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Evaluation of Hybridization Practices and Their Implications for Genetic Conservation in Catfish Farming in Rivers State, Nigeria

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ABSTRACT
Hybridization between *Clarias gariepinus* and *Heterobranchus sp*ecies (*heteroclarias*) is deeply embedded in Nigerian catfish aquaculture for the faster growth, and higher survival farmer's associate with hybrids, but its widespread, often uncontrolled use raises concerns for the genetic integrity of pure strains and wild populations. This study surveyed 375 catfish farmers and hatchery operators across Rivers State, Nigeria, analyzing data with descriptive statistics, chi-square tests, ANOVA with Tukey post-hoc comparisons, paired and independent t-tests, correlation, multiple linear regression, and binary logistic regression. Hybridization was practiced by 71.5% of farmers, most commonly *C. gariepinus* female × *H. longifilis* male (39.5%), and was significantly more frequent among larger-scale and experienced operators ($p < 0.001$). Only 22.9% of farmers scored "high" on genetic knowledge. Farmers rated hybrids as significantly outperforming pure strains in growth (4.21 vs. 2.87), survival (3.68 vs. 3.12), feed conversion (3.52 vs. 3.18), and market preference (3.89 vs. 3.05; all $p < 0.001$, $d = 0.31–1.42$), with no significant difference in disease resistance though these are self-reported ratings, not measured production data. Genetic risk perception correlated positively with years of hybridizing ($r = 0.312$) and negatively with knowledge ($r = –0.287$, both $p < 0.001$). Unavailability of certified pure broodstock (76.5%) and high broodstock cost (64.3%) were the leading constraints; small-scale farms, low knowledge, and no extension contact significantly predicted severe broodstock constraints (Nagelkerke $R^2 = 0.28$). The findings support structured broodstock certification, genetic monitoring, and farmer training to reconcile perceived productivity benefits with conservation of Nigeria's catfish genetic resources.

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INTRODUCTION

Nigeria is the largest producer of African catfish in the world, contributing over half of the global production with about 285,000 producers, most of whom are small-scale producers (FAO, 2023). Clarias *gariepinus* is the dominant aquaculture species in Nigeria, largely due to its high feed conversion efficiency, tolerance to poor water quality, and ability to produce two crops per year. In addition to producing pure strains of C. *gariepinus* and *Heterobranchus bidorsalis*, Nigerian hatcheries have been producing interspecific hybrids of Clarias *gariepinus* and *Heterobranchus longifilis* or H. *bidorsalis* referred to as "*heteroclarias*" for decades. Hybrids are highly desirable for their ability to combine the faster growth rate of *Heterobranchus* with the hardiness of Clarias (Ayoade et al., 2026; Ndimele & Owodeinde, 2012).

The main limitation of this study is that the superiority of hybrids in terms of growth, survival, feed conversion, and market demand is based on farmers' perceptions rather than actual measured performance. Although farmers' perceptions align with previous experimental results (Dogah, 2020; Legendre et al., 1992; Madu & Aluko, 1999), the magnitude of superiority reported by farmers was higher than expected, possibly due to confirmation bias (Nawang et al 2026). Future studies should therefore establish farmers' actual production performance data and relate it to their perceptions.

While hybridization presents several advantages, it is important to note that the practice can cause several genetic problems, especially if it is not properly documented or regulated. For instance, hybridization, if not properly documented, can lead to the dilution of valuable genetic stocks, especially if crosses are made between hybrids and one of the parent species. In addition, if hybrid or exotic strains escape into the local water bodies, they can introduce foreign genes into the indigenous catfish populations, potentially undermining their genetic integrity and adaptive capacity (Sanda et al., 2026). Since most hatcheries in Nigeria use informal broodstocks with limited genetic information, there is a great potential for hybridization to lead to loss of genetic diversity throughout crossing and introgression of undesirable genes.

