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Original Article

Farm to policy: Socioeconomic dynamics and occupational challenges of freshwater fish farmers in the Cauvery Delta region, Tamil Nadu

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Abstract
Freshwater aquaculture is vital for global food security and rural livelihoods. This study examined 120 fish farmers across Thanjavur, Thiruvarur, and Nagapattinam districts in Tamil Nadu's Cauvery Delta to understand socioeconomic dynamics and constraint hierarchies shaping aquaculture development. Using structured interviews and Garrett ranking, the research revealed critical structural vulnerabilities: the farming population is predominantly male (93.3%), aging (average 45 years; 79.2% middle-aged or older), and faces future labour succession challenges despite relatively high literacy (85% educated). Low organizational participation (54.2% non-members) undermines collective bargaining capacity. Most farmers (80.8%) combine aquaculture with other occupations, reflecting income insufficiency rather than strategic diversification. With 65% representing first-generation farmers averaging eleven years' experience, aquaculture emerges as recent livelihood diversification rather than traditional practice. Landholding patterns showed 75% farm ownership averaging 3.5 acres, though 53.3% operate small farms below three acres, limiting economies of scale. Caste composition revealed predominance of marginalized communities—61.7% Other Backward Class and 27.5% Scheduled Caste—facing systematic barriers to credit, technology, and market access. Constraint analysis identified high feed costs as the primary short-term barrier across all districts, followed by insufficient credit access and inadequate extension services, while low farm gate prices emerged as the dominant long-term constraint. Findings demonstrate that effective aquaculture policies must address structural inequities rooted in caste-based exclusion, land fragmentation, organizational deficits, and market asymmetries through targeted interventions including collateral-free credit, farmer producer organizations, district-level feed cooperatives, and differentiated extension programming to transform aquaculture into dignified, profitable livelihoods.

Keywords: Cauvery Delta; constraints; fish farmers; Garrett ranking; socioeconomic profiling; structural vulnerability

1 | INTRODUCTION

India has emerged as a major force in global fisheries, ranking second only to China in total fish production. During the fiscal year 2022–23, the country contributed 8.92% to global fish output, with an estimated production of 17.54 million metric tons (MMT) - 13.11 MMT from inland fisheries and 4.43 MMT from marine capture (Department of Fisheries 2023a, 2023b). The fisheries sector is widely recognized as a "Sunrise Sector" due to its rapid growth, critical role in ensuring food and nutritional security, and its capacity to generate employment and sustain the livelihoods of nearly 30 million people, particularly among marginalized and vulnerable communities (Department of Fisheries 2024). This expansion mirrors broader trends across Asia, where aquaculture has transformed rural economies and food systems over the past three decades (Belton and Thilsted 2014).

India's remarkable expansion in fish production is largely driven by its dynamic aquaculture sector, which now accounts for nearly 75% of the country's total fish yield, establishing India as a frontrunner in inland fish production globally (Department of Fisheries 2024). Recognizing the strategic importance of this sector, the Government of India has launched transformative initiatives such as the Pradhan Mantri Matsya Sampada Yojana (PMMSY), a flagship scheme aimed at promoting sustainable, responsible, and inclusive fisheries development through infrastructure investment, technological modernization, institutional strengthening, and enhanced market integration (Department of Fisheries 2023a, 2023b). These policy interventions reflect growing recognition that aquaculture can serve as a pathway out of poverty for rural communities when supported by appropriate institutional frameworks (Ahmed and Garnett 2011; Belton *et al.* 2014).

Within this national context, Tamil Nadu stands out as a state endowed with substantial and diverse inland water resources: 54 small reservoirs (16,059 hectares), eight medium and large reservoirs (62,015 hectares), tanks and ponds (218,691 hectares), oxbow lakes (7,000 hectares), 7,420 kilometres of rivers and canals, and an additional 35,283 hectares of other water bodies. Despite this extensive aquatic resource base, Tamil Nadu ranks 12th in inland fish production with an annual output of 2.32 lakh tonnes (Department of Fisheries 2023a, 2023b), suggesting substantial untapped potential. Nevertheless, fish production in the state has shown steady growth in recent years, primarily due to adoption of improved aquaculture technologies and proactive institutional support from the Department of Fisheries.

The Cauvery Delta, often referred to as the "rice bowl" of Tamil Nadu, also serves as a vital hub for inland fisheries. Its dense network of rivers, canals, tanks, and ponds offers significant potential for freshwater aquaculture, supporting thousands of smallholder fish farmers and contributing meaningfully to rural livelihoods and regional food security. However, despite this potential, freshwater fish farmers in the Cauvery Delta face persistent and multifaceted challenges characteristic of smallholder aquaculture systems globally (Joffre *et al.* 2015). These include fluctuating market prices leading to income instability, limited access to institutional credit constraining investment capacity, inadequate extension services creating technological and managerial gaps, climate variability affecting water availability and productivity (De Silva and Soto 2009), rising input costs - particularly feed constituting 50–70% of operational expenses (Tacon and Metian 2008) - and environmental pressures such as water pollution, siltation, and encroachment of water bodies.

Although aquaculture is gaining increasing prominence in the region, there remains a significant gap in recent, comprehensive studies focusing specifically on the socio-economic conditions and constraints of freshwater fish farmers in the Cauvery Delta. Existing research often concentrates on broader agrarian transitions (Shylendra 2024) or emphasizes high-value brackish water shrimp aquaculture, thereby overlooking the distinct realities of inland freshwater fish culturists who constitute the majority of aquaculture practitioners in the delta. Addressing this knowledge gap is essential for designing targeted, evidence-based policy interventions that promote inclusive and sustainable growth, particularly given that smallholder aquaculture systems globally are dominated by socioeconomically marginalized communities facing systematic barriers to credit, technology, and market access (Belton and Little 2011).

Earlier studies from other regions have demonstrated the importance of micro- and macro-level socioeconomic assessments in identifying constraints faced by fishing communities. Goswami *et al.* (2002) pioneered comprehensive constraint analysis in Assam's aquaculture sector, while international research has established that socioeconomic factors - caste, landholding size, education, organizational participation—critically shape farmer vulnerability and productivity outcomes (Krishna 2002; Barrett *et al.* 2010). In Tamil Nadu, focused studies on inland freshwater fish farmers remain limited. Notable contributions include Gowsalya *et al.* (2019), who reported high feed prices and limited availability as major constraints in Thanjavur district, and Vignesh *et al.* (2017), who identified restricted access to quality seed and inadequate water supply as critical challenges. More recently, Kachhap *et al.* (2024) examined socioeconomic status and constraints of fish farmers in Jharkhand, reinforcing the need for region-specific analyses to address localized structural barriers shaped by distinct agro-ecological, institutional, and social contexts.

