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CASE STUDY

Environmental status of silky sharks in Eastern Indian Ocean from length-based catch data

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ABSTRACT

BACKGROUND AND OBJECTIVES: Silky sharks (*Carcharhinus falciformis*) are among the most exploited pelagic species in the Eastern Indian Ocean, yet their population dynamics remain poorly documented. The study objectives were to evaluate the status of silky shark populations landed by artisanal fisheries at Tanjung Luar Port, West Nusa Tenggara, by combining length-based indicators with standardized catch-per-unit-effort modelling to detect early warning signs of overexploitation.

METHODS: Data were collected between 2017 and 2023, covering 33,129 individuals captured by bottom longline, surface longline, and gillnet gears. Biological parameters included length-frequency distribution and sex ratio, while operational indicators comprised trip frequency, vessel numbers, and fishing days per trip. Standardization of catch-per-unit-effort was achieved via a dual-component delta framework. The architecture integrated a binomial generalized linear mixed model evaluating encounter probability with a negative-binomial generalized additive model analyzing positive catch rates, while explicitly controlling for provincial fishing grounds, effort duration in fishing days, gear typology, vessel-level random effects, and all potential two-way interactive effects.

FINDINGS: Catch-per-unit-effort displayed consistent biannual peaks in May and November, reflecting seasonal variation in availability or catchability, but overall abundance declined steadily. Length-frequency distributions demonstrated truncated population structures heavily skewed toward juveniles fractions, with the majority of individuals falling below published length-at-maturity thresholds. A persistent female bias was evident, with females comprising more than half of annual catches and reaching ~71 percent in 2023. Effort dynamics showed declining efficiency; Catch-per-unit-effort decreased as trip frequency increased, while total catch was maintained only through increased fishing trips. Furthermore, the manifestation of fleet growth alongside shortened operational windows exemplifies tactical adaptations capable of temporarily concealing structural biological degradation.

CONCLUSION: The convergence of biological and operational signals highlights a fishery increasingly sustained by juvenile recruitment rather than adult spawning biomass, raising precautionary concerns about reduced spawning potential. Precautionary measures are urgently required to safeguard spawning potential and ensure long-term sustainability. Recommended policy measures entail the enforcement of seasonal closures during critical aggregation phases, restrictions on juvenile removal, technical gear adjustments to curtail retention, and the application of effort constraints calibrated against vessel- and trip-level operational parameters.

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INTRODUCTION

Shark fisheries in Indonesia have operated since the 1970s, initially as bycatch in tuna fisheries but later developing into targeted fisheries, particularly among small-scale fishers at major landing sites. This transition has been propelled by escalating domestic and international demand for shark-derived commodities, encompassing meat, fins, and cartilage (Dulvy *et al.,* 2021). At the global scale, reported elasmobranch catches reached approximately 731,000 tons in 1994, with Asia contributing around 60 percent (%) of total landings. Indonesia, together with India, Japan, and Pakistan, accounted for nearly 75% of global shark and ray catches. Notwithstanding a downward trend in average annual landings to 631,393 tonnes over the 2019–2022 interval (FAO 2024), Indonesia persistently commands the position of the world's primary shark producer, having reigned as the principal shark-catching nation across the entire 2007–2022 span (FAO 2024). This sustained exploitation has resulted in global population declines, of pelagic sharks and rays, estimated at more than 71% over the past five decades, largely driven by high fishing pressure and bycatch mortality (Pacoureau *et al.,* 2021). The vulnerability of chondrichthyan species is underscored by Dulvy *et al*., (2021), who noted that over one-third are currently threatened with extinction. Complementary findings from the International Union for Conservation of Nature (IUCN) global reassessment demonstrate that 32.6% of sharks and ray species are threatened, with this proportion escalating to 37.5% when accounting for Data Deficient taxa, largely due to intense overfishing and incidental bycatch mortality. Tropical and subtropical coastal waters, particularly in the Indo-Pacific region, were identified as areas with disproportionately high extinction risk, especially for large-bodied shark species inhabiting shallow waters, and the study further emphasized that current fisheries management measures remain insufficient to reverse ongoing global declines in shark populations. Silky sharks (*Carcharhinus falciformis*) are ecologically important apex predators in the Eastern Indian Ocean, contributing to pelagic food-web stability by regulating prey populations and linking tuna-associated ecosystems (Murray *et al.,* 2023). The life-history traits of slow growth, delayed maturation, and low fecundity impart acute vulnerability to anthropogenic harvesting, threatening to rapidly deplete reproductive stock structure and undermine long-term population resilience. These trends have prompted increasing international concern and the call for strengthening conservation and management measures for exploited shark species. Such management-oriented approaches increasingly require systematic assessment frameworks and evidence-based analytical strategies to support environmental decision-making (Mohamed and Rezk, 2025). The silky shark (*Carcharhinus falciformis*) is among the species of greatest conservation concern and has been listed under Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 2016, allowing international trade only when sustainability, legality, and traceability requirements are met (Dharmadi and Fahm, 2015). Indonesia, issued a non-detriment finding (NDF) for silky sharks in 2019 to support science-based management. The global population trajectory of the silky shark exhibits an estimated decline of 47–54% across three generations, encapsulating regional variations in demographic change. Consequently, the severity of this contraction, when evaluated in conjunction with prevailing data uncertainties, underpins its formal categorization as Vulnerable globally (Rigby *et al.,* 2021). Current evidence from the Indian Ocean shows truncated size structures dominated by juveniles, limited representation of mature individuals, and seasonal recruitment pulses that are insufficient to offset adult depletion (Hall *et al*., 2012; Clavareau *et al*., 2020). These exploitation patterns highlight the risk of

reproductive depletion under sustained fishing pressure. Silky sharks are widely distributed in tropical and subtropical waters and are captured both in targeted shark fisheries and as bycatch in tuna longline and gillnet fisheries (White *et al.,* 2006; Grant *et al.,* 2018). In addition, industrial purse-seine sets deploying fish aggregating devices (FADs) disproportionately capture juvenile silky sharks as primary bycatch, with respective incidence levels markedly elevated in the Indian Ocean (99.7%) compared to the Atlantic (97.9%). Across both oceans, elasmobranch catches were substantially higher in sets associated with FADs (>40%) compared to free-school tuna sets (<17%), although species-specific differences were evident. Elasmobranch catches were dominated by juvenile individuals (30.7–100%), exhibited relatively high at-haulback mortality rates (24.3–63.9%), and showed unbalanced sex ratios, with females comprising 13.3–66.7% of catches. Analyses of Indian Ocean purse-seine sets reveal that silky shark bycatch over FADs was overwhelmingly juvenile-dominated (99.7%), with a marginal female demographic bias and a recorded haulback mortality rate of 60.5%. The identified spatial and seasonal patterns provide important information for improving monitoring and management strategies of elasmobranch bycatch (Clavareau *et al.,* 2020). In Indonesian archipelagic waters, silky sharks are broadly distributed across the Indian Ocean, South China Sea, Makassar Strait, and Banda Sea, with juveniles cohorts frequently captured in coastal fisheries. Available evidence suggests that silky sharks have declined by approximately 70% from historical levels in the Western Central Pacific (WCPFC) due to non sustainable fishing pressure being the only Regional Fisheries Management Organization (RFMO) that has succeeded in performing a stock assessment for silky sharks. According to FAO (2017) data, global catches expanded throughout the 1990s and early 2000s before experiencing a sharp downturn post-2000, ultimately contracting to less than 20% of their initial levels by 2014. IOTC reports an average retained catch of 2,062 t of silky sharks per year (y) for the period of 2020 – 2024, with more than 60% of catches taken by Indonesia, Sri Lanka, and Taiwan in their line, longline, and coastal purse seine fisheries. Pakistan's and Iran's gillnet fisheries also account for about 30% of the retained catches (IOTC, 2025) although silky sharks are often not reported at species level in gillnet fisheries as such reporting is not mandatory for this gear in Indian Ocean Tuna Commission (IOTC) Resolution 15/01. Furthermore, silky sharks are also the most common shark bycatch in industrial DFAD purse seine fisheries and there subject to high at vessel and post release mortality rates (Hutchinson *et al.,* 2015; Onandia *et al.*, 2021). Throughout the 2005–2015 period, Indonesian shark production fluctuated between 2,500 to 6,700 tons annually, with approximately 20% of landings comprising members of the family Carcharhinidae. Major fishing centres include Tanjung Luar, adjacent to the Indian Ocean and operating primarily in fisheries management area (FMA) 573 (Yulianto *et al.,* 2018). Silky sharks dominate landings in these fisheries, accounting for more than 30–40% of total shark catches in several years (y). Fishers in Tanjung Luar primarily target sharks in Southern Sumbawa, Sumba Islands, eastern Flores, and Timor Island, as part of the FMA 573 (Yulianto *et al.,* 2018). The IOTC (2025) reported that the stock status of silky shark (*Carcharhinus falciformis*) in the Indian Ocean remains "Unknown" due to substantial uncertainties in catch data, catch-per-unit-effort (CPUE) trends, and the lack of reliable stock assessment indicators (Hinton and Maunder, 2003). Nevertheless, the species is identified as one of the most vulnerable sharks in Indian Ocean fisheries owing to low biological productivity and high susceptibility to longline and purse seine gears, ranking second and fifth in vulnerability, respectively, within the IOTC ecological risk assessment. Furthermore, available evidence indicates that silky shark abundance has experienced sustained declines over recent decades despite limited quantitative metrics. In

data-limited fisheries such as Indonesia, length-based catch indicators are particularly useful because they provide direct information on population structure, maturity composition, and recruitment signals without requiring full stock assessments. Recognized broadly as diagnostic early-warning proxies for overexploitation, these metrics provide the basis for this investigation; by synthesizing length-based indicators with CPUE modeling, this study bridges regional data gaps across Indonesian waters to evaluate preliminary vulnerabilities. Specifically, we evaluate artisanal landings at Tanjung Luar Port to provide the first combined length-based and standardized CPUE assessment of silky shark environmental status in the Eastern Indian Ocean. This fills a critical gap in understanding how artisanal fisheries contribute to exploitation patterns and population decline. Ultimately, these empirical outcomes are intended to advance an updated scientific framework capable of supporting evidence-based, sustainable governance structures for the local silky shark fishery (Yulianto *et al.,* 2018). The aims of this study are to evaluate the status of silky shark populations landed by artisanal fisheries, by combining length-based indicators with standardized catch-per-unit-effort modelling to detect early warning signs of overexploitation. This study has been contacted in the Tanjung Luar Fishing Port, West Nusa Tenggara Province, during 2017 and 2023.

