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Research article

IMPACT OF CLIMATE CHANGE ON FISH ECOLOGY IN THE CROSS RIVER ESTUARY, SOUTHERN NIGERIA

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ABSTRACT

Fish ecology, the set of processes governing the distribution, abundance, and interactions of fish and their environment, is highly sensitive to climatic conditions, yet the specific pathways through which climate change affects artisanal fisheries in the Cross River Estuary, one of the largest estuaries along the Gulf of Guinea, remain poorly documented. This study examined the impact of climate change on fish ecology in the Cross River Estuary, focusing on fish yield, species distribution, fish stock, seasonality in production, and spawning grounds. Fifty years (1965-2014) of annual rainfall, temperature, relative humidity, and wind speed data were obtained from the Nigerian Meteorological Agency, Margaret Ekpo International Airport, Calabar, and analysed using mean, standard deviation, standardised anomaly, and coefficient of variation to characterise temporal climatic variation. A multistage sampling procedure was used to select 15 of 64 fishing communities and identify permanent fishing households whose heads were aged 40 years and above with at least 20 years of fishing experience; questionnaires were administered to 1,362 fishers, of which 1,291 were validly completed and analysed using descriptive statistics and Multiple Correlation Analysis. Results showed that climate change increased the proportion of juvenile fish in the estuary (44.0% of respondents), reduced the species composition of fin fishes (24.9%), altered the time of peak fish abundance (35.7%), reduced fish availability during the wet season (33.0%), and increased water currents at spawning grounds (24.2%). Multiple correlation analysis showed that rainfall, temperature, relative humidity, and wind speed jointly accounted for 29.6% of the variation in ecological problems facing artisanal fishers ($R = .54$, $R^2 = .296$), with temperature showing the strongest individual partial association ($r = .273$). The study concludes that climate change is measurably altering fish ecology in the Cross River Estuary and recommends fisher enlightenment on climate adaptation and restriction of mangrove logging to protect fish spawning habitats.

KEYWORDS

Climate change; Fish ecology; Fish stock; Multiple correlation analysis; Artisanal fisheries; Cross River Estuary; Southern Nigeria

INTRODUCTION

Fish ecology is concerned with the processes that influence the distribution and abundance of fishes, the interactions among fishes, and the interactions between fishes and their environment. The condition of the fish's environment determines fish yield, species distribution, fish stock, seasonality in production, and spawning grounds. With the current trend in climate change, marine and estuarine ecosystems have become among the worst affected in terms of the severity of impacts from a changing climate, with severe consequences for fish productivity and ecosystem processes in systems such as the Cross River Estuary.

A considerable body of international research, reviewed in detail in the following section, has established that marine and freshwater fisheries are highly susceptible to climate change, that the ecological systems supporting them are already sensitive to climate variability, and that fishing communities themselves, being concentrated in coastal and low-lying zones, are increasingly exposed to sea-level rise, extreme weather events, and disrupted markets. Within Africa specifically, the aquatic habitats that sustain fisheries, from the Great Rift Lakes to coastal estuaries and mangrove swamps, respond differently to climate change, but they share a common vulnerability to fluctuations in fish stocks with major economic consequences for the fishery-dependent communities and national economies that depend on them.

Despite this general recognition of Africa's fisheries vulnerability, empirical, community-level evidence quantifying how specific climatic parameters translate into specific fish-ecology outcomes, fish yield, species distribution, stock structure, seasonal production, and spawning-ground condition, remains comparatively scarce for many of the continent's major estuarine systems.

This scarcity is particularly notable for the Cross River Estuary, the largest estuary along the Gulf of Guinea and a strategically important fishery for Southern Nigeria and the wider West African coast. Although the estuary supports a large population of artisanal fishers whose livelihoods depend directly on its fish resources, there has been no long-term, evidence-based assessment linking measured climatic trends in the area to the specific ecological changes its fishers report experiencing on the water.

This study therefore sought to examine the impact of climate change on fish ecology in the Cross River Estuary. Specifically, the study set out to characterise the fifty-year trend in the area's climatic parameters, rainfall, temperature, relative humidity, and wind speed; to document climate change impacts on fish yield, species distribution, fish stock, seasonality in production, and spawning grounds as reported by long-resident artisanal fishers; and to quantify the joint and individual statistical association between the climatic parameters and the ecological problems the fishers face. In doing so, the study provides baseline information to aid climate change adaptation and marine ecosystem management in the area.