Against this backdrop, the present study seeks to address two research questions central to bridging the "farm to policy" gap: how do socioeconomic factors - caste, landholding size, education, experience, organizational participation—shape farmer vulnerability and constraint severity in the Cauvery Delta? and what are the primary structural barriers preventing effective policy implementation at the farm level, and what specific interventions can address these barriers? By systematically documenting the socioeconomic profile of fish farmers and employing Garrett ranking technique to prioritize constraints, this research aims to generate actionable, evidence-based recommendations that translate farm-level realities into policy frameworks capable of fostering inclusive, sustainable aquaculture development in the Cauvery Delta region.

2 | METHODOLOGY

2.1 Study area

The present study was carried out in the Cauvery Delta region of Tamil Nadu, focusing on the districts of Thanjavur, Thiruvarur, and Nagapattinam (Figure 1). Located on the fertile alluvial plains shaped by the Cauvery River and its tributaries, this region is often referred to as the "rice bowl" of Tamil Nadu owing to its high agricultural productivity and well-developed irrigation system. Beyond its agricultural prominence, the area is characterized by an extensive network of inland water bodies - including reservoirs, tanks, ponds, rivers, and canals - which collectively create highly favourable conditions for freshwater aquaculture (Paramasivan and Pasupathi 2016). These three districts were purposively selected based on their significant contribution to inland fish production in Tamil Nadu, concentration of smallholder fish farmers, and representation of diverse agro-ecological conditions within the delta ecosystem.

The growth of freshwater fish farming in these districts is further bolstered by the presence of training and research institutions, such as the Thanjavur Centre for Sustainable Aquaculture (CeSA) and ICAR-Krishi Vigyan Kendra (KVK) Sikkal, which provide ongoing technical training, extension support, and capacity building to farmers, entrepreneurs, and rural youth (Thanjavur CeSA). Fish farmers in these areas are actively engaged in both traditional extensive systems and modern semi-intensive aquaculture methods, predominantly culturing Indian major carps alongside common carp, making substantial contributions to local livelihoods and regional food security (Pownkumar et al. 2022).

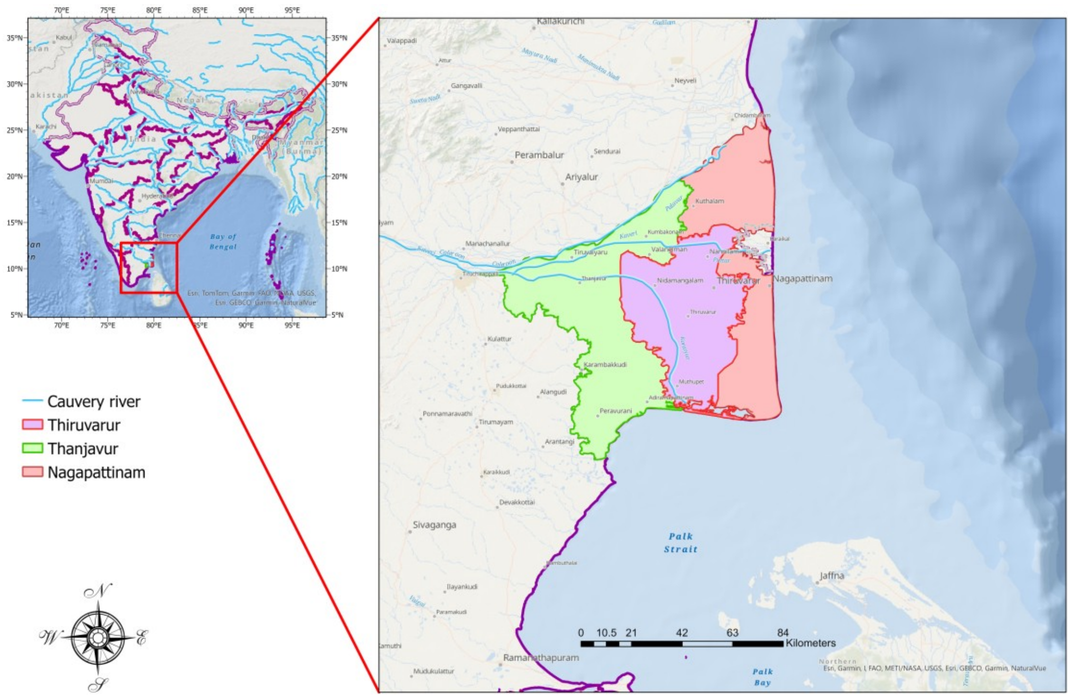

FIGURE 1 Location of the study area– Cauvery Delta region of Tamil Nadu, India.

The region has benefited from various government initiatives aimed at developing freshwater aquaculture, including the Pradhan Mantri Matsya Sampada Yojana (PMMSY) promoting cluster farming approaches, subsidized access to high-quality seed and feed inputs, and enhanced market connectivity through ice plants and cold storage infrastructure (National Fisheries Development Board 2020). However, despite these developmental interventions, local fish farmers continue to encounter persistent challenges including volatile market prices leading to income instability, difficulties in obtaining quality seed and feed at affordable costs, water scarcity and quality deterioration, and environmental pressures arising from competing land use demands and intensification of aquaculture practices (IndiaSpend 2025). These challenges, while documented anecdotally, lack systematic empirical quantification and prioritization - a gap this study addresses.

By systematically assessing the socioeconomic profile and identifying constraints faced by freshwater fish farmers in the study area through rigorous primary data collection, this research aims to generate evidence-based, region-specific recommendations for sustainable and inclusive aquaculture development. The insights derived are expected to inform policy interventions that enhance the socioeconomic well-being of fish farming communities in the Cauvery Delta and contribute to the broader objectives of food security, nutrition, and rural livelihood enhancement in Tamil Nadu (Pownkumar *et al.* 2022).

