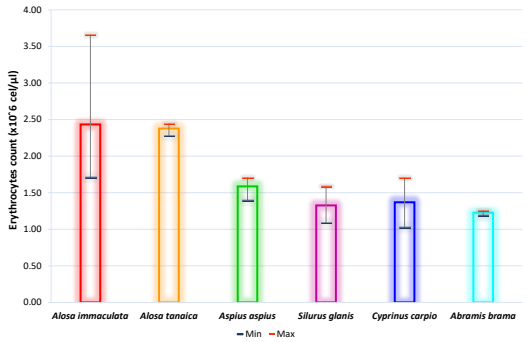


Figure 1. Variation range of RBC in analyzed fish species

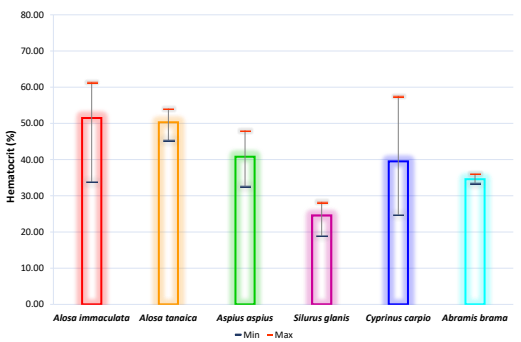


Figure 2. Variation range of Ht in analyzed fish species

Hematocrit is one of the most informative hematological parameters used to evaluate fish health, reflecting the oxygen-carrying capacity of the blood and responding rapidly to

environmental and physiological changes (Witeska et al., 2022). Hematocrit values are influenced by several intrinsic and extrinsic factors, including species, age, nutritional status, reproductive stage, physical activity, temperature, salinity, dissolved oxygen concentration, and stress conditions. The values obtained for the migratory species *Alosa immaculata* and *Alosa tanaica* were significantly higher than those recorded for the other species, suggesting an enhanced oxygen transport capacity required to sustain the elevated metabolic demands of anadromous migration (Figure 2). Increased hematocrit values likely reflect a higher erythrocyte concentration and may result from the mobilization of erythrocytes from hematopoietic tissues, increased erythropoietic activity, splenic contraction, or transient reductions in plasma volume associated with osmotic adjustments during the transition from mesohaline to freshwater environments. Similar hematological responses have been described in migratory fish as adaptive mechanisms that improve oxygen delivery to actively working tissues during prolonged swimming and reproductive migration.

The comparative analysis of the investigated species further supports a positive relationship between hematocrit values and locomotor activity. The highest hematocrit values were recorded in the highly active migratory clupeids (*A. immaculata* and *A. tanaica*), whereas lower values characterized the more sedentary *Silurus glanis*. Intermediate hematocrit values observed in *Aspius aspius*, *Cyprinus carpio*, and *Abramis brama* are consistent with their ecological strategies and metabolic requirements, reflecting differences in swimming performance, foraging behavior, and oxygen demand. These findings agree with previous studies demonstrating that hematological parameters are closely associated with species-specific metabolic activity and ecological adaptation (Witeska, 2013; Witeska et al., 2022).

Hemoglobin concentration is one of the most informative hematological parameters because it directly reflects the oxygen-carrying capacity of the blood and, consequently, the aerobic performance of fish. Hemoglobin levels are known to vary among species according to several biological and environmental factors, including feeding ecology, metabolic activity, age, sex, reproductive status, and environmental conditions (Speckner et al., 1989; Lone et al., 2012; Ighwela et al., 2012; Arthanari, 2016; Arnaudov, 2023; Abhishek, 2023).

The hemoglobin concentrations obtained in the present study differed among the investigated species, reflecting their distinct ecological strategies and physiological requirements (Figure 3). The migratory species *Alosa immaculata* and *Alosa tanaica* exhibited the highest hemoglobin values, consistent with their elevated erythrocyte counts and hematocrit levels. This coordinated increase in the main erythrocyte-related parameters suggests an enhanced oxygen transport capacity required to sustain the high aerobic demands associated with prolonged swimming and anadromous migration.