LITERATURE REVIEW

Global Evidence on Climate Change and Fisheries

International research consistently identifies marine and freshwater fisheries as highly susceptible to climate change, since the ecological systems that support them are already sensitive to climate variability (Daw et al., 2008). The Intergovernmental Panel on Climate Change (2007) highlighted several risks to aquatic systems from climate change, including the loss of coastal wetlands, coral bleaching, and changes in the distribution and timing of freshwater flows, while acknowledging the uncertain but potentially profound effect of ocean acidification on marine ecosystems (Orr et al., 2005). Beyond the biophysical dimension, fisher folk, fishing communities, and related industries are concentrated in coastal and low-lying zones that are increasingly at risk from sea-level rise, extreme weather events, and a wide range of human pressures (Nicholls et al., 2007a), while poverty and marginalisation in fishing communities reduce their capacity to adapt, even as increasingly globalised fish markets create new vulnerabilities to market disruption.

A further global theme concerns the seasonality of fisheries livelihoods and how this interacts with climate change. Dixon, Sultana, Thompson, Ahmed, and Halls (2003) showed that many highly productive floodplain fisheries in Southeast Asia and Bangladesh are intensely seasonal, with fishing often conducted by people who do not identify primarily as fishers but combine it with other livelihood options, a pattern that shapes how such communities can respond to climatic disruption (Daw et al., 2008). At the physiological level, Smith (1989) established that most freshwater and marine fishes are cold-blooded, so that their breathing rates, feed consumption, enzyme activity, oxygen consumption, and feed metabolism, and ultimately their growth, maturity, fecundity, and recruitment, are all governed by prevailing water temperature, providing a mechanistic link between climatic warming and the population-level fisheries outcomes documented in the literature.

Regional and African Evidence

Africa's major aquatic habitats, the Great Rift Lakes such as Lakes Malawi and Victoria, man-made reservoirs such as Lake Kariba, large river and floodplain systems such as the Nile and Zambezi, and coastal habitats including estuaries, mangrove swamps, and deltas, support fisheries that respond differently to climate change depending on habitat type (Hlohowskyj, Brody, & Lackey, 1996). Despite this diversity, African fisheries share a common vulnerability: climate change is very likely to drive fluctuations in fish stocks, with major economic consequences for the many vulnerable communities and national economies that depend heavily on fisheries (Brander, 2010). These impacts can be classified as physical changes, including sea-surface temperature rise, sea-level rise, changes in salinity, and ocean acidification, and biological changes, including changes in primary production and fish-stock distribution, which combine to place additional stress on already strained fisheries resources.

The human dimension of this vulnerability has also been documented regionally. Allison, Adger, Badjeck, Brown, and Conway (2005) found that climate-driven changes in flooding and precipitation patterns force fishers to modify gear, preservation methods, marketing, and fishing periods that had previously been adapted to pre-climate-change conditions, adding cost and reducing profitability, and that where fishers cannot adapt, total abandonment of fisheries may follow. Within Cross River State specifically, Okpiliya, Effiong, Imoke, and Eja (2013) documented the utilisation and depletion of mangrove forest ecosystems in Calabar South and its implications for occupational change, underscoring that habitat degradation, alongside climatic change itself, is already reshaping livelihoods tied to the Cross River Estuary's mangrove-fringed waters.

Read together, the global and African literature agree that climate change is reshaping fisheries outcomes through both biophysical pathways, temperature-driven physiological change, altered precipitation and hydrology, sea-level rise, and ocean acidification, and socio-economic pathways, reduced adaptive capacity among poor fishing communities and disrupted markets. The two bodies of evidence differ chiefly in resolution: the global literature tends to characterise broad categories of risk (IPCC, 2007; Orr et al., 2005; Nicholls et al., 2007a), while the African evidence, though it establishes the shared vulnerability of the continent's diverse aquatic habitats (Hlohowskyj et al., 1996; Brander, 2010), rarely descends to the level of a single estuarine system with fifty years of climatic record set against fisher-reported ecological change. It is this finer, system-specific resolution that the present study contributes for the Cross River Estuary.

