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Popular Article

## Unlocking Fish Superpowers: How NGS Reveals Epigenetics' Hidden Code for Smarter Aquaculture

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### *Abstract*

Aquaculture is rapidly expanding, but it must improve sustainability, efficiency, and animal welfare. Beyond traditional genetics, epigenetics involves heritable changes in gene expression without altering DNA, shaping traits like growth, stress tolerance, disease resistance, and sex determination in fish. Mechanisms such as DNA methylation, histone modifications, and regulatory RNAs enable adaptive responses to environmental conditions. Advances in next-generation sequencing (NGS), including RNA-seq and whole-genome methylation profiling, allow detailed analysis of genomes and epigenomes. Identifying epigenetic biomarkers supports precision breeding, optimized nutrition, and better environmental management, driving more resilient and sustainable aquaculture systems.

**Keywords:** Epigenetics, Aquaculture, Genetics, Next Generation Sequencing, DNA

### **Introduction**

The world's oceans and rivers have always seemed like enigmatic realms. Beneath their shimmering surfaces swim creatures whose lives are shaped by invisible rules, not only by their DNA, but by how their cells choose to read that DNA. Today, a powerful blend of cutting-edge technology and biological insight is unravelling these cryptic instructions, ushering in a new era of smarter, sustainable aquaculture. At the heart of this transformation lie two scientific frontiers: epigenetics and next-generation sequencing (NGS).

Aquaculture, the farming of fish, shellfish, and other aquatic organisms, is one of the fastest-growing food sectors worldwide. As demand for seafood surges, producers are pressed to improve growth rates, resilience, and resource efficiency without compromising animal welfare or the environment. Classic genetics has helped breeders select for desirable traits, but



it's only part of the story. Beneath the surface of the genetic code lies epigenetics, the molecular suite of marks and switches that control *when* and *how* genes are expressed, dramatically shaping traits without altering an organism's DNA sequence itself.

### **Epigenetics: Beyond the Genetic Blueprint**

Imagine two genetically identical fish, same DNA, same ancestry. Yet one grows faster, resists disease better, or thrives under environmental stress. What's going on? Epigenetics holds the answer. This field explores heritable changes in gene expression triggered not by mutations in DNA base pairs but by chemical modifications of DNA and histones, and by interactions with non-coding RNAs. These changes effectively act as switches that can turn genes on or off, depending on the environment and life history.

In fish, epigenetic processes influence growth, metabolism, stress response, and even sex determination, crucial traits for aquaculture success (Liu *et al.*, 2022). In some species, early rearing temperature influences DNA methylation patterns and skewed male–female ratios, highlighting how environmental conditions leave lasting molecular imprints on farmed fish (Aharon and Marlow 2021).

Such insights don't just expand basic biological knowledge, they deliver real benefits to producers. Understanding these hidden layers helps farms manage feeding, breeding, and rearing practices that optimize fish health and productivity.

### **Next-Generation Sequencing: The Molecular Microscope**

To chart this hidden regulatory world, scientists rely on next-generation sequencing (NGS), a suite of technologies that can read millions of DNA and RNA fragments quickly and cheaply. Unlike traditional sequencing, which deciphered one DNA strand at a time, NGS can decode whole genomes and epigenomes in a single experiment. It reveals not just the genetic letters but the dynamic patterns of gene expression and epigenetic marks across the entire genome.

With NGS, researchers can: map DNA methylation across all genes; profile histone modifications that open or close chromatin; identify small regulatory RNAs that fine-tune gene activity. These datasets provide actionable insights into how fish respond to diet, stress, disease challenges, and rearing environments.

For example, NGS-based transcriptome analyses (RNA-seq) uncover genes with sex-specific expression patterns in species like the giant tropical fish *Arapaima gigas*, informing strategies for sex-controlled breeding (Watanabe *et al.*, 2018). Additionally, large NGS-supported databases, such as iFish, aggregate omic data across dozens of economically

