From Reef to Landing Site: Trophic-Level Responses to Fishing Technology and Spatial Variation in Kenyan Small-Scale Fisheries

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1. Introduction

Mean Trophic Level (MTL) and Trophic CPUE serve as powerful indicators for evaluating the ecological footprint of fisheries and detecting early signs of declining ecosystem integrity.

Technology as an Ecological Filter: While habitat conditions influence local species assemblages, large-scale data analyses reveal that fishing pressure, fleet behavior, and market forces override much of this natural variation, restructuring food webs and altering the functional roles of key species.

Beyond "Fishing Down": While the "fishing down the food web" hypothesis suggests the removal of apex predators, tropical fisheries often exhibit "fishing through the food web," where effort shifts toward abundant mid- or low-trophic level species.

Management Necessity: Understanding the joint influence of technology, seasonality, and site-specific contexts is essential for designing gear-sensitive management that safeguards the functional integrity of nearshore reef fishery systems.

2. Objectives

i. Compare catch effort and trophic signatures among propulsion–gear combinations To compare how technology shapes functional catch structure.

ii. Assess spatial variation in in Kenya's coastal fisheries to To assess whether ecological or operational differences drive trophic patterns within Kenya's small scale fisheries.

3. Methodology

3.1. Field Surveys and Data Collection

Shore-based Catch Assessment Surveys (CAS) were conducted continuously for 18 months (March 2023–December 2024). Data were collected at five selective landing sites—Shimoni, Gazi, Mkunguni, Kilifi, and Mayungu—spanning a gradient of habitat types and fishing practices

For every landing event, enumerators recorded the propulsion mode, gear type, trip duration, crew size, and taxonomic composition of the catch. All landed fish were identified to the lowest practicable level using regional guides and cross-checked against FishBase for nomenclatural consistency.

