





# Sea turtle bycatch patterns in small-scale fisheries of the East China Sea and South China Sea

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## ABSTRACT

Knowledge regarding sea turtle bycatch in Chinese small-scale fisheries remains limited despite the country's massive fishing fleet and the overlap between fishing grounds and sea turtle migratory routes. This study compares regional sea turtle bycatch patterns in Zhejiang (East China Sea, ECS) and Hainan Island (South China Sea, SCS), using semi-structured interviews with 281 fishers to assess reported frequency, gear use, and species and size composition. Results indicate that 85.4% of respondents have encountered sea turtles, though SCS fishers reported lower bycatch frequencies than those in the ECS (46.3% “never” vs. 10.6%). ECS fishers showed a notably lower ability to identify species (33.9%) compared to SCS fishers (6.7%). While green and loggerhead turtles were commonly reported in both regions, green and hawksbill turtles were significantly more likely to be reported in the SCS. A regional life stage difference was observed: ECS reports mainly involved adults, whereas SCS fishers more often reported subadults and juveniles. Gear type is the primary predictor of bycatch reporting, with stow and trawl nets showing the strongest associations across both regions. Co-reporting patterns identified loggerheads in trawl nets and olive ridleys in stow nets, while greens and hawksbills were frequently associated with gillnets. This regional comparison of sea turtle bycatch in Chinese small-scale fisheries reveals spatially structured threats and provides an evidence base for developing locally adapted, gear-specific conservation measures in data-poor fisheries across China and East Asia.

## 1. Introduction

Despite the fisheries sector's vital role in global food security and coastal economies, bycatch persists as a significant anthropogenic threat to the conservation of marine megafauna (Lewison et al., 2004; Burgess et al., 2018; Gray and Kennelly, 2018). Due to the overlap of fishing activities with habitats of various mobile, delayed-maturity, and long-lived species such as sea turtles (Lewison et al., 2004; Crowder et al., 2008; Burgess et al., 2018), their bycatch mortality can exert disproportionate effects on population trajectories (Curtis and Moore, 2013). Global assessments consistently identify fisheries bycatch as a major threat to sea turtle populations (Wallace et al., 2013, 2025), with estimates suggesting that 8.5 million individuals may be accidentally captured each year (Wallace et al., 2010). While substantial progress has been made in documenting sea turtle bycatch in commercial or offshore

fisheries and implementing mitigation measures (Lucas and Berggren, 2023; Senko et al., 2022, 2014; Shiode et al., 2021; Swimmer et al., 2020), such advances have not translated equally into small-scale fisheries (SSF).

SSF are typically defined as traditional or family-run fishing activities that rely on small vessels or hand-held gear, operate near the coast, and primarily serve local markets and subsistence needs (Food and Agriculture Organization of the United Nations, n.d.). Emerging evidence shows SSF may significantly contribute to sea turtle bycatch, reaching levels comparable to some commercial fisheries (Lewison et al., 2004; Gray and Kennelly, 2018). However, the spatial dispersion, operational diversity, limited regulatory capacity, and monitoring infrastructure of SSF often limit observer programs, causing under-reporting and uncertainty in bycatch estimates, which hinders accurate risk assessment (Moore et al., 2009; Lewison et al., 2011; Carpio et al.,

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2022; Oliveira et al., 2024). Interactions between SSF and sea turtles have been documented across multiple regions and vary by species, geographic region, and fishing gear (Wallace et al., 2013). Country-level estimates from Northwest Africa suggest annual bycatch ranging from 14,000 to 90,000 turtles, with green turtles most frequently reported (de la Hoz Schilling et al., 2023). Similarly, fisher-based assessments in Pacific Mexico identified gear-specific patterns of sea turtle encounters across coastal communities, with olive ridley turtles most commonly reported (Grimm et al., 2025). In both regions, bycatch involved five sea turtle species across multiple gear types. These studies highlight the scale and context-specific nature of SSF–turtle interactions. However, evidence is uneven geographically, with East Asia underrepresented, limiting the broader understanding of SSF bycatch and comparisons across countries.

East Asia's coastal waters support highly productive marine ecosystems that sustain major fisheries and diverse marine megafauna (Sumaila, 2019; Wang et al., 2023). China, located at the centre of this region, is one of the world's largest fisheries producers, with approximately 13 million tonnes of domestic marine catch annually (Kang et al., 2018). Its fisheries are concentrated in the East China Sea (ECS) and South China Sea (SCS), where extensive small-scale fishing communities operate along the coast of Zhejiang and Hainan, contributing substantially to regional economies and food security (Kang et al., 2018). These seas also overlap with habitats used by multiple life stages of sea turtles (Kobayashi et al., 2011; Ng et al., 2018; Hoh et al., 2022; Chen et al., 2024), creating substantial potential for bycatch interactions (Kamezaki, 2010). Available studies across East Asia indicate that sea turtle bycatch frequently occurs in various SSF systems, particularly those using nearshore gears such as gillnets, trawl nets, and pound nets. For instance, four sea turtle species have been documented as incidentally captured in coastal pound net fisheries in Jeju Island, Korea; the east coast of Taiwan, China; and the west coast of Japan (Cheng and Chen, 1997; Kamezaki, 2010; Jang et al., 2018). In northern SCS, a fisher-based survey reported sea turtles as the most frequently encountered megafaunal bycatch, with interactions most commonly associated with gillnets and trawl nets (Lin et al., 2023). These observations suggest diverse turtle–SSF interactions within the East Asian marine region, but a full understanding remains constrained by the lack of empirical data from Chinese SSFs. Within China, the highly heterogeneous SSF systems were reflected by variation in coastal geography, target species, and regional fishing practices. Across the ECS and SCS, fisheries employ a wide range of gear types, including gillnets, trawl nets, stow nets, set nets, and hook-and-line systems, operated by vessels of varying sizes and capacities and differing modes of operation (e.g., mobile vs. fixed, seabed-interacting vs. passive), and distributed across numerous coastal landing sites (Kang et al., 2018; China Fishery Statistical Yearbook Editorial Committee, 2025). Such operational diversity is expected to influence both the likelihood and characteristics of bycatch interactions.

Five sea turtle species are known to inhabit Chinese waters—green turtle *Chelonia mydas*, hawksbill turtle *Eretmochelys imbricata*, leatherback turtle *Dermochelys coriacea*, loggerhead turtle *Caretta caretta*, and olive ridley *Lepidochelys olivacea*—with green turtles being the most commonly encountered, showing occurrence probabilities exceeding 50% across much of the ECS and SCS (Cheng and Chen, 1997; Cheng, 1998; Mou et al., 2013). The SCS supports most of China's nesting activity, whereas the ECS is primarily used by foraging and migratory individuals, indicating regional differences in species composition and life stages with implications for management (Wang et al., 2019; Kobayashi et al., 2011; Song et al., 2022; Zhang et al., 2024; Kim et al., 2024; Ng et al., 2024). Conservation is guided at the national level through frameworks such as the National Sea Turtle Conservation Action Plan (2019–2033), with all sea turtle species designated as Class I protected animals, and implemented through national frameworks involving both fisheries and wildlife authorities (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2019; National Forestry and Grassland Administration of China, 2021). Despite these

measures, populations are generally declining, and current efforts remain focused on nesting-site protection and population monitoring, with bycatch monitoring and mitigation not yet systematically integrated into management. These regional ecological differences provide a critical context for examining how sea turtle–fishery interactions may differ between the ECS and SCS.

