

Fishing Capacity and Environmental Conditions Drive Short Term Patterns of Fishing Effort and Catch in Ghana's Artisanal Marine Fishery

Harriya Musah-Yussif

mharriya651@gmail.com

Kwame Nkrumah University of Science and Technology

Seth Mensah Abobi

Kwame Nkrumah University of Science and Technology

Thomas Kwaku Agyemang

Kwame Nkrumah University of Science and Technology

Benjamin Betey Campion

Kwame Nkrumah University of Science and Technology

Research Article

Keywords: Artisanal fisheries, Small pelagic fishes, Catch per unit effort, Fishing capacity, Generalised additive models, Gulf of Guinea

Posted Date: October 22nd, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11210702/v1>

License:  This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Ghana's marine artisanal (canoe) fishery contributes more than 75% of the country's total marine landings and supports the livelihoods of about 10% of the national population, yet several of the small pelagic stocks that sustain it are fished above the level associated with maximum sustainable yield. Most research on the fishery has relied on annual or seasonal aggregates, which obscure the short-term, daily decisions that determine how much fishers actually land. We analysed 2,203 trip-level records from 316 fishers at 16 landing beaches in Ghana's four coastal regions, collected on 20 dates in July–August and November 2025. Trip duration varied widely among dates, gears and regions, and fisher identity accounted for about 71% of the variance in duration not explained by gear, location and crew size. Catch and catch per unit effort (CPUE) were strongly right-skewed and differed among gears; beach seines had the highest catch rate. Trip duration was only weakly correlated with catch (Spearman's $\rho = 0.14$) and was not significantly associated with it once crew size, gear and fisher identity were included in a mixed-effects model, whereas crew size remained a consistent positive predictor. Generalised additive models (GAMs) showed nonlinear effects of trip duration, chlorophyll-a, wave height and rainfall on catch; refitting them as Tweedie GAMs with a fisher random effect confirmed these effects and additionally detected a nonlinear effect of sea surface temperature. Because chlorophyll-a was unavailable for July–August, the environmental models rest on 905 trips. Catch was more strongly associated with fishing capacity (crew size and gear) and environmental conditions than with hours at sea. Overall, the results indicate that catch in this fishery was more strongly associated with fishing capacity (crew size and gear) and environmental conditions than with hours spent fishing. This has implications for the design of effort-based management measures, such as Ghana's closed fishing season and canoe registration moratorium, and for the interpretation of catch-per-unit-effort as an indicator of stock status in this fishery.

1 Introduction

Artisanal (canoe) fishing is the largest marine fishing sub-sector in Ghana. Canoe crews make short trips close to shore using purse seines (locally Poli/Watsa), beach seines, drift gill nets and other set nets, and they target mainly small pelagic fishes such as sardinellas, anchovy and mackerels, often called the “people's fish” [1–3]. The sector contributes more than 75% of marine landings and supports the livelihoods of about 10% of the population [2, 4]. The 2016 canoe frame survey counted 11,583 canoes operating from 292 landing beaches [5], and the number rose to 12,175 by 2022 [6].

The fishery is under heavy pressure. Catches are reported to have fallen by about 60% between 1996 and 2011, with excess fishing capacity of roughly 40% [2, 7, 8]. *Sardinella* landings dropped from over 120,000 t in the early 2000s to about 17,000 t in recent years [3], catch per unit effort (CPUE) of small pelagics fell to about 25% of its 1992 level by 2019 [9], and four of the five small pelagic stocks were assessed as fished above the level associated with maximum sustainable yield [8]. Assessments also indicate that nominal effort understates the growth in fishing power of the canoe fleet [10]. Management

responses include annual closed seasons, whose effects on landings have been mixed [11], and a three-year moratorium on new canoe entrants that began on 1 October 2023 [12].

Evidence for these policies comes largely from annual or seasonal aggregates [3, 9, 13]. Several studies document the decline, but they average over the daily decisions that determine what a canoe lands: whether to go to sea, how long to stay out, how many crew to carry, which gear to use and how much fuel to burn. These decisions are shaped by weather, fuel costs and fish availability [14, 15]. Short-term fishing dynamics have been studied in other small-scale fisheries [16, 17], but to our knowledge the relationship between daily effort and catch in Ghana's canoe fishery has not been quantified from trip-level data across the coast.

The gap matters for interpretation as well as management. Catch is often modelled as the product of catchability, effort and biomass, and CPUE is used as an index of abundance on the assumption that catchability is constant [18, 19]. In schooling small pelagic fisheries this assumption is fragile: catch per trip depends on finding and capturing a shoal, catchability varies with gear, crew and environment, and CPUE can stay high while abundance falls (hyperstability) [20, 21]. If hours at sea are only loosely coupled to catch, effort measured as time will be a poor guide to fishing pressure. We therefore asked whether trip-level catch in Ghana's canoe fishery is more closely associated with fishing capacity (crew size and gear) and environmental conditions than with hours spent fishing.

Using 2,203 trip-level records from 316 fishers at 16 landing beaches in all four coastal regions, we (1) characterised short-term variation in fishing effort (trip duration); (2) quantified short-term variation in catch and CPUE among days, gears and regions; (3) examined the relationship between effort and catch while accounting for repeated sampling of fishers; and (4) tested the association of catch with sea surface temperature, chlorophyll-a, wave height and rainfall, together with effort.

2 Materials and methods

2.1 Study area and sampling design

Data were collected at 16 landing beaches in Ghana's four coastal regions: Greater Accra, Volta, Central and Western (Fig. 1, Table 1). Four beaches per region were selected purposively because they support intensive canoe activity, depend substantially on small pelagic fishes and are dominated by purse seines (Poli/Watsa), drift gill nets and beach seines. The 2016 canoe frame survey recorded from 47 to more than 400 canoes at the sampled beaches [5]. Because beaches and respondents were not chosen at random, the sample is not statistically representative of the national canoe fleet, and the results describe the sampled beaches and periods.

Respondents were drawn from active fisher lists validated with chief fishermen; where no list existed, every third canoe landing during the morning landing period was selected. Eligible respondents were fishers, canoe owners or crew members with direct knowledge of the day's fishing operation and catch. In total, 316 fishers were sampled repeatedly, giving 2,203 records (median 6 records per fisher, range 1–

20); 150 fishers were sampled in both periods and 166 in one. The unit of observation is a fishing operation reported by a respondent on a given date. In 116 records (5.3%) the same fisher had two records on one date, almost all from beach seine (102) and other set net (14) operations that are worked as multiple hauls or sets per day; these were retained as separate hauls.

Sampling took place on 20 dates in two windows in 2025: 25 July–1 August (8 dates) and 13–24 November (12 dates). The windows fall in different phases of the Ghana–Côte d’Ivoire upwelling cycle. Late July marks the start of the major upwelling season (July–September), when round sardinella (*Sardinella aurita*) is abundant in coastal waters, whereas mid-to-late November lies in the warm period after the major upwelling [22–24]. Canoes were exempt from the 2025 closed season [25], so both windows represent open-fishing conditions.

Table 1
Sampled landing beaches and fishing-trip duration (h) by region and sampling period.

Region	Landing beaches	Period	n	Mean ± SD	Median (IQR)
Greater Accra	Awudun, Ashamang, Sangornaa, Bortianor	July	316	6.81 ± 2.78	7 (4)
		November	348	7.60 ± 3.84	7 (4)
Volta	Dzelukope, Abutiakope, Vodza, Adina	July	408	4.72 ± 3.09	5 (2)
		November	404	5.60 ± 2.09	6 (2)
Central	Abaka Ekyir, Ayipey, Elmina Main, Abandze	July	233	11.00 ± 6.28	12 (8)
		November	235	13.30 ± 10.50	10 (8)
Western	Shama Apo, Aboadze, Nkakemu, Fantiline/Boat-Ase	July	140	24.60 ± 23.60	18 (7)
		November	117	30.60 ± 30.00	18 (6)

n = number of records; IQR = interquartile range. “July” denotes the 25 July–1 August window. The table includes 2,201 of the 2,203 records.

2.2 Fishery data

Data were collected with a structured questionnaire administered on tablets (Survey Solutions Interviewer), pre-tested before fieldwork and administered in English or the local language. Respondents were interviewed repeatedly so that effort and catch were recorded for individual trips rather than by

long-term recall. Fishing effort was operationalised as nominal effort: fishing-trip duration in hours [26]. Catch was the weight of fish landed per trip (kg), as reported by respondents, and CPUE was catch divided by trip duration (kg h^{-1}). Other variables were crew size, fishing gear (beach seine, drifting gill net, pursing net [Poli/Watsa], other set net, and “other (specify)”), fishing location (shallow water, deep water, both, or could not tell) and premix fuel quantity. A total of 143 records had zero duration (days on which the respondent did not fish). These were kept in the effort models on the raw scale but were excluded from CPUE analyses, where CPUE is undefined.

2.3 Environmental data

Four environmental variables were used: chlorophyll-a concentration (mg m^{-3}), sea surface temperature (SST; K), significant wave height (m) and rainfall (mm). They were retrieved as NetCDF files, mainly from the Copernicus Marine Service and NOAA’s ERDDAP, subset to Ghana’s Exclusive Economic Zone and matched by date to the sampling days. Files were inspected in QGIS and processed in ArcGIS Pro 3.4. Chlorophyll-a was not available for download for the July–August window, which accounted for most missing values in this variable. Only records with all four environmental variables were used in the environmental models ($n = 905$; 1,298 records excluded, 57.1% of records missing chlorophyll-a).