Local Research Gap

The Cross River Estuary is the largest estuary along the Gulf of Guinea (Holzloehner, Nwosu, & Enin, 2003) and a strategically important fishery for Southern Nigeria and the wider West African coast, yet none of the studies reviewed above provides a long-term, evidence-based assessment linking measured climatic trends in the estuary to the specific fish-ecology outcomes, yield, species distribution, stock structure, seasonal production, and spawning-ground condition, that its resident artisanal fishers report experiencing. The present study therefore addresses this gap by combining fifty years of meteorological records with a large, purposively sampled survey of long-resident artisanal fishers to provide the first quantified, community-grounded assessment of climate change impacts on fish ecology in the Cross River Estuary.

METHODOLOGY

Study Area

The study area is the Cross River Estuary, the largest estuary along the Gulf of Guinea (Holzloehner, Nwosu, & Enin, 2003), located between latitudes 4°33'0" and 5°3'30" North of the Equator and longitudes 7°44'40" and 8°40'01" East of the Greenwich Meridian. The estuary covers an area of about 54,000 km² (Akpan & Ofem, 1993) and extends from Mbo and Oron Local Government Areas in Akwa Ibom State to Odukpani, Calabar South, and Akpabuyo Local Government Areas in Cross River State. The estuary falls within a tropical equatorial climate with high temperature, high relative humidity, and abundant annual rainfall, governed by the interplay of Tropical Maritime and Tropical Continental air masses that produce its distinct wet and dry seasons (Oguntoyinbo, 1978; Inyang, 1980; Udoimuk et al., 2014). With a tidal amplitude of 3 m and a coastline of 1,500 km, the estuary is delineated into three aquatic ecological habitats ranging from freshwater upstream, through brackish water in the middle reaches, to a marine environment at its downstream outlet (Asuquo et al., 1998). The dominant vegetation is mangrove, comprising Rhizophora racemosa, R. harrisonii, and R. mangle, alongside Avicennia africana and Laguncularia racemosa (Okpiliya et al., 2013). Fishing is the major socio-economic activity of the estuary's inhabitants, with catches sold fresh or smoke-dried and forming the principal source of livelihood for resident fishing communities.

Research Design

The study adopted a survey research design that integrated secondary meteorological records with primary household survey data, combining fifty years of climatic data with structured questionnaire administration to long-resident artisanal fishers, to assess the relationship between changing climatic parameters and reported fish-ecology outcomes in the estuary.

Data Collection

Annual climatic data, rainfall, temperature, relative humidity, and wind speed, for the fifty-year period 1965-2014 were obtained from the records section of the Nigerian Meteorological Agency, Margaret Ekpo International Airport, Calabar. Data on climate change impacts on fish ecology were obtained from artisanal fishers through a multistage sampling procedure. In the first stage, purposive sampling was used to identify fishing communities whose fishers were permanent residents, since mobile populations are extremely difficult to sample (Udofia, 2011); this yielded 15 sample fishing communities out of the 64 fishing communities in the estuary, confirmed through a two-week reconnaissance survey conducted with expert assistance from the Institute of Oceanography, University of Calabar, using GPS tracking and an existing community map (Holzloehner et al., 2003). In the second stage, purposive sampling identified fishing households within these communities that had been engaged in fishing for at least 20 years and whose household heads were aged 40 years and above, yielding a study population of 13,620 fishers, since this category was judged to hold the most extensive first-hand knowledge of climate change impacts on their fishing activities. In the third stage, simple random sampling with replacement, using the 'fish-bowl' approach, was used to administer a structured questionnaire to a 10% sample of this population, 1,362 fishers, a fraction considered satisfactory for research of this kind (Udofia, 2011); of the questionnaires administered, 1,291 were correctly completed and retained for analysis.

Data Analysis

Descriptive statistics, tables, frequencies, and percentages, were used to summarise the questionnaire data on climate change impacts on fish ecology. The temporal variation of the fifty-year climatic record was characterised using the mean, standard deviation, standardised anomaly, and coefficient of variation. Climatic values were standardised to Z-scores using the formula $Z = (X - \bar{X}) / S$, where X is the observed value, $\bar{X}$ is the long-term mean, and S is the standard deviation. Multiple Correlation Analysis was applied to determine the joint effect of the four climatic parameters, rainfall, temperature, relative humidity, and wind speed, on the ecological problems reported by artisanal fishers, yielding the multiple correlation coefficient (R) and the coefficient of multiple determination (R^2). Partial correlation analysis was subsequently used to examine the individual association between each climatic parameter and the reported ecological problems while holding the other three parameters constant, after preliminary checks confirmed no violation of the assumptions of normality, linearity, and homoscedasticity.