We address the limited empirical information on sea turtle bycatch characteristics and patterns in Chinese waters using fisher-reported observations. To do so, we conducted interviews with small-scale fishers in the coastal provinces of Zhejiang and Hainan, representing the contrasting fishery systems of the ECS and SCS, respectively. Specifically, we aim to: (i) characterise the reported species and size composition of bycaught turtles; (ii) examine factors associated with reported bycatch occurrence across regional and operational contexts as indicators of bycatch characteristics; and (iii) quantify and compare the reported bycatch occurrence and frequency between regions. By explicitly linking regional contrasts to species, size, and gear-associated reporting patterns, this study contributes context-specific evidence relevant to the design of outreach, training, and mitigation strategies in the heterogeneous SSF.

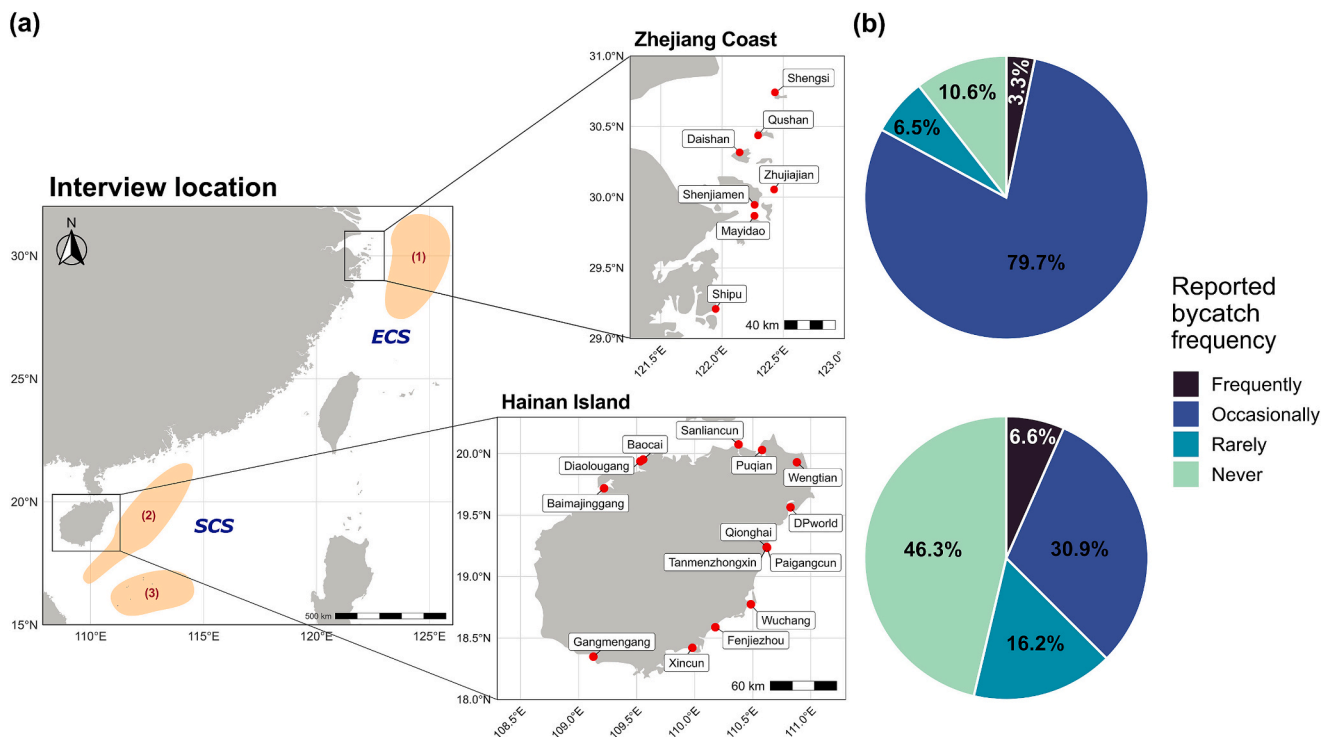
## 2. Methods

### 2.1. Study site

This study employed semi-structured interviews to examine sea turtle bycatch events in Chinese SSF, focusing on two regions: Zhejiang in the ECS and Hainan Island in the SCS. Interviews were conducted at 21 fishing ports and coastal villages (Fig. 1a), each with locality names and decimal coordinates provided in Supplementary File 1. Interviewed fishers were generally unable to provide precise geographic coordinates for fishing and bycatch events, but were able to indicate their fishing grounds. Fishers from Zhejiang reported primarily operating in the Zhoushan fishing grounds. Fishers from Hainan Island reported fishing in the Yuexi fishing grounds, with some indicating that their operations extended as far as the Xisha and Zhongsha Archipelagos. For comparative and analytical purposes, the two study regions were classified and abbreviated as the East China Sea (ECS) and the South China Sea (SCS), representing distinct ecological and fisheries contexts within China's coastal marine environment. To ensure clarity, we distinguish the use of terms between “region” (or “fishing region”), referring to the ECS and SCS used for comparison, and “fishing area,” referring to fishing grounds or areas reported by fishers.

### 2.2. Sampling strategy and interview procedure

Because no formal SSF definition exists in China, fisheries were classified mainly by their non-industrial, community-based operations regardless of vessel size. Data collection therefore targeted fishers engaged in SSF. We employed a hybrid sampling strategy that combined convenience and snowball sampling, which is commonly used in field-based social research for its practicality in dynamic and informal settings. Initial fishers who agreed to participate on-site through convenience sampling (seed respondents) subsequently referred other potential participants through snowball sampling, thereby expanding the sample (Heckathorn, 2011; Bhardwaj, 2019). A total of 423 fishers were interviewed. Interviews with less than 20% response completion, non-SSF fishing operations, or duplicate responses from the same vessel (to avoid potential bycatch event duplication) were excluded, resulting in 281 valid responses (66.4% retained). Of these, 126 and 155 responses were obtained from ECS and SCS, respectively. Interviews were conducted between January 2021 and July 2022 and were administered in Mandarin. For elderly respondents with limited Mandarin proficiency, local interpreters were engaged on-site to facilitate communication. Each interview lasted approximately 20–30 min, balancing the need for detailed responses while minimising participant fatigue.