2.4 Statistical analysis

All statistical analyses and graphical presentations were performed in R version 4.4.2 (R Core Team, 2024) using RStudio version 2026.09.0 + 174 (Posit Software, PBC). Daily patterns of effort, catch and CPUE were summarised by mean, median, standard deviation and coefficient of variation (CV). Differences in trip duration among dates were tested with one-way ANOVA, and the linear trend with study day by simple regression. Because fishers were observed repeatedly, we fitted a linear mixed-effects model of trip duration (raw hours, because zero-duration trips prevent log transformation) with sampling date (as a continuous study day, and in a second model as a factor), crew size, gear and fishing location as fixed effects and fisher identity as a random intercept. Fixed effects were tested with Satterthwaite-adjusted tests, dates were compared with Tukey-adjusted estimated marginal means, and the intraclass correlation coefficient (ICC) was computed from the variance components [27].

Catch and CPUE among gears were compared with ANOVA and the Kruskal–Wallis test, followed by Dunn’s test with Holm adjustment. Because these tests treat repeated observations as independent, we also fitted Tweedie generalised additive models (GAMs; log link) with a fisher random intercept. Catch rates were modelled by adding log trip duration as an offset, so that exponentiated coefficients are catch-rate ratios relative to beach seines [28–30].

The effort–catch relationship was examined with Spearman’s rank correlation (overall, by region and by sampling window) and simple linear regression. A linear mixed-effects model of catch included trip duration, crew size, gear, fishing location and premix quantity as fixed effects and fisher as a random intercept. A GAM with a smooth term for trip duration and parametric terms for crew size, gear and location tested for nonlinearity. This GAM was refitted as a Tweedie model with fisher and landing-beach

random effects. As a sensitivity analysis, the linear model including landing beach was refitted after excluding three high-catch beaches (Shama Apo, Adina and Bortianor).

The association of catch with environmental conditions was tested with a Gaussian GAM (REML) with smooth terms for trip duration, chlorophyll-a, wave height, SST and rainfall and parametric terms for crew size and gear ($n = 905$). Because catch is skewed and fishers were sampled repeatedly, the model was refitted as a Tweedie GAM with the same smooths plus a fisher random intercept. Concurvity among smooth terms was assessed with the concurvity function of the *mgcv* package. Significance was assessed at $\alpha = 0.05$, and both models are reported so that any change in conclusion is explicit.

Data collection formed part of a Fisheries Commission of Ghana research project. All respondents gave prior informed consent, were told the purpose of the study and how the data would be used, and could withdraw at any time.

3 Results

3.1 Variation in fishing effort

Mean trip duration ranged from 5.81 ± 5.85 h on 27 July to 34.70 ± 30.30 h on 23 November (Fig. 2A, Table 2). Medians were 5–9 h on 17 of the 20 dates and reached 18 h or more only on the last three dates (22–24 November; $n = 20, 21$ and 8). Variability within dates was high (CV 7.9–160%), and the lowest CV came from a date with only eight records. Duration differed among dates (ANOVA, $F(19, 2171) = 12.13$, $p < 0.001$). A linear trend with study day was significant but negligible ($\beta = 0.0133 \pm 0.0048$ h per day, $p = 0.005$; $R^2 = 0.0036$).

Table 2
Daily variation in trip duration, catch and catch per unit effort (CPUE) on the 20 sampling dates in 2025. Values are mean (median).

Date	n	Effort (h)	CV (%)	Catch (kg)	CV (%)	CPUE (kg h ⁻¹)	CV (%)
25 Jul	89	16.9 (9.0)	136	248 (160)	113	27.6 (12.5)	166
26 Jul	189	8.34 (7.0)	74.1	356 (45)	267	45.4 (7.75)	229
27 Jul	161	5.81 (5.0)	101	150 (15)	221	27.8 (12.0)	143
28 Jul	165	9.40 (7.0)	110	286 (120)	149	43.4 (15.0)	165
29 Jul	63	6.56 (6.0)	33.7	384 (118)	131	62.1 (24.7)	143
30 Jul	136	10.2 (7.0)	116	385 (200)	129	73.9 (20.4)	175
31 Jul	148	8.59 (7.0)	74.0	126 (53)	130	18.4 (8.47)	147
1 Aug	146	9.91 (7.0)	138	341 (100)	285	52.3 (12.0)	269
13 Nov	90	10.1 (7.0)	120	325 (50)	157	70.6 (14.6)	165
14 Nov	179	8.50 (7.0)	76.1	474 (255)	171	72.8 (34.5)	158
15 Nov	161	7.49 (7.0)	44.2	253 (80)	173	38.8 (13.3)	189
16 Nov	101	8.78 (7.0)	84.1	258 (80)	164	35.2 (12.1)	180
17 Nov	179	12.1 (7.0)	157	417 (160)	148	64.9 (15.6)	163
18 Nov	65	8.28 (6.0)	160	812 (355)	124	144 (60.0)	124
19 Nov	159	11.1 (8.0)	112	377 (200)	160	54.5 (20.0)	162
20 Nov	84	8.22 (6.5)	68.3	256 (110)	137	37.9 (12.4)	137
21 Nov	37	14.4 (8.0)	140	161 (27)	184	11.4 (4.5)	161
22 Nov	20	28.2 (18.0)	94.5	224 (124)	125	7.71 (6.53)	112
23 Nov	21	34.7 (18.0)	87.3	683 (124)	302	11.6 (6.53)	196
24 Nov	8	18.0 (18.5)	7.86	124 (48.5)	129	6.78 (2.89)	126

n = records per date for effort and catch. CPUE is undefined for zero-duration trips, so CPUE n is smaller (2,050 records in total; 8–177 per date). CV = coefficient of variation.

In a mixed-effects model with a fisher random intercept, the study-day effect remained very small ($\beta = 0.0063$ h, $p < 0.001$) and crew size was unrelated to duration ($p = 0.299$; Table 3). Gear and fishing location were related to duration. Relative to beach seines, drifting gill net trips were 1.8 h longer, other set net trips 4.1 h shorter and “other (specify)” trips about 71 h longer. Trips confined to shallow water were 1.5 h shorter than trips covering both shallow and deep water, and trips whose location could not

be identified were 6.7 h shorter. After adjustment, duration differed from the reference date (25 July) on 12 of 19 dates, all positively. Fisher identity was the largest source of variation: the fisher random intercept had a variance of 33.10 against a residual variance of 13.32, an ICC of about 0.71.

Table 3
Linear mixed-effects model of fishing-trip duration (h).

Predictor	Estimate	SE	t	p
Study day	0.0063	0.0018	3.53	< 0.001
Crew size	0.0215	0.0208	1.04	0.299
Drifting gill net (vs beach seine)	1.759	0.632	2.78	0.006
Other (specify) (vs beach seine)	71.230	2.13	33.43	< 0.001
Other set nets (vs beach seine)	-4.085	1.49	-2.74	0.006
Pursing nets (vs beach seine)	0.354	0.732	0.48	0.630
Location: cannot tell (vs both)	-6.697	0.494	-13.55	< 0.001
Location: deep water (vs both)	0.455	0.381	1.19	0.231
Location: shallow water (vs both)	-1.460	0.371	-3.94	< 0.001

Fisher identity was a random intercept (variance 33.10; residual variance 13.32; ICC $\approx$ 0.71).

Trip duration differed strongly among regions (Table 1, Fig. 3). The Western Region had the longest and most variable trips (means 24.6 h in July and 30.6 h in November, but median 18 h with an interquartile range of 6–7 h), and the Volta Region the shortest and most uniform (4.7 and 5.6 h; interquartile range 2 h). Mean duration was higher in November than in July in all four regions.

3.2 Variation in catch and CPUE

Catch per trip ranged from 0 to 9,602 kg (mean 327.36 ± 651.39 kg; median 96 kg; quartiles 10 and 400 kg), with strong right skew (skewness 5.88, kurtosis 54.06). CPUE ranged from 0 to 1,057 kg h⁻¹ (mean 50.34; median 12.86; quartiles 2.50 and 51.61) and was far from normal (Shapiro–Wilk $W = 0.542$, $p < 0.001$). Daily mean catch ranged from 124 kg (24 November) to 812 kg (18 November), and daily CV of catch from 113% to 302% (Table 2). Mean CPUE was highest on 18 November (144 kg h⁻¹; median 60) and fell to 6.8–11.6 kg h⁻¹ on 21–24 November. By region, mean catch was highest in the Volta Region (389.1 kg) and Greater Accra (348.5 kg) and lower in the Western (239.3 kg) and Central Regions (238.5 kg); these regional means were compared descriptively and not tested.

Catch differed among gears (Kruskal–Wallis $\chi^2 = 277.15$, $df = 4$, $p < 0.001$; Fig. 4, Table 4), as did CPUE ($\chi^2 = 198.85$, $df = 4$, $p < 0.001$). Dunn’s tests separated beach seines from drifting gill nets and other set nets for both catch and CPUE (Holm-adjusted $p < 0.001$). The Tweedie model with a fisher random effect

confirmed the ordering ($n = 2,150$; 44.9% deviance explained): relative to beach seines, catch was lower for drifting gill nets ($\beta = -1.89$), other set nets ($\beta = -1.83$) and pursing nets ($\beta = -1.03$) and higher for “other (specify)” gear ($\beta = 0.98$; all $p < 0.001$), and the fisher random effect was highly significant ($p < 0.001$). The catch-rate model ($n = 2,002$; 55.4% deviance explained) gave rate ratios below 1 for every gear relative to beach seines (Table 4). “Other (specify)” gear therefore combined a high catch per trip with a comparatively low catch rate.

Table 4
Catch and CPUE by fishing gear, with Tweedie catch-rate ratios relative to beach seines.