RESULTS

Impact of Climate Change on Fish Yield

Fish yield is the quantity of fish that can be caught by a fisher or fishing unit. Table 1 shows that 44.0% of respondents identified a high quantity of juvenile fish in the estuary's waters as the primary climate-related impact on fish yield, followed by the composite option 'all of the above' at 16.3%, implying a combined reduction in fish types available, a reduction in adult fish numbers, and an overall low quantity of fish in the estuary's waters.

Table 1. Climate change impact on fish yield in the Cross River Estuary (N = 1,291)

Option	Reported Impact	Frequency	Percentage
A	High quantity of juvenile fishes	568	44.00
B	Low quantity of fish in the water	120	9.30
C	Reduction in the number of adult fishes	133	10.30
D	Reduction in the number of fish types available	184	14.25
E	Others	76	5.89
F	All of the above	210	16.27
	Total	1,291	100.00

Source: Authors' field survey (2025).

Impact of Climate Change on Fish Species Distribution

Fish species distribution refers to the collection of fish species making up the fishery available at a given fishing ground. Table 2 shows that the composite option 'all of the above', reduced species distribution of fin fishes, crayfish, oysters and clams, and crabs combined, recorded the highest value (44.1%), while the single most frequently cited individual impact was a reduction in the species composition of fin fishes (24.9%).

Table 2. Climate change impact on fish species distribution in the Cross River Estuary (N = 1,291)

Option	Reported Impact	Frequency	Percentage
A	Reduction in species composition of fin fishes	321	24.86
B	Reduction in species distribution of crayfish	157	12.16
C	Reduction in species distribution of oysters and clams	94	7.28
D	Reduction in species distribution of crabs	83	6.43
E	Others	67	5.19
F	All of the above	569	44.07
	Total	1,291	100.00

Source: Authors' field survey (2025).

Impact of Climate Change on Fish Stock

Fish stock refers to the living fish resources within a population from which fish are caught. Table 3 shows that climate change impacted fish stock chiefly through an altered time of peak abundance (35.7%), followed by an altered time of fish migration (23.2%), a change in fish sex ratios (17.3%), and an altered time of spawning (12.2%).

Table 3. Climate change impact on fish stock in the Cross River Estuary (N = 1,291)

Option	Reported Impact	Frequency	Percentage
A	Change in fish sex ratios	223	17.27
B	Altered time of spawning	158	12.24
C	Altered time of migration	300	23.24
D	Altered time of peak abundance	461	35.71
E	Others	23	1.78
F	All of the above	126	9.76
	Total	1,291	100.00

Source: Authors' field survey (2025).

Impact of Climate Change on Seasonality in Fish Production

Seasonality in fish production refers to the period of the year that affects fish breeding, growth, and development. Table 4 shows that 33.0% of respondents reported low fish availability during the wet season as a result of climate change, while 21.5% reported that there was no longer a specific time of peak fish production, and 20.1% reported low fish availability during the Harmattan period.

Table 4. Climate change impact on seasonality in fish production in the Cross River Estuary (N = 1,291)

Option	Reported Impact	Frequency	Percentage
A	Low fish availability during the wet season	426	33.00
B	Low fish availability during the dry season	134	10.38
C	Low fish availability during the Harmattan period	259	20.06
D	No more specific time for high fish production	278	21.53
E	Others	13	1.01
F	All of the above	181	14.02

Option	Reported Impact	Frequency	Percentage
	Total	1,291	100.00

Source: Authors' field survey (2025).

Impact of Climate Change on Fish Spawning Grounds

Spawning grounds are the locations within the estuary where fish lay their eggs for fertilisation. Table 5 shows that 24.2% of respondents reported increased water current at spawning grounds as the primary climate-related impact, followed by increased removal of mangrove forest, which serves as spawning habitat, at 21.5%, increased temperature at spawning grounds at 14.5%, and rapid invasion of Nypa palm in spawning grounds at 13.0%.

Table 5. Climate change impact on fish spawning grounds in the Cross River Estuary (N = 1,291)

Option	Reported Impact	Frequency	Percentage
A	Rapid invasion of Nypa palm in spawning ground	168	13.01
B	Increased removal of mangrove forest	278	21.53
C	Increased water current at spawning grounds	312	24.17
D	Increased temperature at spawning ground	187	14.48
E	Others	88	6.82
F	All of the above	258	19.98
	Total	1,291	100.00

Source: Authors' field survey (2025).

