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Characterizing gear-based exploitation patterns of artisanal tuna fisheries in the western Indian Ocean: A snapshot from Kenya

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ABSTRACT

This study explores gear-based patterns in catch rates and catch composition of landings by artisanal tuna fishers along the Kenya coast based on data collected at eight landing sites from March 2014 to March 2020, representing 1960 fishing trips and 192 mt of fish. Tuna and tuna-like species constituted 55% and 38% respectively of the sampled catch by weight. Troll lines, ringnets and handlines were the most commonly used representing 52%, 18% and 12% of the sampled fishing trips. Ringnets were the most productive catching an average of 547 ± 99.3 kg of tuna per trip, while handlines caught the lowest (12.6 ± 1.4 kg trip^{-1}). Longlines and drift gillnets caught the highest proportion of tuna representing 95% and 89% respectively of landings, while reef seines and monofilament gillnets caught the lowest. The mean catch per unit effort for tuna was 78.5 ± 7.7 (SE) kg trip^{-1}, while that for tuna-like species was 35.2 ± 1.9 (SE) kg trip^{-1}. Kawakawa (*Euthynnus affinis*), bigeye (*Thunnus obesus*), and yellowfin (*Thunnus albacares*) were the most common and most abundant representing 31.5%, 21.2%, and 20% of the tuna landings, respectively; while skipjack (*Katsuwonus pelamis*) constituted the lowest at 4%. Although tuna was landed year-round, species-specific variations in catch rates and size distribution were observed among the gear types and between seasons. Cluster analysis and non-metric ordination based on combinations of gear type and season defined four groupings with two gear types (ringnets and set gillnets) showing seasonal differentiation in the composition of tuna and tuna-like species. Majority of tuna were above the reported size at first maturity (L_{50}) except for yellowfin and bigeye tuna. Overall, the findings provide new insights on Kenya's artisanal tuna fishery addressing important information gaps on exploitation patterns of artisanal tuna fleets of the western Indian Ocean region.

1. Introduction

Tuna and tuna-like species support important commercial and recreational fisheries worldwide, and are exploited by fleets from more than 70 countries (Li et al., 2022). Global catches of tuna and tuna-like species were estimated at 8 million tonnes in 2020 (FAO, 2022), and provide a significant source of revenue, nutrition and income to millions of people (Chassot et al., 2019; McCluney et al., 2019; McKinney et al., 2020). A total of 61 species are classified as tuna or tuna-like, of which 14 are considered as 'true tunas' (Gillet, 2011a). Taxonomically, the 'true tunas' belong to the family Scombridae which consists of six genera: *Thunnus*, *Katsuwonus*, *Euthynnus*, *Auxis* (tribe Thunnini), *Sarda* (bonitos) and *Gymnosarda* (tribe Sardini) (Collette et al., 2001).

The Indian Ocean represents the world's second-largest tuna producing region landing about 920,000 mt annually (ISSF, 2021) accounting for approximately 21% of the world's tuna supply and 16% of the world's tuna industry revenue (Lecomte et al., 2017), and valued at US$2.3 billion (ISSF, 2021). The principal market species are skipjack *Katsuwonus pelamis*, yellowfin (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*) and albacore (*Thunnus alalonga*). The four species are mainly exploited by industrial fisheries, with a minor artisanal and recreational component. Neritic tuna species including kawakawa (*Euthynnus affinis*), longtail tuna (*Thunnus tonggol*), frigate tuna (*Auxis thazard*), and bullet tuna (*Auxis rochei*) are mainly confined to coastal waters as they do not undertake transoceanic migrations where they are mainly exploited by artisanal fleets (Majkowski et al., 2011). The artisanal fishery is reported to contribute approximately 50% of the Indian Ocean's tuna catches (Artetxe-Arrate et al., 2021) demonstrating the important role the sector play in the region.

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Other tuna-like species such as swordfish (*Xiphias gladius*), narrow barred spanish mackerel (*Scomberomorus commerson*), dolphinfish (*Coryphaena hippurus*), billfish (*Istiophoridae* sp), wahoo (*Acanthocybium solandri*), rainbow runner (*Elagatis bippinulata*) and barracuda (*Sphyraenidae sp*) are also caught while targeting tuna by both artisanal and industrial fleets.

The Western Indian Ocean (WIO) region supplies 78% of the Indian Ocean's tuna production (Pillai and Satheeshkumar, 2012), representing nearly 20% of the world's commercial tuna catch valued at USD1.3 billion (Obura et al., 2017). Artisanal tuna fisheries of the region annually catch about 20,000 mt of tuna and tuna-like species (Chassot et al., 2019). The tuna populations occurring within the WIO region are considered well mixed single stocks and hence managed as shared stocks (Chassot et al., 2019). Most countries of the WIO region rely on tuna as the pillar or 'blue gold' for blue economy development (Andriamahefazafy and Kull, 2019) with the artisanal sector playing a major role, supplying over 80 to 90% of catches consumed locally (Christ et al., 2020). Consequently, there has been a regionwide drive to support artisanal fishers with fishing gears, engines and modern vessels to facilitate better access pelagic and deep-water fisheries resources offshore (Andriamahefazafy and Kull, 2019). The region's artisanal fleet is composed of small vessels propelled by paddles, sails, or outboard engines. Artisanal fishers use diverse gear types that catch a high diversity of species including tuna (Gillet, 2011a; Pillai and Satheeshkumar, 2012; Tuda et al., 2016; Gough et al., 2020). The gear types can be further categorized into those that primarily capture tuna and those that catch tuna as a component of the catch (Gillet, 2011b).