Gear	n	Catch (kg), mean $\pm$ SD	Median	n	CPUE (kg h ⁻¹), mean $\pm$ SD	Median	Rate ratio
Beach seine	1,616	390 $\pm$ 687	160	1,530	61.4 $\pm$ 106.0	20.4	1 (ref.)
Drifting gill net	281	36.1 $\pm$ 55.3	20	261	4.81 $\pm$ 6.58	3.00	0.17
Other set net	127	50.0 $\pm$ 72.6	21	93	13.6 $\pm$ 14.3	9.00	0.40
Pursing net (Poli/Watsa)	80	211 $\pm$ 405	30	72	46.7 $\pm$ 94.7	6.61	0.40
Other (specify)	46	834 $\pm$ 1,364	611	46	9.97 $\pm$ 14.9	7.44	0.27

Rate ratios from the Tweedie GAM with log trip duration as offset and a fisher random intercept (all $p \leq 0.005$).

3.3 Relationship between effort and catch

Trip duration and catch were weakly correlated (Spearman’s $\rho = 0.139$, $p < 0.001$), and simple regression gave a slope of 4.82 kg per extra hour (SE 1.12, $p < 0.001$) with $R^2 = 0.008$. The correlation varied among regions: $\rho = 0.118$ in the Central Region ($n = 467$), 0.210 in Greater Accra ($n = 664$), 0.245 in the Volta Region ($n = 805$) and 0.622 in the Western Region ($n = 257$; all $p \leq 0.010$). It also differed between windows (Fig. 5): $\rho = 0.265$ in July–August ($n = 1,096$; $p < 0.001$) and -0.008 in November ($n = 1,095$; $p = 0.784$).

In the mixed-effects model, trip duration was not associated with catch ($\beta = -0.283$ kg h⁻¹, SE 2.561, $p = 0.912$), whereas crew size was strongly and positively associated ($\beta = 19.83$ kg per crew member, SE 2.36, $p < 0.001$; Table 5). Compared with beach seines, catches were lower for drifting gill nets ($\beta = -140.6$, $p = 0.014$), other set nets ($\beta = -440.8$, $p < 0.001$) and pursing nets ($\beta = -169.7$, $p = 0.040$) and higher for “other (specify)” gear ($\beta = 552.0$, $p = 0.009$). Shallow-water trips landed more than trips covering both depths ($\beta = 101.1$, $p = 0.040$), while premix quantity was unrelated to catch ($p = 0.152$). The GAM showed that the relationship with duration was nonlinear (edf = 6.97, $F = 4.42$, $p < 0.001$) and explained 15.2% of the deviance; crew size remained positive ($\beta = 24.45$, SE 1.94, $p < 0.001$).

Landing beach affected the result. In a linear model that included landing beach, the duration coefficient was 6.82 kg h⁻¹ (p = 0.022) and the crew-size coefficient 13.00 (p < 0.001). After excluding the three high-catch beaches, the duration coefficient fell to 1.92 kg h⁻¹ (p = 0.343), while crew size remained positive (5.85, p = 0.004). In the Tweedie GAM with fisher and landing-beach random effects (n = 2,124; 50.6% deviance explained), the beach effect was highly significant (p < 0.001), the nonlinear duration effect remained significant (edf = 6.67, p < 0.001) and crew size remained positive (p < 0.001), whereas the “other (specify)” gear effect was no longer significant (p = 0.100).

Table 5
Association of trip duration and crew size with catch across model specifications.

Model	Trip duration	Crew size (kg per person)
Simple linear regression	4.82 kg h ⁻¹ (p < 0.001)	—
Linear mixed model (fisher random intercept)	-0.28 kg h ⁻¹ (p = 0.912)	19.83 (p < 0.001)
GAM, Gaussian	smooth: edf 6.97 (p < 0.001)	24.45 (p < 0.001)
Linear model including landing beach	6.82 kg h ⁻¹ (p = 0.022)	13.00 (p < 0.001)
same, excluding three high-catch beaches	1.92 kg h ⁻¹ (p = 0.343)	5.85 (p = 0.004)
Tweedie GAM, fisher + landing-beach random effects	smooth: edf 6.67 (p < 0.001)	positive (p < 0.001)
Environmental GAM, Gaussian	smooth: edf 7.54 (p < 0.001)	30.36 (p < 0.001)
Environmental GAM, Tweedie + fisher random effect	smooth: edf 6.20 (p = 0.007)	n.r.

n.r. = not reported. “Smooth” indicates a nonlinear effect of trip duration.

3.4 Environmental conditions and catch

The Gaussian GAM (n = 905; 28.8% deviance explained; adjusted R² = 0.269) detected significant nonlinear effects of trip duration, chlorophyll-a, wave height and rainfall on catch, but not of SST (Table 6, Fig. 6). Chlorophyll-a had a slightly positive partial effect at low concentrations that became progressively negative at higher ones. Wave height had a negative effect at low values, a maximum at about 0.9–1.0 m and a decline at higher values. The rainfall effect rose at low rainfall, was negative at about 12–20 mm and rose again at high values with wide confidence intervals. The duration effect rose sharply at about 80–110 h and declined at longer durations, but only a few trips were that long and uncertainty was large. Crew size was positively associated with catch (β = 30.36, SE 3.40, p < 0.001), and other set nets caught less than beach seines (β = -312.64, p = 0.003).

The Tweedie GAM with a fisher random effect (power parameter 1.57; 58.8% deviance explained; adjusted $R^2 = 0.48$) confirmed the significant effects of duration, chlorophyll-a, wave height and rainfall (Table 6, Fig. 7). In contrast to the Gaussian model, it also detected a significant nonlinear effect of SST (edf = 4.49, $p < 0.001$), and the fisher random effect was highly significant ($p < 0.001$). Concurvity was high between trip duration and the fisher random effect (worst case ≈ 0.99) and moderate to high between chlorophyll-a and SST (≈ 0.83) and between wave height and rainfall (≈ 0.78). The smooth terms should therefore not be read as fully independent effects.

Table 6
Smooth terms in the Gaussian and Tweedie generalised additive models of catch (n = 905).

Smooth term	Gaussian edf	F	p	Tweedie edf	p
Trip duration	7.54	3.853	< 0.001	6.20	0.007
Chlorophyll-a	1.77	4.289	0.011	1.79	0.017
Wave height	2.89	3.656	0.009	6.63	< 0.001
Rainfall	5.17	2.816	0.013	6.55	< 0.001
Sea surface temperature	1.00	0.002	0.976	4.49	< 0.001

edf = effective degrees of freedom. Deviance explained: 28.8% (Gaussian) and 58.8% (Tweedie with fisher random effect); the two are not directly comparable because the error distributions differ.

4 Discussion

Catch in this fishery was more strongly associated with who was fishing, with what gear, at which beach and under what sea conditions than with hours at sea. Trip duration, once crew size, gear and fisher identity were accounted for, added little to explaining catch, while crew size was a consistent positive correlate. We discuss what this implies for how effort and CPUE are measured, and for management.

4.1 Variations in Fishing Effort

Most trips were short single outings, with a tail of overnight and multi-day operations concentrated in the Western Region and in the “other (specify)” gear category. Gear and location shaped duration in plausible ways: passive drift nets are set, drifted and hauled over many hours, and deeper grounds imply longer transit and search. The largest source of variation, however, was the fisher. About 71% of the variance left after accounting for gear, location and crew size lay among fishers, in line with the “skipper effect” documented in other fleets [31–33]. In a canoe fishery this term is best read as the combined signature of skipper, canoe, crew and habitual grounds, which our data cannot separate.

Much of the daily variation in raw means probably reflects which fishers, gears and beaches were sampled on each date. The raw mean of 34.7 h on 23 November corresponded to an adjusted difference of only 6.4 h relative to 25 July once crew size, gear and fisher identity were accounted for. The last four

November dates ($n = 86$ records in total) had median trips of 18–18.5 h, matching the Western Region median in both windows, which suggests that landings on those dates were dominated by that region. Weighted by sample size, mean duration on 13–20 November (9.5 h) was almost identical to that in July–August (9.2 h), but on 21–24 November it was 22.9 h and mean CPUE fell from 60.6 to 10.2 kg h⁻¹ (means weighted by the number of records per date, from the daily summaries in Table 2). Because region and date are partly confounded, we treat the temporal signal as weak.

The two dates with the smallest samples in their windows, 29 July ($n = 63$) and 18 November ($n = 65$), were both Tuesdays, a traditional non-fishing day in many Ghanaian fishing communities, although some fishers do fish on Tuesdays [34–36]. Both dates were atypical. On 29 July the CV of trip duration was the lowest of the July–August window (33.7%) and median CPUE the highest (24.7 kg h⁻¹); on 18 November mean and median catch (812 and 355 kg) and CPUE (144 and 60 kg h⁻¹) were the highest of the study. We did not record whether each fisher observed the holiday, so we cannot say whether this reflects holiday fishing by a subset of fishers, fish accumulating on non-fishing days, or chance. It is a hypothesis for targeted sampling.

4.2 Catch is heavy-tailed and structured by gear and place

Catch and CPUE were more skewed than trip duration. This is the pattern expected when catch is generated by encountering discrete shoals: many trips land little and a few land very large quantities, and aggregation of fish in space and time can decouple catch rates from abundance [37, 38]. Single trips can dominate daily means: on 23 November the mean catch was 683 kg but the standard deviation was 2,062 kg for 21 trips. The largest catch (9,602 kg, from a 91-h trip with a crew of six using “other (specify)” gear and reportedly targeting blue marlin and sailfish) was confirmed against the field records and retained; the next largest catches, up to about 8,500 kg, were beach seine hauls by crews of 20–30 people. Medians, rank-based tests and error distributions suited to skewed, zero-heavy data are therefore preferable to arithmetic means [30, 39, 40]. The Kruskal–Wallis and Tweedie analyses agreed on the gear ordering, which adds confidence to that result.