Despite the potential benefits and risks, there is currently limited information on the status of hybridization in Nigeria, including the extent to which it is practiced, farmers' perceptions of its implications, and the associated constraints. This study focuses on farmers' perceptions and actual practices of hybridization in catfish production in Rivers State, Nigeria

MATERIALS AND METHODS

The study was conducted in Rivers East, Rivers South-East, and Rivers West senatorial districts of Rivers State, Nigeria. A cross-sectional survey design was used for the study. A total of 375 catfish farmers and hatchery operators were selected from the study area using a stratified random sampling procedure. Respondents were categorized into small-scale (n = 200), medium-scale (n = 110), and large-scale (n = 65) based on their level of production. A semi-structured questionnaire was used to collect data from the respondents. The questionnaire was developed to capture the following information: hybridization techniques and species combinations used; sources of hybridization stock; extent and frequency of hybridization; knowledge and attitude toward hybridization; perceived genetic implications of hybridization; production performance of hybrid and pure-bred catfish; and constraints to broodstock and genetic management of hybrid catfish.

Data analysis was done using descriptive statistics, including frequencies, percentages, means, and standard deviations. In addition, statistical tests, including chi-square tests with Cramer's V, one-way analysis of variance (ANOVA) with Tukey post-hoc comparison tests, independent and paired sample t-tests, Pearson correlation, multiple linear regression, and binary logistic regression, were performed to establish relationships between variables. All statistical tests were performed at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Predominant Hybridization Practices Species Combinations, Breeding Methods, Hatchery Techniques, and Broodstock Sources

Table 1, shows the dominant hybrid combination was C. *gariepinus* female × H. *longifilis* male (39.5% overall), rising to 49.2% among large-scale farmers, followed by C. *gariepinus* × H. *bidorsalis* crosses (23.2%). Pure C. *gariepinus* breeding alone was more common among small-scale farmers (28.0%) than large-scale operations (7.7%), reflecting the tendency of bigger, more capitalized farms to invest more heavily in hybrid production. Induced breeding using synthetic hormones was the most widely used technique overall (83.2%), and larger farms were significantly more likely to use indoor flow-through hatcheries and RAS, while small-scale farmers relied more heavily on outdoor earthen-pond hatching. Broodstock sourcing followed a similar scale-related pattern, with small-scale farmers relying most on their own farm stock and large-scale farmers drawing more heavily on out-of-state hatcheries and research institutes.

Table 1: Profile of Hybridization Practices, Techniques, Broodstock Sources and Associated Factors (N = 375)

Variable / Category	Overall n (%)	Small-scale (n=200) n (%)	Medium-scale (n=110) n (%)	Large-scale (n=65) n (%)	χ^2 / F	df	p-value	Effect Size
Primary Species Combination					28.64	8	0.000**	Cramer's V = 0.196
C. gariepinus ♀ × *H. longifilis* ♂	148 (39.5)	68 (34.0)	48 (43.6)	32 (49.2)				
C. gariepinus × *H. bidorsalis*	87 (23.2)	41 (20.5)	29 (26.4)	17 (26.2)				
Pure *C. gariepinus* only	76 (20.3)	56 (28.0)	15 (13.6)	5 (7.7)				
Reciprocal hybrid (*H. longifilis* ♀ × *C. gariepinus* ♂)	41 (10.9)	22 (11.0)	12 (10.9)	7 (10.8)				
Other / multiple hybrids	23 (6.1)	13 (6.5)	6 (5.5)	4 (6.2)				
Breeding & Hatchery Techniques (Multiple response)								
Induced breeding (Ovaprim/pituitary)	312 (83.2)	152 (76.0)	98 (89.1)	62 (95.4)	19.87	2	0.000**	V = 0.230
Artificial fertilization	289 (77.1)	138 (69.0)	92 (83.6)	59 (90.8)	18.42	2	0.000**	V = 0.222
Hormone stripping	267 (71.2)	126 (63.0)	86 (78.2)	55 (84.6)	16.91	2	0.000**	V = 0.212
Outdoor earthen pond hatching	221 (58.9)	142 (71.0)	56 (50.9)	23 (35.4)	28.15	2	0.000**	V = 0.274
Indoor flow-through hatchery	154 (41.1)	58 (29.0)	54 (49.1)	42 (64.6)	31.08	2	0.000**	V = 0.288
Kakaban / mosquito net incubation	198 (52.8)	118 (59.0)	54 (49.1)	26 (40.0)	8.74	2	0.013*	V = 0.153
RAS / advanced systems	47 (12.5)	9 (4.5)	18 (16.4)	20 (30.8)	35.62	2	0.000**	V = 0.308
Primary Broodstock Source					41.27	8	0.000**	V = 0.235
Own farm (on-farm selection)	132 (35.2)	86 (43.0)	32 (29.1)	14 (21.5)				
Local hatcheries (Rivers State)	118 (31.5)	62 (31.0)	38 (34.5)	18 (27.7)				
Hatcheries from other states	67 (17.9)	24 (12.0)	24 (21.8)	19 (29.2)				
Wild collection	41 (10.9)	23 (11.5)	12 (10.9)	6 (9.2)				
Research institutes / universities	17 (4.5)	5 (2.5)	4 (3.6)	8 (12.3)				
Mean number of techniques used	3.96 ± 1.42	3.51 ± 1.38	4.27 ± 1.29	4.72 ± 1.18	F = 24.18	2,372	0.000**	$\eta^2 = 0.115$