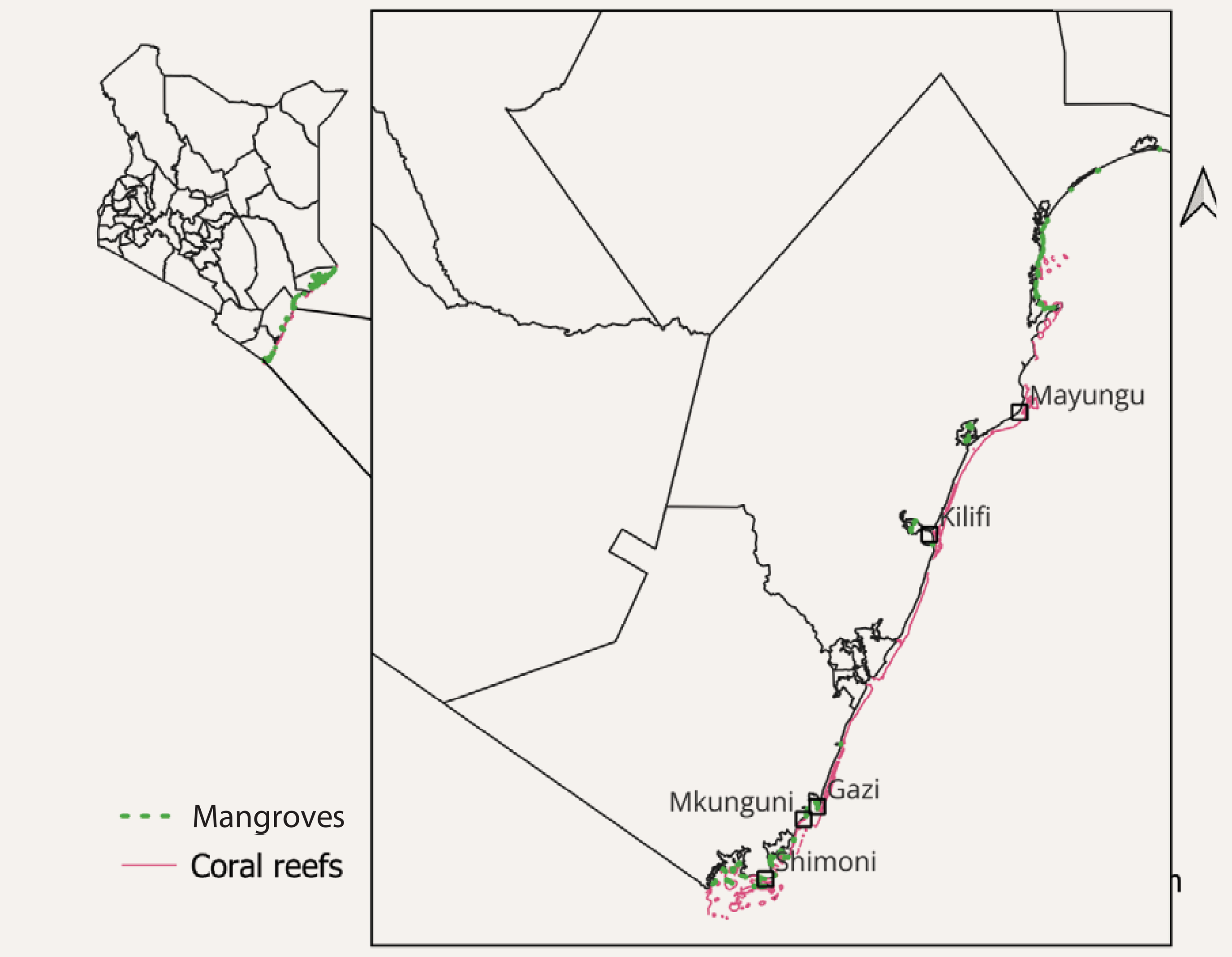

Figure 1. A map of Kenya coastline showing the fish landing sites of Mayungu, Kilifi, Gazi, Mkunguni and Shimoni

3.2. Data Processing and Analysis

- Catch per unit effort (CPUE) was calculated for each fishing trip as total landed biomass (kg) standardized by fishing effort expressed as hours fished.

- Trophic Level (TL) Assignment: Species-specific TL values were extracted from FishBase. For records identified only to genus or family, the study assigned the mean TL of all regional species within that taxon.

- Mean Trophic Level (MTL): Calculated at the trip level using a biomass-weighted approach:

$$\text{MTL} = \frac{\sum_{i=1}^{n} (TL_i \times C_i)}{\sum_{i=1}^{n} C_i}$$

where TL_i is the trophic level of the species I and C_i is its catch weight.

Trophic CPUE: This metric represents the effort-standardized sum of trophic-weighted catch, expressed as.

$$\text{trophic CPUE} = \frac{\sum_{i=1}^{n} (TL_i \times C_i)}{\text{time fished}}$$

3.3. Data Processing and Statistical Modeling

Data Transformation: To stabilize variance and satisfy normality assumptions, both CPUE and Trophic CPUE were log-transformed. MTL values were symmetrically distributed and analyzed without transformation.

Linear Modeling (LM): The study utilized linear models to test the effects of three fixed factors: Propulsion–Gear Combination, Monsoon Season (NEM vs. SEM) and Landing Site.

Interaction Testing: A propulsion–gear × season interaction was included to determine if the ecological impact of specific fishing technologies varied across the sites.

Model-Based Inference: Significance was evaluated using Type I ANOVA, followed by Tukey-adjusted pairwise contrasts among categories to identify specific differences between gear types and sites.

3.4. Results

Catch Performance (CPUE)

Technological Dominance: Propulsion–gear combinations explain the vast majority of catch variation (R^2 =0.89), with motorized dhow-based fisheries (Gillnets and Ring nets) consistently achieving significantly higher log-CPUE than non-motorized canoe-based operations across both seasons (Fig. 2).

Spatial Flux vs. Seasonal Stability: While monsoon seasonality alone was not a significant predictor of catch yield, strong spatial structuring exists; log-CPUE peaks at sites like Shimoni and Gazi but remained consistently low at Mkunguni (Fig. 2).