Beach seines had the highest catch rate, and every other gear had a rate ratio of 0.17–0.40 relative to them. Gears differ in mode of operation, selectivity, fishing depth and target species [41], so two fishers spending the same hours at sea can land very different catches. The Ghanaian sardinella fleet includes vessels of 5–23 m with nets from 54 m to almost 1,000 m and crews of 2–30 people [42], so large differences in fishing power are expected. The high productivity of beach seines is closely tied to the capture of small fish: their bycatch is dominated by juveniles of commercially important species [43], and sardinella landings are dominated by immature fish [42]. The “other (specify)” category had a high catch per trip but a low catch rate, consistent with long, low-intensity, multi-day operations, and part of its apparent gear effect disappeared when landing beach was a random effect. Differences in CPUE among gears combine efficiency, target species, hold capacity and how effort is defined. For passive gears, net length and soak time describe effective effort better than time at sea [44]. These comparisons describe gear performance, not relative abundance [18].

Regional mean catch (Volta 389 kg, Greater Accra 349 kg, Western and Central 239 kg) followed almost the reverse order of trip duration (shortest in the Volta Region, longest in the Western Region). This contrast is consistent with length of trip and size of catch reflecting different processes. Regional differences in gear mix, canoe and crew size, target species and local shoal availability probably all contribute, but we did not test regional differences in catch formally.

4.3 Effort and catch relationship

The relationship between trip duration and catch was weak ($p = 0.14$; $R^2 < 1\%$) and disappeared once crew size, gear, location and fisher identity were included ($\beta = -0.28 \text{ kg h}^{-1}$, $p = 0.91$). This follows from what trip duration measures. The standard catch equation relates catch to effective effort, catchability and abundance [18]. Trip duration is nominal effort: it combines transit, search, setting, hauling and idle time and is only loosely tied to effective effort. In fisheries that harvest schools, catch per set depends largely on school size and net capacity, and the appropriate effort unit depends on gear [45]. Catch per trip is also bounded by hold capacity, the number of hands available to haul and handle fish, and what can be sold, so extra hours probably bring diminishing returns once a shoal has been found. The GAM supports a nonlinear relationship, but the hump at about 80–110 h rests on few trips, probably from the Western Region and the “other (specify)” category. We read it only as an indication that multi-day operations can land large catches [28].

The strength of the relationship varied with context. It was weak in three regions ($p = 0.12$ – 0.25), where trips are uniformly short (interquartile range 2–8 h) and there is little variation in duration to relate to catch, and strong in the Western Region ($p = 0.62$), where trips range from overnight to multi-day. It was positive in July–August ($p = 0.27$) and absent in November ($p = -0.01$). Early in the major upwelling season, sardinella and other small pelagics are abundant near the coast [22, 46], so more time on the water may translate into more successful sets, whereas success in November may depend more on locating a shoal than on time spent searching. The long, low-catch trips on the last sampling dates also contribute to the November result. The landing-beach sensitivity analysis shows that the modest duration effect is sensitive to spatial structure: the coefficient fell from 6.8 to 1.9 kg h^{-1} when three high-catch beaches were excluded, although the nonlinear duration effect persisted in the Tweedie model with beach and fisher random effects. Catch-rate data from this fishery are clearly spatially structured [47].

Crew size was the most consistent positive correlate of catch, adding about 20 kg per person in the mixed model, 24 kg in the effort GAM and 30 kg in the environmental GAM. Crew size is a proxy for canoe size, net length and the capacity to haul large nets, which together determine fishing power, the catch a unit takes per unit of nominal effort [31]. The results suggest that the size and organisation of the fishing unit were more strongly associated with catch than the hours it spent at sea, and stock assessments likewise indicate that nominal effort does not capture the growth in fishing power of the canoe fleet [10]. Premix quantity was not related to catch. Subsidised premix is subject to diversion, hoarding and irregular supply [48, 49], and fuel use depends on distance and engine power as much as on catch, so the quantity recorded per trip is a weak proxy for effective effort.

The weak coupling between effort and catch, together with heavy-tailed catches dominated by occasional large hauls, bears on the use of CPUE as an indicator of stock status. When fishers target aggregations, CPUE can stay high while abundance declines, a phenomenon that has masked collapses in other fisheries [20, 37, 38]. This is plausible for schooling small pelagics, and the assessment of Ghana's small pelagic stocks notes that CPUE trends can be over-optimistic when increases in fishing power are not accounted for [10]. Our results are consistent with this concern: marginal hours yielded little additional catch, whereas catch scaled with the size and number of fishing units. We did not measure abundance, so we cannot show that hyperstability occurs.

4.4 Environmental conditions and catch

Because chlorophyll-a was unavailable for the whole July–August window, the 905 complete-case trips used in the environmental models necessarily come from the November window, after the major upwelling. The SST smooth spans only about 1.25 K (301.0–302.25 K, or roughly 27.9–29.1°C). The environmental results therefore describe variation within one warm-season window and cannot be extended to the upwelling season. Because the variables were matched to trips by date rather than measured at the fishing ground, and because the smooth terms show moderate to high concavity with one another and with the fisher random effect, the curves are best read as candidate environmental windows for further testing, not as precisely estimated independent effects. The interpretation below relies on the Tweedie model, which is more appropriate for skewed, repeated data; where it changes a conclusion from the Gaussian model, we say so. The deviance explained by the two models (28.8% and 58.8%) is not directly comparable because the error distributions differ.

The partial effect of chlorophyll-a was slightly positive at low concentrations and became progressively negative at higher ones. Two considerations make a negative association credible. First, in coastal waters influenced by river discharge and resuspended sediment, satellite chlorophyll-a includes non-algal constituents [50], so high nearshore values may mark turbid, freshwater-influenced water rather than productive water holding fish; chlorophyll-a variability in the Gulf of Guinea is also closely related to physical variables [51]. Second, fish respond to phytoplankton production with a delay because energy passes through zooplankton [52], and fish can graze down the plankton on which they aggregate. On the Ivorian shelf, interannual catches of *S. aurita* were inversely related to same-year chlorophyll-a, which was interpreted as grazing by sardinella larvae [24], and zooplankton in the Gulf of Guinea upwelling region may be under top-down control by sardinella [53]. Those studies used annual data, whereas ours are trip-level, so the comparison supports the direction of the relationship rather than its magnitude.

Catch was lowest at low wave heights, peaked at about 0.9–1.0 m and declined at higher wave heights. A unimodal response is what the optimal environmental window concept predicts for upwelling systems: moderate mixing enriches the surface layer and retains production, whereas too little limits nutrient supply and too much disperses shoals [54]. Operational factors probably reinforce this. Rough seas restrict launching from surf beaches, gear deployment and safety, and fishers in West Africa use weather information to decide when to go to sea [55], so trips made in rough conditions are likely to be those of the best-equipped units.

The rainfall effect was nonlinear, with the range between 0 and about 20 mm best supported. Rainfall can act through runoff, which lowers salinity and adds nutrients and turbidity and can shift species composition (flat sardinella, *S. maderensis*, tolerates variation in salinity and temperature better than *S. aurita* [22]); through squalls and strong winds that make fishers delay trips; and through coupling with upwelling, since cold coastal sea surface temperatures in July–September are associated with reduced coastal rainfall [56]. Rainfall and drought have long been linked to the performance of the Ivorian–Ghanaian sardinella fishery [57], and in tropical artisanal fisheries rainfall effects on production often appear with a lag [58]. The same-day effect we found more likely reflects behaviour, turbidity and salinity, and lagged effects on recruitment are a complementary line of enquiry.

SST had no detectable effect in the Gaussian model (edf = 1.00, $p = 0.976$) but a significant nonlinear effect in the Tweedie model with a fisher random effect (edf = 4.49, $p < 0.001$). This is a genuine change in conclusion. It is consistent with SST being the surface expression of upwelling, whose timing and intensity have been linked to sardinella catch in the Gulf of Guinea [23, 24, 53]. It should be interpreted cautiously, however. SST showed moderate concavity with chlorophyll-a, and SST integrates processes operating over weeks to years, so an effect detected from trip-level data matched to daily SST is better treated as a correlate of the broader upwelling state on each date than as a physiological response of fish to temperature at the scale of one trip.

4.5 Implications for management and monitoring

Fishing capacity (crew size and gear) was more strongly associated with catch than trip duration in the sampled data. This suggests that measures aimed at the number and size of fishing units deserve consideration alongside measures that regulate time spent fishing. The moratorium on new canoe entrants was scheduled to run from 1 October 2023 to 30 September 2026 [12, 59]; our findings provide empirical support for considering capacity, alongside duration, in designing and evaluating such measures, and for exploring complementary controls on net dimensions and engine power monitored through the canoe register. As an observational study, however, this work describes associations. It does not test how a change in registration policy, net dimensions or engine power would affect fishing mortality, and any such measure would need to be evaluated on its own terms.

Monitoring should record effort measures that better reflect effective effort than trip duration, such as the number of sets, net length and soak time [44], and CPUE should be interpreted cautiously as an indicator of stock abundance and should be appropriately standardised for gear, fishing capacity, landing site, fisher-level heterogeneity and other relevant sources of variation before being used for stock-status inference. Canoes were exempt from the 2025 and 2026 closed seasons, although communities' fishing holidays continue to apply [25, 60]. Our data were therefore collected without a canoe closure and can serve as a baseline against which future closures and holidays are evaluated, particularly if later monitoring follows the same protocol at the same beaches. Beach seines had the highest catch and CPUE and also take large numbers of juveniles [43], so mesh regulation, limits on hauling effort and seasonal or spatial protection of nursery areas merit consideration. Finally, chlorophyll-a, wave height and rainfall carried information about catch and are freely available from remote sensing at suitable

frequency; they could contribute to a fisheries information system of the type proposed for Ivorian waters [24] and to weather services that fishers already use to manage risk [55].