2.2 Sampling design and data collection

Farmers were identified using official beneficiary lists provided by the District Department of Fisheries in Thanjavur, Thiruvarur, and Nagapattinam, which maintain comprehensive records of registered aquaculture practitioners. From a total registered population of 950 active fish farmers across the three districts, a sample of 120 respondents (40 per district) was selected using systematic random sampling to ensure geographic representation and minimize selection bias (Cochran 1977). The sample size was determined based on the formula for finite population sampling with 95% confidence level and 5% margin of error, considered adequate for exploratory socioeconomic research in smallholder aquaculture systems.

Primary data were collected through face-to-face interviews conducted during January - April 2025 using a structured interview schedule. The schedule was developed based on extensive review of established literature on aquaculture socioeconomics (Belton *et al.* 2014) and consultation with fisheries extension specialists and researchers from Tamil Nadu Dr. J. Jayalalithaa Fisheries University. The instrument was pre-tested with 10 non-sampled farmers (excluded from the final sample) to assess clarity, comprehension, and reliability, and subsequently refined based on feedback. Content validity was ensured through expert panel review comprising fisheries economists, extension specialists, and aquaculture researchers. Reliability was confirmed through test-retest method with a subsample of five farmers interviewed twice at a two-week interval, yielding a consistency coefficient exceeding 0.85 for key variables.

2.3 Data analysis

Demographic and socioeconomic characteristics - including age, gender, marital status, education level, farming experience, religion, caste category, family type and size, occupational diversification, generational involvement in aquaculture, pond area, land ownership patterns, and organizational participation - were analyzed using descriptive statistics (frequencies, percentages, means) to develop a comprehensive farmer typology. These variables were selected based on their documented influence on technology adoption, productivity, and vulnerability in agricultural and aquaculture systems globally (Barrett *et al.* 2010).

Short-term and long-term constraints faced by fish farmers were systematically identified through focus group discussions with progressive farmers and key informant interviews with extension personnel, followed by constraint prioritization using the Garrett Ranking Technique (Garrett and Woodworth 1969). This non-parametric method converts ordinal rankings into interval-scale scores, enabling statistical comparison of constraint severity (Kumar *et al.* 2009). Respondents were asked to rank constraints in order of perceived importance, with these ranks subsequently converted to Garrett scores using the formula:

$$\text{Per cent position} = 100 \times [(R_{ij} - 0.5) / N_j]$$

Where R_{ij} represents the rank assigned to the ith factor by the jth respondent, and N_j denotes the total number of constraints ranked by the jth respondent. Percent positions were then converted to Garrett scores using standardized Garrett tables (Garrett and Woodworth 1969). Mean Garrett scores for each constraint were calculated across all respondents, with higher scores indicating greater perceived severity. Constraints were subsequently ranked in descending order of mean Garrett scores, providing a priority hierarchy for policy intervention targeting. This approach has been widely validated in agricultural constraint analysis across diverse contexts (Kumar *et al.* 2009; Vignesh *et al.* 2017).

3 | RESULTS AND DISCUSSION

3.1 Age and its implications for sector sustainability

Age was defined as the number of years the respondent had completed at the time of the study. Fish farmers were classified into three age categories: young (less than 36 years), middle-aged (36–50 years), and older (above 50 years), following the methodology outlined in the Population Census Report (2011). The average age of fish farmers in the study area was 45 years, with 45.8% falling into the middle-aged category, 33.3% classified as older, and only 20.8% as younger (Table 1). District-level variations were notable: Thanjavur exhibited an aging farmer profile with 47.5% in the older age group, while Nagapattinam showed relatively better youth participation at 22.5%.

This age distribution reveals a critical vulnerability in the freshwater aquaculture sector of the Cauvery Delta - an aging workforce with limited youth engagement, a phenomenon increasingly documented across global small-scale fisheries and aquaculture systems (Pinkerton and Davis 2015). The predominance of middle-aged and older farmers (79.2% combined) creates challenges for technology adoption, as international evidence demonstrates that older farmers exhibit lower rates of innovation uptake, particularly for information communication technologies and precision aquaculture methods (Ndah *et al.* 2014). While experience remains valuable, the aging demographic threatens sector sustainability through reduced physical labour capacity and limited intergenerational knowledge transfer - a "graying" pattern observed in European aquaculture and Asian rice-fish systems (Frei and Becker 2005). The spatial variation across districts illuminates underlying socioeconomic dynamics: Thanjavur's older profile may reflect established farmers continuing operations without attracting younger entrants - a pattern consistent with global findings that youth avoid agriculture due to perceptions of low profitability, arduous labour, and limited social status (White 2012). Nagapattinam's relatively higher youth participation (22.5%) could be attributed to recent governmental interventions and better market linkages, though this remains below the youth engagement necessary for long-term sector viability (Sumberg *et al.* 2017). Without targeted interventions to attract and retain youth through mechanization, improved income stability, and modernized infrastructure, the sector risks a labour crisis within the next decade - a concern that directly links to the inadequate extension services constraint, as extension systems globally have struggled to adapt programming for aging farmer populations (Franz *et al.* 2010).

3.2 Family structure and its influence on labour availability and economic resilience

Socioeconomic analysis revealed that the majority of fish farmers belonged to medium-sized families (50.8%), comprising five to ten members, followed by small families with fewer than five members (40.8%), and large families exceeding ten members (8.3%). The average family size was six members. Family structure showed spatial variation: nuclear and joint family systems were equally distributed overall (50% each), but Nagapattinam district exhibited a stronger joint family presence (57.5%) compared to Thanjavur (45%) and Thiruvarur (47.5%), where nuclear families predominated (Table 1).

Family type and size have direct implications for farm labour availability, economic resilience, and decision-making autonomy in aquaculture operations, as documented extensively in Asian agricultural economics literature (Quisumbing *et al.* 2014). Joint family systems, more prevalent in Nagapattinam, potentially provide critical advantages through access to unpaid family labour for pond maintenance, harvesting, and daily feeding operations - labour buffers that research shows significantly reduce operational costs in labour-intensive aquaculture systems (Ahmed *et al.* 2012). However, the shift toward nuclear families in Thanjavur (55%) and Thiruvarur (52.5%) reflects broader demographic transitions across rural South Asia driven by urbanization and out-migration of youth for non-farm employment (Mu and van de Walle 2011), creating labour shortages that elevate dependency on hired labour and directly contribute to the high cost of production constraint. International evidence demonstrates that larger households, while providing labour, face higher consumption demands that force risk-averse behaviour and distress sales at unfavourable prices (Barrett *et al.* 2001) - dynamics that link directly to the low farm gate price constraint documented in this study. The prevalence of medium-sized families (50.8%) represents a precarious balance between labour availability and economic burden, though this equilibrium is vulnerable without adequate access to credit for hiring supplementary labour during peak periods - a structural constraint well-documented in smallholder aquaculture systems globally (Belton *et al.* 2017).