Kenya's Exclusive Economic Zone (EEZ) lies within the richest tuna belt located within the upwelling region of the WIO. Pelagic species comprise approximately 30% of the estimated 24,000 tonnes of marine fish catches that is landed annually (Maina and Osuka, 2014; Government of Kenya, 2016). According to Ndegwa et al. (2020), tuna constituted approximately 2,740 tonnes and was landed by an estimated 600 artisanal tuna fishers using a fleet of 414 vessels. Artisanal tuna fishers operate close to shore within 5 nautical miles of the coastline, and hence interact with other inshore fisheries targeting other pelagic and demersal species. Due to heavy fishing pressure, Kenya's inshore reef fisheries is considered overexploited (Hicks and McClanahan, 2012; Tuda et al., 2016; Samoilys et al., 2017) and various management measures are being implemented to support recovery of the stocks including restrictions on use of highly destructive fishing gears, seasonal and spatial closures and gear modifications. While acknowledging the declining resource base from nearshore reef-associated fisheries, artisanal fisheries targeting tuna and tuna-like species are receiving increased attention as a frontier for the blue economy. Experimental trials of fabricated fish aggregating devices (FADs) to enhance catching efficiency of tuna and tuna-like species (Osuka et al., 2016; Mbaru et al., 2018) have elicited mixed perceptions on the economic benefits and environmental impacts hampering adoption of the technology by artisanal fishers (Onyango et al., 2021).

Artisanal tuna fisheries of the Indian Ocean region have generally received limited attention in comparison to industrial fisheries. Data on retained catches for major industrial tuna fisheries of the Indian Ocean are well reported by the Indian Ocean Tuna Commission (IOTC), the regional fisheries management organization that manages the exploitation of highly migratory tuna and tuna-like species. IOTC has continued to emphasize the need for improved data collection and monitoring of artisanal tuna fleets to capture species and gear disaggregated information (IOTC, 2015). This in turn has led to calls for more intensive data collection and assessments of target and non-target species exploited by the fishery (Pons et al., 2018). Moreover, available published studies on artisanal tuna fisheries of the WIO region mainly focus on single-species biological assessments (e.g. Johnson and Tamatamah, 2013; Grande et al., 2014; Dhurmeea et al., 2016; Mildenberger et al., 2018; Kimakwa et al., 2021) with little attention on the multi-species and multi-gear catch dynamics. Thus, this study aims to improve understanding of species and gear-based exploitation patterns along the Kenya coast to support decision-making on potential investment and gear management strategies. The study characterizes gear-based catch dynamics of the artisanal tuna fishery by assessing spatial and seasonal variations in catch rates, species and length composition of tuna and tuna-like species.

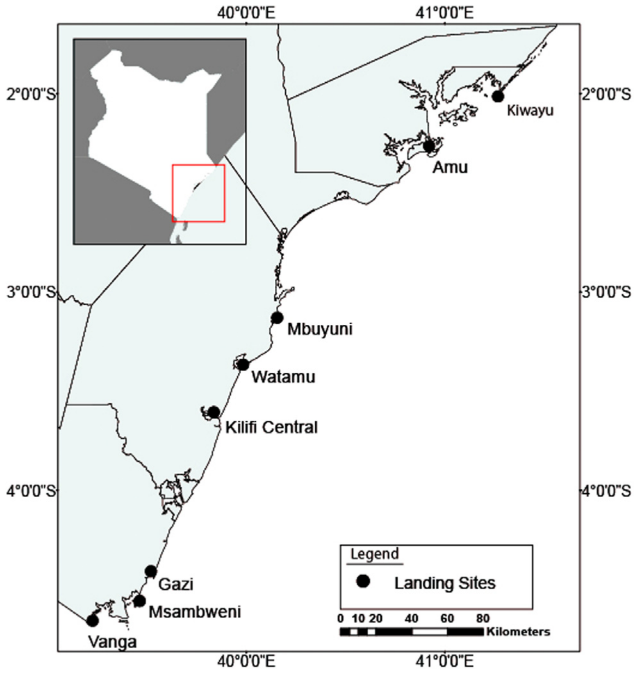

Fig. 1. Map of the Kenya coastline showing the location of landing sites where data was collected.

2. Methods

2.1. Study area

Kenya has a coastline of about 647 km and the Exclusive Economic Zone includes 142,400 km2 of marine waters (Government of Kenya, 2017). Artisanal fishing effort in Kenya is constrained to the nearshore within 5 nautical miles of the coastline in fishing grounds that are easily accessed within a few hours. However, some fishing operations do extend further offshore to target pelagic species including tuna. Catch assessment surveys were conducted across eight landing sites which were selected due to prior knowledge of their contribution to tuna landings on the Kenya coast (Fig. 1). The selected sites were delineated into two regions: northcoast sites (Kiwayu, Amu, Mbuyuni, Watamu, and Kilifi central), and southcoast sites (Gazi, Mkunguni and Vanga). The southcoast sites are characterized by fringing reefs, while the northcoast sites are characterized by patch reefs. Higher fishing effort occurs during the northeast monsoon season typified by calm waters, high water temperatures, low wave energy and water-column mixing, limited rainfall, and high salinity from November to March (Mayorga-Adame et al., 2016; Schott and McCreary, 2001). Environmental parameters and fishing effort reverses during the southeast monsoon (SEM) from May to September when strong winds occur across the entire western Indian Ocean (Schott and McCreary, 2001; Collins et al., 2012). A transition inter-monsoon period occurs in April and October as winds change direction (Mayorga-Adame et al., 2016).

2.2. Catch sampling

Shore-based catch sampling was conducted from September 2019 to March 2021. Data was collected over a period of four to six days during each month. Fishermen were intercepted by data enumerators as they brought their catch for weighing at the landing site facilities. Information recorded for each fishing trip included the vessel and gear type, fishing grounds, number of crew and total catch. The catch was weighed on site and all fish were identified to species with reference to identification guides (Smith and Heemstra, 1998; Anam and Mostarda, 2012) when needed. The fish were then grouped by species and each individual was weighed to the nearest gram using a hand-held digital balance and the fork length (FL) was measured using a measuring board. In cases of large catches of schooling species with a high number of individuals, a representative sample of the catch constituting 10% to 20% of the catch was sampled for catch composition. For a more comprehensive analysis, we supplemented data collected similarly from July 2014 to June 2015.