5 Conclusions

Fishing effort, catch and CPUE in Ghana's marine artisanal fishery varied strongly over short time scales, and most of this variation was associated with who was fishing, with which gear and at which site, more than with the calendar day. Trip duration was a weak predictor of catch, whereas crew size and gear, the main components of fishing power, were consistently related to catch. The effort–catch relationship was strongest in the Western Region and in July and depended on landing site. Catch was also associated, nonlinearly, with chlorophyll-a, wave height and rainfall, in a pattern consistent with an environmental window for fishing on this upwelling coast. These findings suggest that fishing capacity and gear characteristics should be considered alongside trip duration when assessing and managing fishing effort.

Declarations

Acknowledgements

This study formed part of a larger research project of the Fisheries Commission of Ghana, which funded the field data collection. We thank the chief fishermen and community leaders who facilitated respondent selection, and the artisanal fishers at all 16 landing beaches who gave their time to participate in this study.

Funding

This research was supported by the Fisheries Commission of Ghana.

AI use declaration

Artificial intelligence (AI) tools were used solely for grammatical review and language editing of this manuscript. They were not used to generate scientific content, interpret results, or draft substantive sections of the text.

Competing interests

The authors declare no competing interests.

Ethics approval and consent to participate

This study used field survey data collected in 2025 involving human participants. Because the project was conducted as an institutional monitoring initiative managed by a state regulatory body, the Marine Fisheries Management Division (MFMD) of the Fisheries Commission of Ghana waived the requirement for formal academic Institutional Review Board (IRB) approval, and the data collection protocol was

carried out by the Commission in accordance with its standard statutory regulatory framework for national fisheries evaluations. One of the authors participated directly in the fieldwork as part of the Commission's institutional team. Prior informed consent was obtained from all participants before their involvement in the study; participants were informed of the purpose of the research, the voluntary nature of their participation, and the confidentiality of the information provided, and were free to decline or withdraw at any time without consequence. The Fisheries Commission of Ghana granted the authors formal authorisation to analyse the dataset and publish the findings for academic purposes.

Consent for publication

Not applicable.

Clinical trial number: not applicable

Data availability

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

Author contributions

Conceptualization: H.M.Y., S.M.A., T.K.A.; Methodology: H.M.-Y., S.M.A.; Formal analysis: H.M.-Y., S.M.A.; Investigation: H.M.-Y., B.B.C.; Resources: B.B.C.; Data curation: H.M.-Y.; Writing – original draft: H.M.-Y.; Writing – review and editing: all authors; Supervision: S.M.A., T.K.A.; Funding acquisition: B.B.C., S.M.A. All authors read and approved the final manuscript.

References

1. Guyader O, Berthou P, Koutsikopoulos C, et al. Small scale fisheries in Europe: a comparative analysis based on a selection of case studies. *Fish Res.* 2013;140:1–13.
2. Akpalu W. Cost-benefit analysis of interventions. Copenhagen Consensus Center: Ghana Priorities; 2020.
3. Asiedu B, Okpei P, Nunoo FKE, Failler P. A fishery in distress: an analysis of the small pelagic fishery of Ghana. *Mar Policy.* 2021;129:104500.
4. Owusu V, Andriesse E. From open access regime to closed fishing season: lessons from small-scale coastal fisheries in the Western Region of Ghana. *Mar Policy.* 2020;121:104162.
5. Dovlo E, Amador K, Nkrumah B. (2016) Report on the 2016 Ghana marine canoe frame survey. Information Report No. 36. Fisheries Scientific Survey Division, Fisheries Commission, Ministry of Fisheries and Aquaculture Development, Accra. <https://www.crc.uri.edu/download/Final-2016-Canoe-Frame-Survey-Report.pdf>
6. Ministry of Fisheries and Aquaculture Development. (2024) 2023 annual performance report. https://www.mofaq.gov.gh/wp-content/uploads/2025/04/Very-final_2023-APR-FINAL-

7. Ameyaw GA, Tsamenyi M, McIlgorm A, Aheto DW. Challenges in the management of small-scale marine fisheries conflicts in Ghana. *Ocean Coast Manag.* 2021;211:105791.
8. Cook R, Nyarko BK, Aggrey-Fynn J, Acheampong E, Asiedu G. (2021) Assessment of small pelagic fish stocks in Ghanaian and adjacent waters. SSRN 3956447.
9. Lazar N, Yankson K, Blay J, et al. Status of the small pelagic stocks in Ghana in 2019. Scientific and Technical Working Group, USAID/Ghana Sustainable Fisheries Management Project. Narragansett: Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island; 2020.
10. Cook R, Acheampong E, Aggrey-Fynn J, Heath M. A fleet based surplus production model that accounts for increases in fishing power with application to two West African pelagic stocks. *Fish Res.* 2021;243:106048.
11. Owusu V. Effects of the closed fishing season on small-scale fisheries and coastal livelihoods in Ghana. *Fish Aquat Sci.* 2024;27(11):753–68.
12. Ghanaian Times. (2023) Regulating increasing fishing canoe fleet: no new entrants for 3 years, govt to suspend registration effective Oct 1. <https://ghanaiantimes.com.gh/regulating-increasing-fishing-canoe-fleet-no-new-entrants-for-3years-govt-to-suspend-registration-effective-oct-1>
13. Braimah LI. Stock assessment and current biological viability of small pelagic fish stocks in Ghana. *Appl Sci Res Period.* 2025;3(3):81–98.
14. Rahim A, Hastuti DR. Factors that influence catch production and fishing decisions of small-scale fishers during extreme weather. *AACL Bioflux.* 2023;16(6):3365–77.
15. Owusu V. Effect of rising fuel prices on small-scale fisheries livelihoods and marine sustainability in Ghana. *PLoS ONE.* 2025;20(1):e0317260.
16. Gianelli I, Ortega L, Defeo O. Modeling short-term fishing dynamics in a small-scale intertidal shellfishery. *Fish Res.* 2019;209:242–50.
17. Keppeler FW, Hallwass G, Santos F, da Silva LHT, Silvano RAM. What makes a good catch? Effects of variables from individual to regional scales on tropical small-scale fisheries. *Fish Res.* 2020;229:105571.
18. Hilborn R, Walters CJ. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. New York: Chapman & Hall; 1992.
19. Hoyle SD, Campbell RA, Ducharme-Barth ND, et al. Catch per unit effort modelling for stock assessment: a summary of good practices. *Fish Res.* 2024;269:106860.
20. Harley SJ, Myers RA, Dunn A. Is catch-per-unit-effort proportional to abundance? *Can J Fish Aquat Sci.* 2001;58(9):1760–72.
21. Demirel N, Nauen CE, Palomares MLD. Fishing effort and the evolving nature of its efficiency. *Front Mar Sci.* 2023;10:1180174.
22. Koranteng KA. Some aspects of the sardinella fishery in Ghana. In: Cury P, Roy C, editors. *Pêcheries ouest-africaines: variabilité, instabilité et changement.* Paris: ORSTOM; 1991.

23. Binet D, Servain J. Have the recent hydrological changes in the northern Gulf of Guinea induced the *Sardinella aurita* outburst? *Oceanol Acta*. 1993;16(3):247–60.
24. Kassi JB, Racault MF, Mobio BA, et al. Remotely sensing the biophysical drivers of *Sardinella aurita* variability in Ivorian waters. *Remote Sens*. 2018;10(5):785.
25. Ministry of Fisheries and Aquaculture Development. (2025) 2025 closed season notification. <https://henmpoano.org/wp-content/uploads/2025/04/2025-CLOSED-SEASON-NOTIFICATION.pdf>
26. Wallace AP, Jones JP, Milner-Gulland EJ, et al. Drivers of the distribution of fisher effort at Lake Alaotra, Madagascar. *Hum Ecol*. 2016;44(1):105–17.
27. Nakagawa S, Johnson PCD, Schielzeth H. The coefficient of determination R^2 and intra-class correlation coefficient from generalized linear mixed-effects models revisited and expanded. *J R Soc Interface*. 2017;14(134):20170213.
28. Wood SN. Generalized additive models: an introduction with R. 2nd ed. Boca Raton: Chapman and Hall/CRC; 2017.
29. Zuur AF, Ieno EN, Walker NJ, Saveliev AA, Smith GM. Mixed effects models and extensions in ecology with R. New York: Springer; 2009.
30. Bolker BM, Brooks ME, Clark CJ, et al. Generalized linear mixed models: a practical guide for ecology and evolution. *Trends Ecol Evol*. 2009;24(3):127–35.
31. Marchal P, Andersen B, Bromley D, et al. Improving the definition of fishing effort for important European fleets by accounting for the skipper effect. *Can J Fish Aquat Sci*. 2006;63(3):510–33.
32. Squires D, Kirkley J. Skipper skill and panel data in fishing industries. *Can J Fish Aquat Sci*. 1999;56(11):2011–8.
33. Ruttan LM, Tyedmers PH. Skippers, spotters and seiners: analysis of the skipper effect in US menhaden (*Brevoortia* spp.) purse-seine fisheries. *Fish Res*. 2007;83(1):73–80.
34. Nunoo FKE, Asiedu B, Olauson J, Intsiful G. Achieving sustainable fisheries management: a critical look at traditional fisheries management in the marine artisanal fisheries of Ghana, West Africa. *J Energy Nat Resour Manag*. 2015;2(1):15–23.
35. Coastal Resources Center. Technical brief: the rationale and impact of a proposed second fishing holiday for the artisanal fisheries of Ghana. Narragansett: USAID/Ghana Sustainable Fisheries Management Project, University of Rhode Island; 2018.
36. Ghana News Agency. (2022) Ghana initiates measures to ensure responsible fishing. 12 October. <https://gna.org.gh/2022/10/ghana-initiates-measures-to-ensure-responsible-fishing/>
37. Rose GA, Kulka DW. Hyperaggregation of fish and fisheries: how catch-per-unit-effort increased as the northern cod (*Gadus morhua*) declined. *Can J Fish Aquat Sci*. 1999;56(Suppl 1):118–27.
38. Erisman BE, Allen LG, Claisse JT, Pondella DJII, Miller EF, Murray JH. The illusion of plenty: hyperstability masks collapses in two recreational fisheries that target fish spawning aggregations. *Can J Fish Aquat Sci*. 2011;68(10):1705–16.

