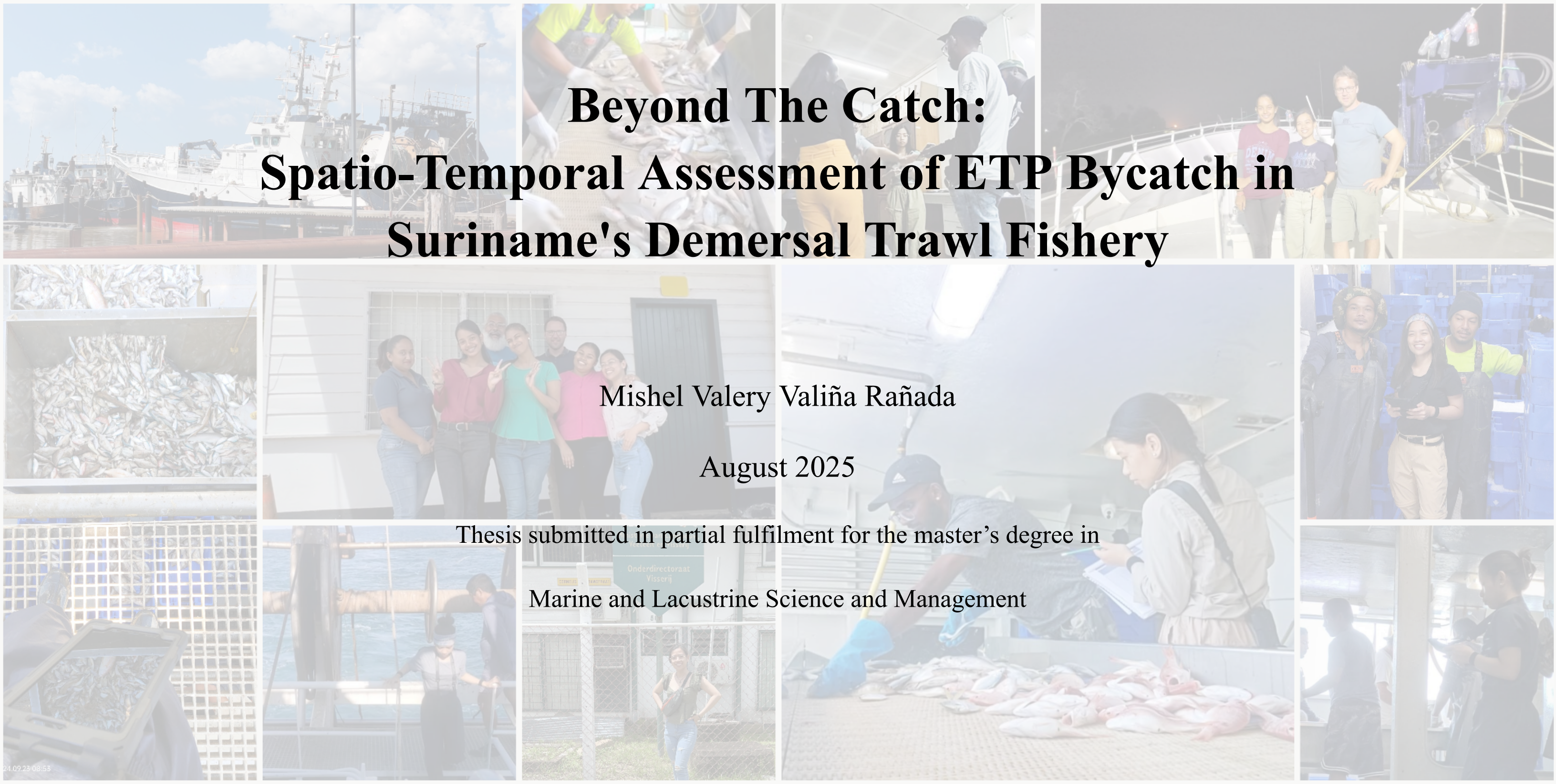
‘OCEANS AND LAKES’

INTERUNIVERSITY MASTER OF SCIENCE IN MARINE AND LACUSTRINE SCIENCE AND MANAGEMENT

OCEANS & LAKES
Master of Marine and Lacustrine Science and Management



Beyond The Catch:
Spatio-Temporal Assessment of ETP Bycatch in Suriname's Demersal Trawl Fishery

Mishel Valery Valiña Rañada

August 2025

Thesis submitted in partial fulfilment for the master’s degree in

Marine and Lacustrine Science and Management

Supervisor: Sven Sebastian Uhlmann

Mentor: Tomas Willems

ILVO
Flanders Research Institute for
Agriculture, Fisheries and Food

LVV

Acknowledgements

This research would not have been possible without the generous support, collaboration, and dedication of many individuals and institutions. I extend my deepest gratitude to the Government of Suriname, particularly the staff of the Research and Statistics Division under the Fisheries Department of the Ministry of Agriculture, Animal Husbandry and Fisheries for their invaluable assistance and providing all kinds of support throughout this study. I gratefully acknowledge the Student Research Grants, part of the Ocean Stewardship Fund program of the Marine Stewardship Council (MSC), awarded under the "Modern Tools for Fishers' Self-Reporting" project. This research benefited from the support of the grant, and forms a complementary contribution to the project's broader objectives. I am especially grateful to the onboard observers, whose dedication to data collection and guidance during the field excursion made this research possible. Special thanks to Marisa Fisheries, the participating trawling company, for their openness and cooperation throughout the project. This work reflects the efforts of many who share a vision of sustainable, science-informed fisheries, and I am deeply appreciative of their contributions.

Table of Contents

Abstract..3
Introduction..4
Materials & Methods..6
    Study Area and Fishery.. 6
    Bycatch Rate (BPUE) Estimation..7
    Scaling BPUE Estimates to Fleet Level.. 7
    Data Analysis..8
Results.. 10
    Observed BPUE Estimates.. 10
    Mean BPUE by Species..12
    Spatial Variations in Observed BPUE.. 13
    Temporal Variations in Observed BPUE.. 14
    Scaling BPUE to Fleet Level..15
    Scaled Total Bycatch Estimates..16
Discussion..20
    Scale and Species Composition of ETP Bycatch.. 20
    Spatial Distribution of Bycatch and Implications for Management..21
    Temporal Patterns in Bycatch and Implications for Management..22
    Potential Bycatch Mitigation Strategies.. 23
    Limitations and Future Research Directions.. 24
Conclusion..25
References.. 26
Appendices..33

Abstract

In fisheries management, monitoring both target and non-target species is essential to be able to estimate quantities and impact —especially when non-target catch includes Endangered, Threatened, and Protected (ETP) species that play vital roles in marine ecosystems. Understanding where and when these bycatch events occur is key to informing effective conservation and management strategies. This study provides the first spatio-temporal assessment of ETP species bycatch in Suriname's demersal finfish trawl fishery. Observer-derived bycatch-per-unit-effort (BPUE) estimates were used to characterize the spatial and seasonal distribution of the five most observed ETP species. These estimates were subsequently scaled using fleet-wide Vessel Monitoring System (VMS) fishing effort data to generate total annual bycatch estimates and evaluate their spatio-temporal patterns. From 360 observed hauls, a total of 19,402 ETP species encounters were recorded, including 25 elasmobranch (14 sharks and 11 batoid fish), three sea turtles, and one marine mammal species. Elasmobranchs dominated the bycatch, with Smalleye smoothhound shark (*Mustelus higmani)* (IUCN Red List status 'endangered') emerging as the most impacted species, exhibiting the highest BPUE (5.96 ind/hr), the broadest spatial distribution, and the greatest temporal variability. When scaled to the entire fleet using VMS effort data, total ETP bycatch of the Suriname demersal finfish trawl fleet was estimated at approximately 241,746 individuals (95% CI: 225,823 - 258,102) in 2023, with *M. higmani* alone comprising an estimated 83,302 (95% CI: 75,487 - 91,295) individuals. Spatial analysis revealed distinct bycatch hotspots, while temporal patterns indicated peak bycatch during the third quarter for most species. These findings underscore the importance of spatially and temporally targeted mitigation strategies, such as area-based closures, seasonal effort reductions and/or use of bycatch reduction devices (BRDs). While observer data provided critical insights, its limited temporal coverage (1.6% of fishing effort) points to the need for improved monitoring, including fisher self-reporting. Nevertheless, this study provides essential baseline information to guide adaptive bycatch mitigation and promote sustainable fisheries management in Suriname.