3.3 Caste, religion, and structural barriers to resource access

The religious demographics revealed that 68.3% of respondents were Hindus, followed by Muslims (20.8%) and Christians (10.8%; Table 1), consistent with the broader Cauvery Delta population. More critically, caste composition showed that 61.7% of farmers belonged to Other Backward Classes (OBC) - encompassing BC, BC Muslim, MBC, and Denotified Communities - 27.5% were from Scheduled Castes (SC), and only 10.8% from the general category. This distribution reveals that freshwater aquaculture in the study area is predominantly practiced by historically marginalized communities (89.2% SC/OBC combined), which has profound implications for understanding structural vulnerabilities and resource access inequities.

The overwhelming representation of SC and OBC farmers reflects patterns of occupational stratification rooted in India's caste system, where marginalized groups have historically been excluded from land ownership and relegated to resource-poor livelihoods (Thorat and Neuman 2012). International research on social hierarchies and rural development demonstrates that such structural exclusion creates persistent barriers to credit access, technology adoption, and market participation (Barrett *et al.* 2019). SC farmers, many descendants of agricultural labourers, typically possess marginal landholdings acquired through government redistribution programs, limiting their collateral value for institutional credit - a constraint documented across South Asian smallholder systems where asset poverty perpetuates exclusion from formal financial services (Boucher *et al.* 2008). This directly explains the insufficient credit access constraint ranked second in this study. OBC farmers, while relatively better positioned in land ownership, face social exclusion from informal networks where critical market information and technology innovations circulate - a phenomenon consistent with research on social capital's role in agricultural development, where caste-based exclusion limits access to knowledge spillovers and collective action benefits (Krishna 2002). The minimal representation of general category farmers (10.8%) indicates that aquaculture is perceived as economically marginal by upper-caste groups, revealing that the persistence of low farm gate prices is structurally linked to the sector's caste composition - when livelihoods are dominated by marginalized communities with limited bargaining power, value chain actors exploit this vulnerability through extractive pricing (Bellemare and Bloem 2018). Addressing these constraints requires affirmative interventions: ensuring SC/OBC representation in farmer cooperatives, mandating equity-focused targeting in extension programs, and providing collateral-free credit instruments - approaches supported by global evidence on inclusive agricultural development (Ksoll *et al.* 2016).

3.4 Gender and marital status: labor dynamics and household decision-making

Female participation in fish farming within the study area was remarkably low at 6.7%, with male dominance at 93.3% (Table 1), consistent with gender patterns documented across Asian aquaculture sectors (Farnworth and Colverson 2015). This gender disparity reflects structural barriers embedded in aquaculture's design as a physically demanding enterprise - pond excavation, de-silting, net hauling, and emergency repairs - activities that presume male labour availability while excluding women who already bear disproportionate domestic and agricultural workloads (Petesch *et al.* 2018). However, characterizing women's absence as "low interest" obscures systemic failures: international evidence demonstrates that when aquaculture value chains create appropriate entry points - post-harvest processing, quality control, marketing - women exhibit equal or superior performance outcomes (Weeratunge *et al.* 2014). The constraint of inadequate mechanization perpetuates gender exclusion, as research across agricultural systems shows that labour-saving technologies disproportionately benefit women by reducing physical barriers to participation (Peterman *et al.* 2014). Without investments in automated feeding systems, mechanical aerators, or harvesting equipment, aquaculture remains prohibitive for women, excluding half the potential workforce and limiting household income diversification strategies documented as critical for poverty reduction (Alkire *et al.* 2013).

The marital status distribution showed that 90% of farmers were married while only 10% were single. Married farmers face greater household consumption pressures that induce risk-averse behaviour, as documented in agricultural household models globally - farmers prioritize food security over profit maximization, preferring low-input extensive systems despite higher potential returns from intensive aquaculture. The spousal division of labour in married households theoretically enables task specialization and efficiency gains (Doss 2013), yet the 93.3% male dominance reveals that wives are largely excluded from aquaculture decision-making, limiting their economic agency and reinforcing intra-household gender inequities documented across South Asian agricultural systems (Malapit *et al.* 2015). The low representation of single farmers (10%) indicates prohibitive entry barriers - particularly credit access and land ownership - for unmarried individuals who lack the household labour and asset base that married farmers leverage, further concentrating the sector among established, married, male-headed households and restricting inclusive livelihood generation, a pattern consistent with global evidence on social capital and asset requirements in aquaculture entry (Belton and Little 2011).

3.5 Education and occupation status: divergent pathways into aquaculture

Educational attainment among respondents showed that only 15% were illiterate, with 42.5% educated up to higher secondary level, 22.5% holding graduate degrees, and 20% having primary education (Table 1). While these literacy levels appear encouraging and align with Gautam *et al.* (2020), the presence of graduates (22.5%) in aquaculture demands critical interpretation beyond simple celebration of "educated farmers." In contexts of limited non-farm employment opportunities, graduate participation in fish farming may signal labour market distress rather than informed entrepreneurial choice - educated youth entering aquaculture not because of its attractiveness but due to absence of alternative livelihoods commensurate with their qualifications, a phenomenon documented across South Asian fisheries where educated entrants view aquaculture as temporary rather than career-long commitments (Belton *et al.* 2014). Education's relationship with aquaculture productivity is non-linear: while basic literacy enables technology adoption and comprehension of extension materials, over-educated entrants may lack commitment to long-term investments in pond infrastructure, water quality management, or skills development. The constraint of inadequate extension services disproportionately affects less-educated farmers (35% with primary or no formal education) who require participatory, demonstration-based approaches rather than text-heavy materials - a gap highlighted in smallholder aquaculture extension studies globally where one-size-fits-all messaging fails to accommodate cognitive diversity (Macfadyen *et al.* 2012).