**Fig. 1.** Survey locations and self-reported sea turtle bycatch frequency. (a) Map showing interview sites in Zhejiang and Hainan Island of China. ECS and SCS denote the East China Sea and the South China Sea, respectively. Orange polygons represent the main fishing operation areas reported by interviewed fishers. ECS fishers primarily operate in the Zhoushan fishing grounds (1), whereas SCS fishers operate in Yuexi (2) and the areas across Xisha and Zhongsha Archipelagos (3). The overlay of fishing grounds/areas was illustrated based on <https://osgeo.cn/map/m01d0/>. Red dots in the inset maps indicate surveyed fishing ports or villages ( $n = 21$ ). (b) Pie charts showing self-reported bycatch frequency among fishers from the ECS (top) and SCS (bottom). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Volunteer interviewers received training prior to field data collection. The interview team consisted of university students from East China Normal University and staff members from an environmental conservation non-governmental organization, the Global Environmental Institute and the Society of Entrepreneurs and Ecology. Before the survey, interviewers attended training reviewing the guide and procedures together. They discussed questions, response categories, and potential scenarios to standardise interpretation and recording, ensuring consistency across interviewers. During the interviews, interviewers explained all questions and response categories to fishers verbally to ensure a consistent understanding of the survey items.

### 2.3. Ethical considerations

Prior to each interview, informed consent was obtained, and the study's objectives and its conservation relevance were explained to participants. Participation was voluntary, and respondents were informed that they could decline to answer any question or withdraw from the interview at any time. No personal identifying information was collected to ensure participant anonymity.

### 2.4. Interview guide and response structure

The interview guide (Supplementary File 2) comprised thematic questions covering three components: fisher characteristics (fishing region and years of fishing experience), fishing practices (vessel and gear types used; Supplementary File 3), and bycatch experience (sea turtle bycatch frequency, species and size of turtles encountered, and gears associated with bycatch events). The interview was designed using standardised questions with predefined response categories. Because small-scale fishers rarely maintain detailed records, most questions used categorical or ordinal response scales rather than exact numerical

values. Unless otherwise specified, responses referred to fishers' cumulative experiences throughout their fishing careers rather than to events within a defined time period. Moreover, recognising that individual fishers may use multiple gears during their careers (Kang et al., 2018) and may have experienced multiple bycatch events, questions on vessel and gear types, bycatch-associated gears, and sea turtle species/sizes allowed multiple responses.

### 2.5. Variable definitions and measurement clarification

Vessel size classification followed the Regulations on the Administration of Fishing Permits (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2018), categorising vessels  $\geq 24$  m as large-scale, 12–24 m as medium-scale, and  $< 12$  m as small-scale. The survey of vessel size was intended to examine whether vessel class was associated with reported bycatch occurrence as an indicator of variation in fishing capacity and operational context. Fishing gear reported as “set net” was classified under “other”, as this term is used inconsistently across regions and may refer to different gear types. Due to this ambiguity, the “other” category, which includes gear other than set net, was excluded from statistical analyses. Self-reported bycatch frequency refers to fishers' recollections of encountering sea turtles in their fishing gear over the course of their fishing experience. Responses were recorded using predefined ordinal categories during interviews. The response categories were defined as frequent (encountering sea turtles in fishing gear at least once per year), occasional (encountering sea turtles approximately once every two to three years), rare (encountering sea turtles fewer than three times over the fisher's entire fishing career), and never (no encounters reported). To improve recall accuracy for bycatch events, fishers were provided with visual identification guides consisting of photographs of sea turtles, and interviewers verbally highlighted the diagnostic features of the five sea turtle species occurring in the region.

When estimating turtle size during interviews, the green turtle's size range was used as a reference for life stages, as this species is the most commonly encountered in the study regions and therefore more familiar to respondents. Interviewers also used hand gestures to indicate the approximate length of the turtle to aid recall. Turtles larger than 80 cm were classified as adults, individuals between 65 and 80 cm as subadults, and those smaller than 65 cm as juveniles (Witherington et al., 2006).

## 2.6. Data analyses

All statistical analyses were conducted in R (version 4.4.2; R Core Team, 2024), with graphical refinements performed in Inkscape (version 1.4; Inkscape Project, 2024). All analyses were implemented as reproducible R scripts and are provided in Supplementary File 4. Interview responses were summarised using descriptive statistics. For interview questions that permitted multiple responses, each reported category was treated as an individual observation. Percentages were calculated as the proportion of respondents reporting a given category for each question; therefore, summed percentages could exceed 100% because some questions permitted multiple responses.

A combination of contingency-based tests, correlation analyses, and regression-based models was applied to examine patterns in bycatch reporting and to characterise both bivariate and multivariable relationships among variables. Differences in categorical distributions between groups were assessed using chi-square tests (`chisq.test()`), with all expected cell counts meeting the required threshold ( $>5$ ). For contingency tables with sparse data or low expected frequencies, Fisher's exact test (`fisher.test()`) with Monte Carlo simulation ( $B = 1 \times 10^7$  replicates) was used as a robust alternative. This approach was applied to examine pairwise co-reporting associations between gear type and bycaught turtle species. Subsequent standardised residuals were examined to identify specific gear-species combinations contributing to deviations from expected frequencies. *P*-values from pairwise comparisons were adjusted using the Benjamini–Hochberg procedure. To aid interpretation, heatmaps were constructed to visualise raw counts and standardised residuals from contingency tables, and these were examined to identify cells that contributed most strongly to deviations from independence. Positive residuals indicate combinations reported more frequently than expected, whereas negative residuals indicate lower-than-expected reporting.

To evaluate associations between fishing experience and self-reported bycatch frequency, Kendall's tau correlation coefficient (`cor.test(method = "kendall")`) was applied. This non-parametric measure accounts for the ordered nature of the data without assuming linear relationships or normality. Sensitivity analysis was conducted using refined records with complete data on self-reported bycatch frequency and at least 1 year of fishing experience ( $n = 259$ ) to ensure data robustness. The refined dataset was then used to run the following model: to examine the effects of fishing region and fishing experience (predictor variables) on reported bycatch frequency, an ordinal logistic regression model was fitted using the `polr` function in the MASS package (Venables and Ripley, 2002). Fishing experience was grouped into four categories (1–5, 5–10, 10–20, and  $> 20$  years). The response variable was treated as an ordered factor with four levels (“never”, “rarely”, “occasionally”, “frequently”). The 10–20 years experience category was used as the reference level, while ECS served as the reference category for the fishing region. Model coefficients were estimated on the log-odds scale, and statistical significance was assessed using Wald *z*-tests.

Generalised linear models were applied to examine binary outcomes related to reported bycatch patterns. For analyses of reported species and size composition, separate binomial logistic regression models (`glm` (family = binomial)) were fitted, with each response variable defined as the presence or absence of a given species or size class. Fishing region was included as the sole predictor variable to evaluate regional differences in reporting likelihood. For the occurrence of bycatch incidents (yes/no), a Firth logistic regression model was fitted using mean bias-

reduced estimation (`glm` with method = “brglmFit”, type = “AS\_mean”; Kosmidis, 2023). This model included fishing region, vessel size class, and gear types reported for bycatch events as predictors. The Firth method was selected to address small-sample bias, sparse data, and potential separation issues in standard logistic regression. The ECS was set as the reference category for fishing region. Model coefficients are reported as log-odds ( $\beta$ ), with corresponding odds ratios (OR). Multiple comparisons arise from the simultaneous testing of multiple predictor coefficients within the model (i.e., region, vessel size categories, and gear types). To control for the increased risk of Type I error, *p*-values associated with individual coefficients were adjusted using the false discovery rate (FDR) method. The adjustment was applied within each model across all tested coefficients. Models were specified a priori based on the study objectives and variables collected, rather than selected through data-driven procedures.