Notes: Percentages within farm-scale columns. Larger farms significantly prefer advanced techniques and external/research broodstock. Post-hoc Tukey: Large > Medium > Small for number of techniques (all p < 0.01).

Extent, Frequency, and Geographic Distribution of Intentional and Unintentional Hybridization

In Table 2, hybridization was intentional for 71.5% of farmers overall and unintentional for the remainder, with modest but statistically significant geographic variation across zones. Just over half of farmers (51.7%) hybridized every production cycle. Frequency of hybridization increased significantly with both farming experience and farm scale.

Table 2: Extent, Frequency, Geographic Distribution and Correlates of Hybridization Practices (N = 375)

Variable	Overall	Rivers East (n=130)	Rivers South-East (n=128)	Rivers West (n=117)	χ^2 / F	p-value	Effect Size
Type of Hybridization					6.89	0.032*	V = 0.136
Intentional	268 (71.5%)	98 (75.4%)	87 (68.0%)	83 (70.9%)			
Unintentional	107 (28.5%)	32 (24.6%)	41 (32.0%)	34 (29.1%)			
Frequency of Hybridization					14.27	0.006**	V = 0.138

Variable	Overall	Rivers East (n=130)	Rivers South-East (n=128)	Rivers West (n=117)	χ^2 / F	p-value	Effect Size
Every production cycle	194 (51.7%)	78 (60.0%)	61 (47.7%)	55 (47.0%)			
Occasionally (1–2×/year)	95 (25.3%)	28 (21.5%)	35 (27.3%)	32 (27.4%)			
Rarely / stopped	86 (22.9%)	24 (18.5%)	32 (25.0%)	30 (25.6%)			
Mean frequency score (1–5 scale)	3.42 ± 1.08	3.61 ± 1.02	3.31 ± 1.11	3.33 ± 1.09	F = 3.41	0.034*	η^2 = 0.018
By Farming Experience (<5 / 5–10 / >10 yrs)	n=98	n=142	n=135				
Mean frequency score	2.87 ± 1.12	3.41 ± 0.98	3.68 ± 0.89	F = 9.46	0.000**	η^2 = 0.048	
Intentional hybridization (%)	58.2%	73.2%	79.3%	χ^2 = 13.84	0.001**	V = 0.192	
By Farm Scale (Small / Medium / Large)	n=200	n=110	n=65				
Intentional hybridization (%)	63.5%	80.0%	86.2%	χ^2 = 18.74	0.000**	V = 0.224	
Mean frequency score	3.18 ± 1.11	3.62 ± 0.98	3.89 ± 0.91	F = 14.27	0.000**	η^2 = 0.071	

Tukey post-hoc: Frequency score significantly higher among >10 years vs <5 years (p < 0.001) and large vs small farms (p < 0.001). Geographic variation is modest but statistically significant.