Introduction

Bycatch, defined as unwanted non-target species incidentally captured by fishing gear, frequently includes Endangered, Threatened, or Protected (ETP) marine species that are legally protected or of conservation concern (Hall et al., 2000; Harrington et al., 2006; Lewison et al., 2004). These ETP species often play crucial roles in marine ecosystems, where significant population losses can cause ecosystem imbalance and trophic downgrading (Estes et al., 2011) and in the most adverse case species' extinctions (Dulvy et al., 2013). Anthropogenic activities, particularly extensive and destructive fishing practices, are the primary threat to ETP species worldwide. Globally, bycatch accounts for 40.4% of marine catches, revealing a lack of effective fishery policy and management strategies (Davies et al., 2009; Rogan et al., 2021) and/or resources. Bycatch is considered particularly harmful and wasteful when discarded back into the sea, often dead or dying (Davies et al., 2009). In 2019, FAO estimated 9.1 million tons of global discards. The major contributor to annual discards by gear type is bottom trawling—including otter trawls, twin otter trawls, beam trawls, pair bottom trawls, and shrimp trawls—with levels reaching 4.2 million tons per year (Pérez Roda et al., 2019). Otter trawls alone contribute 56.8% of annual discard levels (Pérez Roda et al., 2019).

Of particular concern within these discards are endangered, threatened, and protected (ETP) species, with approximately 20 million ETP individuals captured and discarded globally each year (Gray and Kennelly, 2018). This includes an estimated (average) 85,000 sea turtles bycaught (Wallace et al., 2010), 400,000 seabirds (Žydelis et al., 2013), 653,365 marine mammals (Read et al., 2006), and 69,471,000 sharks (Worm et al., 2013) killed annually by fishing activities. This substantial impact on vulnerable species populations highlights the urgent need for effective bycatch mitigation efforts before these species decline to extinction (Dulvy et al., 2003). Bycatch mitigation strategies have been proposed and implemented in several fisheries worldwide, including gear modifications, selective fishing practices, effort reduction, and spatial and temporal management (Cox et al., 2007; FAO, 2021; Gilman et al., 2007; Huang et al., 2024; Kerstetter & Graves, 2006; Murray et al., 2000; Sacchi, 2021; Slooten, 2013). However, fisheries interactions with ETP species remain poorly understood in many parts of the world, and reducing ETP interactions remains challenging, especially in developing countries (Moore et al., 2010; Pérez Roda et al., 2019; Senko & Nalovic, 2021; Soykan et al., 2008).

In Suriname, a trawling fleet of ~35 vessels target demersal finfish species on the continental shelf, which is part of the North-Brazil Shelf Large Marine Ecosystem (Isaac and Ferrari, 2017; Spalding et al., 2007). This fishery is known to incidentally capture ETP species including sharks, rays, and sea turtles listed in the IUCN Red List of Threatened Species (De Getrouwe, unpublished data, 2018), including *Fontitrygon geijskesi* (Wingfin stingray, '*critically endangered'*), *Carcharhinus porosus* (Smalltail shark, '*critically endangered'*), *Mustelus higmani* (Smalleye smooth-hound, '*endangered'*), *Pseudobatos percellens* (Chola guitarfish, '*endangered'*), *Lepidochelys olivacea* (Olive ridley, '*vulnerable'*), and *Rhinoptera bonasus* (American cownose ray, '*vulnerable'*), among others (IUCN, 2025).

To efficiently implement bycatch mitigation measures that protect and conserve ETP species, it is critical to first understand where, when, and how many fatal interactions with fisheries occur (Pérez Roda et al., 2019) to optimally allocate often scarce resources for conservation (Moilanen et al., 2009; Wilson et al., 2006). For this reason, the Fisheries Department under the Suriname Ministry of Agriculture, Animal Husbandry and Fisheries runs an onboard observer programme (OOP) in the demersal trawl fishery. While several methods exist to monitor, log, and quantify ETP species interactions with fisheries (e.g., remote electronic monitoring using cameras (Emery et al., 2019; Piasente et al., 2012), paper-based or electronic logbooks (Furqan & Schlüter, 2024; Merrifield et al., 2019; Zhu et al., 2021), and citizen science programmes (Happywhale, 2024; Scott et al., 2024), OOP remain the most reliable method for recording bycatch data, despite financial and logistical challenges that limit data coverage (Babcock et al., 2003; Gray and Kennelly, 2018; Kennelly, 1995; Kennelly, 2020; Roda et al., 2019; Williams and Corral, 1999), although different qualities can exist among OOP depending on design, coverage and resources (Benaka et al., 2021).

Previous studies in Suriname have investigated ray bycatch in shrimp trawl fisheries, revealing species- and size-specific escape patterns when using bycatch reduction devices (BRDs) and turtle excluder devices (TEDs) (Willems et al., 2016). Sea turtle bycatch in gillnets, longlines, and njawarie artisanal fisheries has also been documented, with 342 individuals recorded across three species (leatherback, green, and olive ridley) (Sys, 2019). Additionally, de Getrouwe (unpublished data, 2018) conducted a detailed analysis of catch composition in the Suriname finfish trawl fishery, providing further context on species composition and discarded bycatch. The data collected in the Suriname demersal trawl fishery OOP were used to gain insight in bycatch rates and occurrence of ETP species (Kalpoe & Willems, unpublished data, 2025). The current study, however, aims to do a deeper analysis of these data and combine the observer data (i.e., a sample of observed fishing trips) with the spatially explicit fishing effort exerted by the entire Suriname demersal trawl fleet, as recorded by their boat's Vessel Monitoring Systems (VMS). By doing so, the aim is to (i) develop bycatch rate (BPUE) estimates for the five most observed ETP species and (ii) produce spatially explicit total bycatch estimates by scaling up observed rates with available fishing effort data across the study area. This was done to reveal when and where bycatch hotspots of ETP species exist.. These insights are critical to guide targeted and effective bycatch reduction strategies in Suriname's demersal trawl fishery.