2.3. Data processing and statistical analysis

Catch per unit effort (CPUE). This study only focused on artisanal gear types that caught tuna and tuna-like species. Since the catch sampling did not discriminate gear types and species, we first filtered the data set to retain data for the gear types that caught tuna and tuna-like species for analysis. We defined fishing effort using two metrics: (i) the number of fishers per trip and (ii) and the cumulative number of fishers for each gear type (fisher days). Catch per unit effort (CPUE) was defined as the total catch (kg) per fishing trip. For fishing trips that were sampled, a raising factor was applied to estimate the total catch for each species by multiplying the ratio of each species in the sample (in number and weight) by the total catch weight using the formula:

$$\text{Total catch}_{\text{species}} = \text{Total catch} \times \text{Proportion}_{\text{species}}$$

A nominal CPUE was estimated for each species during each fishing trip as the raised biomass in fresh weight (kg). The Kruskal–Wallis (KW) non-parametric ANOVA test was then applied to determine significant seasonal differences in nominal CPUE for each gear type following confirmation that the data did not meet assumptions of parametric tests using the Shapiro–Wilk test for normality (Shapiro and Wilk, 1965) and Levene's test (Levene, 1960) for homogeneity of variances. Statistical significance for all tests was designated at $p < 0.05$. A heat map plot was then generated using a standardized scale of 0 to 1 with 1 being the highest mean CPUE value recorded across all observations for species i to visualize monthly and seasonal patterns of abundance for the most abundant tuna and tuna-like species.

Species composition: The proportion of tuna and tuna-like species in the landed catch was determined for each gear type and landing site by categorizing the sampled catch into four broad groups: tuna, tuna-like, other pelagic species and reef-associated demersals. The number of fish landed for each species was estimated for each fishing trip by multiplying the number of fish in each sample with a raising factor calculated as the ratio of the sampled catch weight and weight of the total catch. An index of relative importance (IRI) was then calculated based on the formula by Kolding and Skålevik (2009) as:

$$\%IRIi = \frac{(\%\mathrm{Wi} + \%\mathrm{Ni})(\%\mathrm{Fi})}{\sum_{j=1}^{s}(\%\mathrm{Wj} + \%\mathrm{Nj})(\%\mathrm{Fj})}.100$$

Where $\%W_i$ and $\%N_i$ is the percentage weight and number of individuals for each species in the total catch, $\%F_i$ is the percentage frequency of occurrence of each species in the total number of fishing operations, and S is the total number of species. The index standardizes the relative importance of a species in the catch based on the proportion by weight, the total number of individuals, and the frequency of occurrence representing the number of fishing trips in which each species was recorded. Calculation and graphical display of the IRI was done using PASGEAR 2 software programme (Kolding and Skålevik, 2009).

A data matrix summing the catch per trip for each species was constructed with 'species' as the variable and 'gear-season' (NEM vs SEM) as factors. The data was first standardized on a percentile scale and then square root transformed to reduce the influence of highly abundant species (Clarke and Warwick, 2001). A similarity matrix was then generated using the Bray–Curtis coefficient index (Bray and Curtis, 1957) and cluster analysis applied to identify groupings of gear type-season combinations that were similar in the composition of tuna and tuna-like species. Non-metric Multidimensional Scaling (nMDS) ordination was applied and eclipses of the identified clusters were overlaid on the ordination plot for a visual presentation of patterns. An ordination with a stress value < 0.2 was considered as adequate as recommended by Clarke and Warwick (2001). Pairwise one-way analyses of similarity (ANOSIM) was applied based on the global test statistic (R) at a significance level of $p < 0.05$ to test for significant differences in species composition between identified gear type-season clusters. Paired groups become more dissimilar as R approaches 1. A similarity percentage (SIMPER) analysis (Clarke and Warwick, 2001) was further performed to identify which species contributed most to dissimilarities between groups. All multivariate analyses were performed using PRIMER software (version 6.2.1).

Length and maturity composition: Length and maturity composition information provides insights on how fisheries select and interact with target species. The length range (fork length, cm ± SE), modal length, and mean length was derived for the more abundant tuna and tuna-like species based on the pooled data (i.e. not gear disaggregated). The Mann Whitney U test was performed to determine significant differences in mean lengths between seasons. Length frequency histograms of the fork lengths were generated for six of the most abundant species. The proportion of fish below length at which 50% of fish are mature (L_{50}) was then estimated for each species using L_{50} estimates for the selected species compiled from published literature (Rohit et al., 2012; Zudaire et al., 2013; Ghosh et al., 2012; Grande et al., 2014; Johnson et al., 2014; Ahmed et al., 2015; Zudaire et al., 2016); see Table A1.

3. Results

3.1. Fishing gears and fishing effort

A total of 1960 fishing trips landing tuna and tuna-like species were sampled during the study period, representing 192 metric tonnes, 8 gear types and 6 vessel types which are described in Supplementary Table A2. The 2014–2015 catch data represented 378 fishing trips and 23.6 metric tonnes; while the 2019–2021 data represented 1583 fishing trips and 168.4 metric tonnes. All gear types caught tuna during both NEM and SEM seasons except for drift gillnets which were only used during the NEM

Table 1
Summary of the sampled fishing trips by gear type, fishing effort, and catch per unit effort(CPUE)for 8 gear types that captured tuna 617and tuna-like species along the Kenya coast.

Gear type	Sampling effort		Fishing effort		Average CPUE (kg $trip^{-1}$)	
	Number of trips	Total catch (kg)	Average number of crew per vessel	Number of fisher days	Tuna species	Tuna-like species
Ringnet	351	107,582.31	23	4,356 (18%)	546.96 ± 99.27	85.46 ± 15.74
Reef seine	95	9,686.44	14	682 (2%)	248.28 ± 144.26	101.89 ± 59.88
Handline	242	4,660.70	3	1,444 (6%)	12.64 ± 1.36	13.31 ± 1.64
Longline	30	1,318.75	5	280 (1%)	41.37 ± 5.94	13.22 ± 3.15
Troll line	1,013	48,287.20	4	13,475 (55%)	38.86 ± 3.25	29.99 ± 1.07
Drift gillnet	139	18,403.14	6	3,576 (15%)	112.03 ± 9.3	53.57 ± 4.34
Set gillnet	77	1,891.63	5	778 (3%)	16.93 ± 3.93	18.72 ± 4.92
Monofilament gillnet	13	529.35	4	132 (0.5%)	31.57 ± 12.32	95.57 ± 93.43
Overall	1,960	192,359.543	–/–	24,723	78.49 ± 7.66	35.17 ± 1.87

season. The duration of fishing operations targeting tuna and tuna-like species ranged from four to six hours. The number of fishers per trip ranged from 3 for handlines to 23 for ringnets resulting in a total of fishing effort of 24,723 fisher days. Troll lines, ringnets and handlines represented 88% of the fishing effort (Table 1). A total of 27 vessel-gear combinations were recorded (detailed in Supplementary Table A3), dominated by fibreglass vessel-troll lines representing 45% of the fishing trips, followed by mashua-ringnet (15%). Two vessel-gear combinations contributed significantly to tuna landings: mashua-ringnet (40%) and fibreglass vessels-troll lines (28%). Spatial differences in gear use were also observed with troll lines, longlines and set gillnets being the most common at the northern coast sites (Kiwayu, Amu, Watamu and Kilifi), while ringnets and reef seines were dominant at the southern coast sites (Gazi and Vanga).