Knowledge, Attitudes, Motivations, and Decision-making Factors

As seen in Table 3, the genetic knowledge was modest, with only 22.9% of farmers scoring in the "high knowledge" category, and knowledge increased significantly with farm scale. Attitudes toward hybridization were generally favorable, though a substantial majority also believed pure strains should be conserved. Among farmers who hybridized, the leading motivations were faster growth rate, higher market demand, and better survival, and regression results showed knowledge of hybrid vigor, perceived market advantage, and farming experience as significant positive predictors of the decision to hybridize, while access to pure broodstock was a significant negative predictor.

Table 3: Knowledge, Attitude, Motivations and Multivariate Predictors of Hybridization Decision (N = 375)

Domain/Variable	Overall Mean ± SD or n (%)	Low/Disagree n (%)	Moderate / Undecided n (%)	High/Agree n (%)	Test Statistic	p-value
Knowledge Scores (1–5 scale)						
Hybrid vigour knowledge	3.12 ± 1.08	89 (23.7)	167 (44.5)	119 (31.7)		
Genetic dilution risk knowledge	2.71 ± 1.14	142 (37.9)	148 (39.5)	85 (22.7)		
Pure strain conservation knowledge	2.58 ± 1.09	156 (41.6)	139 (37.1)	80 (21.3)		
Overall knowledge index	2.80 ± 0.97	128 (34.1)	161 (42.9)	86 (22.9)		
Knowledge × Farm scale Small 2.61±0.94; Medium 2.94±0.92; Large 3.21±0.98					F = 11.87	0.000**
Attitude Scores (1–5 Likert)						
Hybridization improves profitability	4.21 ± 0.76	18 (4.8)	41 (10.9)	316 (84.3)		
Pure strains should be conserved	3.68 ± 1.02	58 (15.5)	89 (23.7)	228 (60.8)		
Continuous hybridization poses genetic risk	2.94 ± 1.18	142 (37.9)	98 (26.1)	135 (36.0)		
Willing to maintain pure lines if supported	3.87 ± 0.94	41 (10.9)	72 (19.2)	262 (69.9)		
Overall attitude index	3.68 ± 0.81					
Top Motivations (among 268 hybrid users) Rank in final column						
Faster growth rate	241 (89.9)	Rank 1				
Higher market demand / price	198 (73.9)	Rank 2				
Better survival / disease resistance	176 (65.7)	Rank 3				
Peer / neighbour influence	112 (41.8)	Rank 4				
Extension / input dealer advice	87 (32.5)	Rank 5				
Lack of pure broodstock	64 (23.9)	Rank 6				
Regression Predictor	β	SE	t	p		
Knowledge of hybrid vigour	0.312	0.048	6.50	0.000**		
Perceived market advantage	0.287	0.051	5.63	0.000**		
Years of farming experience	0.154	0.039	3.95	0.000**		
Access to pure broodstock (1=yes)	–0.198	0.045	–4.40	0.000**		
Extension contact frequency	0.089	0.042	2.12	0.035*		
Model summary	R^2 = 0.41; Adj. R^2 = 0.40; F(5,369) = 51.27; p < 0.001					

Knowledge is significantly higher among larger and more experienced farmers. Market and growth motives dominate decision-making; access to pure stock is a strong negative predictor of hybridization. Model summary: R^2 = 0.41; Adj. R^2 = 0.40; F (5,369) = 51.27; p < 0.001.

Genetic Implications of Prevailing Hybridization Practices

As seen in Table 4, Farmers expressed moderate to substantial concern about genetic consequences. Risk perception correlated positively with years of hybridization experience and negatively with genetic knowledge, and rose steeply with both duration of hybridization and reliance on external or wild-sourced broodstock.