39. Pennington M. Estimating the mean and variance from highly skewed marine data. *Fish Bull.* 1996;94(3):498–505.
40. Maunder MN, Punt AE. Standardizing catch and effort data: a review of recent approaches. *Fish Res.* 2004;70(2–3):141–59.
41. Mehdi H, Lau SC, Synyshyn C, et al. A comparison of passive and active gear in fish community assessments in summer versus winter. *Fish Res.* 2021;242:106016.
42. Arizi EK, Collie JS, Castro K, Humphries AT. Fishing characteristics and catch composition of the sardinella fishery in Ghana indicate urgent management is needed. *Reg Stud Mar Sci.* 2022;52:102348.
43. Akwetey MFA, Faseyi CA, Mensah PK, et al. Juvenile species in beach seine bycatch along the coast of Ghana: any implications for fisheries? *Mar Ecol.* 2025;46(2):e70014.
44. Mendo T, Glemarec G, Mendo J, et al. Estimating fishing effort from highly resolved geospatial data: focusing on passive gears. *Ecol Indic.* 2023;154:110822.
45. Sparre P. Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fisheries Technical Paper 306. Rome: FAO; 1998.
46. Neokye EO, Dossou S, Iniga M, Alabi-Doku BN. The role of oceanic environmental conditions on catch of *Sardinella* spp. in Ghana. *Reg Stud Mar Sci.* 2021;44:101768.
47. Walters C. Folly and fantasy in the analysis of spatial catch rate data. *Can J Fish Aquat Sci.* 2003;60(12):1433–6.
48. Ghana News Agency. (2024) Majority of fisherfolks want premix fuel subsidy removed – study. 16 September. <https://gna.org.gh/2024/09/majority-of-fisherfolks-want-premix-fuel-subsidy-removed-study/>
49. Ghana News Agency. (2025) Scrap premix fuel subsidy – committee urges government. 26 May. <https://gna.org.gh/2025/05/scrap-premix-fuel-subsidy-committee-urges-government/>
50. IOCCG. Remote sensing of ocean colour in coastal, and other optically-complex, waters. In: Sathyendranath S, editor. Reports of the International Ocean-Colour Coordinating Group, No. 3. Dartmouth: IOCCG; 2000.
51. Nieto K, Mélin F. Variability of chlorophyll-a concentration in the Gulf of Guinea and its relation to physical oceanographic variables. *Prog Oceanogr.* 2017;151:97–115.
52. Cushing DH. Plankton production and year-class strength in fish populations: an update of the match/mismatch hypothesis. *Adv Mar Biol.* 1990;26:249–93.
53. Wiafe G, Yaqub HB, Mensah MA, Frid CL. Impact of climate change on long-term zooplankton biomass in the upwelling region of the Gulf of Guinea. *ICES J Mar Sci.* 2008;65(3):318–24.
54. Cury P, Roy C. Optimal environmental window and pelagic fish recruitment success in upwelling areas. *Can J Fish Aquat Sci.* 1989;46(4):670–80.
55. Okeke-Ogbuafor N, Taylor A, Dougill A, Stead S, Gray T. Alleviating impacts of climate change on fishing communities using weather information to improve fishers’ resilience. *Front Environ Sci.*

2022;10:951245.

56. Ali KE, Kouadio KY, Zahiri EP, Aman A, Assamoi AP, Bourlès B. Influence of the Gulf of Guinea coastal and equatorial upwellings on the precipitations along its northern coasts during the boreal summer period. *Asian J Appl Sci.* 2011;4(3):271–85.
57. Binet D. Influences des variations climatiques sur la pêche des *Sardinella aurita* ivoiro-ghanéennes: relation sécheresse–surpêche. *Oceanol Acta.* 1982;5:443–52.
58. Hogue AM, Cuamba EL, Gammelstrød T. (2012) Influence of rainfall on tropical coastal artisanal fisheries: a case study of northern Mozambique. *Rev Gestão Costeira Integr* 12(4).
59. Graphic Online. (2023) New fishing canoes banned. <https://www.graphic.com.gh/news/general-news/new-fishing-canoes-banned.html>
60. Anokye-Gyimah AK. (2026) 2026 closed fishing season for Ghana's marine fishing fleet. *Modern Ghana*, 28 April. <https://www.modernghana.com/news/1489260/2026-closed-fishing-season-for-ghanas-marine-fish.html>

Figures

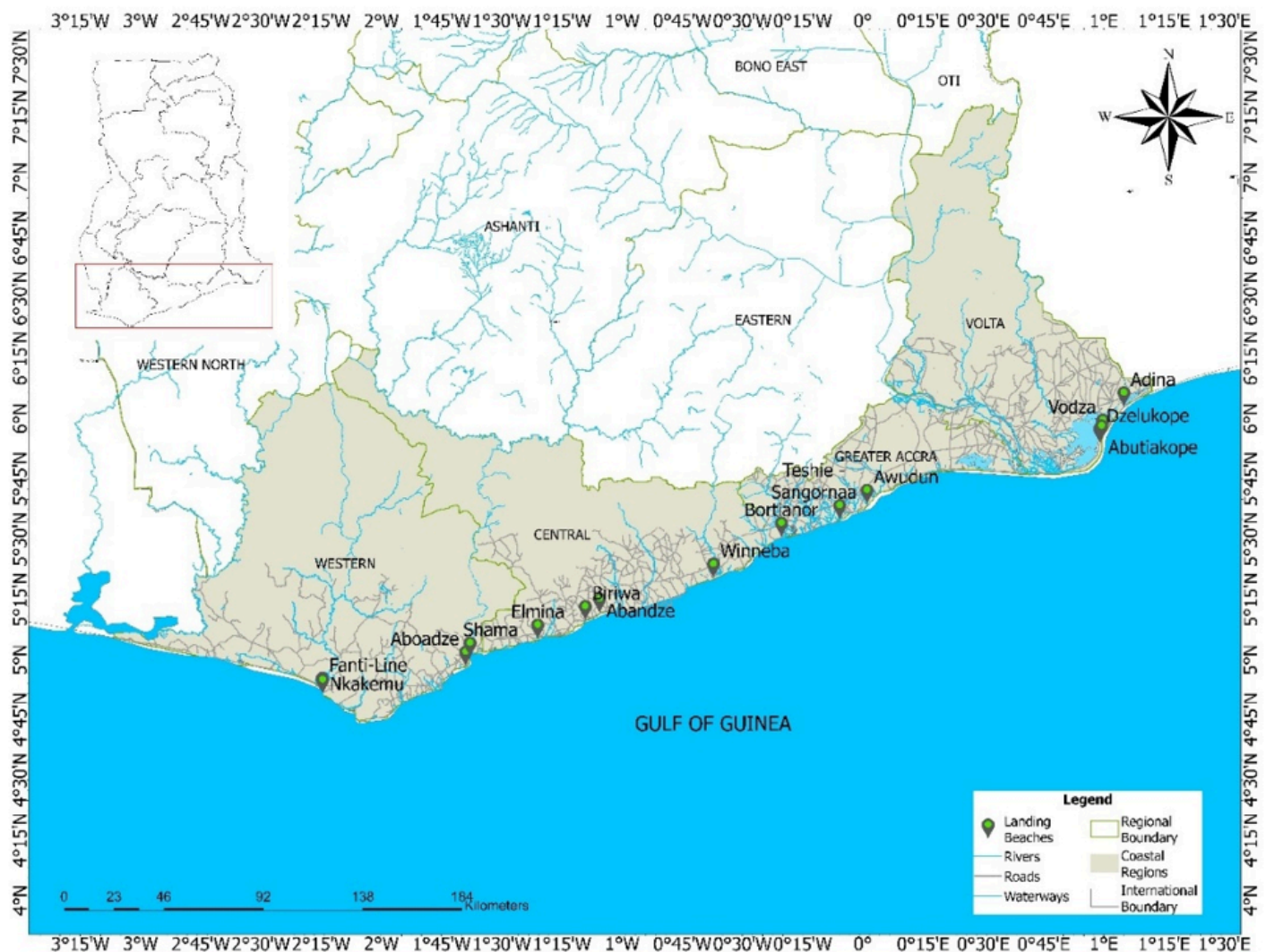


Figure 1

Sampled landing beaches along the coast of Ghana (Greater Accra, Volta, Central and Western regions).