3.2. Nominal catch per unit effort (CPUE)

Overall, the mean aggregated catch per unit effort for tuna was 78.5 ± 7.7 (±SE) kg $trip^{-1}$ and varied among gear types ranging from 12 .6 ± 1.4 kg $trip^{-1}$ for handlines to 547 ± 99.3 kg $trip^{-1}$ for ringnets (Table 1). A The species-specific nominal CPUE for the more abundant tuna and tuna-like species caught by the eight gear types is summarized in Supplementary Table A4. Results of the Kruskal–Wallis (KW) test revealed significant differences between seasons among all gear types ($p < 0.05$). Ringnets had the highest mean CPUE for *E. affinis* (350.7 ± 71.9), *A. thazard* (1136.5 ± 546.7), *A. rochei* (692.2 ± 118.5) and *S. commerson* (81.0 ± 36.9) and *T. albacares* (343.1 ± 101.8) during the NEM season. Similarly, drift gillnets had the highest CPUE for *T. obesus* (99.24 ± 12.9), while troll lines had the highest CPUE for *T. tonggol* and *A. solandri*. The monthly heat map trend revealed increasing higher nominal CPUE during the NEM season months from December to April for most species and lower CPUE values were recorded during the SEM season (Fig. 2).

3.3. Catch composition

Species composition: Tuna and tuna-like species represented 55% and 38% of the catches respective of the total sampled catch. The bulk was caught by three gear types: troll lines (39%), ringnets (37%) and drift gillnets (15%). The proportion of tuna and tuna-like species greatly differed among the gear types (Fig. 3a). The majority of longline and drift gillnet catch was composed of tuna species constituting 95% and 89% respectively. On the other hand, monofilament gillnets, troll lines and handlines captured a higher proportion of tuna-like species constituting 38.5%, 37.3%, and 27.4% respectively. The lowest proportion of tuna and tuna-like species was captured by set gillnets, while reef seines, handlines and set gillnets captured a higher proportion of other pelagic species and reef-associated demersal species. There were spatial variations in the types of gears used to target tuna and tuna-like species between landing sites (Fig. 3b). Troll lines and longlines contributed over 90% of the catch at the northern sites of Kiwayu, Amu, Mbuyuni and Watamu. Southwards, drift gillnets and ringnets captured the majority (96%) of tuna landed at Kilifi central. Seventy percent of tuna landings at Vanga were captured by ringnets, 20% by reef seines and 10% by handlines (10%). Handlines were exclusively used at Mkunguni to target tuna and tuna-like species. At Gazi, tuna was mainly caught by drift gillnets and ringnets accounting for 57% and 39% respectively.

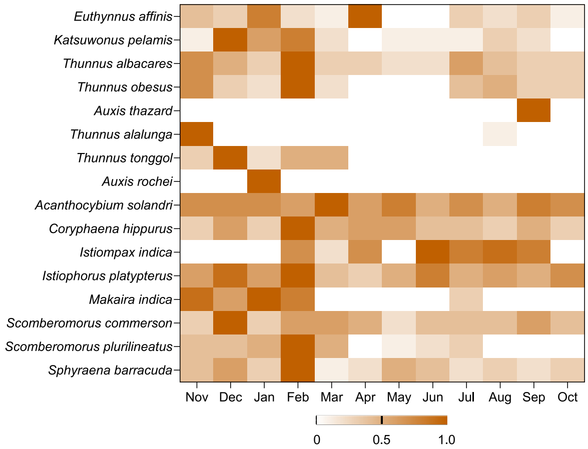

Fig. 2. A heat map plot illustrating seasonality of selected tuna and tuna-like species based on the mean monthly catch per unit effort (Kg/trip) estimates along the Kenya coast. The mean CPUE in each cell is standardized to a scale of 0 to 1, with 1 being the highest mean CPUE value recorded. The darker scale indicates higher values of CPUE.

Eight tuna species known to be present in the Indian Ocean were encountered at the study sites. The IRI index showed that *E. affinis*, *T. albacares*, *T. obesus* and *A. thazard* constituted the bulk of tuna caught by artisanal fishers along the Kenya coast (Fig. 4). The neritic species (*E. affinis*, *A. thazard* and *A. rochei*) collectively represented 70% of the sampled catch by number. Among the tuna-like species, the IRI ranked the narrow-barred *S. commerson* and wahoo *A. solandri* among the most important. The contribution of gear types to catches varied by species (Fig. 5). Troll lines primarily caught *T. albacares* while *T. obesus* was caught by both troll lines and drift gillnets in almost equal proportions with a minor proportion by longlines. Neritic species were primarily caught by ringnets and reef seines. Tuna-like species were mainly caught by troll lines constituting 26% of the sampled catch by weight. The results also showed that handlines caught the highest

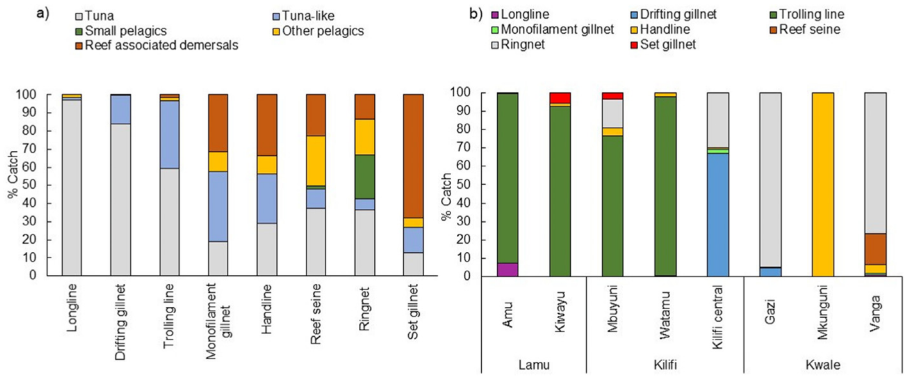

Fig. 3. (a) The relative contribution of tuna, tuna-like species, small pelagics, other pelagic species in sampled catches of eight gear types along the Kenya coast; and (b) The relative contribution of the gear types to landings of tuna and tuna like species among 8 sampled landing sites.