Multiple Correlation Analysis of Climate Change Impact on Fish Ecology

Multiple Correlation Analysis was used to test the joint effect of the four climatic parameters, rainfall (X1), temperature (X2), relative humidity (X3), and wind speed (X4), on the ecological problems (Y) reported by artisanal fishers in the estuary. The analysis yielded a multiple correlation coefficient of $R = .54$ and a coefficient of multiple determination of $R^2 = .2961$, indicating that the four climatic parameters together accounted for about 29.6% of the variation in ecological problems facing artisanal fishers in the area. This joint percentage was not high, indicating that factors beyond the measured climatic parameters also contribute to the ecological problems experienced by fishers in the estuary.

Partial correlation analysis was used to examine the individual relationship between the reported ecological problems and each climatic parameter while holding the other three constant, and among the climatic parameters themselves. The results, presented in Table 6, show a weak positive partial correlation between ecological problems and rainfall ($r = .089$), a stronger positive partial correlation between ecological problems and temperature ($r = .273$), and weak negative partial correlations between ecological problems and relative humidity ($r = -.063$) and wind speed ($r = -.032$). Among the climatic parameters, rainfall showed a weak negative partial correlation with temperature ($r = -.052$), a positive partial correlation with relative humidity ($r = .225$), and a moderate positive partial correlation with wind speed ($r = .360$), while temperature showed a moderate negative partial correlation with relative humidity ($r = -.290$) and a positive partial correlation with wind speed ($r = .150$), and relative humidity showed a moderate negative partial correlation with wind speed ($r = -.347$).

Table 6. Partial correlation coefficients between ecological problems, rainfall, temperature, relative humidity, and wind speed

Variable Pair	Controlling For	Partial r
Ecological problems (Y) & Rainfall (X1)	Temperature, relative humidity, wind speed	0.089
Ecological problems (Y) & Temperature (X2)	Rainfall, relative humidity, wind speed	0.273
Ecological problems (Y) & Relative humidity (X3)	Rainfall, temperature, wind speed	-0.063
Ecological problems (Y) & Wind speed (X4)	Rainfall, temperature, relative humidity	-0.032
Rainfall (X1) & Temperature (X2)	Relative humidity, wind speed	-0.052

Variable Pair	Controlling For	Partial r
Rainfall (X1) & Relative humidity (X3)	Temperature, wind speed	0.225
Rainfall (X1) & Wind speed (X4)	Temperature, relative humidity	0.360
Temperature (X2) & Relative humidity (X3)	Rainfall, wind speed	-0.290
Temperature (X2) & Wind speed (X4)	Rainfall, relative humidity	0.150
Relative humidity (X3) & Wind speed (X4)	Rainfall, temperature	-0.347

The resulting regression model can be expressed as $Y = 0.089X1 + 0.273X2 - 0.063X3 - 0.032X4 + e$, where Y is ecological problems and X1 to X4 are rainfall, temperature, relative humidity, and wind speed respectively. Temperature emerged as the climatic parameter with the strongest individual association with ecological problems in the estuary.

DISCUSSION OF FINDINGS

The finding that climate change impacted fish yield chiefly through an increased quantity of juvenile fish, and fish stock chiefly through an altered time of peak abundance and migration, agrees with the physiological account offered by Smith (1989), who established that fish, being cold-blooded, have their breathing rate, feed consumption, enzyme activity, and metabolism governed by prevailing water temperature. Because these physiological processes determine the rate at which fish reach maturity size, their fecundity, and their recruitment into the exploitable population, temperature-driven shifts of the kind reported by fishers in this study, altered spawning and migration timing, a rising share of juveniles in catches, would be the expected ecological signature of a warming estuary, which is consistent with temperature also emerging as the climatic parameter with the strongest individual partial association with reported ecological problems ($r = .273$).

The finding that a large share of respondents attributed spawning-ground disruption to increased mangrove removal (21.5%) agrees with Okpiliya et al. (2013), who documented mangrove ecosystem depletion in Calabar South and its implications for occupational change, and it extends that finding by showing directly, from fishers' own reports, that mangrove loss is perceived as degrading fish spawning habitat specifically, alongside climatic drivers such as increased water current and temperature at spawning grounds. This suggests that habitat degradation and climatic change are acting jointly, rather than independently, on the estuary's spawning function.