Occupational patterns revealed that only 20% of respondents engaged exclusively in fish farming, while 40.8% combined it with other professions and 39.2% integrated it with agriculture, consistent with Islam *et al.*'s (2014) classification framework. This pronounced occupational pluralism (80%) aligns with patterns documented across Asian aquaculture systems, where income insufficiency rather than strategic risk management drives livelihood diversification (Belton and Azad 2012). Part-time fish farmers achieve 30-40% lower productivity than full-time operators due to time allocation conflicts during critical management periods - pond preparation, daily feeding schedules, and harvest timing often coincide with agricultural peak seasons or non-farm employment demands, forcing suboptimal compromises that depress yields (Ahmed and Garnett 2011). Those combining fish farming with non-farm professions (40.8%) may possess better credit access through stable salaried income, yet their part-time engagement precludes labour-intensive best management practices or timely responses to disease outbreaks and water quality crises (Joffre *et al.* 2015). The high proportion of fish farming-agriculture integration (39.2%) in the Cauvery Delta reflects classic Integrated Agriculture-Aquaculture (IAA) systems where farmers utilize agricultural by-products (rice bran, broken rice, livestock manure) as organic fertilizers and integrate pond-agriculture water management (Edwards 2015). However, international evidence cautions that such integration creates compound climate vulnerabilities: drought or flood events simultaneously devastate both enterprises, amplifying rather than buffering household income shocks and directly linking to the climate-related constraints identified in this study (Bunting *et al.* 2017).

3.6 Farm size and ownership: implications for economies of scale and financial vulnerability

Farm size analysis revealed that 53.3% of farmers operated small farms (less than 3 acres), 34.2% managed medium farms (3-6 acres), and only 12.5% controlled large farms (exceeding 6 acres), with an average farm area of 3.5 acres (Table 1). This skewed distribution toward small landholdings has critical implications for productivity and profitability, as extensive agricultural economics literature demonstrates strong positive relationships between farm size and efficiency in capital-intensive systems (Barrett *et al.* 2010). Small farms face structural disadvantages in achieving economies of scale - fixed costs for pond preparation, seed procurement, and hired labour are distributed over limited production volumes, inflating per-unit production costs (Belton *et al.* 2014). Furthermore, small farmers lack bargaining power in both input procurement and output marketing, as they cannot leverage bulk transactions - a vulnerability extensively documented in value chain studies where monopsony power suppresses farmgate prices (Michelson *et al.* 2012). This fragmented farm structure also limits adoption of capital-intensive technologies like mechanical aerators or automated feeders, which require minimum operational scales to justify investment (Foster and Rosenzweig 2010), perpetuating productivity gaps between small and large operators and directly contributing to the high cost of production constraint identified in this study.

Ownership patterns showed that 75% of respondents owned their land while 25% operated on leased arrangements. While land ownership theoretically provides collateral for institutional credit, the reality is more complex: small landholdings generate insufficient collateral value for securing adequate working capital loans, as financial institutions impose minimum asset thresholds documented across South Asian rural credit markets (Boucher *et al.* 2008). Leased farmers (25%) face compounded vulnerabilities - lacking asset collateral entirely, they are excluded from formal credit and forced toward exploitative informal lending at usurious rates (Conning and Udry 2007). Short-term lease durations (typically 1–3 years in the study area) create perverse incentives for extractive farming practices that maximize immediate returns at the expense of pond sustainability - a temporal discounting problem well-documented in natural resource economics (Costello *et al.* 2008). The interaction between small farm size and ownership insecurity creates poverty traps: farmers cannot invest in productivity-enhancing technologies due to credit constraints, perpetuating low yields and incomes that prevent asset accumulation, which reinforces credit inaccessibility (Carter and Barrett 2006) - a vicious cycle that underpins the persistent low farm gate price constraint as distressed small farmers accept unfavourable terms from buyers to meet immediate cash needs.

TABLE 1 Demographic profile characteristics of the respondents.

Attributes	Thanjavur (*n*=40)		Thiruvarur (*n*=40)		Nagapattinam (*n*=40)		Total (*N*=120)	
	F	%	F	%	F	%	F	%
Age								
<36 years	8	10	8	20	9	22.5	25	20.8
36-50 years	19	47.5	18	45	21	52.5	54	45.8
>50 years	13	32.5	14	35	10	25	41	33.3
								Average age = 45 years
Gender								
Male	37	92.5	37	92.5	38	95	112	93.3
Female	3	7.5	3	7.5	2	5	8	6.7

TABLE 1 Continued.

Attributes	Thanjavur (*n*=40)		Thiruvarur (*n*=40)		Nagapattinam (*n*=40)		Total (*N*=120)	
	F	%	F	%	F	%	F	%
Religion								
Hindu	32	80	26	65	24	60	82	68.3
Muslim	5	12.5	10	25	10	25	25	20.8
Christian	3	7.5	4	10	6	15	13	10.8
Caste								
OBC	26	65	25	62.5	23	57.5	74	61.7
SC	10	25	11	27.5	12	30	33	27.5
GEN	4	10	4	10	5	12.5	13	10.8
Education								
Illiterate	6	15	8	20	4	10	18	15
Primary	11	27.5	4	10	9	22.5	24	20
High	14	35	15	37.5	22	55	51	42.5
Graduate	9	22.5	13	32.5	5	12.5	27	22.5
Marital status								
Yes	35	87.5	35	87.5	38	95	108	90
No	5	12.5	5	12.5	2	5	12	10
Generation								
1st Generation	26	65	28	70	24	60	78	65
2nd Generation	14	35	12	30	16	40	42	35
Family type								
Nuclear	22	55	21	52.5	17	42.5	60	50
Joint	18	45	19	47.5	23	57.5	60	50
Family size								
<5 members	17	42.5	16	40	16	40	49	40.8
5-10 members	20	50	22	55	19	47.5	61	50.8
>10 members	3	7.5	2	5	5	12.5	10	8.3
Average family size = 6 members								
Experience								
<8 years	13	32.5	18	45	14	35	45	37.5
8-16 years	16	40	15	37.5	17	42.5	48	40
>16 years	11	27.5	7	17.5	9	22.5	27	22.5
Average experience = 11 years								
Occupation								
With other profession	18	45	16	40	15	37.5	49	40.8
With agriculture	14	35	15	37.5	18	45	47	39.2
Solely fish farming	8	20	9	22.5	7	17.5	24	20
Nature of ownership								
Owned	33	82.5	27	67.5	30	75	90	75
Lease	7	17.5	13	32.5	10	25	30	25
Area of farm								
<3 acres	17	42.5	20	50	27	67.5	64	53.3
3-6 acres	16	40	15	37.5	10	25	41	34.2
>6 acres	7	17.5	5	12.5	3	7.5	15	12.5
Average farm area = 3.5 acres								
Social Participation								
No member in any organisation	19	47.5	22	55	24	60	65	54.2
Member in any organisation	14	35	11	27.5	12	30	37	30.8
Leaders or Office bearers	7	17.5	7	17.5	4	10	18	15