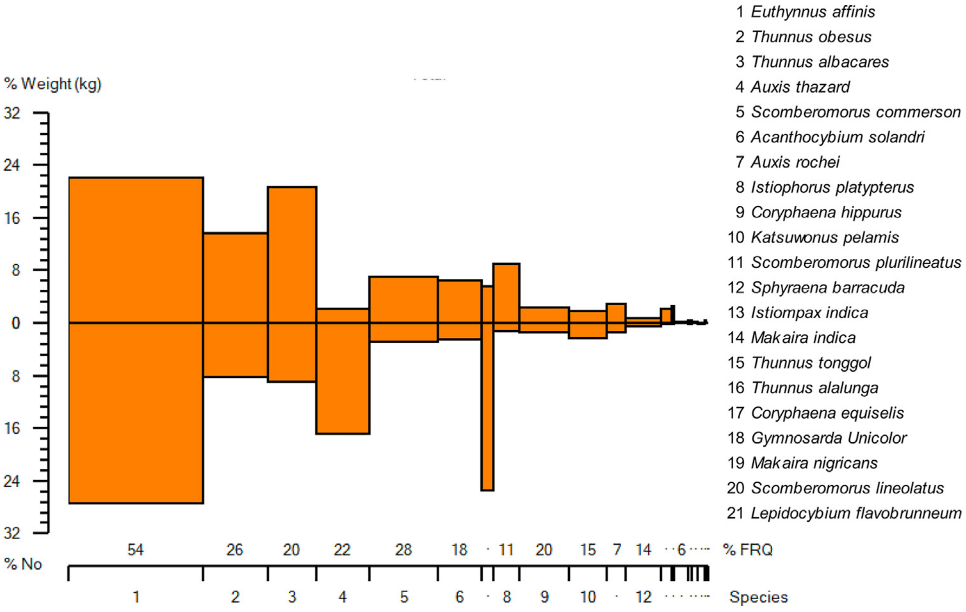

Fig. 4. Index of Relative Importance (IRI) for 21 tuna and tuna-like species caught by Kenya's artisanal fishery between 2014 and 2020.

Table 2
Pairwise Analysis of Similarity (ANOSIM) test showing differences in species composition of tuna and tuna-like species between gear types and between gear-season groups identified through cluster analysis. Differences between paired groups increase as the R value approaches 1. (Global R gear types = 0.60, Global R gear-season groups = 0.70.)

(a) Gear types	Drifting gillnet	Set gillnet	Handline	Longline	Monofilament gillnet	Reef seine	Ringnet
Set gillnet	1						
Handline	1	0.5					
Longline	1	1	1				
Monofilament gillnet	−0.5	0	0.25	0.375			
Reef seine	1	0.75	1	1	0.25		
Ringnet	0	0	0.75	1	0	0.25	
Troll line	1	1	0.75	1	0.25	1	1

(b) Gear-season clusters	Group III	Group II	Group IV	Group I
Group II	0.69*			
Group IV	0.64	0.41		
Group I	0.99	0.36	1	

*$P < 0.05$.

diversity of species, dominated by *S. commerson*, *T. albacares* and *E. affinis* altogether constituting 52% of the total sampled catch (Fig. 6).

Cluster analysis and nMDS ordination of the gear type-season data defined two groups at a similarity level of 20%, and four groups at a similarity level of 40% with ringnets and set gillnets showing seasonal differentiation (Fig. 7). Pairwise ANOSIM tests between gear types revealed varying levels of differentiation in species composition (Table 2a). The differences were generally not significant at the gear level (Global $R = 0.60$, $p > 0.05$);

Table 3
Results of SIMPER analysis showing the tuna and tuna-like species contributing to a cumulative 90% of the within group similarity defined through cluster analysis and non-metric multidimensional scaling.

Species	Similarity contribution (%)			
	Group I	Group II	Group III	Group IV
Euthynnus affinis	99	38.4	18	
Auxis thazard		60.7		
Thunnus albacares			17.4	
Thunnus obesus			23	100
Istiophorus platypterus			12.4	
Scomberomorus commerson			8.6	
Acanthocybium solandri			7.2	
Coryphaena hippurus			6.7	
Average group similarity (%)	66.7	54.5	48.6	61.1

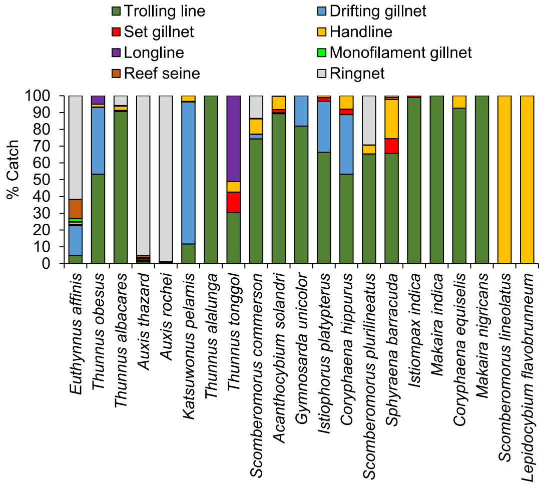

Fig. 5. The contribution of artisanal gear types to landed catches of tuna species caught at selected study sites.

