The evolution of coloration in rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792)

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Abstract. The coloration of rainbow trout (*Oncorhynchus mykiss*), a species native to North America and now widely distributed globally, exemplifies an extraordinary case of evolutionary adaptation. This paper explores the genetic, ecological, and selective pressures that have influenced the evolution of coloration in this species. The vibrant hues of rainbow trout, ranging from deep reds and greens to silvery tones, are shaped by an intricate interplay between genetic mechanisms and environmental factors. Key drivers include sexual selection, natural selection for camouflage and predator avoidance, and artificial selection under domestication. Moreover, the effects of environmental changes, such as climate fluctuations, on pigmentation patterns are discussed. This work highlights how understanding the factors behind the coloration of rainbow trout provides broader insights into adaptation and speciation in aquatic organisms.
Key Words: aquaculture, carotenoids, ecological adaptation, genetic adaptation, *Oncorhynchus mykiss*, pigmentation, sexual selection.

Introduction. The coloration of rainbow trout [*Oncorhynchus mykiss* (Walbaum, 1792)], a species native to North America and widely distributed across the globe, represents a remarkable case of evolutionary adaptation (Bud et al 2016). Understanding the origins and the evolutionary dynamics of coloration in this species requires an exploration of its ecological context, genetic mechanisms, and the selective pressures that shaped its physical appearance over time. This short paper examines the factors influencing the evolution of coloration in rainbow trout, including ecological adaptations, sexual selection, and the role of genetic variation.

The Genetic and Ecological Basis of Coloration. The vibrant colors of rainbow trout, which can range from deep reds and greens to silvery hues, are primarily determined by the interactions between genetics and environmental factors. Genetic studies reveal that the pigmentation of rainbow trout is controlled by a complex interplay of multiple genes, including those involved in the production of carotenoids, melanins, and other pigmentary compounds (Liu et al 2024) (Figure 1). These pigments not only determine the coloration of the fish, but also play crucial roles in thermoregulation, protection against UV radiation, and camouflage in natural habitats (Luo et al 2021).

Ecologically, rainbow trout coloration serves several purposes, including camouflage, predator avoidance, and communication among individuals (Price et al 2008; Rodríguez et al 2019). In wild habitats, juvenile trout tend to exhibit a silvery or brownish coloration, allowing them to blend with the riverbed and surrounding environment. However, as they mature, males often develop more intense colors, including iridescent hues and the accentuation of the pink or red lateral stripe. This shift in coloration is linked to changes in their reproductive biology, where males with more vibrant colors tend to attract females during spawning seasons (Newcombe & Hartman 1980).

Figure 1. Rainbow trout from the Fiad trout farm, Romania (photo: Daniel Cocan).

The Role of Sexual Selection in Coloration. As in the case of many other fish species, one of the most significant factors driving the evolution of coloration in rainbow trout is sexual selection (Lindholm & Breden 2002; Petrescu & Mag 2006; Lehnert et al 2016; Auld et al 2019). During the breeding season, male trout display bright, striking colors, including vivid reds, greens, and blues, which are thought to signal health and genetic fitness to females. Females also suffer color changes, but to a lesser extent than males (Figure 2).

Figure 2. Female rainbow trout from Plopiș trout farm, Romania (original photo).

The accentuated pink or red stripe that is characteristic of mature males is a direct result of carotenoid pigments, which are obtained from the trout's diet. Studies conducted on other model organisms, such as the guppy (*Poecilia reticulata* Peters, 1859), suggest that the intensity and brightness of body coloration are often correlated with the quality of the male's diet, particularly its ability to accumulate carotenoids (Jayasooriya et al 2002;

Petrescu-Mag 2009) from food sources like aquatic invertebrates and algae (Nakano & Wiegertjes 2020) (Figure 3). The sexual selection hypothesis posits that females prefer males with the most intense colors, as these are perceived as indicators of superior genetic quality and the ability to acquire high-quality food sources (Lindlom & Breden 2002). This preference for brightly colored males leads to a reinforcement of the traits through successive generations, ultimately resulting in the evolution of more vibrant coloration in the species (Miller et al 2010).