Materials & Methods

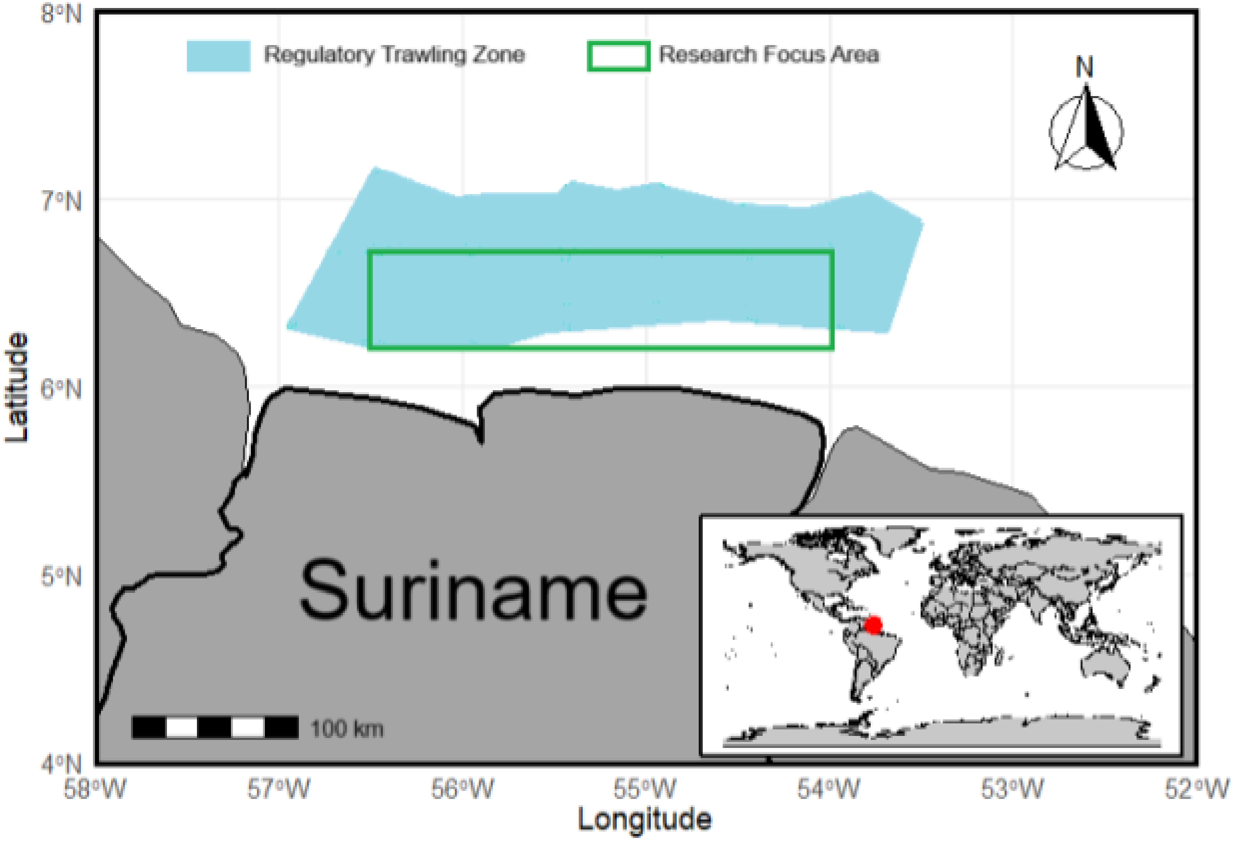


Figure 1. Map showing the regulatory trawling zone marked in blue polygon and the research focus area represented by green rectangle within Suriname's Exclusive Economic Zone.

Study Area and Fishery

The study was conducted in the demersal trawl fishing grounds of Suriname, located within its Exclusive Economic Zone (EEZ) on the wide, gently sloping continental shelf of the North Brazil Shelf Large Marine Ecosystem (Isaac and Ferrari, 2017; Spalding et al., 2007). Shelf waters are influenced by the Amazon River's freshwater discharge, creating a gradient from turbid nearshore to clearer offshore habitats that support high biodiversity, including commercially important weakfishes, croakers, and snappers (LVV, 2021).

As specified in Suriname's Fisheries Legal Framework, the demersal trawl fleet is permitted to operate between the 15-fathom and 35-fathom depth contours (approximately 27–64 m) within the EEZ (LVV, 2021). In practice, trawling effort is concentrated in only part of this zone, which was the focus area of this study (Figure 1, green rectangle).

The finfish trawl fishery began in the 1980s and now lands over 40 species (LVV, 2021; De Getrouwe, unpublished data, 2018). The fleet consists of 35 stern trawlers (≤32 m), operating single or twin-rigged otter trawlers with a codend mesh size of ≥80 mm. Trips last about six days, with trawling conducted between 05:00 and 23:00 at speeds of 1.5–4.5 knots, which was used as a reference for extracting fishing effort from the VMS dataset. Vessels are permitted to operate up to 170 days annually under current management regulations (LVV, 2021).

Bycatch Rate (BPUE) Estimation

For the calculation of bycatch rates, observer data was used. As part of a Fishery Improvement Program (FIP), the Suriname Fisheries Department re-initiated an OOP for the demersal trawl fishery in May 2023 (Ministry of Agriculture, Livestock and Fisheries, 2024). Trained fisheries observers are deployed in rotation and follow a standardized protocol (Kalpoe & Willems, 2025; LVV, unpublished data, 2023) to guarantee consistency, transparency, and scientific validation. For each haul, all metadata are recorded (time, position, depth, among other variables) before the catch is sampled according to a fixed protocol that aims to collect data on both retained and discarded catch, estimating weights of catch fractions and gathering length data for selected species.

The OOP aims to monitor at least one fishing trip per month, but deployment of observers is dependent on the activity of the vessels and available space onboard. The OOP is currently implemented only for trawlers operated by FIP partners (CeDePesca, 2023; FisheryProgress, 2024). Since the FIP partners represent over half of the active demersal trawl fleet, the OOP is considered to collect data that are representative for the entire fleet. The OOP was initially conducted using paper forms but transitioned to a digital version in April 2024 using tablets with a digital form deployed in the KoboToolbox platform (Fishery Progress, 2024). The dataset used in the current study included 360 monitored hauls, collected during 16 fishing trips aboard five different vessels from May 2023 to February 2025.

Scaling BPUE Estimates to Fleet Level

To scale BPUE estimates to fleet level, required VMS data as a proxy for fishing effort. All demersal trawl vessels in the Suriname fleet are obliged to use a Vessel Monitoring System (VMS) that signals vessel's position, speed, and course every 30 to 60 minutes. The 2023 VMS data from the entire demersal trawl fleet was retrieved from the Fisheries Department under the Suriname Ministry of Agriculture, Animal Husbandry and Fisheries.

Observer data used to calculate BPUE were collected between May 2023 and February 2025 due to limited sampling opportunities and logistical constraints. Limiting the analysis to 2023 alone would result in a small sample size (6–7 trips), reducing the robustness of bycatch estimation. To increase statistical power while maintaining temporal relevance, we included observer data across multiple years and grouped analyses by calendar quarter (Q1–Q4). Scaling-up to fleet-wide estimates was conducted using trawling effort data from the 2023 fishing year only, as recorded by VMS.

Data Analysis

The observer dataset was used (i) to assess which ETP species bycatch are most frequently captured, (ii) to calculate the bycatch per unit effort (BPUE), (iii) to map out BPUE spatial variation, and (iv) to visualise BPUE temporal trends. Species in the catch were considered 'ETP' based on their occurrence in WWF (2018) "On-Board Guide for the Identification of Marine ETP and Other Key Species of the Guianas". This guide includes sharks, batoid fishes, sea turtles, marine mammals, and fish species commonly found in Guianan waters that are either commercially relevant, vulnerable to exploitation, or listed on the IUCN Red List. The species categories used in this study follow the WWF (2018) guide, which is the reference standard for the local Fisheries Department and reflects ecological and management considerations. The total individual counts of the ETP species from the observer data were calculated (Appendix A) and the top 5 most frequently observed, by-caught ETP species were selected for analysis in this study.

The observer dataset was first cleaned by modifying obvious signs of typos and removing outliers. Trawling hours were calculated based on the gear set and haulback time difference. The resulting data were then filtered, retaining only the top five most observed species. Bycatch composition based on species diversity and individual abundance were calculated and plotted.

Based on regulatory fishing limits, the theoretical fishing zone of Suriname's demersal trawl fleet (Figure 1, blue polygon) lies between the 15-fathom and 35-fathom depth contours, approximately 27 to 64 meters deep (LVV, 2021). This nominal depth range, where bottom trawling is expected to occur, was used as a general reference. Trawl locations from the observer dataset were then plotted within this zone to visualize the actual spatial extent of fishing activities. The observer data points were found to cluster tightly between longitudes -56.5 to -54 and latitudes 6.2 to 6.8. A rectangular bounding box was created around this distribution to define the 'focus area'—a simplified spatial frame used for subsequent analysis. Limiting analyses to this area ensured that we concentrated on the locations where the observer data and most fishing effort actually occurred and reduced the inclusion of large non-fished areas.