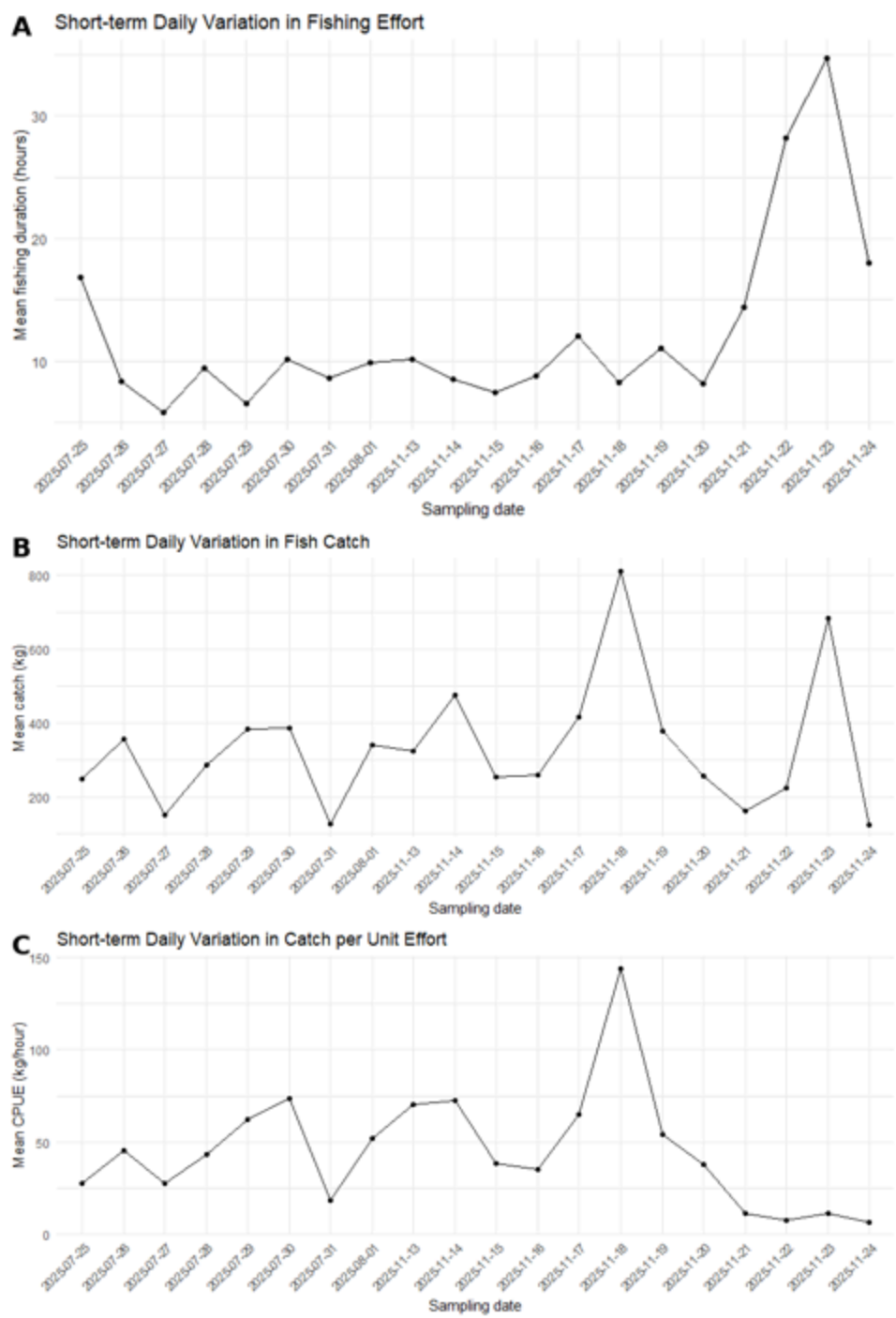


Figure 2

Daily variation in mean (A) fishing-trip duration, (B) catch and (C) catch per unit effort (CPUE) across the 20 sampling dates in July–August and November 2025.

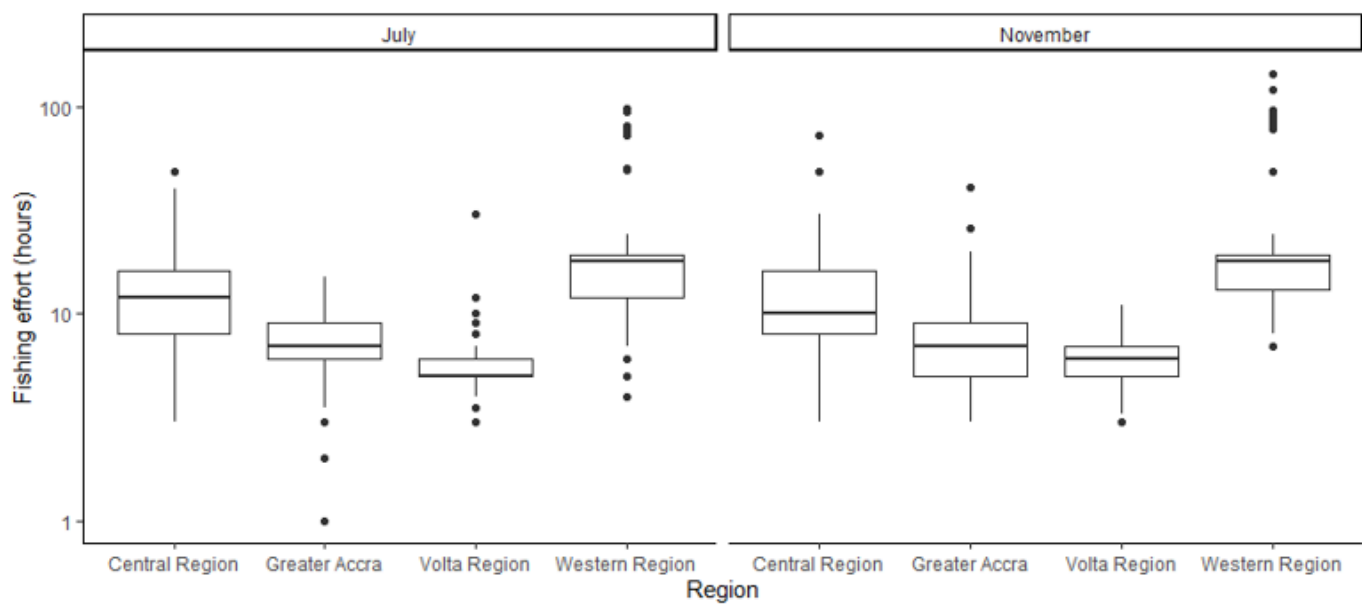


Figure 3

Fishing-trip duration (h; log scale) by region and sampling window. Boxes show the median and interquartile range.

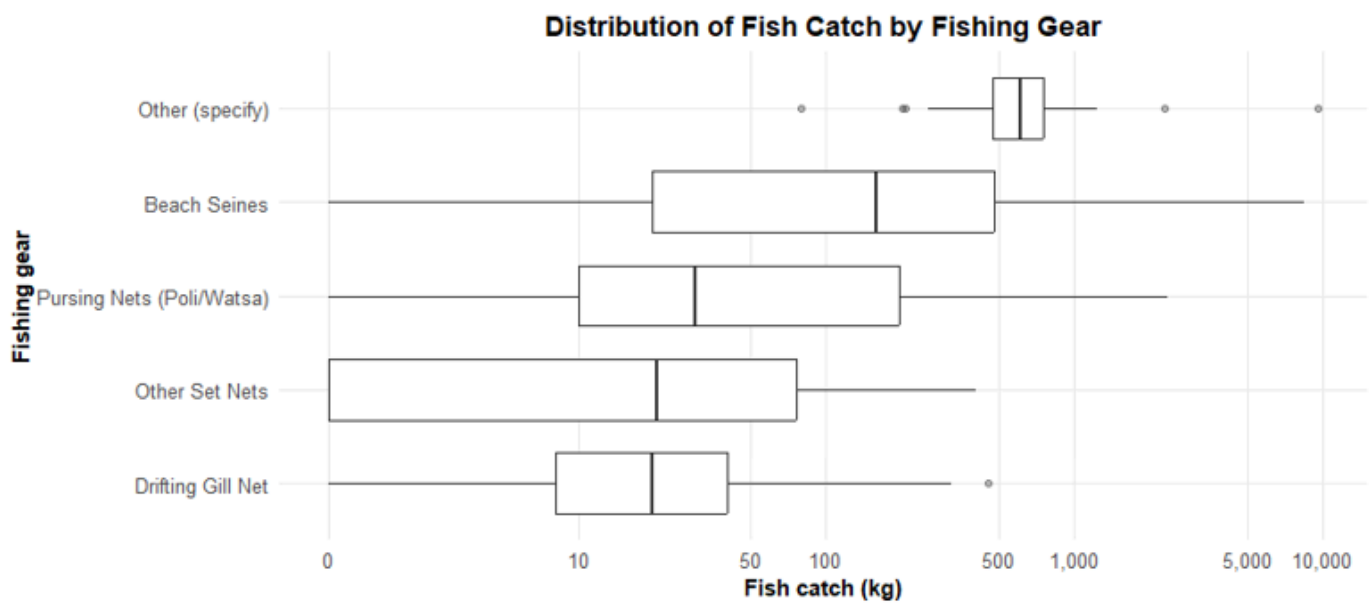


Figure 4

Distribution of catch per trip by fishing gear. Boxes show the median and interquartile range.