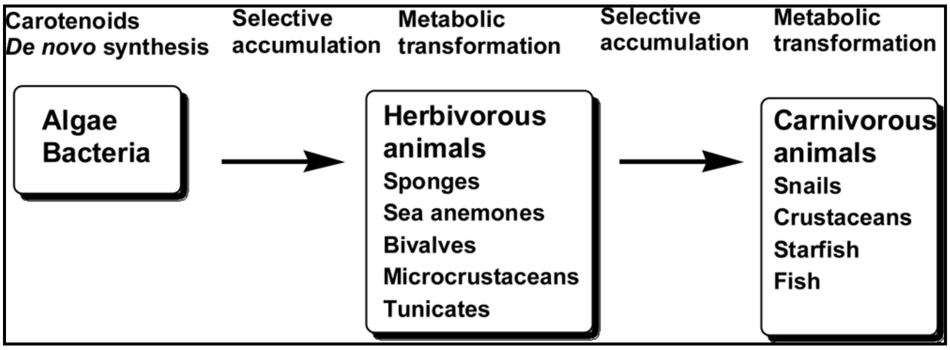

Figure 3. Accumulation and metabolism of carotenoids in marine animals through food chain (Maoka 2011).

Camouflage and Crypsis in the Evolution of Coloration. In addition to sexual selection, natural selection has also influenced the evolution of coloration in rainbow trout, particularly in relation to camouflage and predator avoidance (Price et al 2008). In their early life stages, juvenile trout need to remain hidden from predators, such as larger fish, birds, and mammals. Their muted coloration helps them blend into the stream or riverbed, reducing their visibility to potential threats. As trout mature and become more capable of defending themselves or migrating to different habitats, their coloration may shift toward brighter hues, signaling sexual maturity and readiness for reproduction (Price et al 2008).

However, the evolution of coloration in rainbow trout is not solely driven by predator-prey dynamics. In certain environments, factors like water turbidity, light penetration, and substrate color can influence the way trout express their coloration (Leclercq et al 2010). For example, trout living in clearer, fast-moving rivers may develop brighter, more iridescent hues compared to those residing in murkier waters, where darker and more subdued colors are beneficial for camouflage.

The Influence of Domestication on Coloration. Domestication has had a significant impact on the coloration of rainbow trout, especially in farmed populations. In natural settings, selection pressures related to predation and reproduction have guided the evolution of coloration. However, in aquaculture environments, where predator-prey interactions are absent, the primary selection pressure shifts to factors such as growth rate, disease resistance, and feed efficiency (Bud et al 2009).

Over the past several decades, selective breeding programs in aquaculture have led to the development of rainbow trout strains with specific coloration traits (Kause et al 2003). For instance, some farmed rainbow trout are selectively bred to maintain or enhance specific colors for market preference, as certain hues may appeal to consumers or have culinary significance. This artificial selection has reduced the genetic diversity of coloration traits in certain farmed populations and led to the emergence of new patterns and hues (Kause et al 2003).

Additionally, farmed rainbow trout often exhibit less vibrant coloration than their wild counterparts. This is partly due to differences in diet, as farmed trout may not consume the same carotenoid-rich foods that wild trout eat. Consequently, the red or pink coloration of wild trout is often less pronounced in farmed trout, which may display more muted or silver hues. Thus, more and more farms decide to use carotenoid-enhanced feed, be it natural or synthetic, to obtain a better exterior color of the fish, for customers who buy live fish, but also for the color of the fillet, many times the product being processed before reaching the market (Păpuc et al 2024).

Environmental and Climate Change Effects on Coloration. Recent studies have highlighted the potential impact of climate change on the coloration of rainbow trout. Rising water temperatures and changing food availability may alter the pigment composition in trout. For example, warmer waters may affect the distribution and availability of algae and invertebrates, which provide carotenoids essential for the development of bright colors. Additionally, changes in river flow patterns and water clarity could impact the selection pressures for camouflage, leading to a shift in the pigmentation of trout populations in response to altered environmental conditions (Brander 2007; Luchiari & Pirhonen 2008).

Conclusions. The evolution of coloration in rainbow trout is a multifaceted process driven by genetic, ecological, and selective factors. From the early stages of life, when juvenile trout require camouflage to avoid predators, to the vibrant colors displayed by mature males during the breeding season, coloration plays an essential role in both survival and reproduction. Sexual selection, natural selection, and ecological factors all interact to shape the stunning variety of hues observed in this species. Moreover, human-induced changes such as domestication and climate change may continue to influence the dynamics of color evolution in rainbow trout, making the study of their coloration an ongoing area of scientific interest.

Through a better understanding of the genetic and environmental factors that govern coloration, scientists can gain deeper insights into the processes of adaptation and speciation in fish populations, shedding light on broader ecological and evolutionary principles.

Conflict of Interests. The authors declare that there is no conflict of interest.

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Received: 16 October 2024. Accepted: 03 December 2024. Published online: 30 December 2024.
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How to cite this article:
Păpuc T., Boaru A., 2024 The evolution of coloration in rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792). ABAH Bioflux 16(1):64-68.