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GENETIC IMPROVEMENT OF NIGERIAN FISH SPECIES IN THE DOWNSTREAM RIVER BENUE, TARABA STATE: REVIEW

By

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Abstract

The genetic improvement of indigenous fish species holds significant potential for enhancing aquaculture productivity and sustainability in Nigeria. This review focuses on the genetic improvement efforts of fish species found in the downstream of River Benue, it is a major water body in Taraba State known for its rich biodiversity and fisheries potential. Some key species such as Clarias gariepinus (African Catfish), Heterobranchus spp.; Tilapia spp. have been the subject of various genetic enhancement Programmes aimed at improving traits such as growth rate, disease resistance, environmental tolerance, and reproductive performance. The review highlights methods employed in these programmes, including selective breeding, hybridization, and molecular genetic techniques. It also explores the role of research institutions, government initiatives, and local fish farmers in promoting genetic improvement strategies. Despite notable progress, challenges such as limited technical expertise, inadequate funding, and poor dissemination of improved stock to rural farmers persist. The review recommends stronger policy support, capacity building, and community participation to fully realize the benefits of genetic improvement in Nigerian fisheries, particularly in the downstream River Benue region. It underscores the importance of integrating scientific innovation with traditional knowledge to ensure the long-term sustainability and productivity of Nigeria's aquaculture sector to secure food security and sovereignty.

KEYWORDS: *Food Security, Biodiversity, River Benue, Fish Genetics, Fish Species*

INTRODUCTION

The fisheries sector plays a critical role in the socio-economic development of Nigeria, contributing significantly to food security, employment, and income generation. Among the various inland water bodies in Nigeria, River Ibi, located in Taraba State, is an important aquatic ecosystem supporting diverse fish species and serving as a major source of livelihood for local fishing communities (Wuyep & Rampedi, 2018). However, like many freshwater systems in the country, the fish resources in River Ibi face growing threats from overfishing, habitat degradation, pollution, and climate variability. These challenges have contributed to declining fish stocks and reduced productivity, highlighting the urgent need for sustainable management strategies, including genetic improvement of native fish species (Wuyep & Rampedi, 2018).

Genetic improvement

This involves the application of selective breeding, hybridization, and biotechnological tools to enhance desirable traits in fish, such as growth rate, disease resistance, and environmental tolerance (Rotowa *et al.*, 2019). In Nigeria, efforts to improve the genetic quality of cultured and wild fish species have gained attention in recent decades, particularly with the growing demand for aquaculture development. Indigenous species such as *Clarias gariepinus* (African catfish), *Heterobranchus* spp., and *Tilapia* spp. are of particular interest due to their economic importance and adaptability to local conditions (Rotowa *et al,* 2019).

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This review aims to assess the progress, challenges, and prospects of genetic improvement initiatives targeting fish species in River Ibi and their implications for fisheries sustainability in the region. By examining available literature and ongoing research, the study seeks to provide insights into the potential of genetic enhancement as a tool for boosting fish productivity and conserving aquatic biodiversity in Nigeria's inland waters (Rotowa *et al*., 2019).

Aim and Objectives

Aim of the Review

The aim of this review is on the genetic improvement of Nigerian fish species in the downstream River Benue in Taraba State.

Objectives of the Review

The specific objectives of the this review are to:

- Identify key fish species in the lower River Benue,
- Review the current genetic diversity of these fish species,
- Review challenges limiting the success of genetic improvement programmes in the lower River Benue.

Key Fish Species in the Lower River Benue, Ibi axis

Some dominant and economically important species include:

- *C. gariepinus* (African catfish)
- *Heterobranchus* spp.
- *Tilapia* spp.
- *Synodontis* spp.
- *Labeo* spp.

These species are vital for local consumption and aquaculture.

Status of Genetic Diversity

Studies show that many native species in River Ibi have suffered from:

i. **Inbreeding due to Small, Isolated Populations**

This means that fish species in the Lower River Benue, Ibi axis are mating within a limited group of closely related individuals. This situation often arises when a population becomes small and geographically or ecologically isolated from others of its kind, reducing the chances of new genetic material entering the gene pool (Waples & Gaggiotti, 2006).
Factors affecting inbreeding maybe caused due to:

a. **Reduced Genetic Variation:** In small populations, there is less genetic diversity. When fish breed with close relatives, the offspring inherit many of the same genes from both parents. This reduces the overall variation in the population's gene pool (Neff *et al*., 2011).