MATERIALS AND METHODS

Data collection

The study evaluated a major shark landing site in West Nusa Tenggara, Indonesia (Fig. 1). Data were collected from 83 fishing vessels operating between 2017 and 2023. These vessels employed three types of fishing gear: bottom longline (BL), surface longline (SL), and gillnet (GN). The trip and catch composition data were collected to ensure standardized records detailed in Table 1. The fleet operating in Tanjung Luar was dominated by wooden vessels, with approximately 75% having a gross tonnage (GT) of 5 or less, while only 25% ranged between 6 and 28 GT. Engine power is modest (15–60 HP), which constrains operational range and confirms that these vessels are artisanal to semi-industrial in scale. With an average length of 15 to 20 meters (m) and operations restricted exclusively to the Indonesian EEZ, these vessels are exempt from mandatory inclusion in the IOTC register of active vessels (RAV) and its corresponding regulatory mandates. Fishing grounds reported by the fleet span across West Nusa Tenggara (NTB) and East Nusa Tenggara (NTT), with occasional records from other provinces. Larger vessels (46–60 HP) are capable of reaching fishing grounds further afield, including Sumba Island, Savu Sea, Flores Sea, Java Sea, and Makassar Strait, whereas smaller vessels (<46 HP) remain closer to Lombok and Sumbawa, typically operating in Awang Bay, Alas Strait, and Panjang Island (Yulianto *et al.*, 2018). The silky shark (*Carcharhinus falciformis*) as shown in Fig. 2 is a member of the family Carcharhinidae within the order Carcharhiniformes, class Chondrichthyes. It is widely distributed in tropical and subtropical waters, occurring from the surface to depths of around 500 m, but records extend to 4000 m in some regions. In the Indian Ocean, individuals are born at 65–81 centimeters (cm) total length (TL) and reach maturity at approximately 216 cm in females TL and 208 cm TL in males (Rigby *et al.,* 2021), with an estimated lifespan of about 20 y (Hall *et al.,* 2012). Sexual maturity is attained around 13 y in males and around 15 y in females. The species is viviparous, exhibiting a gestation period of 9–12 months and fecundity ranging from 2 to 18 pups per litter at intervals of 2 to 3 y, with reproductive output increasing as a function of female body size. Silky sharks are highly migratory and often associated with tuna schools, a behavioral trait that increases their exposure to fishing pressure. Their slow growth, late maturity, and low reproductive output make them particularly vulnerable to sustained and intensive overexploitation.

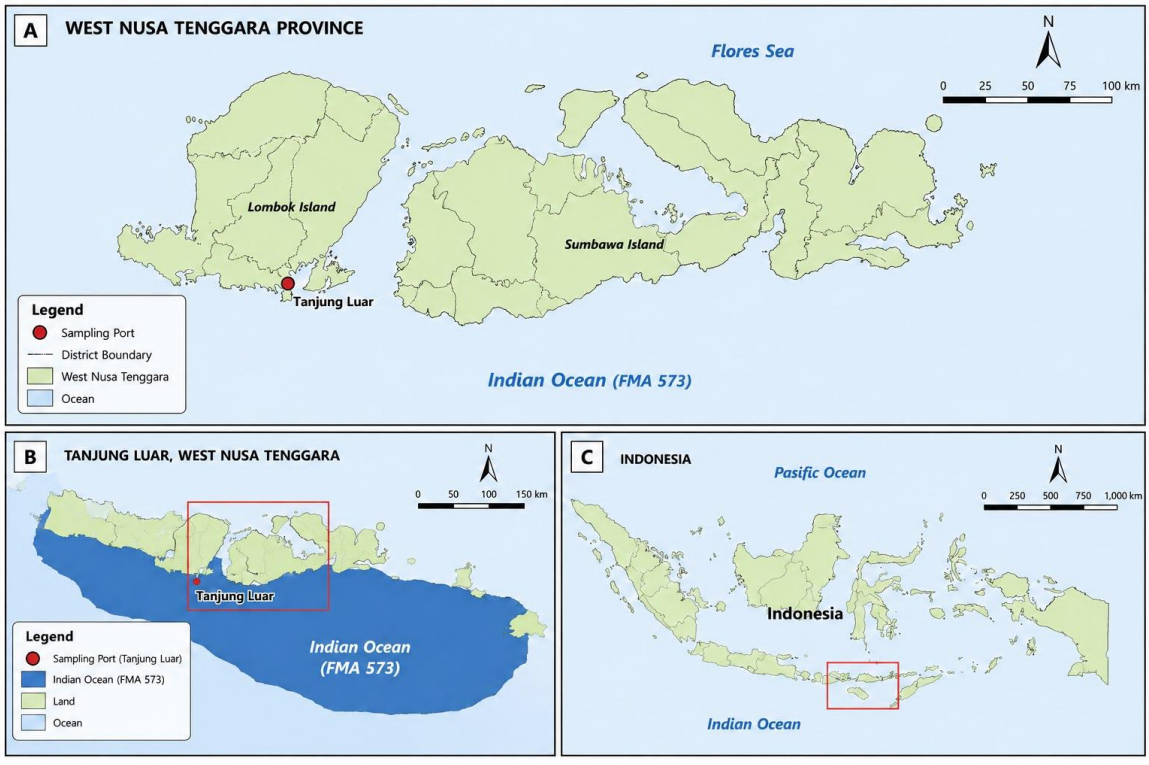


Fig. 1: Geographical location of the study area in Tanjung Luar, West Nusa Tenggara, Indonesia



Fig. 2: Silky shark measurement at Tanjung Luar Port

A cumulative total of 33,129 silky sharks were measured across 2017–2023 from the catch landings of 83 commercial vessels deploying bottom longline, surface longline, and gillnet gears. Dedicated enumerators were present at Tanjung Luar Port throughout the year to continuously record the data using the parameter data shown in Table 1.

Table 1: Parameters data for the fishing trip in Tanjung Luar fishing port

Category	Variable	Description
Trip information	Trip ID and date	Unique identifier and date of fishing trip
	Vessel name	Name of the fishing boat; engine power, and tonnage
	Fishing gear type and code	Fishing Gear: Bottom longline (BL), Surface longline (SL), Gillnet (GN)
	Trip duration (days)	Number of days spent fishing
	Fishing ground	Area of operation at provincial level (West Nusa Tenggara, East Nusa Tenggara, and Others)
Catch composition	Family and species	Taxonomic identification
	Morphometric measurements	Body size metrics recorded per individual
	— Total Length	Measured in cm
	— Fork Length	Measured in cm
	Sex (F/M)	Biological sex is determined at landing

Data analysis

Three main analyses were conducted to evaluate the biology and fishing effort of silky sharks (*Carcharhinus falciformis*), including length frequency distribution (LFD), sex ratio, and standardized CPUE. LFD data were analysed to explore the size distribution of the silky sharks across ys, sexes, and fishing gear. Distributions were constructed using 1 cm TL intervals and stratified by sex and gear type. Annual and seasonal variation was visualized using ridgeline density plots to elucidate recruitment pulses, the truncation of larger size classes, and gear-specific selectivity. This analytical approach facilitated the evaluation of juvenile-to-adult ratios, recruitment dynamics, and gear selectivity, patterns, thereby yielding critical insights into stock status and overall population health (Dharmadi and Fahm, 2015). Sex composition was used to detect potential bias in catches. The proportion of females and males was calculated annually and by gear type. Statistical differences in the sex ratio were tested using chi-square tests, with significance set at $p < 0.05$. To further evaluate variation across ys, size classes, seasons, and gears, a generalized linear model (GLM, binomial logit) was fitted with sex as the response variable and predictors including y, month, gear, fishing ground, and total length. This analytical approach enabled the identification of seasonal segregation, gear specific selectivity, and size-related variations in sex composition. Female proportions with 95% confidence intervals were reported annually, and effect sizes were emphasised over p-values given the large sample sizes. Deviations from a 1:1 sex ratio were interpreted in relation to reproductive dynamics and possible selective fishing pressure. Because direct stock assessment data are frequently unavailable, CPUE serves as a standard proxy for relative abundance (Maunder *et al.*, 2006; Campbell, 2004). In this study, CPUE was applied to standardize catch rates and determine the primary variables influencing shark abundance. By standardizing CPUE, temporal and spatial variation in fishing effort can be accounted for, allowing more reliable inference about population trends and fishing pressure. CPUE was calculated as the number of sharks caught per trip, adjusted for the duration of each trip. Standardized catch per unit effort (CPUE) was estimated using a two-stage delta-model framework to accommodate the zero catches typically observed in shark fisheries (Lo *et al.*, 1992). The delta approach decomposes the catch process into an encounter-probability component and a positive-catch component, thereby enabling the independent modeling of factors governing occurrence and relative abundance. For the encounter component, a generalized linear mixed model (GLMM) with a binomial error distribution and logit link was fitted using y, month, fishing gear (gear), provincial level fishing ground (FG), and all plausible two-way interactions among these variables. Vessel identity (boat name) was included as a random intercept to account for differences in fishing power among vessels.