## 3. Results

### 3.1. Fishers' reported bycatch occurrence and frequency patterns

Fishers were surveyed about their personal experiences and direct witness to turtle bycatch events throughout their fishing careers. In total, 85.4% of respondents ( $n = 240/281$ ) reported at least one such encounter, while 14.6% reported none. Following dataset refinement to include only records with complete data on self-reported bycatch frequency and at least 1 year of fishing experience, 259 responses were retained. Among these, 4.9% reported frequent bycatch, 52.6% reported occasional bycatch, 11.6% reported rare bycatch, and 29.3% reported no experience of bycatch. The Kendall's rank correlation coefficient indicated a positive association between fishing experience and the reported frequency of sea turtle bycatch ( $\tau = 0.208$ ,  $p < 0.001$ ; Supplementary Files 5 & 6). This association remained consistent after excluding fishers with less than one year of experience in a sensitivity analysis ( $\tau = 0.206$ ,  $p < 0.001$ ), suggesting that responses from early-career fishers do not primarily drive the observed pattern.

When compared on a regional basis, 46.3% of SCS respondents ( $n = 63/136$ ; Fig. 1b) reported no personal encounters with sea turtle bycatch, which is substantially higher than the 10.6% reported in ECS fishers ( $n = 13/123$ ), indicating a marked regional difference. Reported bycatch in the ECS was dominated by occasional encounters, with relatively few reports of rare or frequent events. In the SCS, non-“never” responses showed a broader spread across the remaining frequency categories. Despite this spread, the overall distribution in the SCS remained weighted toward lower bycatch frequency owing to the substantially higher proportion of “never” responses. The distribution of self-reported bycatch frequency categories differed significantly between fishing regions ( $\chi^2 = 63.26$ ,  $p < 0.001$ ). We further examined the effects of fishing region and fishing experience on reported bycatch frequency categories using an ordinal logistic regression model (Table 1). Fishing region was identified as a significant predictor, with

**Table 1**

Results of an ordinal logistic regression examining the effects of fishing region and experience on self-reported sea turtle bycatch frequency (response variables). Coefficients ( $\beta$ ) are presented on the log-odds scale with standard errors (SE), Wald *z*-statistics, and *p*-values; odds ratios (OR) with 95% confidence intervals (CI) are also reported. The ECS and fishers with 10–20 years of experience served as reference categories. Negative coefficients indicate lower odds of reporting higher bycatch frequency categories. Asterisk (\*) indicates statistical significance.

Predictor	$\beta$ (SE)	<i>z</i>	<i>p</i> -value	OR (95% CI)
Fishing region (SCS vs ECS)	−1.66 (0.28)	−5.94	* < 0.001	0.19 (0.11–0.33)
Working years: 5–10	−0.87 (0.29)	−2.98	* 0.003	0.42 (0.24–0.74)
Working years: 1–5	−0.61 (0.39)	−1.58	0.113	0.54 (0.25–1.16)
Working years: >20	−0.24 (0.60)	−0.40	0.690	0.79 (0.24–2.56)

fishers operating in the SCS having 81% lower odds of reporting higher bycatch frequency categories (i.e. less frequent bycatch occurrences) than those in the ECS ( $\beta = -1.66$ ,  $SE = 0.28$ ,  $p < 0.001$ ), reflecting the overall distributional shift across all ordered categories rather than any single frequency category in isolation. Fishing experience showed a limited association with reported bycatch frequency. Compared to fishers with 10–20 years of experience, those with 5–10 years had 58% lower odds of reporting higher bycatch frequency ( $\beta = -0.87$ ,  $SE = 0.29$ ,  $p = 0.003$ ;  $OR = 0.42$ ), while other experience groups did not differ significantly from the reference category (all  $p > 0.05$ ).

3.2. Species and size composition of reported turtle bycatch

Green turtles were the most frequently reported bycatch species by all respondents (42.9%), followed by loggerhead (22.1%), hawksbill (15.8%), and both olive ridley and leatherback turtles (10.8% each; Fig. 2a). Regionally, reported bycatch species composition differed significantly between the two fishing regions ( $\chi^2 = 13.8$ ,  $p = 0.008$ ). Green turtles accounted for the largest proportion of reports by the SCS fishers (57.1%), followed by hawksbill (26.1%), loggerhead (23.5%), olive ridley (11.8%), and leatherback (9.2%). Moreover, ECS fishers reported bycatch of green turtles (28.9%), loggerhead (20.7%), leatherback (12.4%), olive ridley (9.9%), and hawksbill (5.8%). Notably, a greater proportion of ECS fishers (33.9%;  $n = 41/121$ ) reported being unable to identify bycaught species or only able to identify some species, compared to those in the SCS (6.7%;  $n = 8/120$ ). Species-specific logistic regression analyses indicated significant regional differences in reported bycatch for selected species (Table 2). Fishers in the SCS were 3.28 times more likely to report bycatch of green turtles and 5.74 times more likely to report hawksbill turtles compared to those in the ECS. No significant regional differences were detected for the reporting of loggerhead, olive ridley, or leatherback turtles.

Furthermore, a regional pattern was evident in the size composition of reported bycaught sea turtles ( $\chi^2 = 56.5$ ,  $p < 0.001$ ). In the ECS, adults were reported most frequently (72.7%), followed by subadults (11.6%) and juveniles (5.0%; Fig. 2b). In contrast, reports from the SCS were more evenly distributed across size classes, with adults comprising 35.3%, subadults 37.8%, and juveniles 33.6%. Size-specific logistic regression analyses revealed strong regional differences in reported

Table 2

Results of species-specific binary logistic regression models examining the association between fishing region (ECS vs. SCS) and reported sea turtle bycatch. Each model assessed the effect of fishing region on the likelihood of reporting each species. N represents the number of fishers reporting each species. Coefficients ( $\beta$ ) are presented on the log-odds scale with standard errors (SE). P-values were adjusted using the false discovery rate (FDR) method to account for multiple comparisons across species. Odds ratios (OR) with 95% confidence intervals (CI) are also reported for interpretability. The ECS was used as the reference category. Asterisk (\*) indicates statistical significance.

Species	n	$\beta$ (SE)	p-value (FDR)	OR (95% CI)
Green	103	1.19 (0.27)	* < 0.001	3.28 (1.92–5.59)
Hawksbill	38	1.75 (0.44)	* < 0.001	5.74 (2.41–13.60)
Loggerhead	53	0.17 (0.31)	0.646	1.18 (0.64–2.18)
Olive ridley	26	0.19 (0.42)	0.646	1.21 (0.54–2.74)
Leatherback	26	-0.33 (0.42)	0.542	0.72 (0.32–1.64)

bycatch composition across size classes (Table 3). Fishers in the SCS had significantly lower odds of reporting bycatch of adult turtles ( $OR = 0.21$ ,  $p < 0.001$ ), corresponding to approximately 4.9 times lower odds relative to ECS. In contrast, SCS fishers had significantly higher odds of reporting subadult ( $OR = 4.65$ ,  $p < 0.001$ ) and juvenile turtles ( $OR = 9.70$ ,  $p < 0.001$ ).