A grid cell size of 7.5 nm was selected, resulting in a 20 × 5 grid (100 total cells), which covers almost the entire focus area without leaving gaps or extending beyond the boundaries. Each haul in the observer dataset was assigned to one of the 100 spatial grid cells based on gear set coordinates (start position of a trawl). To evaluate the spatial representativeness of observer sampling relative to the spatial effort of the entire fleet, a Spearman's rank correlation test was conducted between the number of observer-recorded hauls and the total trawling hours from VMS data per grid cell.

For each of the five target ETP species per haul, BPUE were calculated as bycatch observed divided by effort observed (Moore, et al., 2021):

$$BPUE\ (observed\ vessels)\ =\ number\ of\ individuals\ (ind)\ \div\ trawling\ hours\ (hr)$$

These haul-level BPUE values were then aggregated by spatial grid cell and quarter (Q1: Jan–Mar, Q2: Apr–Jun, Q3: Jul–Sep, Q4: Oct–Dec). Since BPUE values exhibited a non-normal distribution (Lilliefors Test, $n = 993$, $D = 0.2239$, $p < 2.2 \times 10^{-16}$), we applied non-parametric bootstrapping (10,000 resamples;

adjusted percentile method) to estimate 95% confidence intervals without assuming any underlying distribution. Bootstrapping is a robust method for quantifying uncertainty, particularly when extrapolating from limited or non-random sample data to the fleet level, and is increasingly used in bycatch assessments (e.g., Casale et al., 2017; Wakefield et al., 2018).

To examine temporal and spatial patterns in bycatch rates prior to scaling, we conducted Kruskal-Wallis tests on observed BPUE values at the haul level. Temporal variation was assessed by comparing BPUE across the four quarters of the year, while spatial variation was evaluated across spatial grid cells. Due to the non-normal distribution of BPUE data, the Kruskal-Wallis test was selected as an appropriate non-parametric method. Effect sizes were quantified using Epsilon squared (ε^2) to assess the magnitude of temporal and spatial differences.

For each grid–species–quarter combination with at least two non-missing and non-identical BPUE values, 10,000 bootstrap replicates were generated. Two outputs were produced:

(1) summary statistics (mean BPUE and 95% confidence intervals), and

(2) the full bootstrap distributions of replicate means.

The former were used in visualizations such as bar plots and heat maps, while the latter were used in scaling-up calculations to propagate uncertainty. A full set of 10,000 bootstrap replicate means per grid–species–quarter combination was used in the scaling-up process with Vessel Monitoring System (VMS) data. This approach propagated observation-level uncertainty from the BPUE estimates to total bycatch estimates at the fleet level. Specifically, for each bootstrap iteration, the BPUE value (individuals per trawling hour) was multiplied by the total number of VMS-derived trawling hours for the corresponding grid and quarter:

$$Bycatch\ Estimate\ (entire\ fleet)\ =\ bootstrapped\ BPUE\ (ind/\ hr)\ \ x\ VMS\ trawling\ hours\ (hr)$$

This procedure yielded a distribution of total bycatch estimates that reflects both uncertainty in observed catch rates and variation in spatial fishing effort. It assumes that observer-derived BPUE values are representative of the fishing behavior and bycatch rates of the entire fleet within each spatial–temporal unit, and that the spatial distribution and relative bycatch rates of ETP species remained broadly consistent over the study period. All the data analyses were done in RStudio (R version 4.5.1) using the R packages, boot, tidyverse and sf, among others (see Appendix B) .

Results

Observed BPUE Estimates

Between May 2023 and February 2025, 360 hauls were observed across 16 trips, capturing 19,402 individuals of ETP species (Figure 2; Appendix A). A total of 29 ETP species were recorded, including 25 elasmobranch species (14 sharks and 11 batoid fish), three sea turtle species, and one marine mammal species. Five species dominated the bycatch (Table 1): Longnose stingray (*Hypanus guttatus*; Bloch & Schneider, 1801), Smalleye smooth-hound (*Mustelus higmani;* Springer & Lowe, 1963), American cownose ray (*Rhinoptera bonasus;* Mitchill, 1815), Brazilian sharpnose shark (*Rhizoprionodon lalandii*; Valenciennes, 1839), and Caribbean sharpnose shark (*Rhizoprionodon porosus;* Poey, 1861). The capture also included 1,121 individuals from 6 'Critically Endangered' species of sharks and batoids, with the Wingfin stingray (*Fontitrygon geijskesi;* Boeseman,1948) alone contributing 977 individuals to this total (Figure 2).

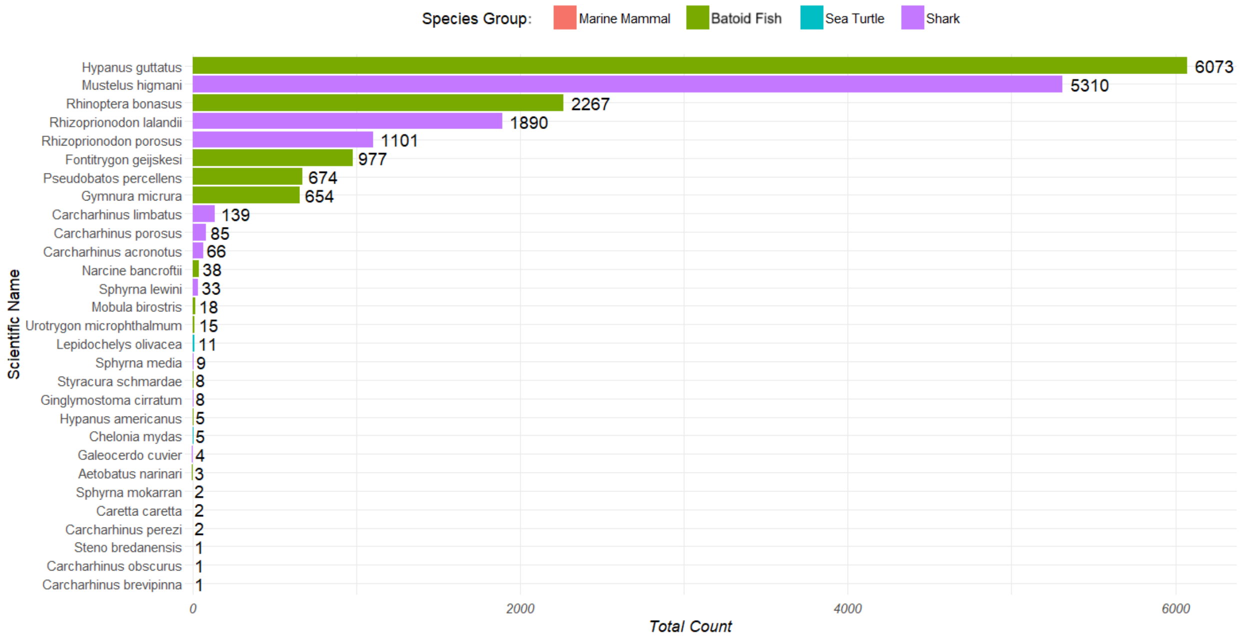


Figure 2. *Total counts of endangered, threatened, and protected species observed between May 2023 and February 2025, color-coded by species group: marine mammals (pink), batoid fishes (green), sea turtles (blue), and sharks (purple).*

Together, these five species represented 85.77% of all ETP bycatch (16,641 individuals) and were therefore selected for the spatial and temporal analysis of bycatch rates (Table 1). The conservation statuses of these dominant species varies considerably according to the 2019 IUCN Red List, ranging from Near Threatened (*H. guttatus*) to Vulnerable (R. *bonasus, R. lalandii,* and *R. porosus*) to Endangered (*M. higmani*) (Table 1).