Among the non-migratory species, *Cyprinus carpio* presented relatively high hemoglobin concentrations (10.48 g/dL), whereas the lowest values were recorded in *Silurus glanis* (7.72 g/dL). These differences are likely related to species-specific metabolic requirements, swimming performance, and ecological strategy rather than to feeding habits alone. Active swimmers generally require a greater oxygen transport capacity than more sedentary species, resulting in higher hemoglobin concentrations.

The elevated hemoglobin values observed in *A. immaculata* and *A. tanaica* are consistent with previous studies on migratory clupeids, including *Alosa sapidissima* (Leonard et al., 1999) and *Tenualosa ilisha* (Anwar et al., 2025), in which hemoglobin concentration

increased during migration as an adaptive response to the progressively greater energetic and oxygen demands associated with upstream movement and reproduction.

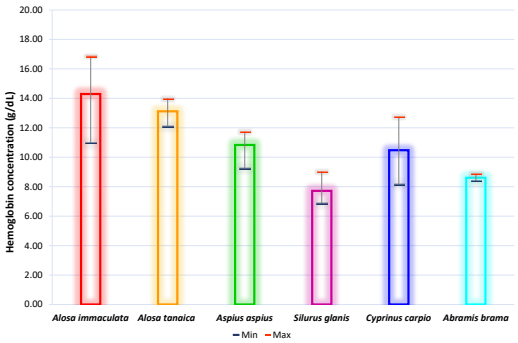


Figure 3. Variation range of Hb in analyzed fish species

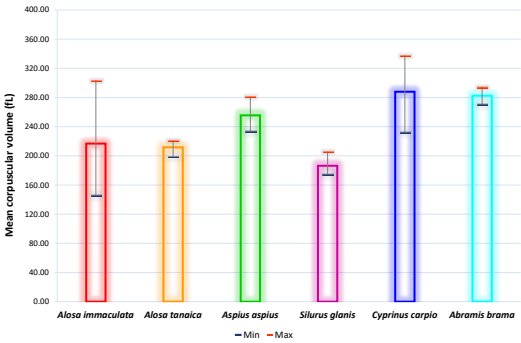


Figure 4. Variation range of MCV in analyzed fish species

The simultaneous increase in RBCc, Hb, and Ht observed in *Alosa immaculata* and *Alosa tanaica* demonstrates an integrated hematological adaptation that enhances oxygen transport capacity during migration. The concordant variation of these three parameters indicates that the elevated oxygen requirements associated with prolonged swimming are met through coordinated adjustments of both erythrocyte number and blood oxygen-carrying capacity. To better understand the characteristics of these erythrocytes, the erythrocyte indices (MCV, MCH, and MCHC) were subsequently analyzed.

Mean corpuscular volume (MCV) is an important erythrocyte index that reflects the average volume of circulating erythrocytes and provides information on erythrocyte maturation, erythropoietic activity, and physiological adaptation (Witeska et al., 2022). Variations in MCV may result from differences in species, erythrocyte age, osmoregulatory processes, or hematopoietic activity.

In the present study, MCV values did not differ significantly among the investigated species ($p = 0.087$), indicating that erythrocyte volume was relatively conserved despite the distinct ecological strategies of the analyzed fish (Figure 4). Nevertheless, a tendency toward higher MCV values was observed in *Cyprinus carpio* (287.90 fL), *Abramis brama* (282.46 fL), and *Aspius aspius* (255.60 fL). The MCV values obtained for all investigated species fell within the reference interval reported for teleost fishes (146.37–337.85 fL), confirming the considerable interspecific variability described in the literature.

Although the migratory species *Alosa immaculata* and *Alosa tanaica* exhibited significantly higher erythrocyte counts, hemoglobin concentrations, and hematocrit values, their MCV values remained comparable to those of the non-migratory species. This finding suggests that the increased oxygen transport capacity observed in the migratory species resulted primarily from an increase in erythrocyte number rather than from changes in erythrocyte size. Moreover, the presence of immature erythrocytes observed in peripheral blood smears, particularly in *A. tanaica*, may indicate active erythropoiesis during migration while maintaining a relatively stable mean erythrocyte volume.

Mean corpuscular hemoglobin (MCH) represents the average amount of hemoglobin contained in a single erythrocyte and provides information on the oxygen-carrying capacity of individual red blood cells. Although relatively wide intra-specific variation was observed,

particularly in *Cyprinus carpio* (67.57–91.02 pg), the obtained values remained within the physiological range reported for teleost fishes (Figure 5). The observed variability is likely associated with differences in erythrocyte maturation, metabolic activity, and physiological condition rather than with a single ecological factor.