Table 3

Results of size-specific binary logistic regression models examining the association between fishing region and reported sea turtle size classes. Each model assessed the effect of fishing region (ECS vs SCS) on the likelihood of reporting each size class. N represents the number of fishers reporting each size class. Coefficients ( $\beta$ ) are presented on the log-odds scale with standard errors (SE), and odds ratios (OR) with 95% confidence intervals (CI). P-values were adjusted using the false discovery rate (FDR) method to account for multiple comparisons across size classes. The ECS was used as the reference category. Asterisk (\*) indicates statistical significance.

Size class	n	$\beta$ (SE)	p-value (FDR)	OR (95% CI)
Adult	130	-1.59 (0.28)	* < 0.001	0.21 (0.12–0.35)
Subadult	59	1.54 (0.34)	* < 0.001	4.65 (2.38–9.07)
Juvenile	46	2.27 (0.46)	* < 0.001	9.70 (3.93–24.0)

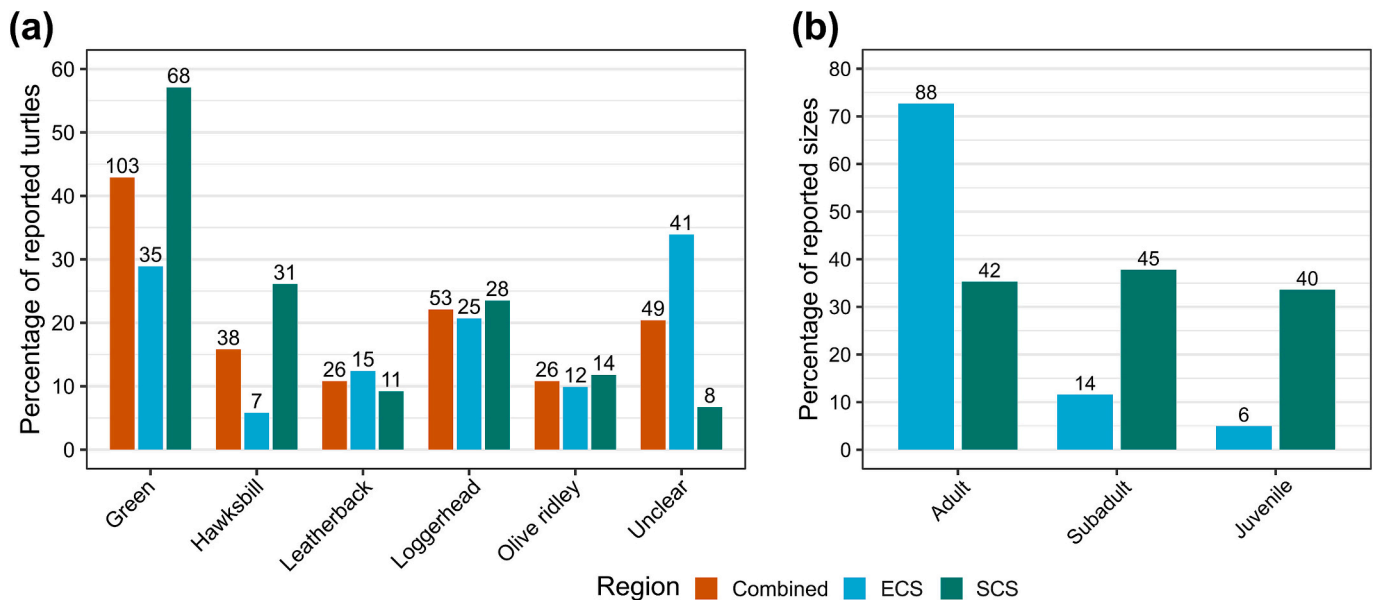


Fig. 2. Reported characteristics of sea turtle bycatch based on fisher interviews. The plots respectively show (a) reported species composition of bycatch and (b) reported size classes of bycaught turtles. Bars represent the percentage of respondents reporting each category by the combined dataset, the East China Sea (ECS), and the South China Sea (SCS). Numbers above bars indicate the number of respondents reporting each category. Species and size categories were not mutually exclusive, and respondents could report multiple categories.

3.3. Vessel and gear use and their association with reported bycatch

Among interviewed fishers in the ECS, the fleet was strongly dominated by large vessels (88.9%;  $n = 112/126$ ; Fig. 3a). In contrast, the SCS showed a more even fleet composition, with 34.8%, 32.9%, and 32.9% of fishers ( $n = 155$ ) operating large, medium, and small vessels, respectively. Marked regional differences were also evident in gear use (Fig. 3b). In the ECS, stow nets were most frequently reported (61.1%), followed by trawl nets (38.9%) and gillnets (15.9%). In the SCS, gillnets predominated (40.6%), with notable contributions from hook-and-line (28.4%). These regional contrasts in vessel composition and gear use were statistically significant (vessel:  $\chi^2 = 84.8$ ; gear:  $\chi^2 = 153.3$ ; both  $p < 0.001$ ).

The distribution of gears associated with reported bycatch broadly reflected patterns of overall gear use, but with notable deviations (Fig. 3c). In the ECS, stow nets accounted for the majority of reported bycatch cases (55.6%), followed by trawl nets (34.9%), whereas gillnets contributed only 1.6% of reported bycatch despite representing 15.9% of overall gear use. In the SCS, gillnets were the most frequently reported gear associated with bycatch (18.7%), whereas hook-and-line gear, although commonly used (28.4%), was infrequently linked to bycatch events (1.9%). To examine how reported bycatch is structured across gears, a Firth logistic regression model was fitted, including fishing region, vessel size, and gear-specific bycatch reporting variables (Table 4). After accounting for overlap among predictors, gear type emerged as the primary factor associated with bycatch reporting patterns. Reports involving stow nets and trawl nets were strongly associated with overall bycatch reporting (OR = 89.1 and 65.5, respectively;  $p < 0.05$ ), while gillnets showed a similar but marginally non-significant association (OR = 32.5;  $p = 0.051$ ). The association of vessel size and fishing region with bycatch reporting was not significant.