Table 4: Perceived Genetic Implications, Risk Perception and Correlates (N = 375)

Genetic Implication Statement	Mean ± SD	Agree n (%)	Disagree n (%)	Undecided n (%)	Corr. w/ Years Hybridizing (r)	Corr. w/ Knowledge Index (r)
Loss of pure Clarias genetic identity	3.48 ± 1.21	214 (57.1)	89 (23.7)	72 (19.2)	0.298**	–0.312**
Reduced genetic diversity in local stocks	3.36 ± 1.18	198 (52.8)	102 (27.2)	75 (20.0)	0.276**	–0.289**
Introgression risk into wild populations	3.15 ± 1.24	167 (44.5)	124 (33.1)	84 (22.4)	0.241**	–0.254**
Difficulty maintaining pure broodstock lines	3.72 ± 1.09	241 (64.3)	67 (17.9)	67 (17.9)	0.341**	–0.198**
Long-term decline in hybrid performance (inbreeding)	3.08 ± 1.19	156 (41.6)	131 (34.9)	88 (23.5)	0.267**	–0.221**
Overall genetic risk perception index	3.36 ± 0.98				0.312**	–0.287**
Risk Perception by Duration of Hybridization (<3 / 3–7 / >7 yrs)	n=124	n=160	n=91			
High risk perception (%)	38.7%	55.6%	70.3%	χ^2 = 22.41, df=2, p=0.000**		
Mean risk score	2.98 ± 1.02	3.41 ± 0.94	3.78 ± 0.87	F = 17.84, p=0.000**, η^2 = 0.087		
Risk Perception by Broodstock Source (Own farm / Local hatchery / Other-state or Wild)						
Mean risk score	3.12 ± 1.01	3.29 ± 0.96	3.68 ± 0.92	F = 9.67, p=0.000**, η^2 = 0.049		

Longer hybridization history and reliance on external/wild broodstock significantly elevate perceived genetic risk. Higher knowledge is protective (negative correlation).

Farmer-perceived Impacts of Hybridization on Production Performance and Genetic Resource Sustainability

Farmers rated hybrids as significantly outperforming pure strains across growth rate, survival, feed conversion efficiency, and market preference, though perceived disease resistance showed no significant difference (Table 5). These findings reflect farmer perceptions captured on 1–5 rating scales rather than independently measured production data (e.g., verified weight gain, counted survival, or feed-conversion records), and should be interpreted as an indicator of farmer confidence in hybrid performance rather than confirmed biological superiority. Perceived performance varied by hybrid type, with *C. gariepinus* × *H. longifilis* crosses rated highest. Sustainability concerns were widespread despite farmers' generally favorable perception of hybrid production traits.

Table 5: Production Performance Impacts, Sustainability Perceptions and Comparative Analysis (N = 375; hybrid users n = 268)

Performance / Sustainability Variable	Hybrid rating (1–5)	Pure strain rating (1–5)	Mean Difference	t (paired)	p-value	Effect Size (d)
Growth rate (1–5 scale)	4.21 ± 0.87	2.87 ± 1.04	+1.34	18.64	0.000**	1.42
Survival rate	3.68 ± 1.05	3.12 ± 1.12	+0.56	7.89	0.000**	0.51
Feed conversion efficiency	3.52 ± 1.11	3.18 ± 1.09	+0.34	4.12	0.000**	0.31
Disease resistance	3.31 ± 1.18	3.24 ± 1.15	+0.07	0.89	0.374	0.06
Market preference / price	3.89 ± 0.98	3.05 ± 1.14	+0.84	10.47	0.000**	0.79
Overall performance index	3.72 ± 0.81	3.09 ± 0.89	+0.63	11.27	0.000**	0.74
Performance by Hybrid Type C.g.×H.l. (n=148) / C.g.×H.b. (n=87) / Other (n=64)						
Overall performance mean	3.89 ± 0.76	3.61 ± 0.91	3.42 ± 0.98	F = 6.12	0.002**	η^2 = 0.044
Sustainability Perceptions (Full sample N=375)	Mean ± SD	Agree n (%)				
Hybridization threatens long-term genetic sustainability	3.54 ± 1.14	218 (58.1)				
Continuous hybrid use reduces pure strain availability	3.71 ± 1.08	241 (64.3)				
Current practices are sustainable without intervention	2.48 ± 1.21	89 (23.7)				
Structured genetic conservation programme is needed	4.09 ± 0.82	312 (83.2)				
Sustainability concern × Experience <5yrs 3.21±1.09 / 5–10 3.48±1.05 / >10 3.79±0.98				F = 9.14	0.000**	η^2 = 0.047

Hybrids are perceived as significantly superior in growth, survival, FCR and market traits, but disease resistance shows no advantage. Sustainability concerns rise with experience and duration of hybridization.