Fishing effort (trip day) was incorporated as a logarithmic offset term to standardize catches to a common unit of effort. For the positive-catch component, a generalized additive model (GAM) featuring a negative-binomial error distribution and a log-link function was fitted using identical explanatory variables and interaction terms. This model yielded the lowest Akaike's Information Criterion (AIC) value of 13,193 alongside acceptable levels of overdispersion, while simultaneously generating biologically interpretable CPUE estimates. Vessel-specific effects were incorporated using a random-effect smooth terms (boat name, bs = "re"). The model fpr GAM with negative binomial, using Eq. 1 (Wood, 2017):

Catch ~ Year + Month + Gear + Fishing ground + offset[log(Trip Days)] (1)

To determine the optimal models for both the encounter-probability and a positive-catch components, a global model incorporating year (Y), month, fishing gear (gear), provincial level FG, and all plausible two-way interactions among these variables were fitted and evaluated to explain the variance in CPUE. Model selection was conducted using the MuMIn package. Candidate models were generated using the pdredge function, which systematically constructs and evaluates all permissible subsets of the global model. Models were ranked according to AIC, providing a balance between model fit and complexity. The effort offset and vessel effects were retained throughout the model selection process, as they functioned as foundational standardization parameters rather than candidate explanatory variables. Parallel processing was implemented using doParallel to improve computational efficiency, using Eqs. 2 to 7 (Hoyle *et al.*, 2024):

$$CPUE_t = P_t \, x \, C_t \quad (2)$$

Where:

$P_t = P_r \, (Y_t > 0)$

$C_t = E(Y_t \mid Y_t > 0$

$Y_i \sim Binomial \, (1, p_i)$

$$logit(pi) = \beta_0 + \beta_{year} + \beta_{month} + \beta_{Gear} + \beta_{fg} + \beta(gear \, x \, fg) + boat \, name \, (i) + offset \, (\log(effort)) \quad (3)$$

$$Boat \, name \, (i) \sim N \, (0, \sigma^2 boat \, name)$$
$$Y_i \mid Y_i > 0 \sim NB(\mu_i, \theta) \quad (4)$$

$$\log(\mu_i) = \beta_0 + \beta_{year} + \beta_{month} + \beta_{Gear} + \beta_{fg} + \beta(gear \, x \, fg) + s(boat \, name \,) + offset \, (\log(effort) \quad (5)$$

$$AIC = -2 \log(L) + 2K \quad (6)$$

$$Var(CPUE) = C^2 Var(P) + P^2 Var(C) \quad (7)$$

$$SE \, (CPUE) = \sqrt{Var(CPUE)}$$

$$95\% \, CI = CPUE \, \pm 1.96 \, x \, SE$$

The final encounter model selected by AIC retained y, month, gear, fishing ground, and the gear × fishing ground interaction, together with the vessel random effect and effort offset. The final positive-catch GAM retained y, month, gear, fishing round, gear × fishing, the vessel random-effect smooth term, and the effort offset. Annual and monthly standardized indices were subsequently estimated using marginal means obtained from the emmeans package (Lenth, 2023). The delta method was applied to compute the variance and confidence intervals of the delta-CPUE index (Walter and Ortiz, 2012).

RESULTS AND DISCUSSION

Fishing catches and trips

The silky sharks, landed at Tanjung Luar Fishing Port between 2017 and 2023, were dominated by surface longline vessels (Tables 2 and 3). 149 fishing trips were recorded in 2017 and 388 fishing trips in 2023. In contrast, bottom longline vessels

Table 2: Number of trips with silky sharks landed in Tanjung Luar port, West Nusa Tenggara from 2017 to 2023

Fishing gear	2017	2018	2019	2020	2021	2022	2023
Bottom longline	43	48	18	16	35	41	60
Gillnet	-	-	-	-	-	-	1
Surface longline	149	217	265	174	199	247	388

Table 3. Number of individuals landed in Tanjung Luar port, West Nusa Tenggara from 2017 to 2023

Fishing gear	2017	2018	2019	2020	2021	2022	2023
Bottom longline	123	89	22	33	64	85	161
Gillnet	-	-	-	-	-	-	5
Surface longline	2,905	4,899	5,935	3,811	4,505	5,253	5,239

made fewer trips, ranging from 16 in 2020 to 60 in 2023, and only one trip of gillnet was recorded in 2023. The number of individuals landed reflected this pattern of fishing effort. Surface longlines consistently accounted for the majority of silky shark catches, with annual landings ranging from 2,905 individuals in 2017 to a peak of 5,935 in 2019, and remaining above 3,800 individuals thereafter. Throughout the monitoring period, annual yields of silky sharks captured by bottom longlines did not exceed 170 individuals, with gillnet operations similarly recording a negligible catch of 5 individuals in 2023. A total of 33.129 individuals were measured, with morphometric data recorded for total length (TL) and sex. Surface longline was the predominant fishing gear for silky shark exploitation in Tanjung Luar, accounting for the highest number of trips and landed individuals across all years. Although cumulative landings experienced significant growth from 2017 to 2022, the sharp escalation in fishing trips observed in 2023 was not mirrored by proportional increase in catch volumes, thereby precipitating a marked decline in catch per trip. This sharp increase in trips coincided with a growth in the number of active vessels operating from Tanjung Luar, reflecting an expansion of the fleets. Median trip duration remained relatively stable, but overall fishing days and cumulative effort rose, indicating that catch levels were sustained through intensified activity rather than stable population productivity. The observed pattern may stem from diminished stock availability or catchability induced by heightened fishing pressure, thereby pointing toward potential early warnings of overexploitation. These indications of declining catch efficiency are further contextualized by sex-ratio evaluations, providing critical insights into demographic stability and population vulnerabilities under prolonged fishing mortality.

Sex ratio

Of the 33,129 samples collected between 2017 and 2023, the sex of 32,077 individuals was successfully determined females consistently comprised more than 50% of the catch. (Fig. 3a). Male proportions ranged from 29.1% in 2023 to 47.8% in 2019, with the strongest female dominance observed in 2022 and 2023. Based on chi-square test, the sex ratio was significantly skewed toward females ($p < 0.001$) in six of seven years (Table 4). The year 2019 was the most balanced, with males comprising 47.8% of the catch and a p-value of 0.009, indicating a weaker but still statistically significant deviation. To evaluate sex-specific patterns, a generalized linear model utilizing a binomial logit link was constructed; sex served as the dependent variable, while gear configuration, management zone, year, month, and total length functioned as independent predictors. The model confirmed that female probability increased significantly over time ($p < 0.001$) and declined with increasing size ($p < 0.001$). Importantly, several monthly contrasts were significant ($p < 0.05$), indicating seasonal variation in sex ratios, consistent with potential migration or segregation. Gear and zoning effects were weaker and not statistically

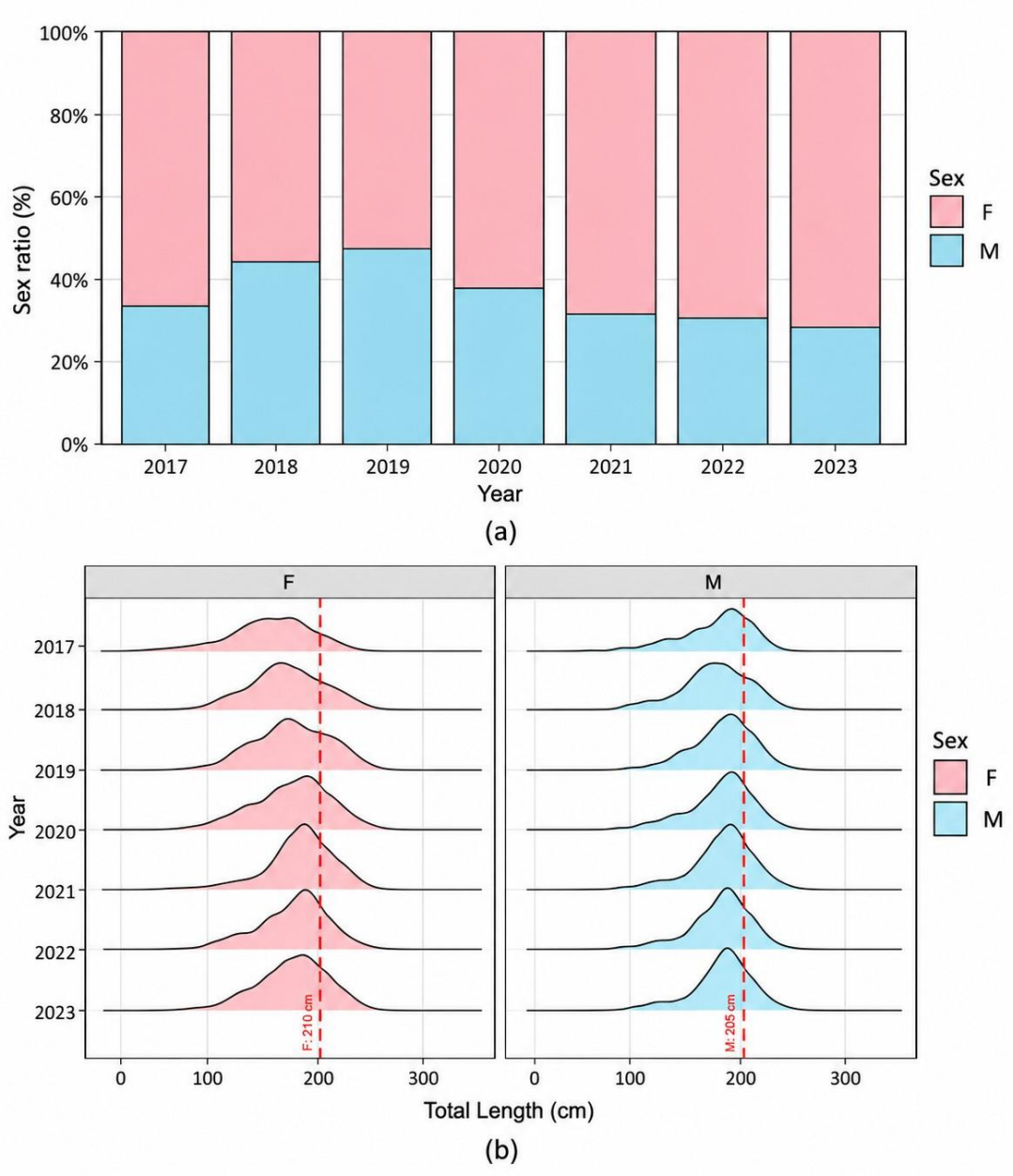


Fig. 3. Annual sex ratio (%) (a) and length-frequency distribution by sex (b) of silky sharks (Carcharhinus falciformis) landed at Tanjung Luar fishing port, Eastern Indian Ocean, 2017–2023