3.7 Experience and generational continuity: knowledge accumulation versus structural lock-in

Experience in fish farming was categorized into three levels: low (less than 8 years, 37.5%), medium (8–16 years, 40%), and high (exceeding 16 years, 22.5%), with an average of 11 years. While experience typically correlates positively with productivity through learning-by-doing effects (Conley and Udry 2010), the distribution observed reveals important temporal dynamics. The concentration of farmers in the medium experience category (40%) suggests cohort effects - a wave of aquaculture adoption during the late 2000s and early 2010s, likely stimulated by government promotional schemes and rising fish prices during India's aquaculture expansion phase (Bostock *et al.* 2010). However, the relatively small proportion of highly experienced farmers (22.5%) indicates limited persistence beyond 16 years, reflecting either exit of discouraged farmers due to persistent low profitability (Joffre *et al.* 2015) or late sector entry by the current farming population. Farmers with medium experience (8–16 years) theoretically occupy an optimal zone for technology adoption - possessing sufficient operational knowledge while remaining receptive to change, unlike highly experienced farmers who may exhibit cognitive rigidity or "status quo bias" (Samuelson and Zeckhauser 1988) - yet this potential remains unrealized due to inadequate extension services that deliver generic messages failing to resonate with heterogeneous farmer needs (Davis *et al.* 2012).

Generational analysis revealed that 65% of respondents represented the first generation in fish farming, while only 35% were second-generation practitioners, contradicting assumptions about aquaculture as a traditional livelihood and revealing it as a relatively recent livelihood diversification strategy consistent with aquaculture's rapid expansion across Asia over the past three decades (Belton and Thilsted 2014). The dominance of first-generation farmers suggests entrepreneurial dynamism but also indicates absence of intergenerational knowledge transfer and institutional memory that buffer against recurrent challenges - second and third-generation farmers in other regions demonstrate superior crisis management capabilities accumulated through familial learning (Bunting *et al.* 2017). The limited second-generation participation (35%) signals concerning trends about sector attractiveness to youth, reinforcing earlier findings on aging demographics: when children observe parents struggling with low farm gate prices, production uncertainties, and inadequate institutional support, they rationally choose alternative pathways (Sumberg *et al.* 2017). This creates a vicious cycle where lack of youth entry perpetuates aging farmer populations with declining innovation capacity, further depressing sector dynamism and reinforcing negative perceptions that deter the next generation - breaking this cycle requires fundamental improvements in aquaculture profitability, risk mitigation, and social recognition rather than merely exhortations for "youth engagement" (White 2012).

3.8 Social participation and collective action: missed opportunities for network benefits

Social participation was assessed through membership in formal organizations including cooperatives, self-help groups (SHGs), and welfare associations. The findings revealed that the majority of respondents (54.2%) were not members of any organization, while 30.8% held membership, and only 15% advanced to leadership positions as office bearers. This low organizational participation rate has profound implications for farmers' access to collective benefits documented extensively in social capital literature (Krishna 2002). International evidence demonstrates that farmer cooperatives and producer organizations generate multiple advantages: enhanced bargaining power in input procurement and output marketing (Fischer and Qaim 2012), risk pooling through collective insurance mechanisms, knowledge spillovers through peer-to-peer learning (Krishnan and Patnam 2014), and reduced transaction costs in accessing credit and extension services (Markelova *et al.* 2009). The low farm gate price constraint ranked as the primary long-term challenge directly reflects this collective action failure - atomized individual farmers lack market power to negotiate favourable prices with intermediaries who exploit their weak bargaining position, a monopsony exploitation pattern well-documented globally (Sexton 2013). Similarly, insufficient credit access is exacerbated by low organizational participation: group-based lending models through cooperatives or SHGs have proven effective in overcoming collateral constraints that exclude smallholders from formal credit markets, yet only 30.8% of farmers participate in such organizations, suggesting either inadequate promotional efforts, historical cooperative failures that eroded trust (Baland *et al.* 2007), or social exclusion dynamics where SC/OBC farmers face barriers to joining organizations controlled by dominant caste groups (Anderson *et al.* 2015).

The minimal progression to leadership positions (15%) reveals power asymmetries within existing organizations where leadership roles provide access to privileged information, political connections, and decision-making authority that accrue disproportionately to elite members while marginal farmers remain passive beneficiaries with limited voice (Mansuri and Rao 2004). In the context of caste-stratified communities documented earlier, this leadership gap likely reflects systemic exclusion where SC/OBC farmers are members in name but excluded from governance, perpetuating vulnerability rather than empowering collective action. Addressing this collective action deficit requires interventions beyond generic exhortations to "form cooperatives" - international evidence suggests success depends on ensuring inclusive governance with mandatory SC/OBC representation in leadership (Besley *et al.* 2005), providing intensive facilitation support during organizational formation and early operation phases (Bernard *et al.* 2008), and linking producer groups to tangible benefits like bulk input procurement discounts or guaranteed offtake contracts that demonstrate immediate value (Wossen *et al.* 2017). Without such strategic interventions, the current pattern of low social participation will continue to undermine collective solutions to the price, credit, and market access constraints that individual farmers cannot resolve in isolation.

3.9 Constraints faced by freshwater fish farmers: systemic barriers to productivity and profitability

The constraints encountered by freshwater fish farmers in the Cauvery Delta were systematically analyzed and ranked through a mixed-methods approach combining literature review, focus group discussions with progressive farmers, and structured surveys, following constraint identification methodologies established in agricultural development research (Dethier and Effenberger 2012). Constraints were categorized into short-term operational challenges amenable to immediate interventions and long-term structural barriers requiring systemic policy reforms - a classification framework consistent with sustainable livelihoods approaches (Scoones 2009).