Constraints, and Gaps in Hybridization and Broodstock Management

Table 6, shows the constraints in hybridization management, with the most severe constraint was unavailability of certified pure broodstock, followed by high cost of quality broodstock and limited technical knowledge of hybridization procedures. Small-scale farmers reported significantly higher rates of broodstock unavailability than large-scale farmers. However, in Table 7, Logistic regression identified small farm scale, low genetic knowledge, and absence of regular extension contact as significant predictors of experiencing a severe pure-broodstock constraint, while years of farming experience was protective.

Table 6: Constraints Profile, Severity Ranking and Group Differences by Farm Scale (N = 375)

Constraint	Frequency n (%)	Mean Severity (1–5) ± SD	Rank	Small-scale %	Medium %	Large %	χ^2	p-value
Unavailability of certified pure broodstock	287 (76.5)	4.28 ± 0.81	1	84.5	71.8	60.0	18.92	0.000**
High cost of quality broodstock	241 (64.3)	3.97 ± 0.94	2	71.0	60.9	49.2	11.48	0.003**
Limited technical knowledge of proper hybridization	198 (52.8)	3.64 ± 1.07	3	61.5	45.5	33.8	17.64	0.000**
Poor parentage / record-keeping	187 (49.9)	3.42 ± 1.09	4	55.0	47.3	36.9	7.21	0.027*
Lack of government regulation / monitoring	176 (46.9)	3.51 ± 1.12	5	48.0	45.5	46.2	0.24	0.887
Inbreeding depression in later generations	154 (41.1)	3.28 ± 1.15	6	38.5	42.7	46.2	1.42	0.492
Difficulty distinguishing hybrids from pure strains	142 (37.9)	3.19 ± 1.18	7	41.0	36.4	30.8	2.41	0.300
Inadequate extension support on genetic management	131 (34.9)	3.11 ± 1.21	8	41.5	30.0	21.5	10.87	0.004**

Table7: Binary Logistic Regression: Predictors of Severe Pure Broodstock Constraint (1 = severe)

Predictor (Severe Pure Broodstock Constraint, 1 = severe)	B	SE	Wald	Exp(B)	95% CI	p-value
Small-scale farm (ref: large)	0.874	0.241	13.15	2.40	1.50–3.84	0.000**
Low overall knowledge score	0.612	0.198	9.56	1.84	1.25–2.72	0.002**
No regular extension contact	0.489	0.217	5.08	1.63	1.07–2.50	0.024*
Years of farming experience	–0.087	0.031	7.89	0.92	0.86–0.97	0.005**
Constant	–1.124	0.356	9.97	0.32		0.002

Model fit: χ^2 = 48.76 (df=4), $p < 0.001$; Nagelkerke R^2 = 0.28; Correct classification = 74.1%. Small-scale farmers, those with low knowledge, and those lacking extension contact are significantly more likely to face severe pure-broodstock constraints. Experience reduces the odds of severe constraint

Discussion

The finding that 71.5% of the sampled catfish farmers and hatchery operators in Rivers State practised hybridization, with the *C. gariepinus* female × *H. longifilis* male cross dominating (39.5% overall, rising to 49.2% among large-scale operators), confirms that heteroclarias production remains the default breeding strategy in Nigerian catfish aquaculture rather than an occasional or experimental practice. This is consistent with the long-established literature on heterosis in growth and survival arising from Clarias–Heterobranchus crosses (Legendre et al., 1992; Madu & Aluko, 1999; Akinwande et al., 2009), and it is reinforced by more recent work. Ataguba and Angela (2024), working with progeny from reciprocal *Clarias gariepinus* × *Heterobranchus sp*. crosses in Benue State, similarly reported an additive genetic effect from the combination of pure-line gametes, with hybrid vigour expressed more strongly for growth in crosses using *Heterobranchus sp*. males than in the reciprocal direction, and with the maternal *H. longifilis* line contributing disproportionately to survival. A recent comprehensive review of clariid catfish hybridization by Uno et al. (2025) likewise identifies *Clarias gariepinus* × *Heterobranchus longifilis* as one of the most consistently documented and commercially favoured crosses in African and Asian clariid aquaculture, attributing its persistence to reliably improved growth, feed efficiency, and stress tolerance relative to either parent species. Taken together, these sources corroborate the present study's finding that hybridization is now structurally embedded in Rivers State catfish production rather than being an isolated regional idiosyncrasy.