Table 4: Annual sex ratio of silky sharks landed at Tanjung Luar fishing port (2017–2023)

Year	Female	Male	Total	prop_M	p_value
2017	2041	987	3028	0.326	2.61e- 83
2018	2764	2189	4953	0.442	3.21e- 16
2019	3056	2802	5858	0.478	9.46e- 4
2020	2441	1403	3844	0.365	1.48e- 63
2021	3090	1465	4555	0.322	9.57E-131
2022	3671	1667	5338	0.312	1.56E-169
2023	3853	1578	5431	0.291	1.41E-215

significant. Across years, modal total lengths were concentrated at approximately 150–200 cm TL. Females consistently had broader distributions and larger median lengths than males (Fig. 3b). However, the upper tail of the distribution became progressively thinner, particularly between 2019 and 2023, and the interquartile ranges narrowed slightly in 2019 and 2023. A post-2018 decline was likewise observed in the median length of females, in contrast to male median lengths, which varied without exhibiting any clear directional trend. This pattern is consistent with disproportionate removal of larger females, however, sexual segregation, habitat use, and gear selectivity may also contribute to the observed female bias. Female proportions ranged from 52% to 71% annually. A salient feature of the landings is a persistent female bias (> 50% females annually and ~71% in 2023) alongside larger median TLs in females (this study). Sex-biased catches can arise from sexual segregation, gear selectivity, and seasonal movement. Furthermore, sex-specific spatial segregation, such as the utilization of distinct migration routes or depth zones by adult females, may result in heightened seasonal susceptibility to longline fisheries interactions. Evidence of sexual segregation is well documented in other shark species, such as *Squalus acanthias* and grey reef sharks (*Carcharhinus amblyrhynchos*) (Heupel and Simpfendorfer, 2014). Although less studied in silky sharks, emerging research indicates spatial structuring and potential sex-specific segregation in the Indo-Pacific and Eastern Pacific (Li *et al.*, 2023; Talwar *et al.*, 2025). These findings indicate that female silky sharks experience spatially and temporally variable vulnerability to specific fisheries. Furthermore, the convergence of sex-ratio biases with size-class truncation leads to the selective removal of larger, late-maturing females—a demographic shift that substantially depresses population fecundity and aggregate spawning biomass (Joung *et al.*, 2008; Grant *et al.*, 2018). Reports from the Indian Ocean similarly note the high vulnerability of silky sharks to longline and purse seine, consistent with the ecological risk assessment that ranked the species among the least productive and most susceptible to these gears. The IOTC Scientific Committee further highlighted that silky sharks are long-lived, late maturing, and have low reproductive output, making them particularly prone to overfishing, with current stock status in the Indian Ocean considered uncertain (IOTC, 2025; Simeon *et al.*, 2018; Curnick *et al.*, 2020). From a monitoring perspective, sex ratio and sex-specific size distributions are sensitive key indicators of reproductive stress in elasmobranch fisheries. A consistently female-skewed catch, which shows a reduction in the number of large females as detailed in this document, supports the need for sex-specific strategies and targeted conservation measures. These include protecting mature females through size/slot limits, minimizing retention via gear modifications and live-release protocols, and restricting catch effort to prevent overfishing in seasonal hotspots frequently visited by adult females during critical reproductive periods and aggregation seasons (Joung *et al.*, 2008; Curnick *et al.*, 2020).

Stock status and health from length-based indicators

From the recorded data, the modal peaks were found being between 150–200 cm TL, with females generally exhibiting broader distributions and higher frequencies than males (Fig 3b). Median lengths ranged from 191.0 cm to 198.2 cm for females and 183.4 cm to 189.6 cm for males, indicating that females were consistently larger across all ys. The temporal trend in length by sex showed stable median lengths across the study period, with females consistently larger than males. This sex-specific divergence is evident in Fig. 4, where male size distributions remain variable but stable, while female medians compress downward over time (Fig. 4b). Slight contractions in the interquartile ranges during 2019 and 2023 indicated a decrease in dispersion among landed body sizes (Fig. 4a).

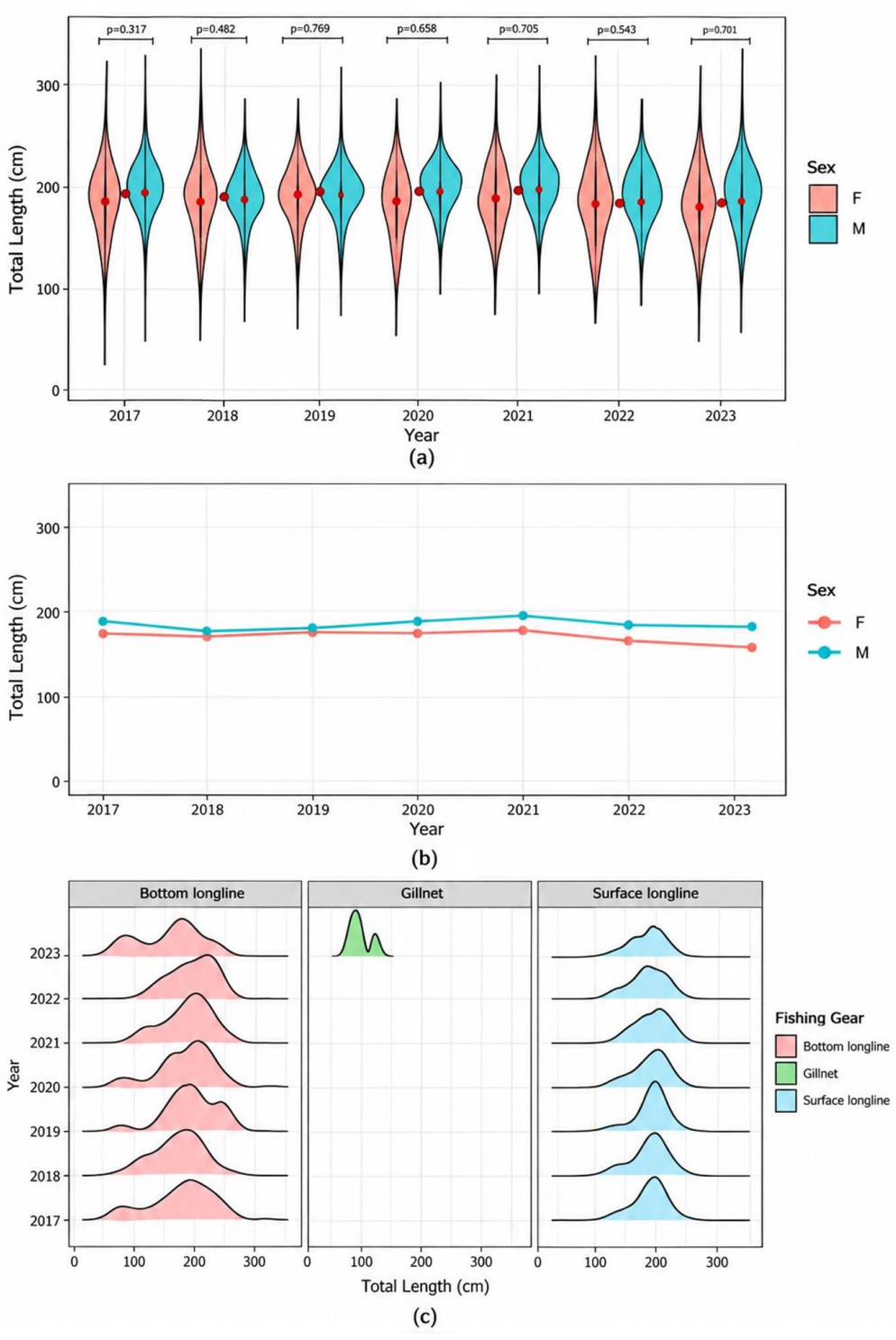


Fig. 4: The LFD of silky shark total length (cm) by y and sex (F = female, M = male) (a and b) and by fishing gear (c) landed at Tanjung Luar fishing port, 2017–2023