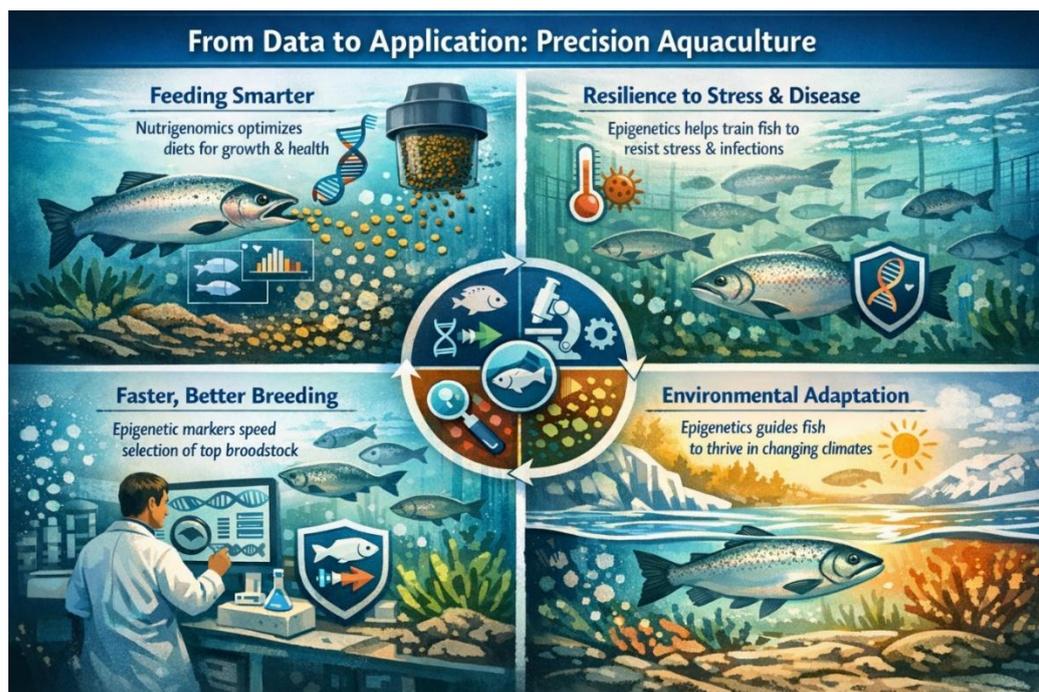


important fish species, providing a treasure trove for researchers and breeders alike (Liu *et al.*, 2025).

### From Data to Application: Precision Aquaculture

So how does this molecular knowledge translate into “superpowered” aquaculture?

1. **Feeding Smarter:** NGS coupled with epigenetic profiling helps reveal how diet influences gene expression and metabolism. Nutrigenomics, where nutrition and genomics intersect, uses RNA-seq data to tailor feeds that boost growth and immunity while reducing waste and environmental impact (Iqbal *et al.*, 2025).
2. **Resilience to Stress and Disease:** Farmed fish often face fluctuating temperatures, crowded conditions, and pathogens. Epigenetic marks arising from early life stress can influence how fish cope with future stressors. By recognizing these signatures, farms can adjust conditions to “train” fish for better resilience, reducing the need for antibiotics or chemicals.
3. **Faster, Better Breeding:** Traditional breeding takes generations. With epigenetic biomarkers discovered via NGS, breeders can more rapidly identify broodstock that carry desirable traits, not just in their genes but in how those genes are expressed. This speeds genetic gain without genetic modification, which can reduce regulatory hurdles and public concerns.
4. **Environmental Adaptation:** As climate change alters water temperature and chemistry, understanding how environmental signals affect epigenetic states equips producers to select or manage fish lines better suited to future conditions.



## Looking Forward: Challenges and Promise

While the prospects are thrilling, obstacles remain. NGS generates colossal volumes of data. Analysing and interpreting these complex datasets requires robust bioinformatics and cross-disciplinary expertise. Many commercially important species still lack fully annotated genomes, making it harder. Moreover, translating molecular insights to daily farm practice requires collaboration between scientists, hatchery managers, nutritionists, and regulators. Yet the trajectory is clear: the convergence of epigenetics and NGS is not a distant dream but a rapidly evolving reality in aquaculture.

## Conclusion

Aquaculture stands at a scientific inflection point. No longer confined to traditional breeding practices, producers are tapping into the language of molecular regulation, reading the epigenetic “notes” that modulate fish biology. With next-generation sequencing as both compass and microscope, this hidden code is being transformed into practical strategies that enhance sustainability, productivity, and animal welfare. Through this synergy, farmed fish are becoming smarter, hardier, and better suited to meet the nutritional needs of a rapidly growing global population.

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