3.10 Short-term constraints: input cost pressures and market failures

Among nine identified short-term constraints (Table 2), high feed costs emerged as the primary challenge across all three districts (Thanjavur: 86.3; Thiruvarur: I; Nagapattinam: I), reflecting a global phenomenon in aquaculture where feed constitutes 50–70% of operational costs (Tacon and Metian 2008). The dominance of this constraint links directly to earlier findings on farm size and collective action deficits: small-scale farmers (53.3% with <3 acres) lack economies of scale in feed procurement and cannot access bulk purchase discounts, while low organizational participation (54.2% non-members) prevents collective bargaining with feed suppliers - a market power asymmetry documented extensively in agricultural value chain literature. The reliance on homemade feed among 40% of farmers in Thanjavur (Gowsalya *et al.* 2019) represents a rational but suboptimal adaptation to high commercial feed costs: while reducing cash expenditures, homemade feeds often exhibit poor feed conversion ratios and nutritional imbalances that depress fish growth and productivity (Tacon and Metian 2015), perpetuating the low productivity constraint (ranked 6–7th across districts) in a vicious cycle.

Insufficient credit access ranked second in Thanjavur (84.6) and third in Thiruvarur and Nagapattinam, validating earlier analysis linking SC/OBC caste composition (89.2%) and small landholdings (53.3% <3 acres) to collateral constraints that exclude farmers from formal financial services. International evidence demonstrates that credit constraints in aquaculture create cascading productivity effects: farmers cannot purchase optimal feed quantities, delay pond preparation, reduce stocking densities, or forgo disease prevention measures - all behaviours that suppress yields and incomes (Belton *et al.* 2017). The coexistence of high feed costs and credit constraints creates a particularly pernicious bind: farmers need credit most when input prices spike, yet credit access becomes most restricted precisely when risk-averse lenders perceive heightened default probabilities - a procyclical lending pattern documented across developing country agriculture (Boucher *et al.* 2008).

The demand for enhanced extension services (ranked 3rd–4th across districts) must be reinterpreted beyond simple knowledge deficits. International research demonstrates that extension effectiveness depends critically on participatory approaches, farmer-to-farmer learning platforms, and integration with input supply chains (Anderson and Feder 2007) - modalities conspicuously absent in traditional top-down extension systems prevalent in India. The heterogeneity documented earlier - spanning age (young to old), experience (low to high), education (illiterate to graduate), and farm size (small to large) - demands differentiated extension programming rather than uniform technical messages (Ragasa *et al.* 2013). Yet current systems treat farmers as homogeneous, delivering generic recommendations that resonate poorly with diverse knowledge needs and resource endowments.

Absence of organized markets (ranked 2nd–4th) directly reflects the collective action failure documented earlier and connects to the farm gate price crisis discussed below. The dominance of spot markets controlled by intermediaries - rather than contract farming arrangements, cooperative marketing, or farmer-owned processing facilities - exposes producers to monopsony exploitation (Bellemare and Bloem 2018). Spatial variation in this constraint's ranking (2nd in Thiruvarur vs. 4th in Nagapattinam) may reflect differential market infrastructure: Nagapattinam's proximity to coastal fish landing centers potentially provides alternative marketing channels that reduce dependence on single intermediaries, while landlocked Thiruvarur farmers face more concentrated buyer markets.

Water supply inadequacy ranked 2nd in Nagapattinam but 7–8th in Thanjavur and Thiruvarur, revealing critical spatial heterogeneity in resource constraints. Nagapattinam's coastal location subjects it to saltwater intrusion and groundwater salinization documented across the Cauvery Delta (Kumarasamy *et al.* 2014), rendering aquifers unsuitable for freshwater aquaculture without expensive reverse osmosis treatment. This connects to climate vulnerability discussed in long-term constraints:

sea level rise and storm surge events increasingly threaten freshwater pond systems in coastal zones globally (Bunting *et al.* 2017).

3.11 Long-term constraints: price suppression, climate vulnerability, and disease risks

Low farm gate prices emerged as the primary or secondary long-term constraint across all districts (1st in Thanjavur and Thiruvarur; 2nd in Nagapattinam; Table 3), representing the fundamental profitability crisis undermining sector sustainability. This constraint is not incidental but structurally determined by multiple factors identified earlier: fragmented farm structure preventing collective bargaining (Swinnen and Vandeplas 2010), caste-based marginalization limiting market power (Thorat and Neuman 2012), absence of organized markets enabling intermediary exploitation, and distress sales driven by credit constraints and household consumption pressures (Stephens and Barrett 2011). International aquaculture value chain studies demonstrate that producers capture only 20–35% of final consumer prices, with intermediaries, processors, and retailers extracting disproportionate margins (Belton and Thilsted 2014) - a pattern likely replicated in the Cauvery Delta where atomized farmers lack countervailing power.

TABLE 2 Short term constraints analysis of fish farmers in the study area.

Short term constraints	Thanjavur (*n*=40)		Thiruvarur (*n*=40)		Nagapattinam (*n*=40)	
	Mean score	Order of merit	Mean score	Order of merit	Mean score	Order of merit
Lack of credit	84.6	II	81.2	III	81.8	III
High cost of feed	86.3	I	86.7	I	85.9	I
Lack of water supply	69.7	VIII	69.6	VII	83.9	II
Non availability of skilled labours	74.7	V	67.0	IX	72.6	VI
Low total productivity	69.8	VII	72.4	VI	69.5	VII
Lack of organised market	76.4	IV	82.4	II	78.5	IV
Lack of fingerlings & seed availability	71.2	VI	74.5	V	74.8	V
Transportation facility	68.4	IX	69.3	VIII	66.6	IX
Improve extension services	81.8	III	79.8	IV	68.9	VIII

TABLE 3 Long-term constraints analysis of fish farmers in the study area.

Long term constraints	Thanjavur (*n*=40)		Thiruvarur (*n*=40)		Nagapattinam (*n*=40)	
	Mean score	Order of merit	Mean score	Order of merit	Mean score	Order of merit
Lack of availability of good quality water	78.9	IV	79.2	IV	86.8	I
Low farm gate price	85.9	I	88.7	I	84.2	II
Disease & pest	82.1	II	80.6	III	79.9	IV
Climatic condition	81.9	III	84.5	II	82.1	III

Unfavourable climatic conditions ranked 2nd–3rd across districts, reflecting aquaculture's high climate sensitivity documented globally (de Silva and Soto 2009). The Cauvery Delta faces compound climate risks: erratic monsoons affecting water availability, extreme temperature events inducing fish stress and mortality, and intensifying cyclones causing pond breaches and stock losses. Climate change projections for South Asia predict increased frequency of extreme events and greater rainfall variability, threatening to escalate this constraint. The interaction between climate vulnerability and earlier findings on low insurance penetration and weak collective action creates catastrophic risk exposure: farmers lack formal insurance mechanisms to buffer climate shocks, forcing distress asset sales and perpetuating poverty traps (Barrett and Carter 2013).