The length distribution by gear (Fig 4c) showed revealed clear differences in selectivity. Surface longlines consistently captured the widest range of sizes, including individuals above the published length-at-maturity thresholds (F ≈ 216 cm TL; M ≈ 208 cm TL). In contrast, bottom longline catches were heavily skewed toward smaller sharks, with most individuals below maturity size. Gillnets (GN), were introduced only in 2023, and therefore contribute only limited data, but captured mid-sized individuals (~180 cm TL). Apparent shifts in selectivity between years are driven primarily by changes in fleet gear composition, such as the introduction of gillnets, rather than alterations in longline configuration. Length–frequency patterns from 2017–2023 point to a landed catch increasingly composed of sub-mature individuals. Modal sizes were concentrated at 150–200 cm TL, female medians exceeded male medians throughout, and the upper tail of the distribution became progressively thinner between 2019 and 2023 (Fig 4a), indicative of size truncation under sustained overexploitation. As illustrated in Fig. 4b, male median values fluctuate without a discernible directional trend, while female medians have exhibited a downward trajectory since 2018. Formal statistical testing confirmed significant interannual variation in female median lengths (Kruskal–Wallis $\chi^2 = 668.78$, df = 6, $p < 0.001$), with pairwise Wilcoxon tests indicating that female median TL in 2023 was significantly lower than in earlier years (adjusted $p < 0.001$). This pattern suggests that the decline in female size is driven not by narrowing of the median per se, but by reduced frequency of large females in landings. When benchmarked against published length-at-maturity (Lm) thresholds for silky sharks in the Indian Ocean, females ≈ 216 cm TL and males ≈ 208 cm TL (Rigby *et al.,* 2021) the majority of landed individuals at Tanjung Luar are caught below published length-at-maturity thresholds (immature). That pattern raises precautionary concerns regarding diminished spawning potential, given that the fishery lands predominantly sub-mature individuals that have not yet contributed to the reproductive output of the stock (Joung *et al.*, 2008; IOTC, 2025). Notwithstanding the absence of statistical significance for gear effects in the models, documented evidence reveals that the use of wire leaders and shark lines elevates shark retention efficiency compared to nylon monofilament leaders; thus, prohibiting such gear could mitigate longline-related mortality in silky sharks populations by >30% (D'Alberto *et al.*, 2024). The life-history backdrop reinforces the risk of over-exploitation: silky sharks grow slowly and mature late (e.g., sexes-combined k ≈ 0.084/y; $L\infty$ ≈ 332 cm TL), implying limited capacity to rebound once spawning stock diminishes (Joung *et al.*, 2008; Grant *et al.*, 2018). At the ocean-basin scale, the ~71% decline in oceanic shark and ray abundance since 1970 underscores that exploitation rates typical of contemporary pelagic fleets readily outpace the replacement potential of slow-growing elasmobranchs (Pacoureau *et al.*, 2021). Collectively, the dominance of sub-Lm fish, the loss of large size classes, and the female–male size separation in this study indicate a fishery in which spawning cohorts are being eroded, and recruitment is increasingly relied upon to sustain catches. While length-based monitoring offers a robust early-warning framework under data-limited scenarios, sustained compression of maximum size distributions, especially within female cohorts, reflects elevated fishing mortality and stock overexploitation, necessitating urgent precautionary oversight (Joung *et al.*, 2008; Pacoureau *et al.*, 2021). The compression of size structure is consistent with precautionary warning signals about reduced contribution of large mature individuals. These length-based patterns are complemented by the standardized CPUE trends.

Stock status and health from standardized CPUE

Based on the selected model (GAM-NB within a two-stage delta approach), the standardized CPUE for silky sharks showed a clear peak in 2018 (10.81 ± 1.32), before declining steadily to

5.18 ± 0.88 in 2023. Annual values demonstrate a gradual downward trajectory: 8.32 ± 1.14 in 2017, 7.83 ± 1.33 in 2019, 7.62 ± 1.37 in 2020, 9.97 ± 1.18 in 2021, and 9.00 ± 0.99 in 2022 (Fig. 5a). A linear regression revealed a significant negative temporal trend (slope = –0.64 CPUE/y, 95% CI: –0.95 to –0.49, p = 0.020), explaining ~56% of the variance. This confirms that CPUE experienced a significant temporal decline, despite the absence of statistically significant differences among annual medians when evaluated independently. The monthly CPUE (Fig. 5b.) across seven years of data collection showed that the highest values consistently occurred in May and November, indicating a biannual seasonal pattern in silky shark availability or catchability within the Eastern Indian Ocean. Based on simulation from the model, a significant positive correlation was detected between catch volumes and trip frequency, whereas standardized CPUE correlated inversely with the total number of fishing trips (Figs. 6a and 6b). Based on the data collected throughout the survey period, the number of fishing trips per boat remained the same, however there was a significant increase in the number of boats (Fig. 6c). To strengthen the analysis, we examined trip-level data (Fig. 5d–e), which provide hundreds of observations per y. Pronounced interannual fluctuations in fishing trip duration were observed (Fig. 6d) , with median values varying across years alongside several outlying data points denoting exceptionally extended trips. The dual-axis plot of annual CPUE and number of trips (Fig. 6e) illustrates the contrasting trajectories of declining catch efficiency and increasing fishing effort, reinforcing the conclusion that effort compensation is insufficient to maintain catch rates. This pattern suggests that changes in fishing effort are not only driven by fleet size but also by the duration of individual trips, which may further influence catchability and standardized CPUE trends. Standardized CPUE revealed a pronounced 2018 peak (~10.8 ind/day) followed by a steady decline to 2023 (~5.2 ind/day). The index shows a sustained downward trajectory since its 2018 peak. This implies that the heightened values recorded in 2018 do not necessarily denote an increase in absolute stock abundance; instead, they are more plausibly attributed to operational modifications, including fleet motorization—that artificially inflated catchability (Maunder *et al.*, 2006; Hoyle *et al.*, 2024). Uncertainty estimates from the delta method provide plausible confidence bounds around the standardized index, though broader structural model uncertainty (spatial redistribution, catchability changes) should be considered when interpreting trends. The IOTC assessment itself emphasizes that nominal CPUE may not reliably reflect abundance, underscoring the need for precautionary interpretation of standardized indices. It is important to emphasize that the patterns identified herein constitute localized signals specific to FMA 573 and should not be extrapolated to resolve the broader regional stock-status ambiguities emphasized by IOTC. Rather, they provide complementary evidence of declining catch rates that must be considered within the wider context of ongoing uncertainty at the Indian Ocean scale. The persistence of seasonal peaks in May and November across seven ys indicates a seasonal signal in availability/catchability, which is consistent with prior work in Indonesia's FMA 573 documenting a seasonal structure in silky shark abundance indices during 2015–2016, and is also supported by tagging and fishery evidence from the central Indian Ocean showing high residence in the upper 100 m, diel use of seamounts, and dominance of juveniles in longline and purse-seine catches (Simeon *et al.*, 2018; Curnick *et al.*, 2020). Temporal and spatial overlap with seasonal aggregations and migratory corridors generates predictable windows of elevated catchability, rendering stocks acutely susceptible to overexploitation absent appropriate limitations on fishing mortality (Simeon *et al.*, 2018; Curnick *et al.*, 2020). Methodologically, the choice of a flexible additive framework accords with CPUE

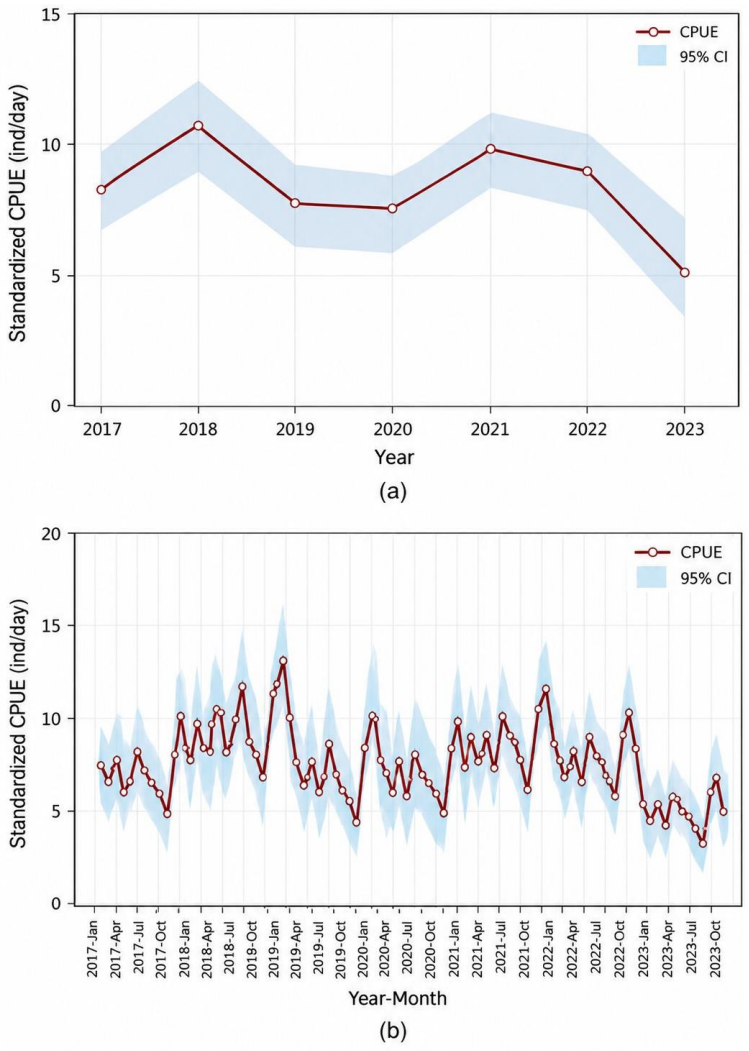
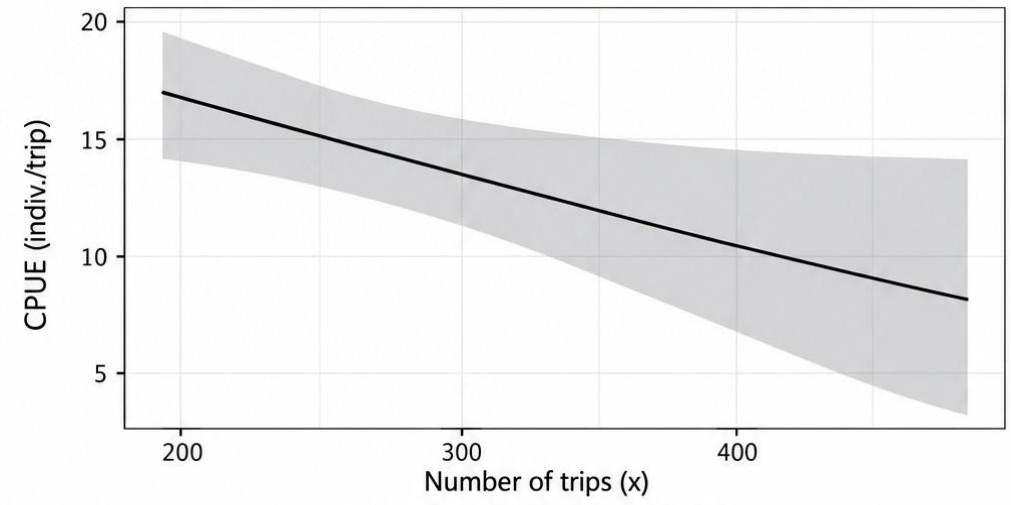
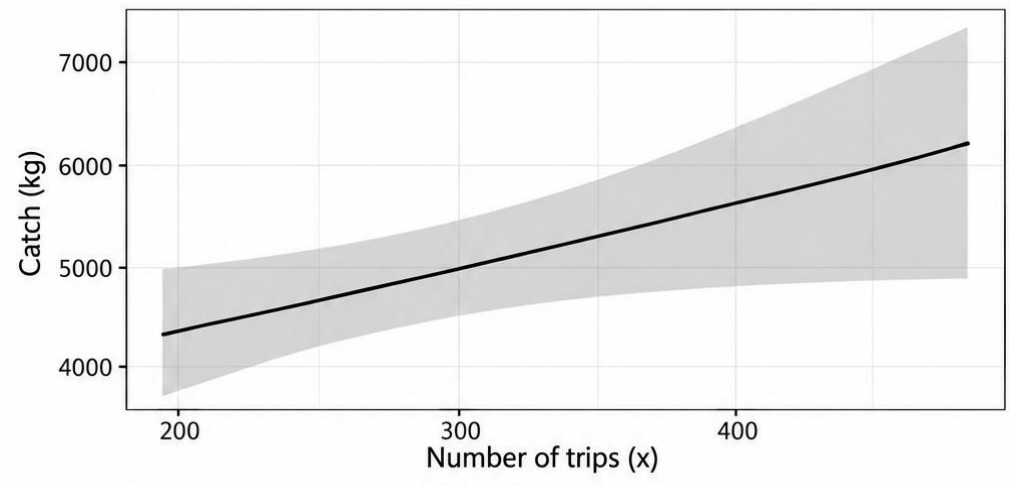