b. **Inbreeding Depression**: Continuous inbreeding can lead to a phenomenon known as "inbreeding depression." This is when harmful genetic traits are more likely to appear, causing reduced fitness, slower growth, lower survival rates, poor reproductive success, and increased susceptibility to diseases (Hedrick & Kalinowski, 2000).

c. **Higher Risk of Extinction:** Small, inbred populations are less able to adapt to environmental changes or disease outbreaks. This puts them at greater risk of local extinction (Hedrick & Kalinowski, 2000).

d. **Isolation Worsens the Problem**: If fish populations are isolated due to natural barriers (e.g., waterfalls, drying streams) or human activities (e.g., dam construction, pollution), they can't mix with other populations. This prevents the flow of new genetic material (gene flow) that could help maintain or restore genetic diversity (Strayer, 2024).

ii. **Genetic Erosion from Habitat Disruption**

Genetic erosion refers to the loss of genetic diversity within a species over time. This process can be triggered or accelerated by habitat disruption, which occurs when natural environments are altered, degraded, or destroyed by human or natural activities (Thormann & Engels, 2015).

How Habitat Disruption Causes Genetic Erosion:

a. **Loss of Habitat, is equal to Loss of Populations**

When habitats like rivers, wetlands, and floodplains are destroyed or degraded (due to pollution, damming, deforestation, farming, sand mining, etc.), fish populations lose their breeding and feeding grounds. This leads to the decline or local extinction of certain populations — along with the unique genetic traits they carry (Thormann & Engels, 2015).

b. **Fragmentation of Habitats**

Disrupted habitats often become fragmented, meaning the river or water system is split into disconnected parts. Fish in one part may no longer be able to migrate or mix with those in other parts. This isolation reduces gene flow and increases inbreeding, leading to a loss of genetic variation (Strayer, 2024).

c. **Selective Pressure**

Habitat changes can act as a form of unnatural selection. For example, if only certain species or individuals (e.g., those tolerant to pollution) can survive in a degraded habitat, others are wiped out. Over time, this reduces the genetic pool, as only a few genetic traits are passed on to future generations (Walker, 2012).

d. **Population Bottlenecks**

Sudden environmental disturbances (e.g., flooding, contamination, or overfishing) can sharply reduce the number of individuals in a population. This "bottleneck" effect results in the loss of rare alleles (forms of genes), which may never return, thereby eroding the species' genetic foundation (Walker, 2012).

iii. **Weak Adaptation to Environmental Stress**

Weak adaptation to environmental stress refers to a reduced ability of fish or other organisms to cope with changes or challenges in their environment. This can be a result of low genetic diversity, previous inbreeding, or long-term habitat degradation (Schulte, 2014).

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a. What is Environmental Stress

Environmental stress includes any external factor that challenges the normal functioning or survival of a species (Wingfield, 2013). In aquatic ecosystems, these stresses may include:

i. Sudden changes in water temperature or pH
ii. Pollution from agricultural runoff, sewage, or mining
iii. Low oxygen levels (hypoxia)
iv. Seasonal drying of river channels
v. Habitat destruction or fragmentation
vi. Invasive species or increased predation
vii. Climate change impacts (e.g., flooding, droughts)

b. How Weak Adaptation Happens

a. Low Genetic Diversity = Limited Response: When a fish population has reduced genetic variation (due to inbreeding, isolation, or genetic erosion), it lacks the range of traits needed to adapt to new challenges. For example, if water becomes warmer and the population lacks individuals with heat tolerance genes, survival rates drop (Bernatchez, 2016).

b. Loss of Adaptive Traits: Habitat disruption or selective pressures may eliminate certain traits that once helped the population survive (e.g., disease resistance, salt tolerance). Without these traits, the population becomes more vulnerable (Bernatchez, 2016).

c. Slow Evolutionary Response: In a healthy, diverse population, some individuals can naturally survive stress and pass on their genes. But when the population is small and genetically weak, there may be too few individuals with the right traits to start this recovery process. This leads to slow or no adaptation (Dato *et al*., 2013).

d. Physiological Weakness: Inbred or genetically poor populations may also have weaker immune systems, slower growth, lower fertility, and reduced stress tolerance, making it harder to cope with environmental changes (Naskar *et al*., 2012).

Preserving and improving the genetic diversity is crucial for long-term sustainability.