At the same time, the literature cautions against treating hybrid superiority as universal or unconditional. Ataguba and Angela (2024) and earlier trials cited within the same programme found that not all cross directions produce positive heterosis: reciprocal crosses in which *Heterobranchus* contributed the maternal line sometimes yielded slower growth than pure *Clarias,* indicating that outcomes are sensitive to parental combination, broodstock quality, and rearing conditions rather than being an automatic consequence of hybridization itself. This is an important qualification for the present study's Table 5 results, in which farmers rated hybrids as superior to pure strains across almost every performance dimension. Because these ratings are farmer perceptions on 1–5 scales rather than measured production data, the magnitude of reported superiority particularly the very large effect size for growth (d = 1.42) should be interpreted cautiously. Nawang et al. (2026) note that farmer-reported hybrid performance in sub-Saharan aquaculture systems frequently exceeds what is documented in controlled trials, a pattern they attribute in part to confirmation bias: once farmers commit to a breeding practice for economic reasons, they tend to selectively notice and recall outcomes that validate that choice while discounting disconfirming experiences. This dynamic is not unique to aquaculture producers; a broader behavioural-economics literature on stakeholder perceptions of aquaculture has documented similar information-processing biases shaping beliefs about production systems independently of objective performance data, with confirmation and availability biases both implicated in the gap between perceived and actual outcomes. The present study's own data offer indirect support for this interpretation: disease resistance was the one performance dimension on which farmers reported no significant hybrid advantage (t = 0.89, p = 0.374), suggesting that where farmers lack a strong prior economic motive to see a difference, their ratings converge with what the wider experimental literature would predict namely, that disease resistance in heteroclarias is not reliably superior to that of pure Clarias.

The result that hybridization frequency and intentionality rise significantly with farm scale and years of experience mirrors the broader technology-adoption literature in African aquaculture. In a study of predictors of aquaculture technology uptake among Kenyan smallholders, Obiero et al. (2019) found that farm size, production level, extension-training attendance, and ease of handling a technology were the strongest positive predictors of adoption, with only about 30% of surveyed farmers classified as high adopters overall. The parallel with the present findings is direct: it is precisely the larger, better-resourced, and more experienced Rivers State operators who hybridize most intensively, invest most heavily in induced breeding and RAS-based hatchery infrastructure, and draw most heavily on external or research-institute broodstock, while small-scale farmers remain comparatively conservative, relying more on outdoor earthen-pond hatching and on-farm broodstock. This scale-differentiated pattern of technology and technique adoption is a recurring feature of African aquaculture systems and suggests that any intervention aimed at regulating or certifying hybridization practice will need to be calibrated differently for large commercial hatcheries than for small-scale producers, since the latter face a distinct configuration of constraints (see below) rather than simply lagging behind on the same adoption trajectory.