Distinct patterns emerged in the co-reporting association between sea turtle species across different fishing gears. A global Fisher's exact test indicated a significant association between gear type and species composition in reported bycatch ( $p = 0.003$ ), suggesting non-random co-reporting patterns of bycatch interaction between fishing gears and turtle species (Fig. 4). Inspection of standardised residuals indicated that loggerhead turtles were reported more frequently than expected in association with trawl nets (residual = +2.9), olive ridley turtles with stow nets (+2.4), and hawksbill and green turtles with gillnets (+1.9 and +1.7). In contrast, loggerhead turtles were under-represented in stow net

Table 4

Firth logistic regression examining how reported bycatch is distributed across fishing gears. Predictor variables include fishing region (ECS vs SCS), vessel size, and gear-specific bycatch reporting (presence/absence for each gear type). The ECS was used as the reference category. Coefficients ( $\beta$ ) are presented with standard errors (SE), together with odds ratios (OR) and 95% confidence intervals (CI). P-values were adjusted for multiple comparisons using the false discovery rate (FDR) method. This model should be interpreted as describing co-reporting structure rather than causal effects of gear on bycatch occurrence. Asterisk (\*) indicates statistical significance.

Predictor	$\beta$ (SE)	p-value (FDR)	OR (95% CI)
(Intercept)	0.305 (1.02)	0.948	1.36 (0.18–10.1)
Fishing region (SCS)	0.170 (0.61)	0.948	1.19 (0.36–3.88)
Vessel size: Large	0.055 (0.84)	0.948	1.06 (0.20–5.57)
Vessel size: Medium	0.085 (0.85)	0.948	1.09 (0.20–5.80)
Vessel size: Small	0.204 (0.86)	0.948	1.23 (0.24–6.38)
Stow net	4.49 (1.51)	* 0.025	89.1 (4.63–1716)
Trawl net	4.18 (1.48)	* 0.025	65.5 (3.55–1210)
Gillnet	3.48 (1.44)	0.051	32.5 (1.95–540)
Purse seine	1.89 (1.63)	0.482	6.59 (0.39–113)
Hook-and-line	0.949 (1.70)	0.948	2.58 (0.09–74.3)

reports (−2.4). However, none of the individual gear–species combinations remained significant after correction for multiple comparisons.

4. Discussion

This study provides a regionally comparative assessment of fisher-reported sea turtle bycatch across Chinese SSF in the ECS and SCS. Reported bycatch patterns differed significantly between regions, including variation in frequency, species and size composition, and gear-related co-reporting patterns. These findings highlight substantial regional heterogeneity in sea turtle–fishery interactions, with implications for targeted mitigation and management.

4.1. Reported species and size composition of bycaught turtles

This study found clear regional differences in reported species composition, with green and loggerhead turtles commonly reported in both regions, while hawksbills were reported more frequently in the SCS than in the ECS. Sea turtles are known to interact with fishing gear across multiple life stages in tropical and subtropical regions (Lewison,

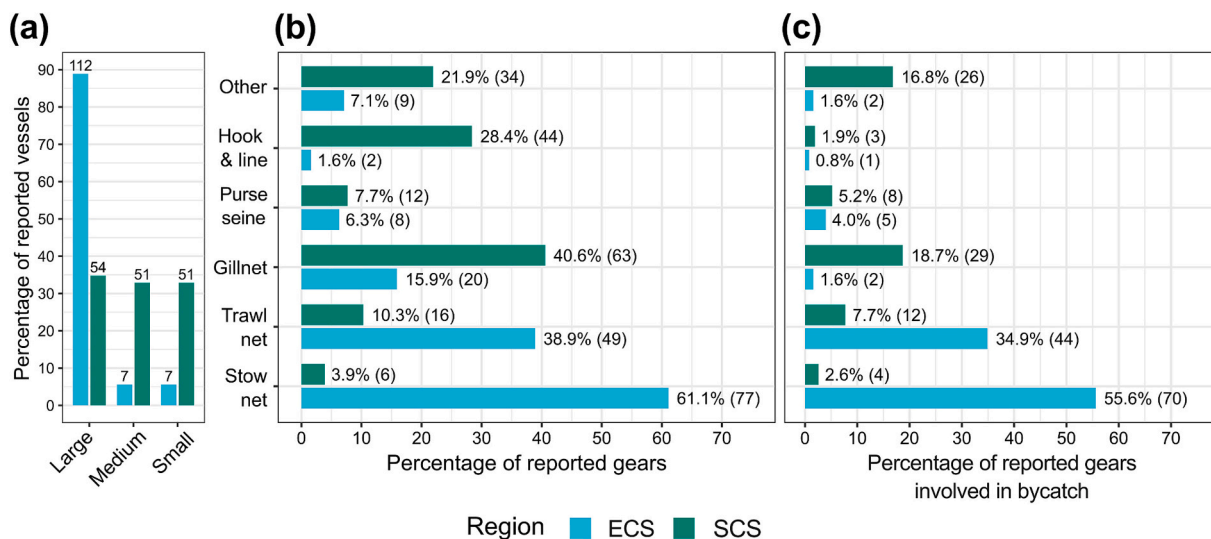
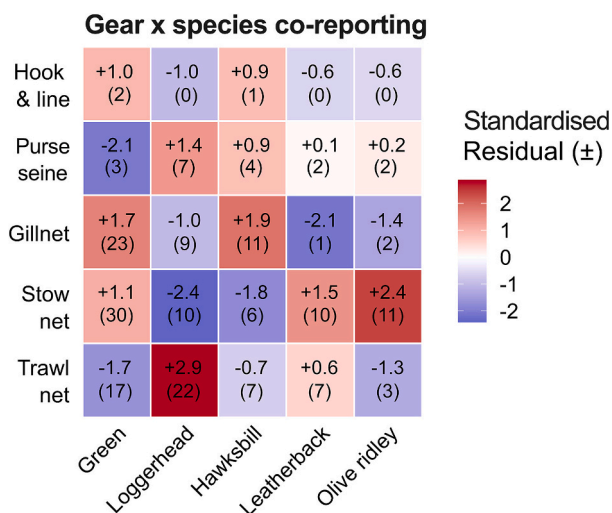


Fig. 3. Fishers' operational attributes based on interview data. (a) Reported vessel size composition, (b) fishing gear types used, and (c) fishing gear types reported to be involved in sea turtle bycatch, each presented by region. Bars represent the percentage of respondents reporting each category for the East China Sea (ECS) and South China Sea (SCS). Numbers above bars in (a) and numbers in parentheses in (b) and (c) indicate the number of respondents reporting each category. Categories were not mutually exclusive, and respondents could report multiple categories.