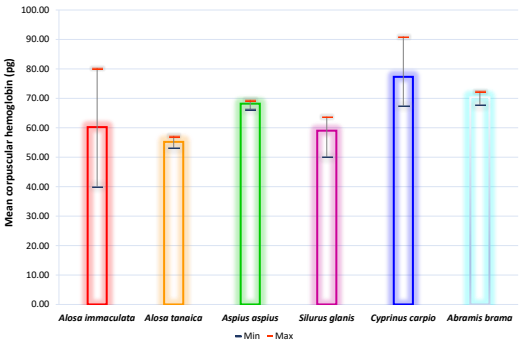


Figure 5. Variation range of MCH dynamics in analyzed fish species

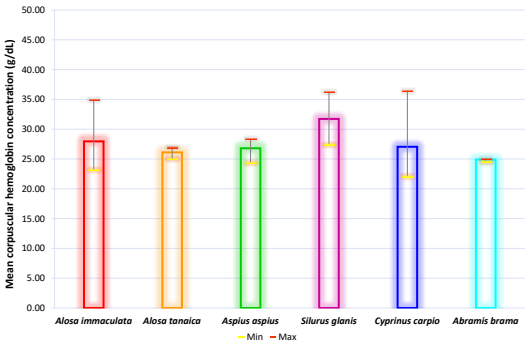


Figure 6. Variation range of MCHC in analyzed fish species

No statistically significant differences were detected in mean corpuscular hemoglobin concentration (Figure 6) among the investigated species ($p > 0.05$), indicating that the intracellular hemoglobin concentration remained relatively stable despite the marked differences observed for erythrocyte count, hemoglobin concentration, and hematocrit. The highest MCHC values were recorded in *Silurus glanis* (31.73 g/dL), whereas the lowest values were observed in *Abramis brama* (24.60–25.07 g/dL). These differences likely reflect species-specific erythrocyte characteristics rather than major differences in oxygen transport efficiency.

Taken together, the erythrocyte indices (MCV, MCH, and MCHC) exhibited lower interspecific variability than erythrocyte count, hemoglobin concentration, and hematocrit. This finding suggests that, although migratory species increased their blood oxygen-carrying capacity primarily by increasing erythrocyte number and total hemoglobin, the structural characteristics of individual erythrocytes remained relatively conserved among the species investigated. Consequently, erythrocyte indices complement the interpretation of hematological profiles by providing information on erythrocyte morphology and hemoglobin content, thereby contributing to the assessment of physiological status and representing valuable indicators for fish health monitoring in both wild populations and aquaculture.

Conclusions

This study provides baseline hematological reference data for economically important fish species inhabiting the lower Danube River, contributing to the limited information currently available for wild fish populations. These data expand the existing knowledge of fish hematology and provide a valuable framework for evaluating fish health, physiological status, and adaptive responses under natural environmental conditions.

A clear distinction was observed between migratory and non-migratory species. The anadromous species *A. immaculata* and *A. tanaica* consistently exhibited higher erythrocyte

counts, hemoglobin concentrations, and hematocrit values than the non-migratory species, indicating an integrated hematological adaptation that enhances blood oxygen transport capacity during migration. In contrast, erythrocyte indices (MCV, MCH, and MCHC) showed comparatively limited interspecific variation, suggesting that the increased oxygen-carrying capacity of migratory species is achieved primarily through an increase in circulating erythrocyte number rather than substantial modifications in erythrocyte morphology or intracellular hemoglobin concentration.

Particular attention was given to *A. tanaica*, an ecologically important anadromous species for which hematological information remains scarce. The presence of immature erythrocytes in peripheral blood smears provides evidence of enhanced erythropoietic activity and supports the hypothesis that hematological remodeling represents an adaptive response to the elevated oxygen demands associated with reproductive migration and transitions between mesohaline and freshwater environments.

Overall, the present findings demonstrate that hematological parameters constitute sensitive indicators of physiological adaptation in fish and represent valuable tools for monitoring the health of wild populations. The reference values established in this study provide a scientific basis for future ecophysiological research, conservation programs, fisheries management, and the development of sustainable monitoring strategies under increasing environmental and anthropogenic pressures.