Fig. 5: Annual (a) and monthly (b) trend of standardized CPUE (ind/day/GT) for silky sharks (*Carcharhinus falciformis*) landed at Tanjung Luar fishing port, Eastern Indian Ocean, 2017-2023

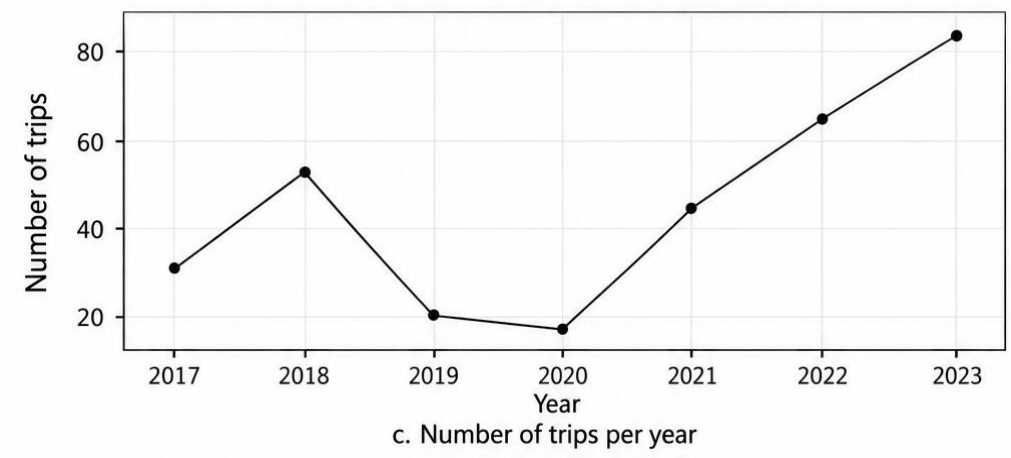
good practice. Contemporary guidance emphasizes distinguishing density and catchability covariates, incorporating spatial/temporal effects, and conducting uncertainty estimation beyond point predictions; adherence to these principles generally yields indices less prone to bias than raw CPUE (Maunder *et al.*, 2006; Hoyle *et al.*, 2024). Notwithstanding rigorous standardization, CPUE indices must be cross-verified against independent biological indicators, including size-frequency distributions, maturity stages, and sex ratios—under conditions of shifting fleet dynamics, given that behavioral redistributions of effort can decouple catch rates from absolute population abundance (Maunder *et al.*, 2006; Hoyle *et al.*, 2024). In the present case, the post-2018 decline in standardized CPUE, together with size truncation and sex skew, strongly suggests declining stock availability and abundance rather than improved catchability. This interpretation aligns with broader Indo-Pacific assessments that highlight the vulnerability of silky sharks to sustained exploitation and the need effective precautionary management measures to support long-term population stability and resilience (IOTC, 2025; Pacoureau *et al.*, 2021).



a. Number of trips (x) vs CPUE (y)



b. Number of trips (x) vs catch (y)



c. Number of trips per year

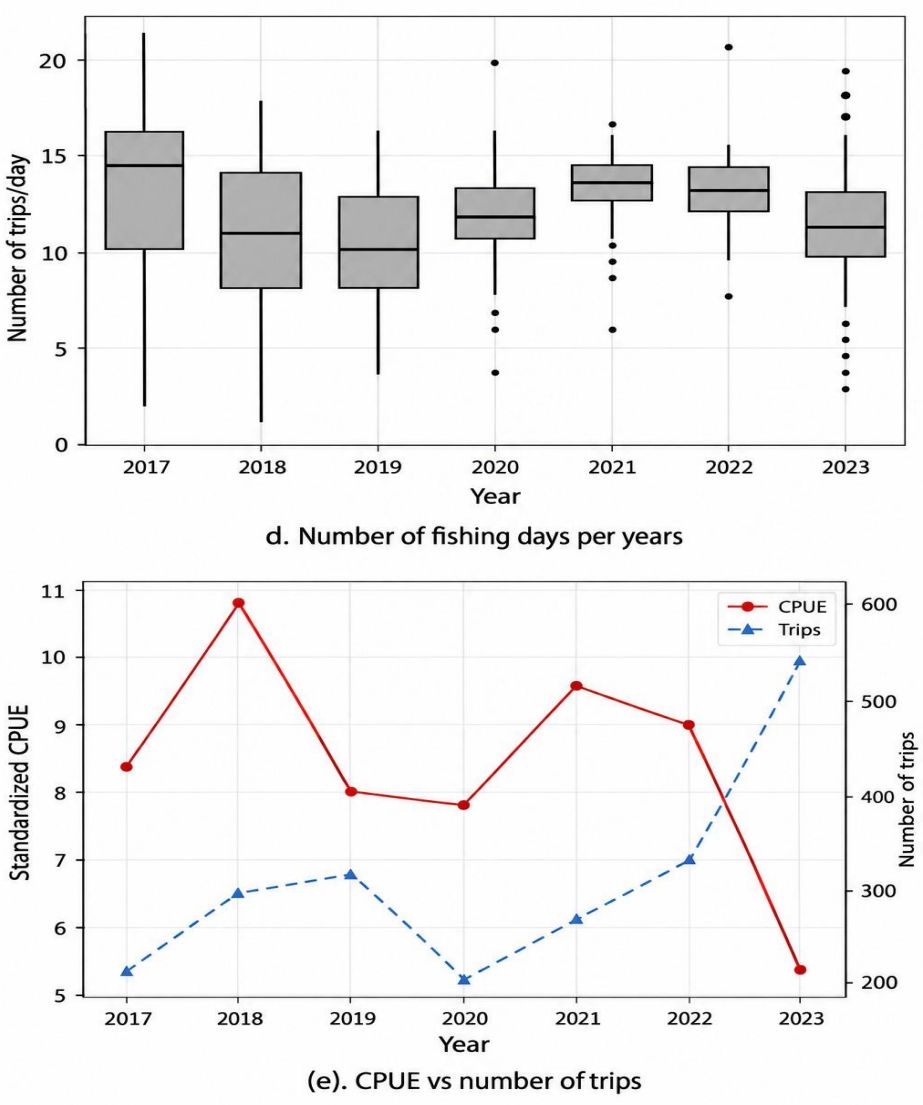


Fig. 6: Key indicators of silky shark fishery dynamics at Tanjung Luar, in the Eastern Indian Ocean

Fleet growth, effort redistribution, and effort creep

Operational signals from this study show that trip frequency increased while standardized CPUE declined, and total catch was maintained primarily by more trips and more boats rather than by stable per-trip efficiency (Figs. 4a and 5b). Such patterns are consistent with an effort-compensation behaviors frequently observed in fisheries experiencing stock depletion; as catch efficiency diminishes, fleets systematically scale up effort to sustain constant aggregate landings, notwithstanding the requirement for trip-level verification (Harley *et al.*, 2001; Maunder *et al.*, 2006). Simultaneously, growth in vessel numbers and shifts in trip characteristics can lead to spatial expansion or concentration of effort, increasing overlap with nursery grounds and migratory corridors. The literature terms the underlying process effort creep, technological and behavioral changes that raise effective fishing power relative to nominal effort, thereby biasing CPUE and potentially masking biological decline unless standardization explicitly accounts for spatial/temporal redistribution and targeting

(Campbell, 2004; Hoyle *et al.,* 2024). In Indonesia, the 2014 policy package, including the moratorium on ex-foreign vessels and the ban on at-sea transshipment, reduced industrial effort and re-shaped fleet behavior, with mixed short-term production effects but evidence of local fleet adjustments (more domestic vessels and trips) that can elevate exposure of oceanic/coastal shark habitats (Arthatiani and Apriliani, 2016; Zulbainarni *et al.*, 2022). Within this policy context, the trend of increasing landings through additional trips, coupled with diminishing returns per trip is both economically and biologically unsustainable. This observation is consistent with theoretical frameworks and case studies that indicate CPUE may appear stable or decline gradually even as fish abundance decreases, especially in fisheries characterized by aggregation (Harley *et al.*, 2001; Maunder *et al.*, 2006).