however, the differentiation was significant between gear-season groups (Global $R = 0.70$, $p < 0.05$) due to differentiation between Groups II and III (Table 2b). Results of SIMPER analysis showed that *E. affinis* contributed significantly (99%) to similarities within Group I cluster (Table 3). Group II cluster was driven by an abundance of *A. thazard* and *E. affinis* contributing 60.7% and 39.4% respectively to the similarity. Group III cluster was influenced by six species altogether contributing over 90%, with the most abundant being *T. obesus*; and Group IV (longline) clustered as a distinct due to abundance of *T. obesus* during both seasons. The species contributed 100% to the similarity because it was the only species common to the two seasons. Five species contributed about 77% of the seasonal dissimilarity in the species composition of ringnet catch which was dominated by *E. affinis* contributing 30% to the dissimilarity (Table 4). Seven species contributed most to seasonal dissimilarities among set gillnets with *E. affinis* contributing 20% of the dissimilarity. Spatial variations in the species composition of tuna and tuna-like species were also observed between landing sites with *T. albacares* and *T. obesus* dominating landings at the north coast sites (Watamu, Mbuyuni, Kiwayu and Amu) representing 92% and 97% of the total sampled catch respectively. At the south coast, *E. affinis* and *A. thazard* dominated landings at Mkunguni and Vanga representing 92% and 73% of the total sampled catch respectively.

Length and maturity composition: The range of length bins among tuna species was widest for *T. obesus* and *T. albacares* and narrowest for *K. pelamis* and bullet tuna *A. rochei* (Table 5). The results of the Mann Whitney U test revealed significant differences in mean lengths between seasons for *T. obesus*, *S. commerson*, Indo-pacific sailfish *I. platypterus* and the king mackerel *Scomberomorous plurilineatus* with larger lengths being observed during the SEM season ($p < 0.05$). Overall, the proportion of catch below size at maturity (L_{50}) ranged from very high for *T. obesus* (99%) and *T. albacares* (93%) to low for *K. pelamis* (12%), *E. affinis* (3%), *A. thazard* (2%), and *S. commerson* (1%) (Fig. 8).

4. Discussion

This study represents a first effort to assess species and gear-vessel catch dynamics of Kenya's artisanal tuna fishery. The study reveals that tuna and tuna-like species are actively targeted along the Kenya coast, although other species groups (demersal reef species and other pelagic species) are also caught in varying proportions. There was spatial variation in gear use with ringnets being dominant from southwards from Kilifi to Vanga, while troll lines and drift gillnets were dominant northwards to Lamu. The observed spatial distribution can be attributed to differences in access conditions at the fishing grounds (e.g. habitats, depth profiles and hydrographic conditions). Fishing grounds at the south coast of Kenya coast are relatively sheltered from high wave action making them suitable seining methods, while sites at the north coast towards the North Kenya Banks (Watamu, Amu and Kiwayu) are more exposed and highly influenced by upwelling systems (Jacobs et al., 2020). Apart from this, socioeconomic factors also come into play as the use of ringnets has not been well tolerated northwards from Watamu eliciting resource use conflicts (Okemwa et al., 2016). The higher prevalence of troll lines in Watamu, Mbuyuni, Amu and Kiwayu could also be influenced by the thriving tourist-associated sport fishery occurring within the Watamu area (Kadagi et al., 2021). The neritic tuna (*E. affinis* and *A. thazard*) constituted a significant proportion of ringnet fishery landings. The gear type is highly suitable for targeting schooling pelagic species that aggregate in large numbers. A high abundance of neritic species in ringnet catches has also been reported elsewhere in the Indian Ocean (Rohit et al., 2012; Haputhantri, 2016), unlike in some countries of the Indian Ocean region such as Maldives where *E. affinis* is mainly targeted by troll lines (Anderson et al., 1996), and Pakistan where they are mainly targeted using set gillnets and handlines (Ahmed et al., 2015).

This study also highlights differences in the contribution of gear types to landings of tuna and tuna-line species. Longlines, drift gillnets and troll lines caught higher proportions of tuna and tuna-like species compared to the other gear types (handlines, ringnets, set gillnets, reef seines) indicating higher selectivity to catching the larger highly migratory tuna species (i.e. *T. albacares* and *T. obesus*). Landings of tuna and tuna-like species were recorded throughout the year; however, variations in catch rates were observed among gear types and between seasons. Peaks in catch rates for most species occurred during the NEM

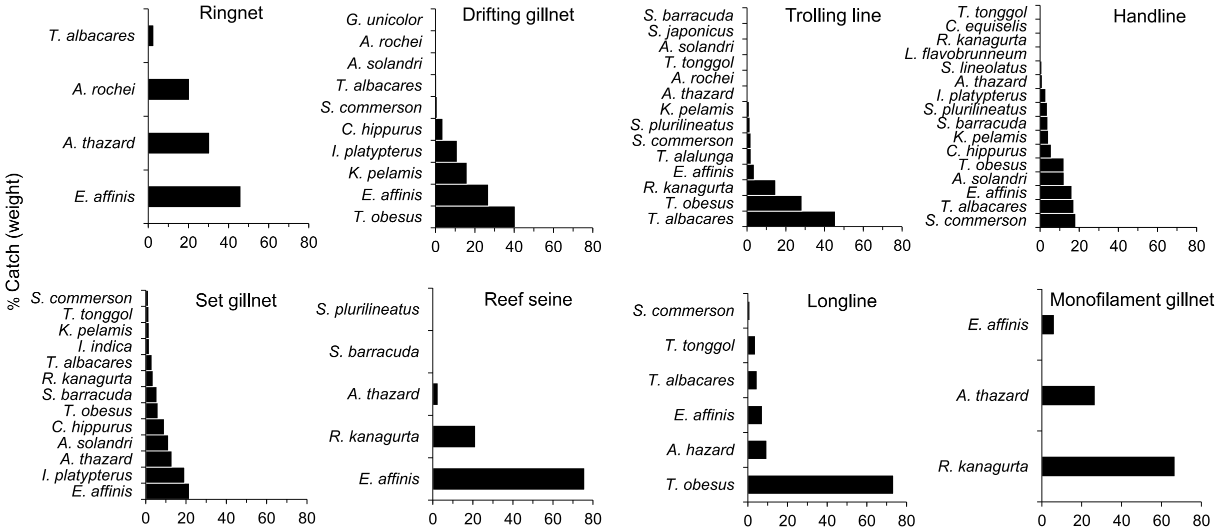

Fig. 6. The relative abundance (% biomass) of tuna and tuna-like species in sampled catches of 8 artisanal gear types along the Kenya coast.