Disease and pest problems ranked 2nd–4th, reflecting a universal challenge in intensive aquaculture systems where high stocking densities facilitate pathogen transmission (Bondad-Reantaso *et al.* 2005). The constraint severity likely understates actual disease burdens, as farmers often misattribute mortalities to "bad water" or "stress" without diagnostic capacity to identify specific pathogens - a knowledge gap extension services should address but currently fail to bridge. Disease vulnerability connects to earlier constraints: credit-constrained farmers cannot afford prophylactic treatments or biosecurity investments, inadequate extension limits disease management knowledge, and small farms cannot implement epidemiologically sound fallowing practices requiring coordinated area-wide implementation (Corsin *et al.* 2009).

Water quality inadequacy (ranked 1st in Nagapattinam, 4th elsewhere) reflects agricultural pollution, industrial effluents, and urban wastewater contamination documented across the Cauvery Basin (Suthar *et al.* 2009). Poor water quality imposes multiple costs: increased disease susceptibility, reduced feed conversion efficiency, higher mortality rates, and need for expensive water treatment inputs. This constraint interacts perniciously with climate change: higher temperatures reduce dissolved oxygen while increasing metabolic demands and pathogen virulence, compounding water quality challenges (Ficke *et al.* 2007).

4 | CONCLUDING REMARKS

This study investigated the socioeconomic dynamics and occupational challenges of 120 freshwater fish farmers across the Cauvery Delta region of Tamil Nadu, bridging the critical gap between farm-level realities and policy formulation implicit in the "farm to policy" framework. The empirical findings reveal that freshwater aquaculture in this region is fundamentally shaped by intersecting structural vulnerabilities: caste-based marginalization (89.2% SC/OBC farmers), land fragmentation (53.3% operating <3 acres), aging demographics (79.2% middle-aged or older), and collective action deficits (54.2% lacking organizational membership). These socioeconomic characteristics determine the constraint hierarchies documented through Garrett ranking analysis - high feed costs emerged as the primary short-term barrier across all districts, followed by insufficient credit access, while low farm gate prices constituted the dominant long-term constraint. Critically, these challenges form mutually reinforcing poverty traps where small landholdings limit credit access, restricting feed purchases and technology adoption, depressing productivity and forcing distress sales at exploitative prices.

The "farm to policy" theme central to this study reflects the imperative to ground policy design in lived farmer realities rather than technocratic assumptions. This study demonstrates that constraints faced by Cauvery Delta fish farmers are not merely technical deficits but manifestations of deeper structural inequities—caste-based exclusion limiting market power, land fragmentation preventing economies of scale, and organizational deficits undermining collective action. Effective interventions must therefore address root causes through specific, actionable measures.

For short-term constraints, establish district-level feed cooperatives enabling bulk procurement at 10-15% discounts and facilitate Public-Private Partnerships for local feed manufacturing utilizing agricultural by-products abundant in the delta. Expand collateral-free Kisan Credit Cards scaled to pond area (minimum ₹50,000 per acre; 1 US Dollar = 90.71 Indian Rupee ₹) with seasonal repayment schedules aligned to harvest cycles, and strengthen Self-Help Group linkages to institutional credit through NABARD. Restructure extension services through Farmer Field Schools emphasizing peer-to-peer learning and deploy mobile veterinary units providing on-site disease diagnosis, ensuring differentiated programming for heterogeneous farmer populations spanning illiterate to graduate education levels. Establish Aquaculture Producer Organizations (minimum 200 members per district) providing collective bargaining power and infrastructure investments including cold storage and insulated transport enabling access to distant urban markets.

For long-term structural constraints, implement minimum support prices for key species calibrated to production costs plus 15% profit margin, and promote value addition through farmer-owned processing units capturing margins currently extracted by intermediaries. Address Nagapattinam's acute water constraint through freshwater storage reservoirs and managed aquifer recharge, while establishing disease surveillance networks with mandatory reporting and coordinated fallowing practices breaking pathogen transmission cycles. Critically, mandate 50% subsidy allocations and 40% cooperative leadership positions for SC/OBC farmers, addressing systematic exclusion that perpetuates vulnerability regardless of technical interventions.

The finding that 65% represent first-generation farmers combined with aging demographics signals urgent need for youth attraction through mechanization reducing physical labour, digital infrastructure connecting youth to modern information systems, and entrepreneurship support for value chain enterprises. Without fundamental improvements in profitability and social recognition through these structural reforms, youth will continue rational exits from aquaculture, threatening sector sustainability. This study's contribution lies in demonstrating that effective policy must address root causes - caste-based exclusion, land fragmentation, organizational deficits - rather than symptoms, translating farm-level insights into frameworks that can genuinely transform aquaculture from distress-driven survival into dignified, profitable livelihoods sustaining current farmers and attracting future generations.

5 | STUDY LIMITATIONS AND FUTURE RESEARCH

While providing detailed baseline data, the cross-sectional design precludes causal inference - longitudinal research tracking intervention impacts over time is essential. Future studies should employ econometric approaches quantifying constraint severity, evaluate alternative institutional arrangements through randomized trials, and develop integrated bioeconomic models simulating policy scenarios for climate-resilient aquaculture development.

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ETHICAL APPROVAL

This study was conducted based on the approval of the ethical committee of TNJFU, Nagapattinam, Tamil Nadu, India.

CONFLICT OF INTEREST

The author declares no conflict of interest.

AUTHORS' CONTRIBUTION

S. Dawood Ibrahim - Conceptualization, acquisition of data, data analysis and interpretation and drafting the manuscript; V. Senthilkumar - Conceptualization, data interpretation, critical review and final approval of the manuscript; T. Umamaheswari and R. Durairaja - Conceptualization, critical review and final approval of the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on a reasonable request from the corresponding author.

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