A central and somewhat troubling finding of this study is the disjunction between awareness of genetic risk and behavioural response to that awareness. Farmers who had hybridized longest and most intensively were also the ones who scored highest on genetic risk perception ($r = 0.312$ with years of hybridizing), yet this heightened awareness did not translate into adoption of broodstock documentation, pedigree tracking, or other genetic-management structures. This pattern is consistent with Duncan et al.'s (2013) observation, in the context of small-scale tilapia broodstock management in Nigeria, that unmanaged and repeated hybridization in the absence of formal genetic-management protocols predictably erodes genetic diversity over time regardless of farmers' stated concern about the outcome. It is also consistent with Nwachukwu and Onuegbu 's (2007) argument that awareness of good practice in Nigerian aquaculture does not reliably convert into adoption because of intervening socio-economic constraints an argument the present study's own constraint data substantiate, since unavailability of certified pure broodstock (76.5%) and high broodstock cost (64.3%) were the two most severe constraints reported, and logistic regression identified small farm scale, low genetic knowledge, and absence of extension contact as significant predictors of experiencing a severe broodstock constraint (Nagelkerke $R^2 = 0.28$). In other words, farmers are not failing to act on their risk perceptions out of indifference; a substantial share is structurally unable to source or afford certified pure broodstock even when they recognize the genetic stakes involved. Onuche et al. (2020), examining perception and uptake of aquaculture technologies in Kogi State, central Nigeria, similarly found that limited access to improved inputs and inconsistent extension contact constrained farmers' ability to translate favourable attitudes toward improved practices into actual adoption, reinforcing the generalizability of this awareness–action gap across Nigerian aquaculture sub-sectors.

The genetic conservation concerns raised by this study's respondents are not merely theoretical. Sanda et al. (2026), using mitochondrial COI sequencing and genome-wide 3RAD analysis of wild and farmed *Clarias gariepinus* populations across Nigeria, found that wild sampling sites retained a broader range of unique haplotypes and higher heterozygosity than farmed stocks, and explicitly flagged hybridization-driven loss of genetic diversity, alongside habitat fragmentation and overfishing, as a threat to the long-term genetic integrity of Nigeria's catfish resource. Their findings that introduced "Dutch Clarias" broodstock lines are now widely used in Nigerian hatcheries alongside wild-caught stock, with limited genetic differentiation being maintained between them, lends empirical weight to the present respondents' concern (57.1% agreement) about loss of pure Clarias genetic identity and to their high level of concern (64.3%) about difficulty maintaining pure broodstock lines. An instructive cautionary parallel comes from outside Africa: Parvez et al. (2022) documented genetic erosion of the indigenous walking catfish, *Clarias batrachus*, in Bangladesh following unregulated introduction and subsequent unplanned hybridization with the exotic African catfish, *Clarias gariepinus*, despite an official government ban on *C. gariepinus* farming. Phylogenetic analysis in that study showed that suspected hybrid individuals clustered with the exotic species rather than with native *C. batrachus*, providing direct molecular evidence that regulatory prohibition alone, without effective enforcement and farmer-level broodstock control, is insufficient to prevent introgression once a hybridization pathway has been established informally at the farm level. This is directly relevant to the Rivers State context, where 28.5% of hybridization was reported as unintentional, implying that even a formal prohibition or certification requirement would need to be paired with practical broodstock segregation measures to be effective.

The regulatory landscape reviewed by Uno et al. (2025) further contextualizes the present study's call for structured broodstock certification. Their review notes considerable international variation in how clariid hybridization is governed: in the United States, Clarias species are restricted under the Lacey Act; the European Union's Council Regulation No. 708/2007 requires formal risk assessment and monitoring for alien aquaculture species; and in Southeast Asian producer countries such as Thailand and Vietnam, interspecific Clarias hybrid production is permitted but subject to containment recommendations. Within Nigeria specifically, the same review characterizes current practice as relying primarily on hatchery supervision and biosecurity measures supported by farm audits and voluntary certification rather than on statutory restriction of hybridization itself. This is broadly consistent with the present study's finding that only 46.9% of farmers perceived a lack of government regulation or monitoring as a severe constraint, ranking it fifth among the eight constraints assessed and well behind broodstock unavailability and cost suggesting that farmers themselves see the practical, input-supply dimension of genetic management as more pressing than the regulatory dimension, and that policy interventions are likely to gain more traction if framed around improving certified-broodstock access and extension delivery than around top-down restriction

CONCLUSION

Hybridization between *C. gariepinus* and *Heterobranchus sp*ecies has become the order of the day in catfish production in Rivers State due to its demonstrable production advantages, but the practice has taken root without the structures to mitigate its effects on genetic stocks, especially with regard to the conservation of pure breeds of catfish. The farmers were aware of the implications of hybridization, as evidenced by the high odds ratio of those who requested for a genetic conservation program, although most of them still practiced hybridization for its production advantages.

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