***Table 1**. Top five most observed marine endangered, threatened, and protected species recorded by the onboard observer programme (May 2023–February 2025), based on total individual counts. Species codes, scientific names, common names, and IUCN Red List status (as assessed in 2019) are shown.*

Species Code	Scientific Name	Common Name	IUCN Red List Status *(assessed in 2019)*	Total Count
RDU	*Hypanus guttatus*	Longnose stingray	Near Threatened (NT)	6073
CTJ	*Mustelus higmani*	Smalleye smoothhound shark	Endangered (EN)	5310
MRB	*Rhinoptera bonasus*	American cownose ray	Vulnerable (VU)	2267
RHL	*Rhizoprionodon lalandii*	Brazilian sharpnose shark	Vulnerable (VU)	1890
RHR	*Rhizoprionodon porosus*	Caribbean sharpnose shark	Vulnerable (VU)	1101

Among all 29 identified ETP species, sharks comprised the highest diversity (48.3%), followed by batoid fishes (37.9%), sea turtles (10.3%), and marine mammals (3.4%) as the least (Figure 3, left). However, batoid fishes dominated in abundance, accounting for more than half of all individuals (55.3%; Figure 3, right) despite lower species diversity than sharks.

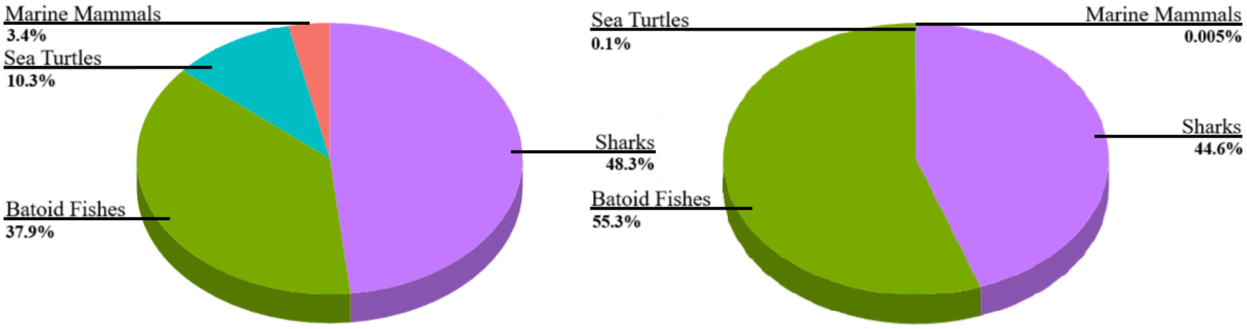


***Figure 3.** Composition of endangered, threatened, and protected species based on (left) species diversity (N = 29 species) and (right) individual abundance (N = 19,402 individuals), grouped into broad taxonomic categories: marine mammals (pink), sea turtles (blue), batoid fishes (green), and sharks (purple).*

Mean BPUE by Species

Among the selected five species, *M. higmani* showed the highest BPUE at 5.96 individuals per hour (95% CI: 5.30 - 6.73; Figure 4, Table 2). *H. guttatus* has the largest sample size (n=335) and high BPUE of 5.57 ind./hr (95% CI: 4.90 - 6.35). Similarly, *R. bonasus* shows a high mean BPUE (5.76 ind/hr) but with the widest confidence interval (95% CI: 4.64 - 7.23). *R. porosus* has notably lowest BPUE (2.70 ind./hr) and the narrowest confidence interval (95% CI: 2.24 - 3.34).

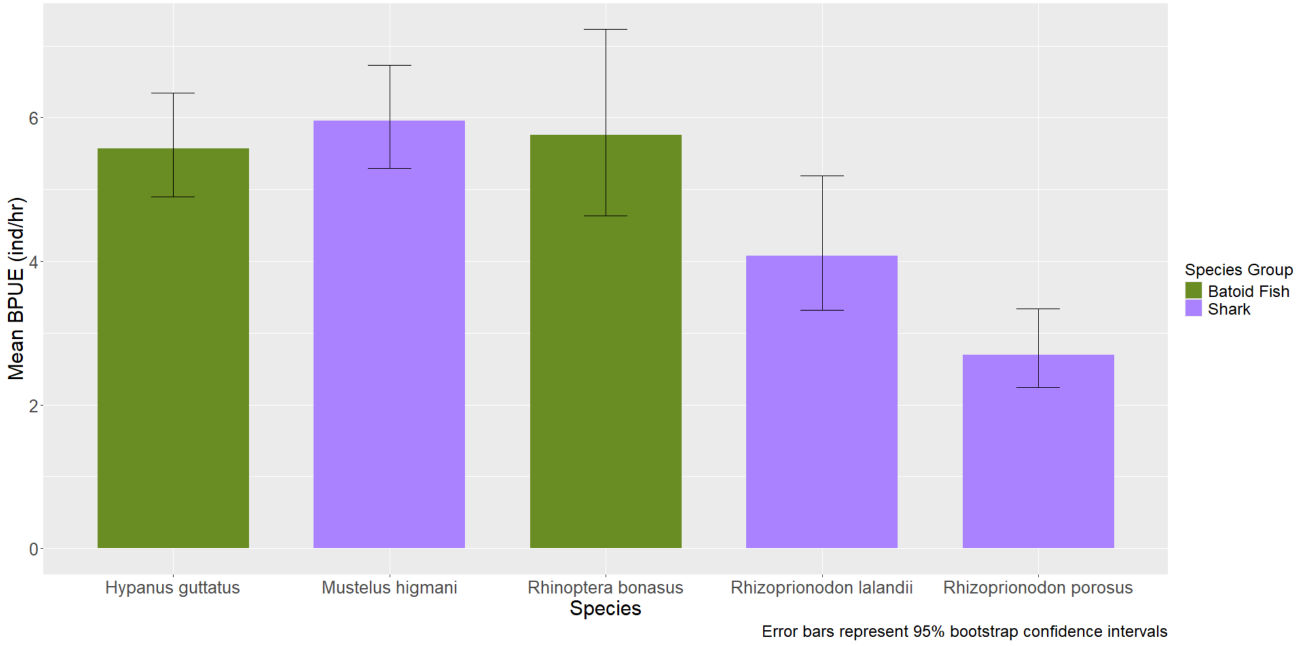


Figure 4. *Mean bycatch per unit effort (BPUE, individuals per hour) for five endangered, threatened, and protected species based on haul-level observer data. Error bars represent 95% confidence intervals from non-parametric bootstrap analysis (10,000 resamples) using the adjusted percentile method. Species are color-coded by species group: batoid fish (green) and sharks (purple).*

Table 2. *Bootstrap statistics for mean BPUE of five endangered, threatened, and protected species from haul-level observer data. Values include mean BPUE (individuals per hour), standard error (se), number of observed hauls (n), and 95% confidence intervals (CI) derived from 10,000 bootstrap resamples using the adjusted percentile method.*

	Hypanus guttatus (RDU)	*Mustelus higmani* (CTJ)	*Rhinoptera bonasus* (MRB)	*Rhizoprionodon lalandii* (RHL)	*Rhizoprionodon porosus* (RHR)
Mean BPUE (ind/hr)	5.57	5.96	5.76	4.07	2.70
Standard Error (se)	0.37	0.36	0.65	0.46	0.27
Sample Size (n)	335	279	109	134	120
Lower 95% CI	4.90	5.30	4.64	3.32	2.24
Upper 95% CI	6.35	6.73	7.23	5.19	3.34

Spatial Variations in Observed BPUE

Observer data were recorded across 53 of the 100 grid cells within the study area. Looking at the combined BPUEs of the five most observed species, the grid cells 23, 27, 30 and 76 are among the highest bycatch rates, as indicated by the darker colors (Figure 5). Within these cells, an average of 12.57 to 14.15 individuals were caught per hour of trawling effort. The fishing operations in these areas have shown a greater impact on ETP species. Conversely, areas with low (lighter colors) can be seen as lower risk zones. This includes the grid cells 57, 60, and 69 with mean BPUEs of ~ 1.3 (ind/hr).