**Fig. 4.** Heatmap of standardised residuals from a contingency analysis of co-reporting patterns between gear type and turtle species. Positive residuals (red) indicate combinations reported more frequently than expected under independence, whereas negative residuals (blue) indicate under-representation. Numbers in parentheses denote the number of respondents reporting each combination. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2013; Wallace et al., 2013). The bycatch data reported in this study indicate differences in species and size composition between the ECS and SCS. The pattern of predominant bycatch reports in green turtles and the commonly reported loggerheads is broadly consistent with previous studies identifying the ECS–SCS system as an important foraging and migratory corridor (Wang et al., 2019; Hoh et al., 2022; Okuyama et al., 2022; Kim et al., 2024). Satellite telemetry studies of green and loggerhead turtles indicate that these species utilise coastal and offshore waters across this region, including areas overlapping with the Zhoushan fishing grounds and, more broadly, waters associated with SCS fishing activity (Kobayashi et al., 2008; Kobayashi et al., 2011; Chen et al., 2024; Ng et al., 2024). Hawksbills were rarely reported in the ECS but more frequently reported in the SCS, which may be associated with the presence of reef-linked habitats around Hainan (Chan et al., 2007; Ji et al., 2024). Although satellite telemetry data for hawksbill turtles remain limited in this region, available studies suggest that individuals utilise coastal reef systems around Hainan (Ng et al., 2017). Moreover, in contrast to regions where stranding data can be integrated with fisheries observations to improve understanding of bycatch incidents (Kamezaki, 2010; Lewison et al., 2011), such complementary datasets are currently limited or not systematically available in China. As a result, the interpretation of species composition in this study relies primarily on fisher-reported observations. Furthermore, fishers from the ECS were less likely to report species-level identification compared with those from the SCS, which may reflect differences in reporting practices or familiarity with sea turtle species; however, this was not directly assessed in this study. Fishing experience may influence species recognition, as more experienced fishers are generally better able to identify species, but the distribution of experience among ECS fishers was not skewed toward less experienced individuals (most reported 10–20 years of fishing experience). This suggests that differences in identification are unlikely to be explained solely by experience and warrant further investigation.

Differences in overall reported size-class composition offer preliminary evidence of life-stage partitioning between these ecologically distinct systems, but these patterns cannot be assigned to specific species because species and size class were recorded as separate multi-response items. The predominance of reported adults in ECS bycatch suggests that this region may function primarily as a migratory corridor and adult

foraging ground—a hypothesis consistent with oceanographic features but previously lacking empirical support, particularly near the Zhejiang coast and the coastal shelf around the Zhoushan fishing grounds. Conversely, the higher representation of juveniles and subadults in the SCS may correspond to the broader coastal–offshore system, including the Yuexi fishing grounds and areas near the Xisha and Zhongsha Islands, which may support mixed developmental stages (Chen et al., 2024; Ng et al., 2024). These patterns are broadly consistent with ontogenetic shifts in habitat use (Fireman et al., 2024). While fishermen’s perceptions provide rare insights into population structure where ecological surveys are lacking, spatial fishing effort and turtle distribution were not directly quantified; hence, these interpretations remain indicative rather than conclusive. Overall, the reported size-class patterns indicate that different components of turtle populations may be subject to fisheries interactions in both regions, highlighting the importance of considering regional variation when interpreting bycatch patterns and when designing context-specific monitoring and management approaches.

#### 4.2. Fishing gear as a primary driver of reported bycatch patterns

Gear-related co-reporting patterns indicated that stow nets and trawl nets, and to a lesser extent gillnets, were associated with reported sea turtle bycatch across both regions. Coastal fisheries feature diverse fishing operations, making it crucial to identify which gears might pose the greatest bycatch risk in the ECS and SCS. Global assessments consistently identify trawl nets, gillnets, and longlines as some of the main contributors to sea turtle bycatch, although their relative impacts vary across regions and fishery scales (Wallace et al., 2013). Despite markedly different gear portfolios between the ECS and SCS, these results suggest that gear type plays an important role in structuring reported bycatch patterns. Moreover, species-specific co-reporting patterns suggest that interactions between turtle ecology and gear characteristics may shape exposure risk, with different species tending to be reported with different gear types. These patterns are broadly consistent with species–gear relationships reported in other regions (Wallace et al., 2013; Cambiè et al., 2020). Trawl nets are widely recognised as a major source of sea turtle bycatch due to their broad spatial coverage (Finkbeiner et al., 2011; Lucchetti et al., 2017). As active gears that sweep large areas of the seabed and water column, trawls increase the likelihood of encountering turtles across a range of habitats and life stages. This is consistent with our co-reporting patterns, where loggerhead turtles were more frequently associated with trawl operations, suggesting that mobile gears may disproportionately interact with species occupying broader or more offshore habitats. The relatively high prevalence of trawl net use in the ECS may therefore contribute to the higher frequency of reported bycatch in this region, particularly where fishing effort is concentrated on continental shelves (Kang et al., 2018).

Gillnets, in contrast, are often associated with high bycatch rates, particularly in SSF where they are widely deployed in nearshore habitats (Wallace et al., 2010; de Castro et al., 2021; de la Hoz Schilling et al., 2023). Evidence from the northern SCS also indicates that gillnets account for the largest proportion of reported megafauna bycatch events, with sea turtles being the most frequently encountered taxon; that study also identified vessel size as an important predictor of sea turtle bycatch probability, although its influence varies among taxa (Lin et al., 2023). In our fisher-level model, however, vessel size and gillnet use were not significant predictors. This does not necessarily indicate low regional bycatch risk, because weak statistical associations at the fisher level may still occur where gillnets are widely used and contribute substantially to overall fishing effort.

Stow nets were strongly associated with reported bycatch in this study, although published evidence on sea turtle bycatch in this gear type remains limited compared with trawl and gillnet fisheries. However, a study on other marine megafauna provides relevant mechanistic insights. For instance, stow nets have been identified as a major source

of finless porpoise bycatch along the Korean west coast (Lee et al., 2022). As passive and anchored bag nets that capture organisms transported by currents, stow nets can entrain large-bodied, mobile animals that are unable to avoid or escape once inside the gear. Although this evidence is derived from marine mammals, the underlying capture mechanism suggests that similar risks may extend to sea turtles occupying overlapping habitats. Comparable insights can also be drawn from studies of pound nets, which operate as passive, stationary gears and share functional similarities with stow nets despite differences in capture mechanisms (entrapment versus current-driven filtration). Studies from nearby regions, including western Japan and Jeju Island, Korea, have reported notable levels of sea turtle bycatch in pound net fisheries (Kamezaki, 2010; Jang et al., 2018), providing useful regional context for interpreting the potential role of stow nets. Collectively, these mechanistic and regional analogues provide supporting context for the significant contribution of stow nets to reported bycatch in this study.

Taken together, although these comparisons are indirect, global and regional evidence provides useful context for interpreting the potential roles of different gear types across sea regions, highlighting the need for region-specific mitigation measures. Given that trawl and stow nets are among the most widely used gears in the ECS (China Fishery Statistical Yearbook Editorial Committee, 2022, 2025), their potential contribution to turtle bycatch in this region warrants further investigation. In contrast, the lower prevalence of stow nets in the SCS suggests that mitigation efforts in this region may need to focus more on dominant gears such as gillnets.

#### 4.3. Implications for region- and gear-specific management

Because trawl nets, stow nets, and gillnets accounted for most reported bycatch in this study, gear-specific mitigation represents one of the most practical approaches to reducing sea turtle bycatch in Chinese fisheries. However, the relative importance of each gear differs between the ECS and SCS, indicating that mitigation strategies should be tailored to regional fishing practices and gear composition. In the ECS, mitigation measures should prioritise reducing interactions associated with both active and passive capture mechanisms.