Genetic Improvement Methods Reviewed

Selective Breeding

Selective breeding is the process of choosing specific broodstock (parent fish) with desirable traits to produce offspring that are likely to inherit those traits. This technique has been widely used in agriculture and is now increasingly applied in aquaculture to improve productivity and sustainability (Naskar *et al*., 2012).

Goals of Selective Breeding

In catfish farming, the main traits targeted for improvement include:

i. **Faster growth rate**: to reduce the time to market size.
ii. **Better Feed Conversion Ratio (FCR):** so fish grow efficiently with less feed, lowering production costs.
iii. **Disease resistance**: reducing mortality and minimizing the need for antibiotics or treatments.
iv. **Body conformation**: such as uniform size and shape, which improves marketability.
v. **Survival rate**: ensuring higher survival from fry to harvest stage.

Hybridization

Hybridization is the process of crossing two different species or strains to combine desirable traits from both parent lines. In catfish aquaculture, hybridization has become an increasingly popular technique for improving performance, especially where selective breeding programs are limited (Barton, 2001).

Clarias × Heterobranchus Hybridization

In Nigeria and other parts of West Africa, the most common hybrid in aquaculture is produced by crossing:

- *C. gariepinus* (African sharp tooth catfish): known for fast growth and widespread acceptance in markets.
- *Heterobranchus bidorsalis* or *H. longifilis* (*Heterobranchus* species): valued for their hardiness, resistance to harsh environmental conditions, and larger adult size.

Marker-Assisted Selection (MAS)

Marker-Assisted Selection (MAS) is a modern breeding technique that uses molecular (DNA) markers to identify and select individuals with desirable genetic traits. Instead of relying solely on physical appearance (phenotype), MAS allows breeders to look directly into the genetic makeup (genotype) of fish to make more informed and accurate breeding decisions (Jiang, 2013).

How It Works

i. Specific DNA markers are linked to traits of interest (e.g., growth rate, disease resistance, feed efficiency).
ii. These markers are detected through genetic testing.
iii. Fish carrying the desired genes are selected as brood stock, even before the traits become visible.

Still limited in Nigeria, but offers precise control over inherited traits using DNA markers.

Cryopreservation and Germplasm Banking

Cryopreservation: This is the process of preserving biological material—such as sperm, eggs, embryos or tissue, at ultra-low temperatures, typically in liquid nitrogen at -196°C (Martínez & Adams, 2008). At this temperature, all biological activity, including cell metabolism and genetic degradation, is halted. The preserved material can later be

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thawed and used for breeding or genetic restoration (Martínez & Adams, 2008).

Germplasm banking: This refers to the systematic collection, storage, and management of these preserved genetic materials (collectively called "germplasm"). It serves as a genetic reservoir that can be used to maintain or reintroduce lost or threatened genetic diversity in the future (Engelmann, 2012).

Current Situation in the Lower River Benue, Ibi axis

At present, cryopreservation and germplasm banking are almost non-existent at the River Ibi level. There are no established facilities, programs, or institutional frameworks dedicated to collecting and preserving the genetic material of native fish species in this region (Kumawat & Tyagi, 2024). This means that if fish populations decline, suffer inbreeding, or become locally extinct, there are currently no genetic backups to support recovery efforts. This represents a major gap in conservation strategy (Kumawat & Tyagi, 2024).

Why It is Important?

i. Safeguarding Genetic Diversity

Cryopreservation allows the storage of diverse genetic material from multiple species and populations, which is essential for long-term conservation and selective breeding (Engdawork *et al*., 2024).

ii. Restocking and Restoration

If wild populations collapse or lose certain traits (e.g., disease resistance, temperature tolerance), preserved germplasm can be used to reintroduce or strengthen those traits in future generations (Engdawork *et al*., 2024).

iii. Support for Aquaculture

Stored germplasm can enhance breeding programs, improve productivity, and help reduce reliance on wild stocks (Smith *et al*., 2021).

iv. Insurance Against Climate and Environmental Change

With the increasing risks of pollution, habitat loss, and climate change, having a frozen genetic library provides a powerful tool for future adaptation and resilience (Smith *et al*., 2021).

Future Potential for Lower River Benue, Ibi axis

Despite its current absence, cryopreservation and germplasm banking offer great potential for sustainable fisheries management and conservation in the lower River Benue, Ibi axis (Antenucci, 2024), with support from government, universities, and research institutions, these technologies could be introduced through:

a. Pilot Projects and Training Programmes:

- Partnerships with aquaculture or conservation centers.
- Integration into national biodiversity strategies.