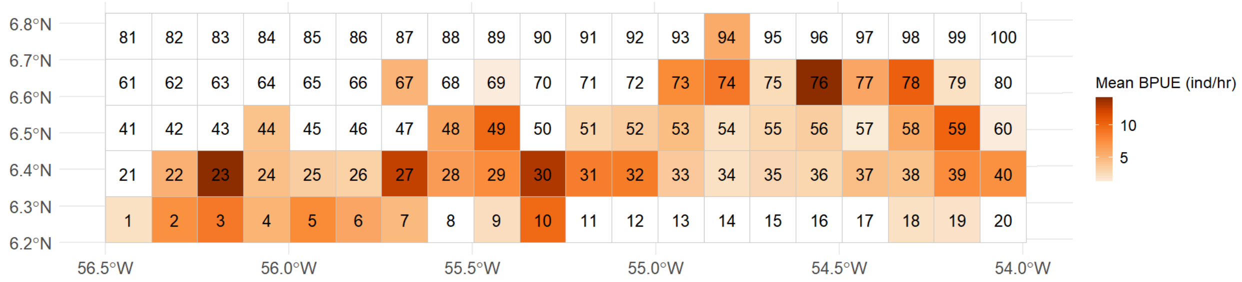


Figure 5. *Heatmap of observer-derived BPUE for the combined five most frequently observed endangered, threatened, and protected species, aggregated by 7.5 × 7.5 nautical mile (nm) grid cells. Grid cells are labeled from 1 to 100, and mean BPUE values are represented using an orange color gradient: darker shades indicate higher BPUE values. White areas indicate grid cells with no observer data available.*

Species-specific hotspots were revealed when plotting each species' mean BPUE separately (Figure 6). Spatial extent and bycatch intensity revealed contrasting patterns among species. *H. guttatus* and *M. higmani* showed the broadest distributions, occupying 49 and 50 of the 53 grid cells containing observer data. Highest bycatch rates were observed in grid cells 30 (20.82 ind/hr) and 74 (15.51 ind/hr), respectively. In contrast, *R. bonasus* exhibited the most restricted distribution, occurring in only 26 grids, with the highest BPUE (25.37 ind/hr) in grid cell 31. *R. lalandii* and *R. porosus* showed intermediate coverage, occupying 35 and 32 grids, respectively. Highest bycatch rate for *R. lalandii* (22.36 ind/hr) was recorded in grid cell 24, whereas, for *R. porosus (*8.49 ind/hr) was in grid cell 10.

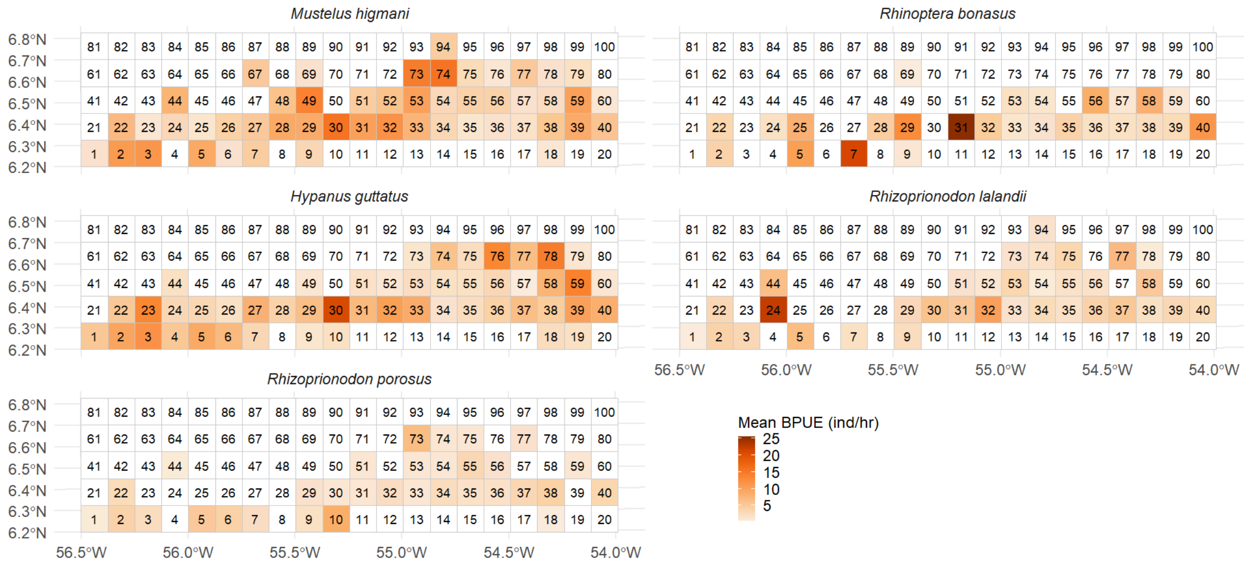


Figure 6. *Spatial distribution of observed mean BPUE for each of the five most observed endangered, threatened, and protected species, aggregated by 7.5 × 7.5 nm grid cells. Grid cells are labeled from 1 to 100, and mean BPUE values are represented using an orange color gradient: darker shades indicate higher BPUE values.*

Spatial variation in BPUE across grid cells was analysed using the Kruskal–Wallis test. All five species exhibited statistically significant spatial differences in BPUE distribution ($p < 0.01$). The strongest spatial effect was observed for *R. bonasus* ($\chi^2 = 58.53$, $p < 0.001$, $\varepsilon^2 = 0.52$). This was followed by *R. lalandii* ($\chi^2 = 65.93$, $df = 34$, $p < 0.001$, $\varepsilon^2 = 0.49$), *M. higmani* ($\chi^2 = 130.37$, $p < 0.001$, $\varepsilon^2 = 0.46$), and *R. porosus* ($\chi^2 = 53.73$, $p = 0.007$, $\varepsilon^2 = 0.44$), which also exhibited highly significant and strong spatial variation. *H. guttatus* has the least effect size ($\varepsilon^2 = 0.366$) but still showed a clear spatial heterogeneity ($\chi^2 = 124.47$, $p < 0.001$).

Temporal Variations in Observed BPUE

Temporal variation in BPUE was assessed for the five most observed ETP species using the Kruskal–Wallis test across quarterly periods (Q1 to Q4). *M. higmani* showed the most pronounced variation ($\chi^2 = 65.81$, $p < 0.001$; $\varepsilon^2 = 0.234$), with peaks in Q1 (9.13 ind/hr) and Q3 (9.95 ind/hr) and lower rates in Q2 (3.61 ind/hr) (Figure 7). *R. bonasus* displayed an even more dramatic Q3 peak (12.04 ind/hr) and extremely wide confidence intervals, but this variation was not statistically significant ($\chi^2 = 5.46$, $p = 0.141$; $\varepsilon^2 = 0.049$). *H. guttatus* peaked in Q1 (8.11 ind/hr), dropped in Q2 (3.05 ind/hr), and increased again in Q3 (7.71 ind/hr), showing strong temporal variation ($\chi^2 = 48.25$, $p < 0.001$; $\varepsilon^2 = 0.142$). *R. lalandii* had relatively stable BPUE (2.07 – 6.11 ind/hr) but still exhibited significant quarterly differences ($p \approx 0.003$; $\varepsilon^2 = 0.102$). *R. porosus* maintained consistently low BPUE (1.80 – 4.38 ind/hr) yet also showed significant variation between quarters ($p \approx 0.003$; $\varepsilon^2 = 0.115$).