For trawl fisheries, Turtle Excluder Devices (TEDs) remain the most widely demonstrated solution, with reductions in turtle bycatch of up to 99% reported in multiple fisheries (Brewer et al., 2006). Recent developments, including flexible TEDs, have shown high effectiveness in multispecies coastal trawl fisheries without substantially affecting commercial catch composition (Vasapollo et al., 2019). To the best of our knowledge, TEDs have not yet been widely tested or implemented in China, aside from one tested in the East China Sea (Diao, 2023); further research is needed to assess their feasibility under local fishing conditions. In SSF, potential barriers to adoption may include concerns over catch loss, gear modification costs, and operational practicality. In addition, limited technical support and incentives may further constrain uptake. These factors highlight the need for context-specific evaluation and stakeholder engagement when considering the implementation of TEDs in Chinese SSF.

For stow nets, the development of finless porpoise excluder devices (EDs) in Korean stow-net fisheries suggests that gear modifications can reduce megafauna interactions without significant catch loss (Lee et al., 2022). In the absence of turtle-specific designs, operational measures such as more frequent net checks or reduced soak times may represent the most feasible short-term options. SSF in the SCS are more strongly characterised by the widespread use of gillnets, so mitigation strategies may focus on both gear modification and effort management. Net illumination using LED or ultraviolet lights has been shown to significantly reduce turtle bycatch in gillnet fisheries, with reported reductions ranging from 61.4% in Indonesian drift gillnets to near-complete avoidance in Mediterranean set nets (Virgili et al., 2018; Gautama et al., 2022; Senko et al., 2022). Given that gillnets are often associated with high mortality rates, likely due to extended soak times, shortening

soak duration represents an additional practical measure to reduce mortality. These approaches are particularly relevant for the SCS, where gillnet fisheries are widespread and interactions with sea turtles are frequent.

Across both regions, the effectiveness of mitigation measures is likely shaped by operational and institutional context. Although this study did not directly assess fishing depth, effort distribution, or socio-economic factors such as subsistence dependence and incentive structures, these variables may influence bycatch risk and warrant further investigation. By identifying region- and gear-related differences in fisher-reported bycatch, this study provides a useful basis for prioritising monitoring and guiding future evidence-based management. In China, where national policies are implemented at provincial and local levels (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2018), mitigation will likely require locally adapted strategies that combine fisher training, clear handling guidelines, and community-based engagement. Overall, reducing sea turtle bycatch in Chinese waters will likely require region-specific, gear-targeted strategies adapted to the ecological and governance contexts of the ECS and SCS, rather than uniform coast-wide approaches.

#### 4.4. Regional variation in reported bycatch occurrence and frequency

A clear regional contrast was observed in the reported occurrence and frequency of sea turtle bycatch between the ECS and SCS. Specifically, a substantially higher proportion of fishers in the SCS reported no encounters or lower bycatch frequency compared to those in the ECS. One possible explanation relates to variation in reporting behaviour. Fishers may be reluctant to disclose interactions with protected or sensitive species due to perceived legal or social consequences (Walsh et al., 2002; Brevé et al., 2024). This effect may be more pronounced in the SCS, where coastal regions have been subject to stronger conservation focus and public attention associated with nearby nesting sites. For instance, Hainan Province has implemented regulations addressing nesting and bycatch around the Xisha Islands (Standing Committee of the People's Congress of Sansha Municipality, 2019), and Guangdong Province established protective measures as early as 1988, including the Guangdong Huidong National Sea Turtle Reserve. In contrast, the ECS relies more heavily on national-level frameworks, with no known region-specific measures identified in this study. These differences in conservation context may influence awareness of regulations and willingness to report interactions, although this cannot be directly evaluated with the available data.

An alternative, non-exclusive explanation is that regional differences in reported bycatch reflect underlying ecological variation, particularly in sea turtle abundance. Previous studies have shown that increases in bycatch rates can track rising turtle populations rather than changes in vulnerability alone (Putman et al., 2020). However, because this study does not include independent estimates of turtle abundance, this mechanism cannot be tested and should be interpreted cautiously. Despite these uncertainties, numerous fishers in both regions reported encountering sea turtle bycatch during their fishing careers, indicating that interactions between SSFs and sea turtles are widespread. Overall, these findings suggest that regional differences in reported bycatch frequency likely reflect a combination of reporting-related factors and ecological variation, and underscore the need to account for potential reporting bias when interpreting fisher-reported data.

#### 4.5. Study limitations

The limitations of our study primarily arise from the use of interview-based, fisher-reported data. Responses reflected cumulative bycatch experiences over individual fishing careers rather than observations within a defined time frame, and may therefore represent long-term perceptions rather than recent patterns. Like similar methods, data may have recall bias and reporting influence, and the absence of

encounters doesn't confirm the true absence of interactions. These limitations may also affect the interpretation of species and size composition. Non-identification may also potentially reflect incomplete recall or uncertainty, and reported size patterns should be interpreted with caution as indicators of perceived encounters rather than as direct evidence of population structure. In addition, the observed species–gear co-reporting patterns may reflect underlying ecological associations; however, these should be interpreted as correlative tendencies rather than causal relationships and warrant further investigation. Future research could strengthen inference by incorporating complementary data sources, such as direct observation of fishing operations, structured monitoring programmes, time-bounded reporting, or rehabilitation and stranding records documenting fisheries-related injuries. Despite these limitations, the interview dataset provides valuable insights in a data-limited context. The reported patterns are broadly consistent with existing knowledge of regional sea turtle occurrence and highlight differences in interaction patterns across regions.

## 5. Conclusions

This study provides a regionally comparative assessment of fisher-reported sea turtle bycatch across SSFs in the Zhejiang (ECS) and Hainan Island (SCS) of China. Our findings reveal distinct regional differences in reported bycatch frequency; fishers from SCS reported lower bycatch frequencies than those from ECS. Reported species and size composition also differed between regions, with green and hawksbill turtles more frequently reported in the SCS, adult turtles more commonly reported in the ECS, and juveniles and subadults more commonly reported in the SCS. Gear-related patterns further indicate that stow nets and trawl nets were strongly associated with reported bycatch, while co-reporting patterns linked loggerheads with trawl nets, olive ridleys with stow nets, and green and hawksbill turtles with gill-nets. Together, these findings show that sea turtle bycatch in Chinese SSF is regionally structured rather than uniform. Reducing bycatch in Chinese coastal waters will therefore require locally adapted, gear-specific mitigation and monitoring strategies that account for regional differences in fishery practices, reported species composition, and life-stage interactions. These findings underscore the wider relevance of regionally tailored mitigation approaches for global conservation efforts.

## CRedit authorship contribution statement

**Jia Xue Li:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Daphne Z. Hoh:** Writing – original draft, Visualization, Validation, Formal analysis, Data curation. **Dayi Nie:** Investigation. **Min Chen:** Writing – original draft, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization.

## Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used OpenAI's ChatGPT and Grammarly's AI in order to improve clarity, grammar, and overall language quality of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

## Declaration of competing interest

The authors declare no conflicts of interest.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.biocon.2026.111926>.

## Data availability

Data will be made available on request.

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