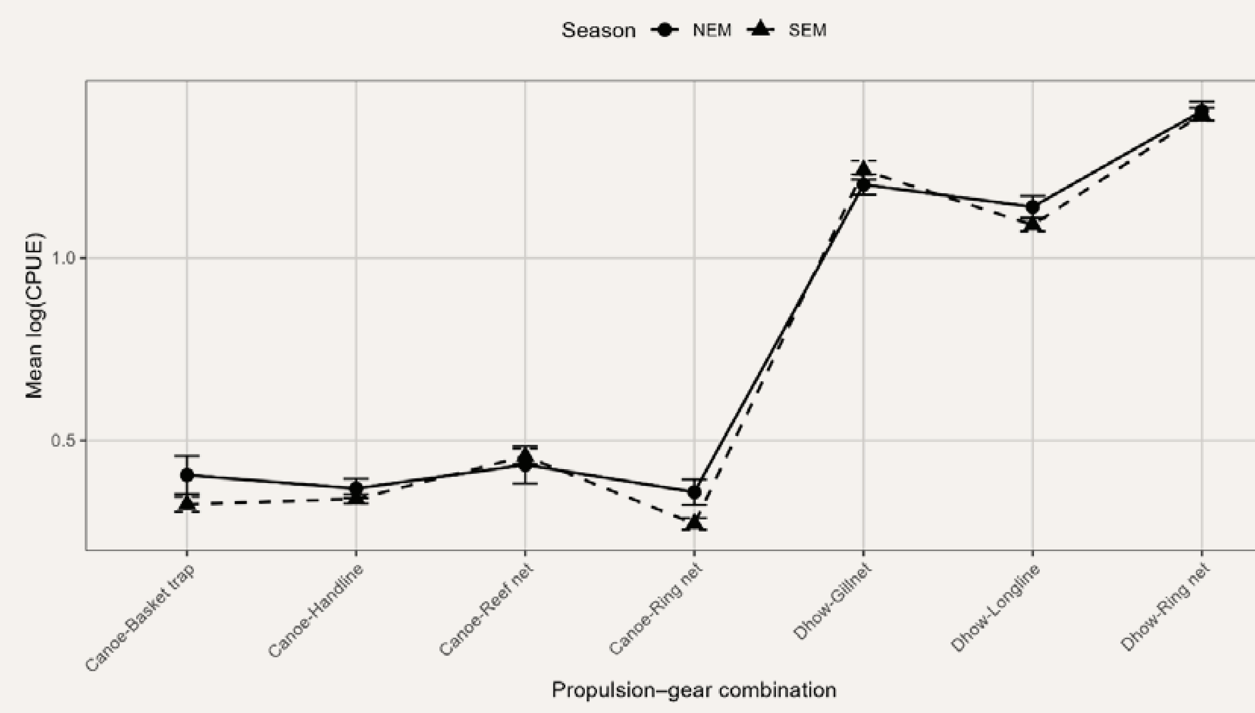

Figure 2: Log-CPUE for the seven most common propulsion gear combinations across all sampling sites

Table 1: Mean trophic level (MTL ± SE) of catches by propulsion–gear combination and monsoon season. Sample size (n) indicates the number of fishing trips included in each group

Season	Propulsion–Gear Combination	Mean MTL	SE	n
NEM	Canoe–Basket trap	3.1	0.213	25
NEM	Canoe–Handline	3.55	0.125	63
NEM	Canoe–Reef net	3.14	0.564	40
NEM	Canoe–Ring net	2.52	0.438	15
NEM	Dhow–Gillnet	3.67	0.092	48
NEM	Dhow–Longline	3.7	0.08	39
NEM	Dhow–Ring net	3.56	0.115	63
SEM	Canoe–Basket trap	2.97	0.078	110
SEM	Canoe–Handline	3.14	0.066	190
SEM	Canoe–Reef net	2.94	0.073	118
SEM	Canoe–Ring net	3	0.079	83
SEM	Dhow–Gillnet	3.39	0.122	47
SEM	Dhow–Longline	3.28	0.074	98
SEM	Dhow–Ring net	3.33	0.073	103