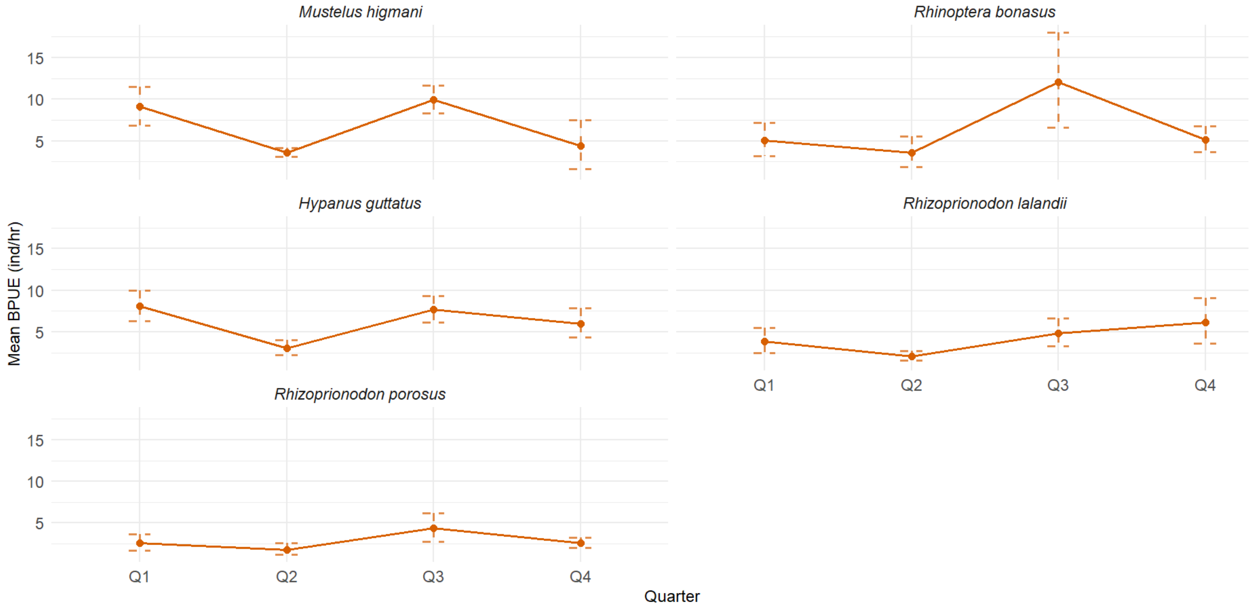


Figure 7. *Quarterly variation in observed mean BPUE with 95% confidence intervals for the five most frequently captured endangered, threatened, and protected species.*

Scaling BPUE to Fleet Level

The 2023 VMS data from Suriname's entire trawling fleet revealed that fishing effort was concentrated along the southern edge of the regulatory fishing zone, closest to the coast (Figure 8). The activities become increasingly sparse as it goes offshore and farther west. Observer data showed a similar spatial pattern, with high observer effort overlapping these concentration zones.

The spatial distributions of fishing effort recorded by observers and the fleet-wide VMS data were significantly correlated (Spearman's rank correlation; $n = 53$, $\rho = 0.62$, $p < 0.001$), indicating consistent spatial patterns of fishing activity across both data sources. This strong correlation validates that observer coverage effectively captured the fleet's spatial fishing patterns, with observers recording proportionally higher effort in areas where VMS data also indicated high fleet activity.

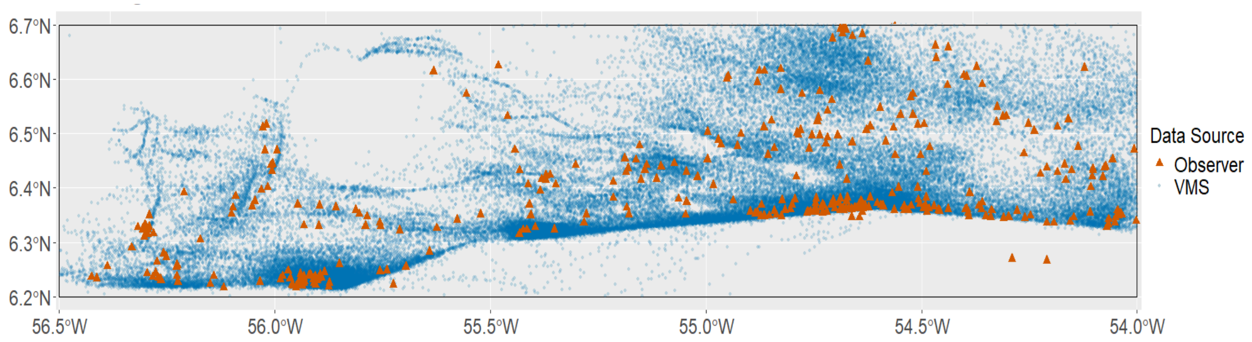


Figure 8. *Spatial distribution of trawling effort in Suriname's fishing zone and observer coverage. VMS data points (blue dots) represent fleet-wide trawl activity, while observer-recorded location (orange triangles) indicate sampled effort used for BPUE estimation. The bounding box delineates the area where trawling activities and observer sampling were concentrated.*

Scaled Total Bycatch Estimates

The total bycatch estimates were calculated for 2023, and were based on a full-year trawling effort data from VMS and extrapolated from observer-based BPUE values (Figure 9). These BPUE values were calculated from data collected between May 2023 and February 2025 and applied to the 2023 fishing effort. To account for uncertainty, 95% confidence intervals for BPUE were calculated using bootstrap adjusted percentiles (10,000 replications).

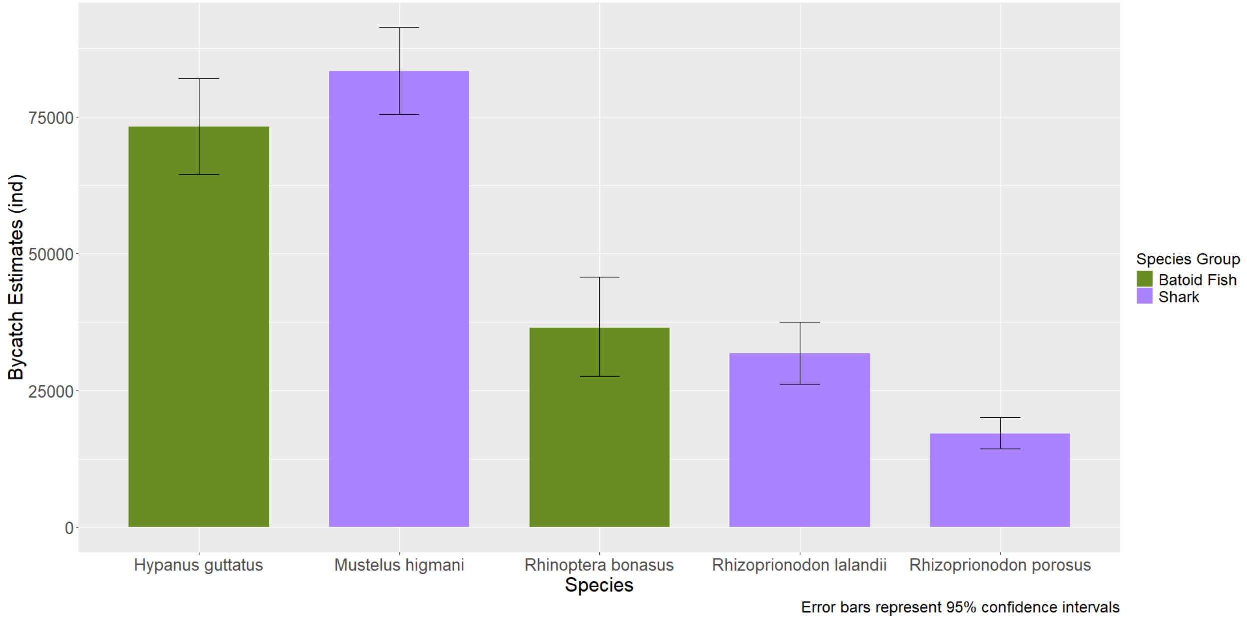


Figure 9. *Total bycatch estimates (individuals) for five endangered, threatened, and protected species derived from scaling observer-based BPUE to fleet-wide fishing effort using VMS data. Error bars represent 95% confidence intervals from bootstrap analysis (10,000 iterations) that propagates*

uncertainty from observer sampling through to fleet-level estimates. Species are color-coded by species group: batoid fish (green) and shark (purple).