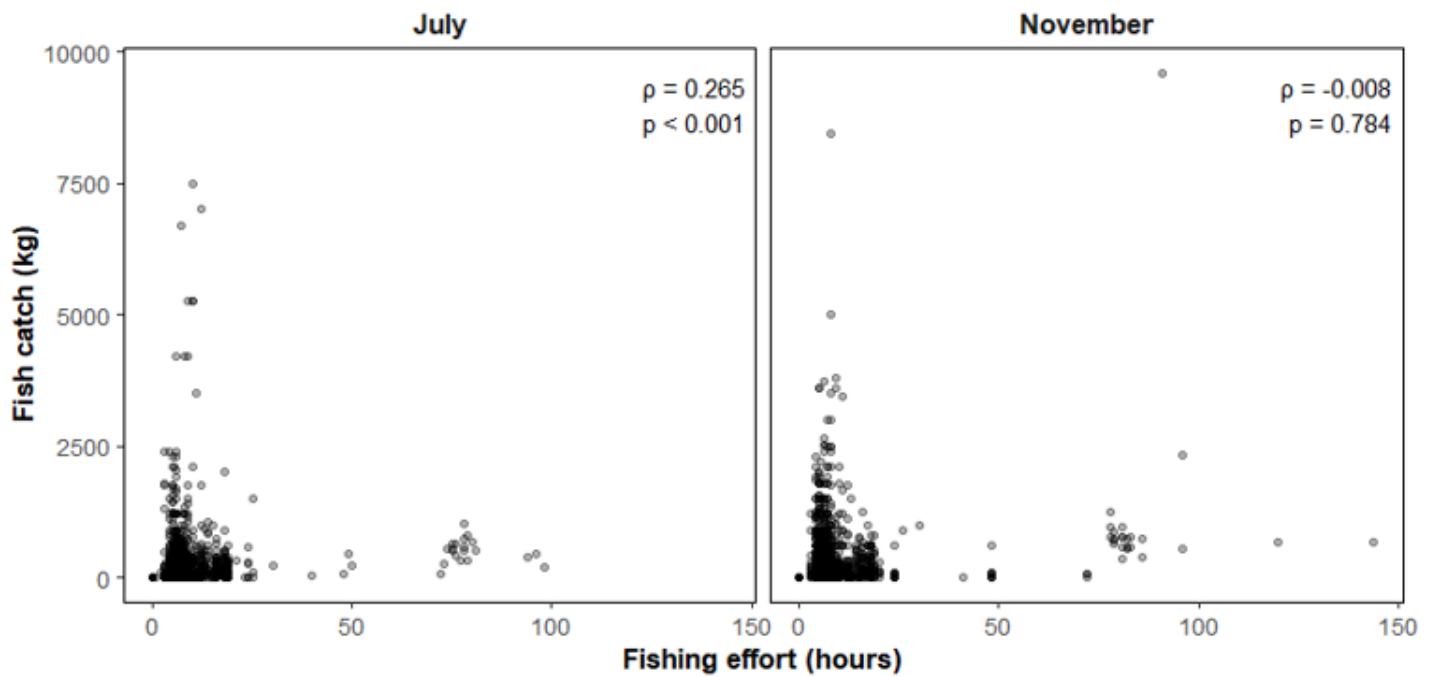


Figure 5

Relationship between fishing-trip duration and catch in the July–August and November windows, with Spearman's ρ .

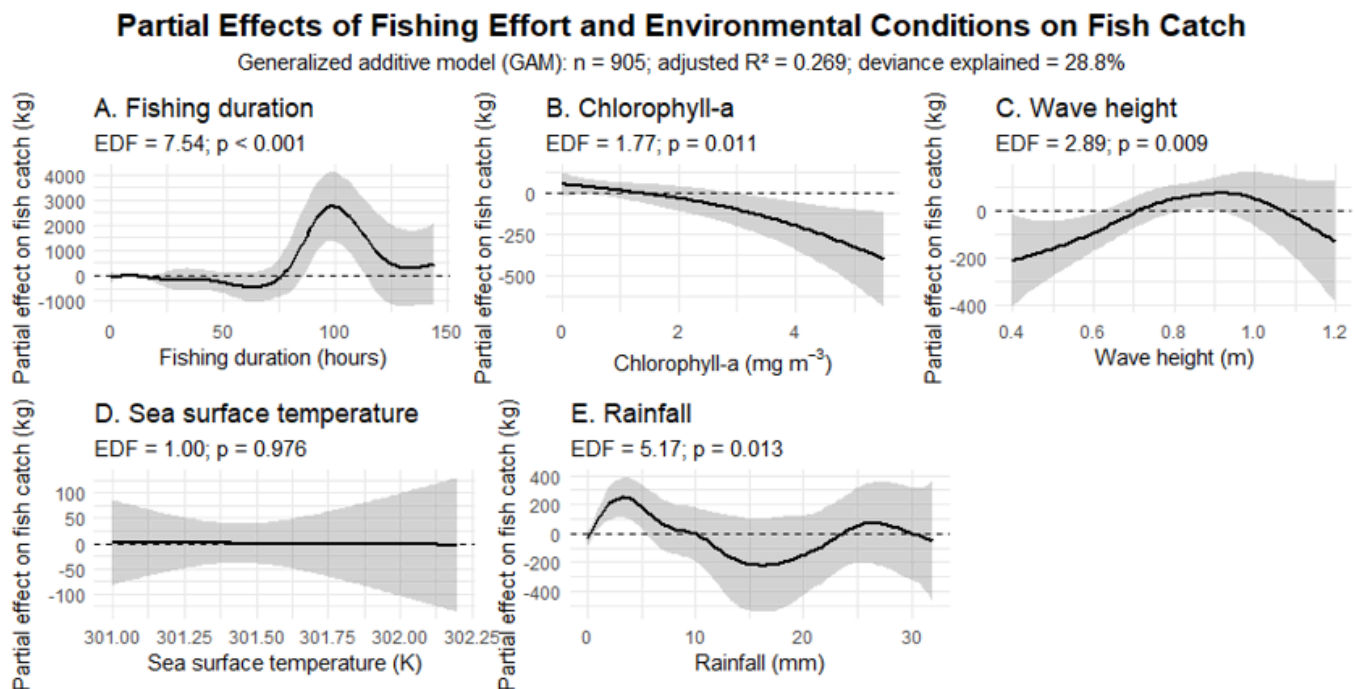


Figure 6

Partial effects of trip duration and environmental variables on catch (kg) from the Gaussian GAM ($n = 905$). Shaded bands are 95% confidence intervals; dashed lines mark zero effect.

Partial Effects of Fishing Effort and Environmental Conditions on Fish Catch (Tweedie GAM with fisher random effect)

n = 905; deviance explained = 58.8%; fisher random effect included, $p < 0.001$

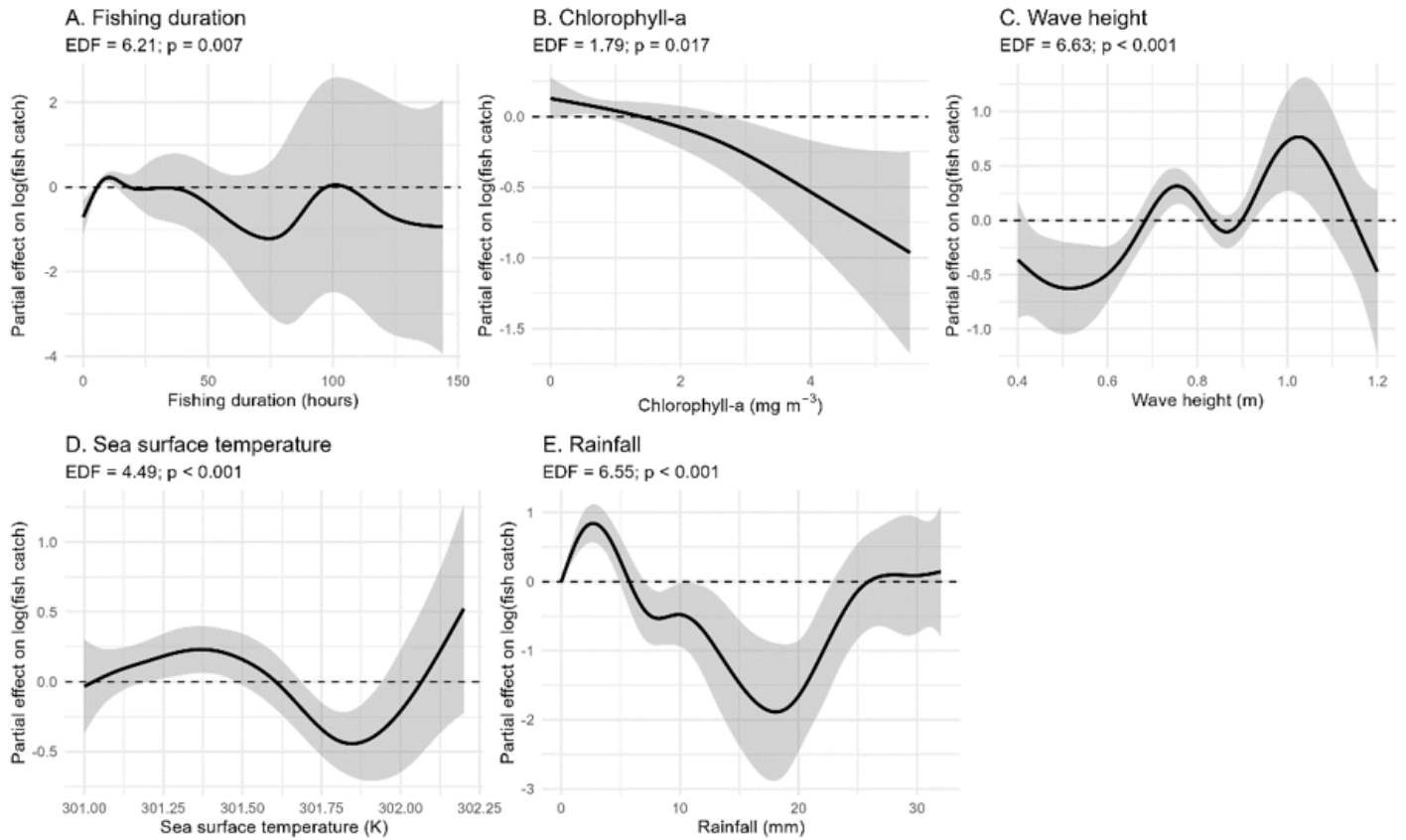


Figure 7

Partial effects on log(catch) from the Tweedie GAM with a fisher random effect (n = 905). On the log scale, a partial effect of +0.5 corresponds to a multiplicative effect of about 1.65 on catch.