Acknowledgments

The authors are grateful for the technical support offered by MoRAS through the Grant POSCCE ID 1815, cod SMIS 48745 (www.moras.ugal.ro)

References

Ahmed, I., Khan, Y. M., Lateef, A., Jan, K., Majeed, A., Shah, M. A. 2023. Effect of fish meal replacement by *Azolla* meal on growth performance, hemato-biochemical and serum parameters in the diet of scale carp, *Cyprinus carpio* var. *communis*. *Journal of the World Aquaculture Society*, **54**(5), 1301–1316.

Alp, D., Bulantekin, Ö. 2021. The microbiological quality of various foods dried by applying different drying methods: A review. *European Food Research and Technology*, **247**, 1333–1343.

Anwar, S., Kader, A., Debnath, S. K., Jarin, F., Sayem, A. S. M., Miah, M. F. 2025. Biophysical assessments and blood profiling reveal physiological adaptations and environmental interactions of hilsa shad (*Tenualosa ilisha*). *PLoS ONE*, **20**(4), e032628.

Arnaudov, A., Arnaudova, D. 2023. Erythrocytes and hemoglobin of fish: Potential indicators of ecological biomonitoring. In *Animal Models and Experimental Research in Medicine*. IntechOpen. Available at: http://dx.doi.org/10.5772/intechopen.107053.

Arthanari, M., Dhanapalan, S. 2016. Assessment of the haematological and serum biochemical parameters of three commercially important freshwater fishes in River Cauvery, Velur, Namakkal District, Tamil Nadu, India. *International Journal of Fisheries and Aquatic Studies*, **4**(1), 155–159.

Chen, H., Luo, D. 2023. Application of haematology parameters for health management in fish farms. *Aquaculture*, **15**(2), 704–737.

Fazio, F. 2019. Fish hematology analysis as an important tool of aquaculture: A review. *Aquaculture*, **500**, 237–242.

Fazio, F., Ferrantelli, V., Fortino, G., Arfuso, F., Giangrosso, G., Faggio, C. 2015. The influence of acute handling stress on some blood parameters in cultured sea bream (*Sparus aurata* Linnaeus, 1758). *Italian Journal of Food Safety*, **4**(1), 4174.

Gupta, K., Raina, S., Sachar, A., Gupta, K. 2012. Age and size related variations in the haematological parameters of *Labeo boga* and *Labeo bata*. *Bioscience Biotechnology Research Asia*, **9**(1), 437-440.

Hayatbakhsh, M. R., Khara, H., Movahed, R., Sayadborani, M., Rohi, J. D., Ahmadnezhad, M., Rahbar, M., Rad, A. S. 2014. Haematological characteristics associated with parasitism in bream, *Abramis brama orientalis*. *Journal of Parasitic Diseases*, **38**(4), 383–388.

Ighwela, K. A., Ahmad, A. B., Abol-Munafi, A. B. 2012. Haematological changes in Nile tilapia (*Oreochromis niloticus*) fed with varying dietary maltose levels. *World Journal of Fish and Marine Sciences*, **4**(4), 376–381.

Jeamah, A., Senarat, S., Kong-Oh, S., Sudtongkong, C., Wirachwong, P., Charoenphon, N., Kawjaeng, N., Kosiyachinda, P., Kenthao, A., Boonyoung, P. 2023. Hematological evaluation of three common teleosts in relation to the environmental changes from Trang Province, Thailand. *Tropical Life Sciences Research*, **34**(3), 113–127.

Kim, J.-H., Yu, Y.-B., Choi, J.-H. 2021. Toxic effects on bioaccumulation, hematological parameters, oxidative stress, immune responses and neurotoxicity in fish exposed to microplastics: A review. *Journal of Hazardous Materials*, **413**, 125423.

Kori-Siakpere, O., Ake, J. E. G., Idoge, E. 2005. Haematological characteristics of the African snakehead, *Parachanna obscura*. *African Journal of Biotechnology*, **4**, 527–530.

Kumar, A., Ahirwal, S. K., Bhatt, R., Singh, I. J. 2023. Certain hematological and biochemical changes in blood of *Labeo rohita* in relation to sex, reproductive status and environmental factors. *The Pharma Innovation Journal*, **12**(2), 3102–3108.