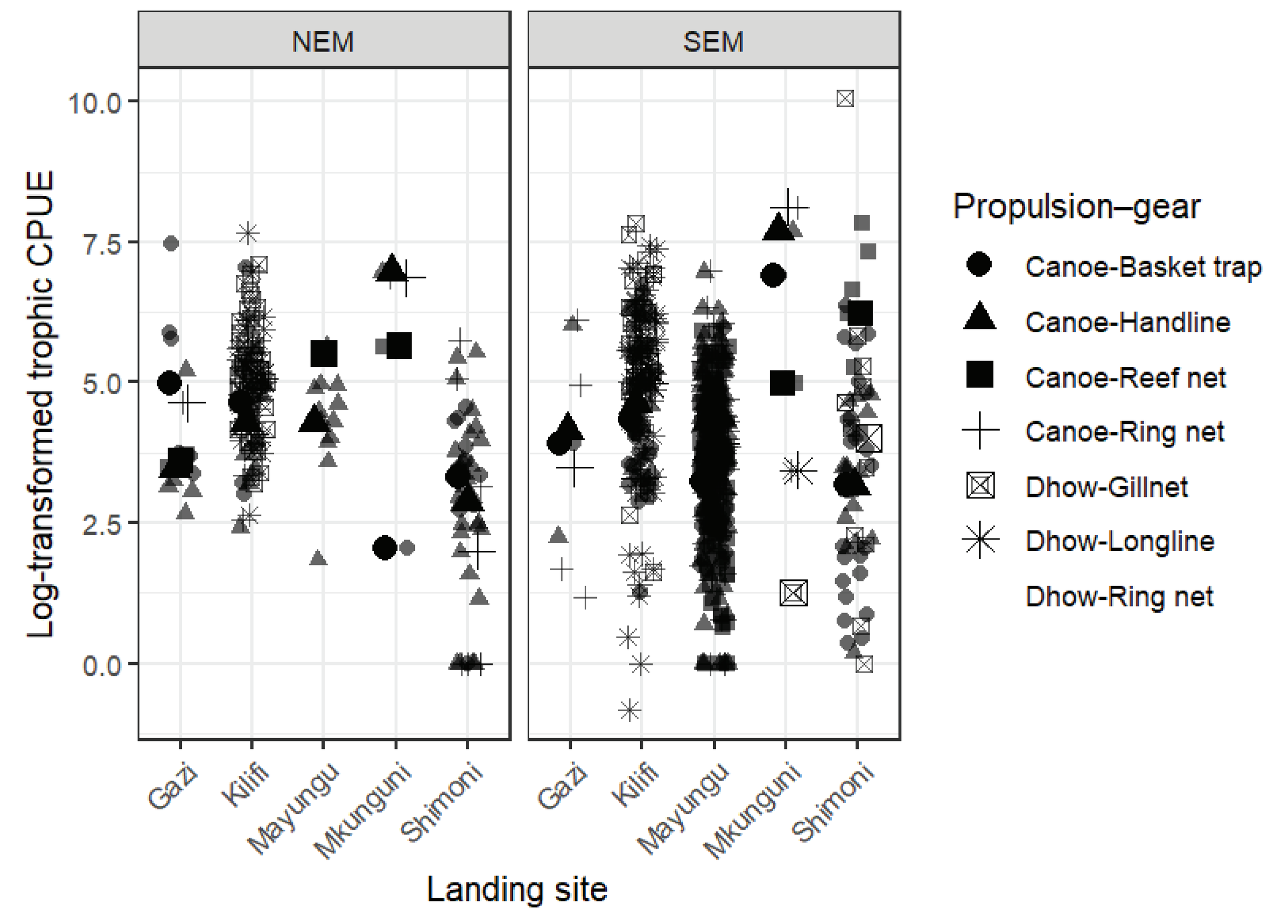

Figure 3: Log-transformed trophic CPUE among propulsion-gear categories, seasons, and sites

Functional Structure (MTL)

Consistent Trophic Filtering: Technology acted as a stable ecological filter regardless of the season, with motorized dhows selectively targeting high-trophic predators (MTL 3.67–3.70) and unmotorized canoe-ring nets targeting the lowest-trophic assemblages (MTL 2.52) (Table 1).

Seasonal Trophic Compression: MTL was significantly influenced by environmental context (p<0.001 for site and season), with landed assemblages becoming more functionally clustered and lower in trophic level during the SEM compared to the NEM .

Integrated Ecological Footprint (Trophic CPUE)

Superior Sensitivity to Seasonality: Unlike biomass metrics, Trophic CPUE identifies a significant ecological decline during the SEM (p=0.027), explaining more community variance (R2 adj =0.37) and serving as a more sensitive indicator of fishery-ecosystem interactions (Table 1).

Technological and Spatial Disparity: There is a massive disparity in trophic footprints, where motorized dhow-gillnets extract up to 10 times more trophic energy per hour than most canoe gears, and Kilifi stands out as a high-productivity hotspot compared to Mkunguni (Fig. 3).

3.5. Conclusion & Management Recommendations

Propulsion–gear combinations are the dominant drivers of trophic structure, overriding seasonal variation. The distinct signatures of mechanized dhow-based fisheries (high-TL) versus canoe-based fisheries (low-TL) confirm that technology dictates the ecological role of the fishery.

As such, regulations should target the specific trophic impact of propulsion-gear combinations, such as managing dhow-longlines for predator conservation and canoe-ring nets for herbivore biomass.

Higher Trophic CPUE in Kilifi suggests its role as a productivity hotspot, requiring spatial protection to maintain ecosystem services.

Trophic CPUE should be adopted as a standard metric to track the ecological health of the Blue Economy, moving beyond simple biomass assessments.

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