Community-Based Broodstock Management

Community-Based Broodstock Management (CBM) is a participatory approach where local fishers and farmers are directly involved in the management, improvement, and conservation of brood stock, the mature, genetically healthy fish used for breeding (Mustefa, 2023). Instead of relying solely on government or research institutions, CBM empowers communities to take active roles in protecting and sustaining the genetic resources of native fish species (Mustefa, 2023).

How CBM Works

1. Collective Ownership and Responsibility

Local stakeholders such as fish farmers, artisanal fishers, and community leaders, work together to maintain selected brood stock populations. This includes ensuring good water quality, proper feeding, preventing inbreeding, and protecting brood fish from overfishing or poaching (Hasan *et al.*, 2020).

2. Use of Native Species

CBM often focuses on native or indigenous fish species that are well-adapted to the local environment but may be declining due to habitat loss, overfishing, or poor management (Brechin *et al.*, 2007). The use of native species in aquaculture and fisheries management refers to the deliberate selection and cultivation of indigenous fish species—those that are naturally found in a particular river, lake, or region—for breeding, farming, restocking, and conservation activities (Brechin *et al*., 2007).

Why Use Native Species?

i. Environmental Compatibility: Native species are naturally adapted to the local environmental conditions such as water temperature, flow, pH, and available food sources. This makes them more resilient and less dependent on artificial inputs like medications, special feeds, or climate control (Wilby *et al*., 2010).

ii. Genetic Conservation: Utilizing native species helps conserve the genetic resources of local ecosystems. It maintains biodiversity and reduces the risk of genetic pollution that can occur when exotic or non-native species are introduced (Schlaepfer *et al*., 2011).

iii. Reduced Ecological Risk: Unlike introduced or exotic species, native species are less likely to become invasive or disrupt the ecological balance of local habitats (Jhariya *et al*., 2022).

iv. Cultural and Economic Value: Many native species hold traditional, cultural, or economic importance for local communities. They are often preferred in local markets and diets, making them more economically viable for small-scale farmers and fishers (Jhariya *et al*., 2022).

v. Improved Survival and Reproduction: Native species usually perform better in the wild and in low-input aquaculture systems because they are better adapted to natural stressor and have established breeding behaviors in their native habitat (Hossain *et al*., 2022).

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Examples of Native Species Use in the Lower River Benue, Ibi axis:

In the Lower River Benue, Ibi axis and surrounding regions of Benue State, examples of native fish species include:

- *C. gariepinus* (West African catfish)
- *Heterobranchus* spp.
- *Tilapia zillii*
- *Labeo* spp.
- *Chrysichthys nigrodigitatus*

3. **Breeding and Seed Distribution:** Breeding and seed distribution refer to the process of producing quality fish seed (fertilized eggs, fry, fingerling or juveniles) through controlled reproduction of brood stock, and then distributing them to fish farmers or for restocking natural water bodies (Nima *et al*., 2024). This process is critical for maintaining a steady supply of fish for aquaculture and for conserving native fish species.

i. **Breeding:** Breeding involves the selection, mating, and management of brood stock (sexually mature fish used for reproduction) to produce healthy and genetically diverse offspring (Sharma & Khati, 2023).

Key Aspects of Breeding:

- Broodstock Selection: Choosing healthy, mature fish with desirable traits (e.g., fast growth, disease resistance, environmental tolerance).
- Spawning Techniques: Using natural or induced breeding methods (e.g., hormonal induction) to stimulate egg laying and fertilization.
- Hatchery Management: Providing proper care during incubation, hatching, and early development stages to ensure high survival rates.
- Genetic Management: Avoiding inbreeding by rotating brood stock and keeping records of genetic lineages to maintain diversity and long-term viability.

ii. **Seed Distribution**: Once fry or fingerling are produced, they are distributed to:

- Small-scale fish farmers for grow-out in ponds, tanks, or cages.
- Community fish farms for income generation and food security.
- Natural water bodies (restocking) to replenish depleted native populations and support biodiversity conservation.

Distribution Strategies:

- Equitable Access: Ensuring fair and affordable access to fish seed for local farmers, especially in rural or underserved areas, Quality Control: Delivering healthy, disease-free, and genetically strong fingerling to prevent production losses, Capacity Building: Training local farmers on fingerling care, transportation, and acclimatization (Echessa, 2024).