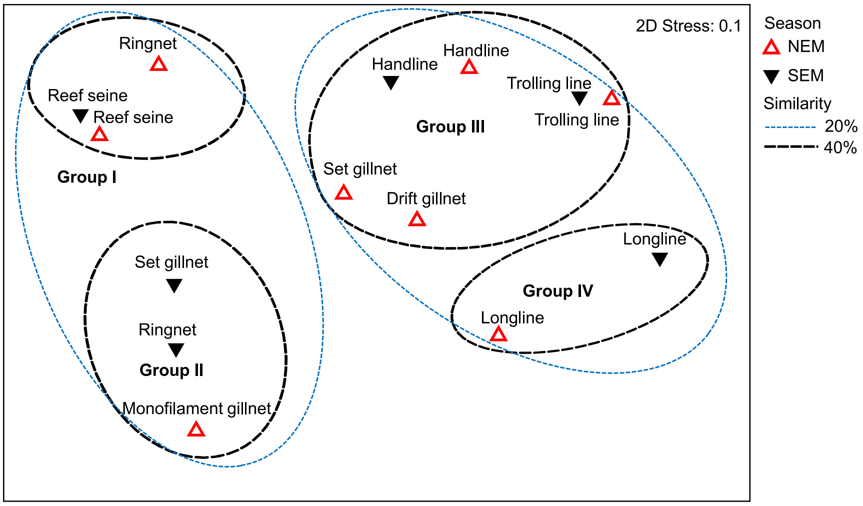

Fig. 7. Non-metric multidimensional scaling ordination showing similarities in the species composition of tuna and tuna-like species between seasons and gear types. Ellipses indicate Bray–Curtis similarity clusters identified at 20 and 40% level.

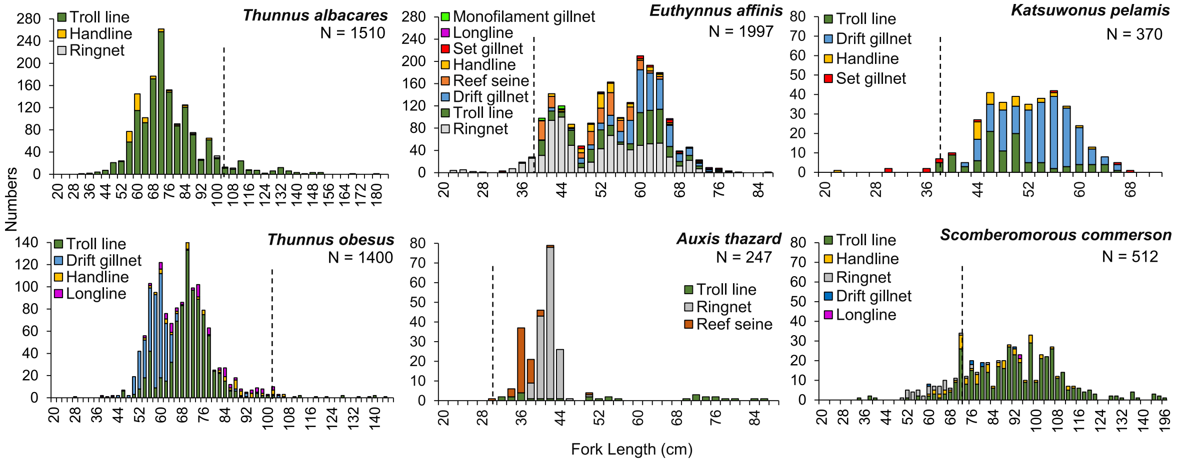

Fig. 8. Length distribution of selected species by gear type caught in Kenya's artisanal tuna fishery observed from July 2016 to June 2017. Dashed lines represent length at first maturity (L_{50}) values obtained from literature (Zhu et al., 2011; Grande et al., 2014; Zudaire et al., 2013, 2016).

Table 4
Results of SIMPER analysis showing species that contributed approximately 70% of the dissimilarity for two gear types (ringnets and set gillnets) which showed significant differences in species composition of tuna and tuna-like between seasons.

Gear	Species	Avg. Abund.		Avg. Dissimilarity	Contribution %	Cumulative Contribution %
		NEM	SEM			
Ringnets	*Euthynnus affinis*	38.6	46.4	20.2	29.4	29.4
	Scomberomorus commerson	19.0	5.9	10.2	15.4	44.6
	Scomberomorus plurilineatus	5.4	16.7	10.1	14.9	59.4
	Auxis thazard	0.2	15.5	7.6	11.2	70.6
Set gillnets	*Euthynnus affinis*	35.3	7.0	17.7	19.5	19.5
	Auxis thazard	21.6	3.4	11.0	12.5	31.5
	Istiophorus platypterus	34.5	0	10.9	12.5	43.6
	Thunnus obesus	10.9	0	9.1	10.0	53.6
	Coryphaena hippurus	16.5	0	7.5	8.2	61.8
	Acanthocybium solandri	20.3	0	7.0	7.7	69.5

Table 5
The length range (fork length, cm ± SE), modal length, and mean length of more abundant tuna and tuna-like species landed by artisanal fishers along the Kenya coast during the study period.