Management implications

The synthesis of biological, abundance, and operational indicators points to a fishery showing multiple precautionary warning signals. Length-based indicators suggest increasing representation of sub-mature individuals alongside a potential reduction in the contribution of large, older fish to commercial landings. Concurrently, standardized CPUE has exhibited a downward trajectory since 2018, despite concurrent increases in annual fishing trips and vessel counts, reflecting an effort-compensation pattern consistent with declining abundance (Maunder *et al.*, 2006; Campbell, 2004). The progressive loss of large females in length-frequency distributions is consistent with the declining CPUE index, together indicating reduced availability of mature individuals and erosion of reproductive potential under sustained fishing pressure. Seasonal CPUE peaks occurring in May and November point to distinct intervals of elevated catch rates, likely driven by increased catchability or stock availability—though any corresponding seasonal management measures implemented during these months should be rigorously validated against independent biological evidence prior to implementation (Simeon *et al.*, 2018; Curnick *et al.*, 2020). These converging signals require immediate, precautionary action. Building on these converging signals and the need for immediate precautionary action, a structured package of management measures must be implemented. First, seasonal closures or effort limitations during May and November are proposed as a precautionary hypothesis, given that these months consistently exhibit elevated CPUE metrics. Although catch rates in isolation do not definitively confirm the presence of spawning aggregations or concentration of mature females, these seasonal signals warrant rigorous investigation and could justify preliminary management trials. Second, the protection of mature females remains an important precautionary consideration, given their critical role in population recovery. Notwithstanding these considerations, the high prevalence of sub-mature specimens in the catch necessitates that size-selective regulations, including minimum landing sizes, maximum limits, or slot configurations, be critically appraised in light of empirical population structure. As a precautionary hypothesis, live-release protocols could be applied for individuals below the published maturity threshold (Lm50 ≈ 216 cm TL for females (Rigby *et al.,* 2021), with complementary gear modifications, particularly in surface longline fisheries to reduce capture rates and minimize haul-back and post-release mortality of large sharks (Joung *et al.*, 2008). Third, effective fishing effort must be strictly controlled and monitored to prevent further decline in stock abundance. Such measures necessitate comprehensive regulatory frameworks that extend beyond restrictions on vessel capacity and trip frequency to incorporate fine-scale variations in fishing power—including hook spacing, set density, and soak duration—thereby avoiding the pitfalls of relying exclusively on nominal effort metrics. Concurrently, spatio-

temporal standardization of CPUE must be maintained, with routine sensitivity analyses to ensure that abundance indices remain robust under changing fleet behavior and fishing strategies (Campbell, 2004; Hoyle *et al.*, 2024). Furthermore, monitoring frameworks must remain streamlined and practical. By institutionalizing sex-ratio and length recording, stratified by gear type and fishing area as core performance indicators, managers can better detect rebuilding of the upper-tail female size clusters essential for sustaining spawning potential. These signals can then be leveraged as near-real-time feedback to dynamically adapt seasonal fishing closures and size regulations (Grant *et al.*,2018; Maunder *et al.*, 2006). Given the post-2014 restructuring of Indonesian industrial fisheries (moratorium on ex-foreign vessels; transshipment ban) and stronger enforcement, local measures at Tanjung Luar should align with national and regional frameworks to avoid displacement and leakage (Arthatiani and Apriliani, 2016; Zulbainarni *et al.*, 2022). Since silky sharks exhibit high mobility and extensive migratory behavior, collaborative frameworks with the IOTC addressing bycatch mitigation, comprehensive data exchange for retained and discarded fractions, and synchronized regional surveillance are paramount to precluding the spatial displacement of fishing mortality that could erode localized conservation achievements (IOTC, 2025). In addition to local and national measures, international cooperation is indispensable. In the IOTC Area of Competence small juveniles of 120 cm and less (Clavareau *et al.*, 2020) are frequently taken as bycatch in industrial purse seine tuna fisheries setting on drifting FADs and subject to high on-board and post release mortality (Hutchinson *et al.*, 2015; Onandia *et al.*, 2021). Thereby, estimates from external studies suggest that purse seiners increase fishing-related mortality of juvenile silky sharks by approximately 100,000 animals per y (Ziegler, 2022; Ziegler, 2025), this estimate derives from sources external to the present study, while sub-adults and adults are removed by industrial and artisanal longliners and gillnetters. Finally, participatory implementation will determine durability. Co-designing the seasonal pilots programs with fishers, maintaining transparency in reporting, and supplying interim transition aid during closures collectively foster regulatory compliance and alleviate immediate socio-economic burdens, thereby reinforcing the conversion of ecological restoration into stable medium-term yields and economic returns (Simeon *et al.*, 2018; Zulbainarni *et al.*, 2022). In summary, this focused set of seasonal, sex-specific, and effort-based measures in the Eastern Indian Ocean silky shark fishery supported by pragmatic monitoring and regional coordination constitutes a clear and implementable pathway to halt decline and start rebuilding spawning biomass of silky sharks in the Eastern Indian Ocean.

CONCLUSION

This study demonstrates that the silky shark fishery in at the FMA 573 in the Eastern Indian Ocean is showing the sign of increasing vulnerability under sustained fishing pressure. Length-based metrics demonstrate that catches are heavily skewed toward immature specimens; coupled with the progressive scarcity of large females, this underscores a population truncation wherein older, larger cohorts contribute minimally to total landings. At the same time, standardized CPUE exhibited a persistent decline after 2018 despite increasing fishing effort, indicating that catch levels are being maintained through greater fishing activity rather than stable population productivity. The synthesis of these biological and fishery-dependent metrics underscores a growing dependency on annual recruitment pulses, signaling that the stock's long-term resilience to contemporary exploitation pressure is severely compromised. The findings highlight the importance of integrating biological indicators with standardized abundance indices to evaluate stock condition in data-limited shark fisheries. Particular priority should be given to monitoring

length-based indicators, including median total length, size-frequency distribution, proportion of individuals below length-at-maturity thresholds, representation of large mature size classes, and sex-specific length distributions. Such indicators furnish pragmatic early-warning signals regarding alterations in demographic structure, reproductive output, and exploitation dynamics across data-limited shark fisheries. Seasonal management measures, improvements in gear selectivity, and more comprehensive effort controls may provide opportunities to reduce mortality on vulnerable life stages and support stock recovery. It is essential to note that although the underlying data derive exclusively from landings at Tanjung Luar within FMA 573, the nomadic nature of silky sharks means that the associated fishing grounds encompass a much wider geographic distribution across various provincial waters within Indonesia's EEZ. The patterns identified herein represent localized signals from FMA 573 that may reflect broader exploitation pressures across the Eastern Indian Ocean basin. Given silky sharks' extensive migrations and transboundary exploitation, these fishery-dependent signals are specific to Tanjung Luar, highlighting localized vulnerabilities while acknowledging unresolved large-scale regional stock-status uncertainty and data gaps requiring monitoring, coordinated assessments, and improved regional fisheries information systems. Conservation outcomes will therefore depend not only on precautionary local implementation but also on alignment between national management actions and wider regional initiatives. Long-term sustainability will require a management approach that balances ecological objectives with the needs of fishing communities. Strengthening collaboration among fishers, managers, researchers, and regional institutions can improve compliance, support adaptive management, and enhance the effectiveness of conservation measures. Synthesizing these lines of evidence specifically, the contraction of standardized catch rates coupled with demographic shifts combined with changes in size and sex distributions, furnishes critical precautionary signals. These trends underscore an imperative for intensified surveillance, rigorous quantitative stock modeling, and adaptive regulatory frameworks designed to secure the long-term ecological persistence of the silky shark fishery across the Eastern Indian Ocean.

AUTHOR CONTRIBUTIONS

A. Budiarto conceived, design, and overseeing sample collection, and prepared the initial manuscript draft. B. Wiryawan reviewed the manuscript and provided critical feedback. I. Yulianto prepared the analysis data, interpreted the results, and assisted in manuscript preparation. A.A. Taurusman contributed to manuscript review and provided comments on the interpretation of results. M.D. Iskandar reviewed the manuscript and provided input on data interpretation. I. Ziegler contributed to the manuscript review and provided feedback on the discussion. S. Gigentika reviewed the manuscript and provided constructive comments. S. Agustina performed the statistical analysis, provided figure and table, and prepared the manuscript draft.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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ABBREVIATIONS

%	Percent
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ACIAR	Australian Centre for International Agricultural Research
AIC	Akaike Information Criterion
BL	Bottom longline
CC BY	Creative Commons Attribution
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
cm	Centimeter
CPUE	Catch-per-unit-effort
dFAD	Drifting fish aggregating device
DOI	Digital object identifier
EEZ	Exclusive economic zone
F	Female
FAD	Fish aggregating device
FAO	Food and Agriculture Organization of the United Nations
FG	fishing ground
Fig.	Figure
FL	Fork length
FMA	Fisheries management area
GAM	Generalized additive model
GAM-NB	Generalized additive model with negative binomial distribution
GJESM	Global Journal of Environmental Science and Management
GLM	Generalized linear model
GN	Gillnet
GT	Gross tonnage
HP	Horsepower
IOTC	Indian Ocean Tuna Commission
IUCN	International Union for Conservation of Nature
LFD	Length-frequency distribution
Lm	Length at maturity
m	Meter
M	Male
MMAF	Ministry of Marine Affairs and Fisheries
NA	Not available
NB	Negative binomial
NDF	Non-detriment finding
NTB	West Nusa Tenggara
NTT	East Nusa Tenggara
RAV	Record of Active Vessels
RFMO	Regional Fisheries Management Organization
SL	Surface longline
TL	Total length
WCPFC	Western and Central Pacific Fisheries Commission
WPEB	Working Party on Ecosystems and Bycatch
y	Years

REFERENCES

Arthatiani, F.Y.; Apriliani, T., (2016). Dampak kebijakan moratorium kapal eks asing terhadap kondisi perikanan tuna: studi kasus di DKI jakarta. Jurnal Kebijakan Sosial Ekonomi Kelautan dan Perikanan. 5: 71 **(8 pages).**

Campbell, R.A., (2004). CPUE standardisation and the construction of indices of stock abundance in a spatially varying fishery using general linear models. Fish. Res., 70(2–3) (**18 pages**).