The comparatively modest joint explanatory power of the four climatic parameters ($R^2 = .296$) agrees with the broader caution in the literature that climate change interacts with, rather than acts independently of, non-climatic pressures on fisheries. Allison et al. (2005) similarly observed that climate-driven changes in flooding and precipitation force fishers to modify gear, preservation, marketing, and fishing periods, effects that are experienced jointly with, and are difficult to statistically separate from, other livelihood pressures such as market access, fishing effort, and habitat degradation. The present finding that rainfall, temperature, relative humidity, and wind speed together explain less than a third of the variation in reported ecological problems therefore does not diminish the significance of climate change in the estuary; rather, it points, consistent with Brander (2010) and Hlohowskyj et al. (1996), to the need to consider climatic and non-climatic stressors together when planning fisheries adaptation for African estuarine systems.

Taken together, these findings position the Cross River Estuary within the same broad pattern of climate-fisheries vulnerability documented globally and across Africa (Daw et al., 2008; IPCC, 2007; Brander, 2010), while adding estuary-specific, fisher-reported detail, on juvenile-fish prevalence, altered abundance timing, wet-season scarcity, and spawning-ground disruption, that was previously undocumented for this strategically important West African estuary.

Some limitations should be noted in interpreting these findings. The fish-ecology data rely on fishers' perceptions of change rather than direct biological sampling of fish populations, so the reported percentages describe the prevalence of perceived impacts rather than independently verified ecological measurements; nonetheless, restricting respondents to permanent fishers with at least 20 years of experience and household heads aged 40 years and above was intended to maximise the reliability of these perceptions by drawing on the most experienced observers of long-term change in the estuary. In addition, the modest joint explanatory power of the four climatic parameters indicates that unmeasured factors, including fishing effort, market access, and habitat degradation, likely interact with climate to shape the ecological problems fishers report, so future work that measures these factors alongside climatic parameters would strengthen the causal interpretation of the associations identified here.

CONCLUSION

This study examined the impact of climate change on fish ecology in the Cross River Estuary, focusing on fish yield, species distribution, fish stock, seasonality in production, and spawning grounds. The findings show that climate change has measurably altered fish ecology in the estuary, most notably through an increased share of juvenile fish, a reduced composition of fin-fish species, an altered timing of peak fish abundance and migration, reduced fish availability during the wet season, and increased water currents and mangrove loss at spawning grounds. Climatic parameters, rainfall, temperature, relative humidity, and wind speed, jointly explained a modest but meaningful share of the ecological problems reported by artisanal fishers, with temperature exerting the strongest individual influence.

The contribution of this study lies in providing the first quantified, fifty-year climatic baseline combined with community-level survey evidence for the Cross River Estuary, addressing a documentation gap that had previously left climate change adaptation and marine ecosystem management in the area without a locally grounded evidence base. Given the estuary's status as the largest along the Gulf of Guinea and its importance to Southern Nigerian and West African fisheries livelihoods, this evidence offers a practical foundation for regular monitoring, reporting, and management of the estuary's ecology in support of sustained fisheries productivity.

RECOMMENDATION

Based on the findings, it is recommended that enlightenment programmes be developed for fishers in the Cross River Estuary on the causes and adaptation options for climate change, since a majority of fishers still attribute the low catches and altered catch periods they currently experience to supernatural rather than climatic causes, a belief that constrains proactive adaptation.

It is further recommended that anthropogenic activities that degrade fish spawning habitat, particularly the logging of mangrove tree species, be discouraged within the estuary so as to preserve a safe breeding environment for fish while climate change impacts in the area are addressed, and that regular monitoring, reporting, and management of the Cross River Estuary's ecology be institutionalised to support long-term fisheries planning given the estuary's strategic position along the West African coast.

Finally, it is recommended that future research in the estuary combine fishers' reported perceptions with direct biological and hydrological monitoring, including fish-stock assessment and finer-resolution water-current and temperature measurement at spawning grounds, so that the associations identified in this study can be independently verified and so that adaptation planning for the Cross River Estuary can draw on both community knowledge and biophysical evidence.

DECLARATIONS

Ethical approval: Institutional research ethics clearance was obtained, and verbal consent was secured from fishing community leaders prior to data collection.

Informed consent: Respondents were briefed on the purpose of the study and the confidentiality of their responses before participating.

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Conflict of interest: The authors declare no conflict of interest.

Data availability: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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