Grouping	Species	N	Length range min – max (FL, cm)	Modal FL, cm	Overall mean FL ± SE (pooled)	Mean FL ± SE (N) between seasons		Significance between seasons (Mann–Whitney U test)
						SEM	NEM	
Tuna	*Thunnus obesus*	1400	27–144	69	67.5 ± 0.3	72.0 ± 0.3 (586)	64.5 ± 0.5 (814)	$P < 0.5$
	Thunnus albacares	1510	32–177	71	74.5 ± 0.4	74.0 ± 0.4 (685)	75.0 ± 0.7 (825)	NS
	Thunnus tonggol	140	67–110	68	82.5 ± 3.6	–/–	82.5 ± 3.7 (14)	NS
	Euthynnus affinis	1997	21–86	60	54.5 ± 0.2	54.0 ± 0.3 (693)	55.0 ± 0.3 (1304)	NS
	Auxis thazard	247	26–60	34	42.5 ± 0.9	39.5 ± 0.3 (138)	46.0 ± 1.9 (109)	NS
	Katsuwonus pelamis	370	30–80.5	45, 55	51.0 ± 0.3	49.5 ± 0.6 (55)	51.5 ± 0.4 (315)	NS
	Auxis rochei	549	28–56	34	34.3 ± 0.1	51 ± 2.1 (9)	34.0 ± 0.1 (540)	NS
Tuna-like	*Acanthocybium solandri*	430	30–152	96	95.6 ± 1.0	94.0 ± 1.2 (187)	97.0 ± 1.4 (245)	NS
	Scomberomorus commerson	512	33–196	71	89.0 ± 0.8	93 ± 0.9 (399)	76.0 ± 1.5 (113)	$P < 0.5$
	Coryphaena hippurus	243	39 –132	78	81.0 ± 0.9	85.0 ± 1.6 (93)	79.0 ± 1.0 (150)	NS
	Istiophorus platypterus	176	19–307	209	189.5 ± 4.2	181.0 ± 5.1 (99)	201.0 ± 6.7 (77)	$P < 0.5$
	Scomberomorus plurilineatus	162	42–144	71	83.0 ± 1.43	70.5 ± 2.1 (41)	87.0 ± 1.6 (121)	$P < 0.5$

season. Such variations are inherent and can be explained by factors related to vertical and horizontal migration patterns, vertical and horizontal placement of gears, gear dimensions (e.g. hook sizes and shapes), and bait type (Cortez-Zaragoza et al., 1989; Løkkeborg and Bjordal, 1992). Gear efficiencies and selectivity may also be influenced prevailing environmental and oceanic conditions within fishing grounds. Gear interactions may also be associated with the behavioural ecology of the different species further influencing catchability (Wright et al., 2021) as well as the spatial–temporal shifts in fishing strategies and fishing effort. Further localized studies including spatial mapping of fishing effort are needed to tease out the influence of these factors.

Four tuna species and three tuna-like species were most abundant in the catches: *E. affinis*, *T. albacares*, *T. obesus*, *A. thazard*, *S. commerson*, *A. solandri* and *C. hippurus*. The dominant tuna species are also reported in the artisanal landings of Comoros, Mozambique, Tanzania and Seychelles (Pereira et al., 2013; Breuil and Grima, 2014; Le Manach et al., 2015; Chassot et al., 2019). The size ranges of tuna species reported in this study are within ranges observed for the Indian Ocean region (Pillai and Satheeshkamur, 2012). However, the wider length ranges observed for *T. obesus* and *T. albacares* indicates presence of multiple length cohorts for these species in the artisanal catches, while the narrower size ranges for *K. pelamis* and *A. rochei* indicates little differentiation in length cohorts. There high proportion of mature *E. affinis* observed in this study concurs with observations by Johnson and Tamatamah (2013) in Tanzania who observed 100% mature fish throughout their study, implying the presence of spawning grounds or a resident spawning stock within the East-African coast. On the other hand, the high abundance of immature *T. obesus* and *T. albacares* below L_{50} in the artisanal landings implies limited accessibility of adult sizes to artisanal fishing gears. Adult *T. obesus* and *T. albacares* prefer deeper depths of between 100 and 280 m (Song et al., 2008, 2009). The observed increase in CPUE of tuna and tuna-like species during the NEM season concurs with that observed in Tanzania by Igulu et al. (2013). The peak during NEM season may be attributed to increased seasonal abundance of migrating tuna as a result of various biological and ecological interactions such as spawning seasonality (Stéquert et al., 2001; Zhu et al., 2008), suitability of environmental conditions including optimal sea temperature conditions, wind speed and circulation patterns (Semba et al., 2019). Feeding conditions for tuna also become optimum during the NEM season driven by a significantly higher chlorophyll-a concentration as reported by Kyewalyanga et al. (2020) triggering a seasonal abundance of prey including sardines, anchovies and mackerel (Kizenga et al., 2021). An increase in fishing effort also occurs during the NEM season, especially attributed to an influx of migrant fishers from Pemba, Tanzania targeting tuna and tuna-like species using ringnets and drift gillnets (Wanyonyi et al., 2016).

5. Conclusion and recommendations

This study provides new insights into gear-based exploitation dynamics of artisanal tuna fisheries in Kenya, within the western Indian Ocean region. The study highlights the importance of understanding species and gear disaggregated exploitation patterns of coastal tuna fisheries. The complexity of managing Kenya's artisanal tuna fishery is evident by the highly and spatially diverse vessel-gear combinations that are used to target tuna and tuna-like species. Currently, there are no management measures to ensure a sustainable artisanal tuna fishery in Kenya. Thus, as Kenya strives to increase the economic contribution of tuna fisheries to local livelihoods and food security, bridging data and information gaps is a crucial first step to informing decision-making. There been a few efforts to improve data collection in the WIO region through trials and adoption of electronic data collection systems in Kenya (Mueni et al., 2019), Tanzania (Kibona, 2020) and Madagascar (Jeffers et al., 2019). However, despite the increasing focus on artisanal tuna fisheries as a frontier for blue economy growth in the WIO region, they remain poorly assessed and managed. Moreover, recent studies have projected large-scale reductions in tuna biomass in the WIO region due to global warming (Marsac, 2017; Wilson et al., 2021) resulting from a loss and deterioration of tuna habitats (Dueri et al., 2014; Roxy et al., 2016), which is a likely long-term factor confounding the sustainability of the artisanal tuna fishery sector in the region. Prioritization of a long-term monitoring programme will aid in obtaining sufficient gear and species disaggregated data to support national and regional fishery management and development needs.

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CRediT authorship contribution statement

Gladys M. Okemwa: Investigation, Formal analysis, visualization, Writing – original draft, Project administration. **Almubarak A. Abubakar:** Investigation, Writing – original draft. **Fatuma Mzingirwa:** Investigation. **Edward N. Kimani:** Writing – review & editing. **Joseph N. Kamau:** Funding acquisition, Writing – review & editing. **James M. Njiru:** Funding acquisition, Writing – review & editing. **Warwick Sauer:** Funding acquisition, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.rsma.2023.102877.

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