CITES, (2016). CoP17 Proposal 42: Inclusion of *Carcharhinus falciformis* in Appendix II. Convention on International Trade in Endangered Species of Wild Fauna and Flora, Geneva. pp. 1–15 **(15 pages).**

Clavareau, L.; Sabarros, P.; Escalle, L.; Bach, P.; Abascal, F.; Lopez, J.; Murua, H.; Alayoón, P.J.; Ramos, M.; Ruiz, J.; Mérigot, B., (2020). Elasmobranch bycatch distributions and mortality: Insights from the European tropical tuna purse-seine fishery. Global Ecol. Conserv., 24: e01211. (**12 pages**).

Curnick, D.J.; Carlisle, A.B.; Gollock, M.; Schallert, R.J.; Hussey, N.E.; Chapple, T.K.; Tickler, D.M.; Block, B.A.; Jacoby, D.M.P., (2020). Behavior and ecology of silky sharks around the Chagos Archipelago and evidence of Indian Ocean-wide movement. Front. Mar. Sci., 7: 596619 (**18 pages**).

D'Alberto, B.; Patterson, H.; Bromhead, D., (2024). The influence of wire leaders and shark lines on shark bycatch in pelagic longline fisheries: A review and implications for the IOTC (ABARES Research Report 24.04). Canberra: Australian Bureau Agriculture Resources Economics and Sciences. (**32 pages**).

Dharmadi, F.; Fahmi. (2015). Pelagic shark fisheries of Indonesia's Eastern Indian Ocean Fisheries Management Region. Afr. J. Mar. Sci., 37(2): 249-258 **(9 pages).**

Dulvy, N.; Pacoureau, N.; Rigby, C.; Pollom, R.; Jabado, R.; Ebert, D.; Finucci, B.; Pollock, C.; Cheok, J.; Derrick, D.; Herman, K.; Sherman, C.; VanderWright, W.; Lawson, J.; Walls, R.; Carlson, J.; Charvet, P.; Bineesh, K.; Fernando, D.; Ralph, G.; Matsushiba, J.; Hilton-Taylor, C.; Fordham, S.; Simpfendorfer, C., (2021). Overfishing drives over one-third of all sharks and rays toward a global extinction crisis. Curr. Biol., 31(21): 4773-4787 (**27 pages**).

FAO, (2024). The State of World Fisheries and Aquaculture 2024: Blue Transformation in action. Food and Agriculture Organization of the United Nations, Rome, **(264 pages).**

Grant, M.; Smart, J.; White, W.; Baje, L.; Simpfendorfer, C., (2018). Life history characteristics of the silky shark Carcharhinus falciformis from the central west Pacific. Mar. Freshwater Res., 69(5): 562–573 (**12 pages**).

Hall, N.G., Bartron, C., White, W.T. Dharmadi, Potter, I.C., (2012). Biology of the silky Fish biol., 80(5): 1320-1341 **(22 pages).**

Harley, S.J.; Myers, R.A.; Dunn, A., (2001). Is catch-per-unit-effort proportional to abundance?. Canad. J. Fish. Aquat. Sci., 58(9): 1760-1772 (**13 pages**).

Heupel, M.R.; Simpfendorfer, C.A., (2014). Importance of environmental and biological drivers in the presence and space use of a reef-associated shark. Mar. Ecol. Progress Series. 496: 47–57 (**11 pages**).

Hinton, M.G.; Maunder, M.N., (2003). Methods for standardizing CPUE and how to select among them (SCRS/2003/034). Inter-American Tropical Tuna Commission. (**11 pages**).

Hoyle, S.D.; Campbell, R.A.; Ducharme-Barth, N.D.; Grüss, A.; Moore, B.R.; Thorson, J.T.; Tremblay-Boyer, L.; Winker, H.; Zhou, S.; Maunder, M.N., (2024). Catch per unit effort modelling for stock assessment: A summary of good practices. Fish. Res., 265: 106860 (**22 pages**).

Hutchinson, M.; Itano, D.; Muir, J.; Leroy, B.; Holland, K., (2015). Post-release survival of juvenile silky sharks captured in tropical tuna purse seine fishery. Mar. Ecol. Progress Series. 521: 143-154 (**12 pages**).

IOTC, (2025). Report of the 28th Session of the IOTC Scientific Committee. China, 1-5 December 2025. IOTC-2025-SC28-R[E]: 269 pp. (Appendix 27: Executive Summary Silky Shark. 194. (**269 pages**).

Joung, S.J.; Chen, C.T.; Lee, H.H.; Liu, K.M., (2008). Age, growth, and reproduction of silky sharks (Carcharhinus falciformis) in northeastern Taiwan waters. Fish. Res., 90(1-3): 78-85 **(8 pages).**

Lenth, R.V., (2023). emmeans: Estimated marginal means, aka least-squares means (Version 1.8.8) [R package]. CRAN. (**1 page**).

Li, C.Y.J.; Tsai, W.P.; Ranatunga, R.R.M.K.P.; Samidon, M.; Liu, S.Y.V. (2023). Genetic stock structure of the silky shark (Carcharhinus falciformis) in the Indo-Pacific Ocean. PLOS ONE. 18(10): e0292743 (**17 pages**).

Lo, N.C.H.; Jacobson, L.D.; Squire, J.L., (1992). Indices of relative abundance from fish spotter data based on delta-lognormal models. Canad. J. Fish. Aquat. Sci., 49(12), (**11 pages**).

Maunder, M.N.; Sibert, J.R.; Fonteneau, A.; Hampton, J.; Kleiber, P.; Harley, S.J., (2006). Interpreting catch per unit effort data to assess the status of individual stocks and communities. ICES J. Mar. Sci., 63(8): 1373-1385 (**13 pages**).

Mohamed, A.F.; Rezk, H., (2025). Neuro-fuzzy inference system and white shark optimization of coagulationflocculation of aquaculture wastewater treatment. Global J. Environ. Sci. Manage., 11(3): 857-874 **(18 pages).**

Murray, S.; Meeuwig, J.J.; Thompson, C.D.H.; Mouillot, D., (2023). Identifying the drivers of silky shark distribution and an evaluation of protection measures. Environ. Biol. Fish., 106: 1693-1713 (**21 pages**).

Pacoureau, N.; Rigby, C.L.; Kyne, P.M.; Sherley, R.B.; Winker, H.; Carlson, J.K.; Fordham, S.V.; Barreto, R.; Fernando, D.; Francis, M.P.; Jabado, R.W.; Herman, K.B.; Liu, K.M.; Marshall, A.D.; Pollom, R.A.; Romanov, E.V.; Simpfendorfer, C.A.; Yin, J.S.; Kindsvater, H.K.; Dulvy, N.K., (2021). Half a century of global decline in oceanic sharks and rays. Nature, 589(7843): 567–571 (**5 pages**).

Rigby, C.L.; Sherman, C.S.; Chin, A.; Simpfendorfer, C., (2021). Carcharhinus falciformis (amended version of 2017 assessment). The IUCN Red List of Threatened Species 2021: e.T39370A205782570. (**27 pages**).

Simeon, B.M.; Muttaqin, E.; Mardhiah, U.; Ichsan, M.; Dharmadi.; Prasetyo, A.P.; Fahmi.; Yulianto, I., (2018). Increasing abundance of silky sharks in the Eastern Indian Ocean: Good news or a reason to be cautious?. Fishes, 3(3): 29 (**12 pages**).

Talwar, B.S.; Semmens, B.X.; Aires-da-Silva, A.; Griffiths, S.; Humberstone, J.; Hutchinson, M.; Lopez, J.; Minte-Vera, C.; Ovando, D.; Román-Verdesoto, M.; Siu, S.; Bellquist, L.F., (2025). Informing the spatial management of silky shark (*Carcharhinus falciformis*) in the Eastern Pacific Ocean. Rev. Fish Biol.Fish., 35(4): 1031-1062 (**32 pages).**

Walter, J.F.; Ortiz, M., (2012). Derivation of the delta-lognormal variance estimator and recommendation for approximating variances for two-stage CPUE standardization models. Collective Volume of Scientific Papers ICCAT, 68 (1), (**5 pages**).

White, W.T.; Last, P.R.; Stevens, J.D.; Yearsley, G.K.; Fahmi.; Dharmadi., (2006). Economically important sharks and rays of Indonesia. ACIAR Monograph No. 124. Canberra: Australian Centre for International Agricultural Research (**338 pages**).

Wood, S.N., (2017). Generalized additive models: An introduction with R (2nd ed.). CRC Press. (**50 pages**).

Yulianto, I.; Booth, H.; Ningtias, P.; Kartawijaya, T.; Santos, J.; Sarmintohadi; Kleinertz, S.; Campbell, S.J.; Palm, H.W.; Hammer, C. (2018). Practical measures for sustainable shark fisheries: Lessons learned from an Indonesian targeted shark fishery. PLoS One, 13(11): e0206437 **(18 pages).**

Ziegler, I., (2022). Carcharhinus falciformis - A massive bycatch in the industrial purse seine industry but systematically underreported and deprived of any protection in the Indian Ocean. IOTC Working Party on Ecosystems, IOTC-2025-WPEB21(AS)-25 **(28 pages)**.

Ziegler I., (2025). Resolution 2025-08, an opportunity to step up science driven conservation and management measures for sharks in tuna and multi-species fisheries at IOTC. IOTC Working Party on Ecosystems and Bycatch, IOTC-2025-WPEB21(AS)-25 **(27 pages).**

Zulbainarni, N.; Sukarsih, Y.; Jahroh, S.; Abdullah, A., (2022). Economic valuation of moratorium and transhipment policy to tuna fisheries business, study case in Bitung, North Sulawesi. J. Manage. Agribisnis. 19(1): 79–92 **(14 pages).**

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