Leonard, J. B. K., McCormick, S. D. 1999. Changes in haematology during upstream migration in American shad. *Journal of Fish Biology*, **54**(6), 1218–1230.

Lone, G. N., Shammi, Q. J., Mir, S. A., Sheikh, I. A., Chalkoo, S. R. 2012. Rainbow trout hematology coinciding with metabolic requirement. *Walailak Journal of Science and Technology*, **9**(4), 309–316.

Malathi, N., Rino, T., Sooriya, J. S., Shalini, M. 2021. Comparative study of haematological parameters in fishes from the natural habitat, Madurai region. *Journal of Experimental Biology and Agricultural Sciences*, **9**, 176–181.

Missinhoun, D., Ezra, T. M., Jun, Q., Tao, Y., Zhu, H.-J., Ngoepe, T., Xu, P. 2023. Effects of acute heat stress on haemato-biochemical parameters, oxidative resistance ability, and immune responses of hybrid yellow catfish (*Pelteobagrus fulvidraco* × *P. vachelli*) juveniles. *Veterinary Research Communications*, **47**(4), 1–13.

Saenphet, K., Saenphet, S., Tanasrivaroottanun, N., Srisuttha, P., Phinrub, W., Panprommin, D., Panase, P. 2025. Assessing thermal stress in silver barb (*Barbonymus gonionotus*): Oxidative stress and biochemical, hematological, hormonal, and operculum responses within survival temperature range. *Fishes*, **10**, 287.

Satheeshkumar, P., Ananthan, G., Senthil Kumar, D., Jagadeesan, L. 2011. Haematology and biochemical parameters of different feeding behaviour of teleost fishes from Vellar Estuary, India. *Comparative Clinical Pathology*, **21**, 275–281.

Satkar, S. G., Bhusare, S., Sahu, A., Aitwar, V. S., Kunjir, S. N., Girkar, M. M. 2024. Stress-induced hematological and serum alterations as biomarkers in fish health assessment. *International Journal of Advanced Biochemistry Research*, **8**(2), 416–420.

Seibel, H., Baßmann, B., Rebl, A. 2021. Blood will tell: What hematological analyses can reveal about fish welfare. *Frontiers in Veterinary Science*, **8**, 616955.

Siddiqui, U., Shah, R. H., Amrita, R., Tudu, K., Kumar, S., Bisht, H. C. S., Pandey, N. N. 2020. Comparative study of hematological variation in healthy and fungal infected *Bangana dero* (Hamilton, 1822). *Iranian Journal of Fisheries Sciences*, **19**(1), 501–509.

Speckner, W., Schindler, J. F., Albers, C. 1989. Age-dependent changes in volume and haemoglobin content of erythrocytes in the carp (*Cyprinus carpio* L.). *Journal of Experimental Biology*, **141**(1), 133–149.

Svobodova, Z., Pravda, D., Modrá, H. 2012. *Metody hematologického vyšetřování ryb*. Edice Metodik č. 122. Výzkumný ústav rybářský a hydrobiologický ve Vodňanech, Jihočeská univerzita v Českých Budějovicích, Vodňany, ISBN 978-80-87437-62-9, 36 p.

Tavares-Dias, M., Moraes, F. R. 2007. Haematological and biochemical reference intervals for farmed channel catfish. *Journal of Fish Biology*, **71**, 383–388.

Tripathi, N. K., Latimer, K. S., Burnley, V. V. 2004. Hematologic reference intervals for koi (*Cyprinus carpio*), including blood cell morphology, cytochemistry, and ultrastructure. *Veterinary Clinical Pathology*, **33**(2), 74–83.

Witeska, M., Kondera, E., Bojarski, B. 2023. Hematological and hematopoietic analysis in fish toxicology—A review. *Animals*, **13**, 2625.

Witeska, M., Kondera, E., Ługowska, K., Bojarski, B. 2022. Hematological methods in fish—Not only for beginners. *Aquaculture*, **547**, 737498.

Witeska, M., Ługowska, K., Kondera, E. 2016. Reference values of hematological parameters for juvenile *Cyprinus carpio*. *Bulletin of the European Association of Fish Pathologists*, **36**(4), 169–176.