Benefits of Effective Breeding and Seed Distribution

A reliable supply of quality fingerling boosts fish farm success and income generation, Breeding native fish species helps reduce pressure on wild stocks and supports environmental sustainability, Proper broodstock management ensures long-term genetic diversity and prevents inbreeding, in community-based systems, local ownership of breeding and seed distribution fosters participation, accountability, and knowledge transfer (Ochieng, 2023).

Relevance to Lower River Benue, Ibi axis

In the lower River Benue, Ibi axis, where native fish species are under threat from habitat disruption and inbreeding, a well-organized breeding and seed distribution programme, especially one led by local communities, can play a crucial role in:

i. Rebuilding fish populations
ii. Supporting aquaculture-based livelihoods
iii. Conserving genetic resources
iv. Enhancing food security in surrounding communities

Benefits of CBM

i. **Preserves Local Genetic Resources:** By using and improving native brood stock,CBM helps conserve genetic diversity and prevents the loss of locally adapted traits.

ii. **Empowers Communities:** Local participation builds a sense of ownership, responsibility, and pride in conservation and aquaculture.

iii. **Sustainable Livelihoods:** Access to quality fingerling improves farm productivity, income, and food security.

iv. **Reduces Inbreeding and Genetic Erosion:** Through proper record-keeping and rotation of broodfish, communities can maintain genetically diverse and healthy stocks.

v. **Cost-effective and Scalable:** CBM is often more sustainable and affordable in the long run compared to centralized hatchery systems, especially in rural or remote areas.

Challenges in Implementing Genetic Improvement

i. Lack of technical expertise and funding
ii. Poor access to quality brood stockiii.
iii. Limited awareness among local fishers
iv. Weak policy and regulatory support
V. Environmental instability (e.g., seasonal flooding, pollution).

Conclusion

The fisheries resources of River Ibi represent a vital component of the local economy and food system in Taraba State, Nigeria. However, increasing pressures from overexploitation, habitat degradation, pollution, and climate-related stressors have significantly undermined the sustainability of fish stocks in the region. In response to these challenges, genetic improvement of native fish species emerges as a promising strategy for enhancing productivity, resilience, and biodiversity conservation. This review has

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highlighted the importance of employing selective breeding, hybridization, and modern biotechnological tools to improve economically valuable species such as *Clarias gariepinus*, *Heterobranchus* spp., and *Tilapia* spp. These species not only hold considerable commercial potential but are also well adapted to local environmental conditions, making them suitable candidates for sustainable aquaculture and stock enhancement programs. Despite growing national interest and isolated research efforts in genetic improvement, progress remains limited at the River Ibi level due to inadequate infrastructure, weak extension services, limited capacity, and the absence of structured breeding programs. Additionally, practices such as cryopreservation, germplasm banking, and community-based brood stock management are underdeveloped but offer significant future potential for preserving genetic diversity and supporting long-term fisheries development. To fully realize the benefits of genetic enhancement in River Ibi, a more integrated approach is needed—one that combines scientific innovation with strong community participation, institutional support, and environmental stewardship. Investing in training, hatchery development, genetic monitoring, and sustainable seed distribution systems will be key to scaling up these efforts. Ultimately, genetic improvement, when implemented thoughtfully and inclusively, can serve as a powerful tool for reversing fish stock declines, supporting livelihoods, and promoting the sustainable development of Nigeria's inland fisheries.

While the Federal University of Wukari hosts active research in aquaculture and biotechnology through its Centre for Biotechnology and Centre for Sustainable Agriculture and Food Security, there is currently no publicly established dedicated genome bank for fish species at the institution. Across Nigeria, fish genomic research is ongoing, with DNA barcoding libraries and genetic diversity studies for various fish species being deposited in international databases such as GenBank. However, Nigeria does not yet have a stand-alone national genome bank specifically for fish species, although broader genetic resource conservation efforts are being advanced through institutions like the IITA Genetic Resources Center and proposed national sequencing initiatives.

Recommendations

i. Capacity building: Train local stakeholders in genetics and brood stock management
ii. Partnerships: Collaborate with research institutions like NIFFR and universities
iii. Policy support: Enforce standards for fish seed production and distribution
iv. Funding: Government and NGOs should support sustainable aquaculture programs
v. Research: Conduct genetic mapping of native species to guide improvement strategies.
vi. Genome bank for fish species: the government should ensure genetic information [NDA] for fish species, to study, protect and breed fish species better.

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