Total bycatch estimates differed between sharks and batoid fishes (Figure 9, Table 3), with an order of magnitude less bycatch for batoid fishes compared to sharks. *M. higmani* and *H. guttatus* showed the highest estimated bycatch of 83,302 (95% CI: 75,487 - 91,295) and 73,125 individuals (95% CI: 64,513 - 82,043), respectively. *R. bonasus* and *R. lalandii* showed moderate bycatch of 36,487 (95% CI: 27,556 - 45,733) and 31,720 individuals (95% CI: 26,166 - 37,557), respectively. *H. guttatus*, *M. higmani* and *R. bonasus* have relatively wide confidence intervals, suggesting more uncertainty in the estimates. The lowest bycatch and narrow confidence interval was observed with *R. porosus* with an estimate of 17,111 individuals (95% CI: 14,347 - 20,035).

Table 3. *Bootstrap statistics for total bycatch estimates of five endangered, threatened, and protected species scaled to fleet level. Values include mean bycatch estimate, standard error (se), and 95% confidence intervals (CI).*

	Hypanus guttatus (RDU)	*Mustelus higmani* (CTJ)	*Rhinoptera bonasus* (MRB)	*Rhizoprionodon lalandii* (RHL)	*Rhizoprionodon porosus* (RHR)
Bycatch Estimate (ind)	73,125	83,302	36,487	31,720	17,111
Standard Error (se)	44.73	40.50	46.82	29.22	14.53
Lower 95% CI	64,513	75,487	27,556	26,166	14,347
Upper 95% CI	82,043	91,295	45,733	37,557	20,035

The spatial heatmap showed that the total ETP bycatch was more concentrated in areas closer to the coast and lessens farther offshore (Figure 10). This was a consistent pattern with the observed BPUE spatial distribution as previously mentioned. However, it differs with the number of hotspots and the location. In this fleet-wide bycatch estimate, only two prominent hotspots were observed—grid cell 5 with the highest estimate of 41,522 individuals, followed by grid cell 31 (29,349 ind).

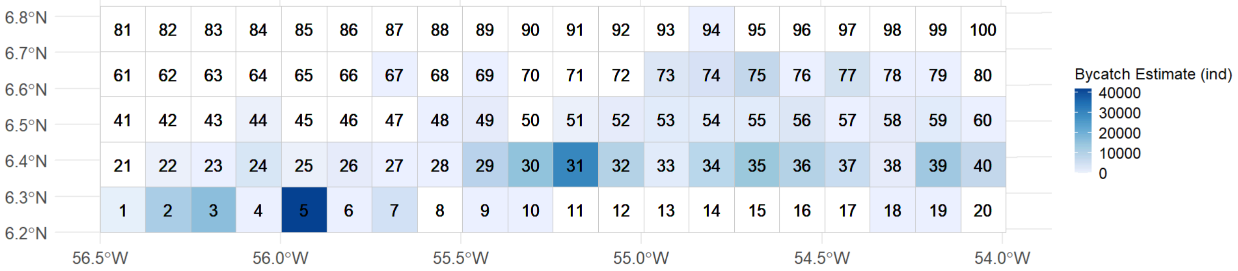


Figure 10. Heatmap of scaled up bycatch estimates (observer x VMS effort) for the combined most frequently caught endangered, threatened, and protected species. Grid cells are numbered sequentially from 1 to 100 and color indicates bycatch levels: darker shades indicate higher bycatch estimates. White areas indicate grid cells with no observer data available.

In the fleet-wide bycatch spatial distribution per species, *M. higmani* displayed the most pronounced spatial clustering, with high bycatch estimates in grid cells 3, 5, 30 and 31 with values ranging from 8,100 to 10,398 individuals (Figure 11). *H. guttatus* showed more moderate spatial aggregation, with high bycatch records in grid cells 3, 5, 31 and 39 (7,066 to 8,571 individuals). *R. bonasus*, *R. lalandii* and *R. porosus* exhibited relatively sparse and scattered distribution patterns where all of them registered a high bycatch in grid cell 5 with an estimate of 10,115 (ind), 7,138 (ind) and 5,549 (ind), respectively.

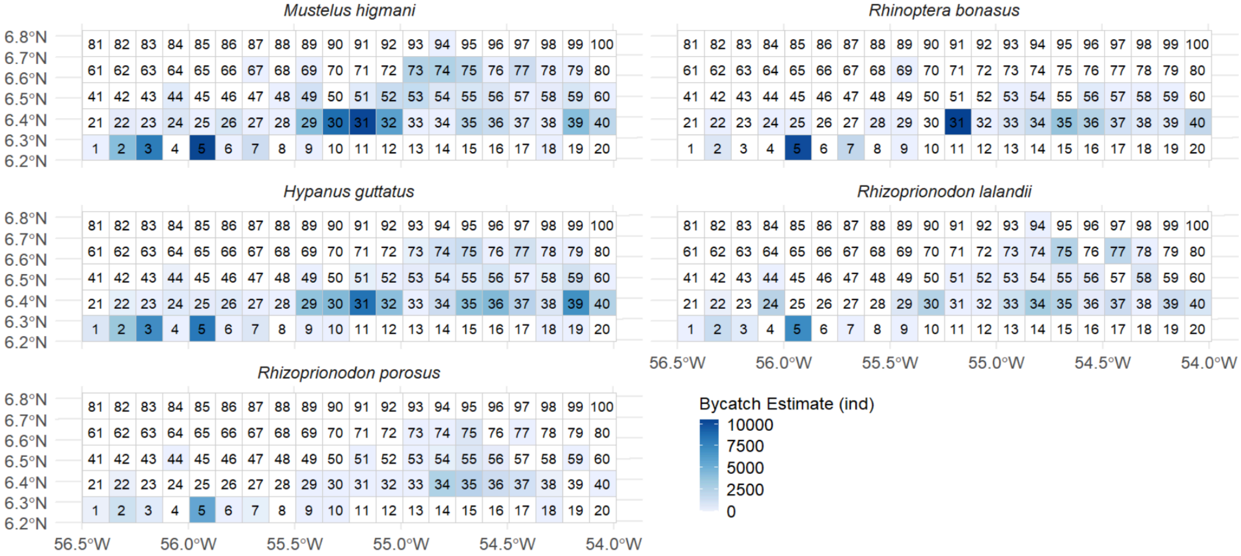


Figure 11. Heatmap of scaled up bycatch estimates (observer x VMS effort) for each of the endangered, threatened, and protected species. Grid cells are numbered sequentially from 1 to 100 and color indicates bycatch levels: darker shades indicate higher bycatch estimates. White areas indicate grid cells with no observer data available.

The scaled bycatch estimates showed different temporal trends compared to the observed bycatch rates (Figure 12). *M. higmani* exhibited the most pronounced seasonal variation, with peak bycatch occurring in Q3 (44,620 individuals) and lowest estimates in Q4 (7,006 individuals). *H. guttatus* showed a similar but less extreme pattern, peaking in Q3 (29,945 individuals) and declining in Q4 (14,920 individuals). *R.*

bonasus showed moderate seasonal variation (1,059 - 16,189 individuals) with highest estimates in Q3-Q4. *R. lalandii* displayed variations with lowest estimates of 2,676 individuals in Q1 that gradually increased to 12,453 individuals in Q3 before slightly dropping to 11,147 in Q4. Meanwhile, *R. porosus* showed minimal seasonal variation, maintaining relatively low and consistent bycatch levels (1,289 to 7,581 ind).

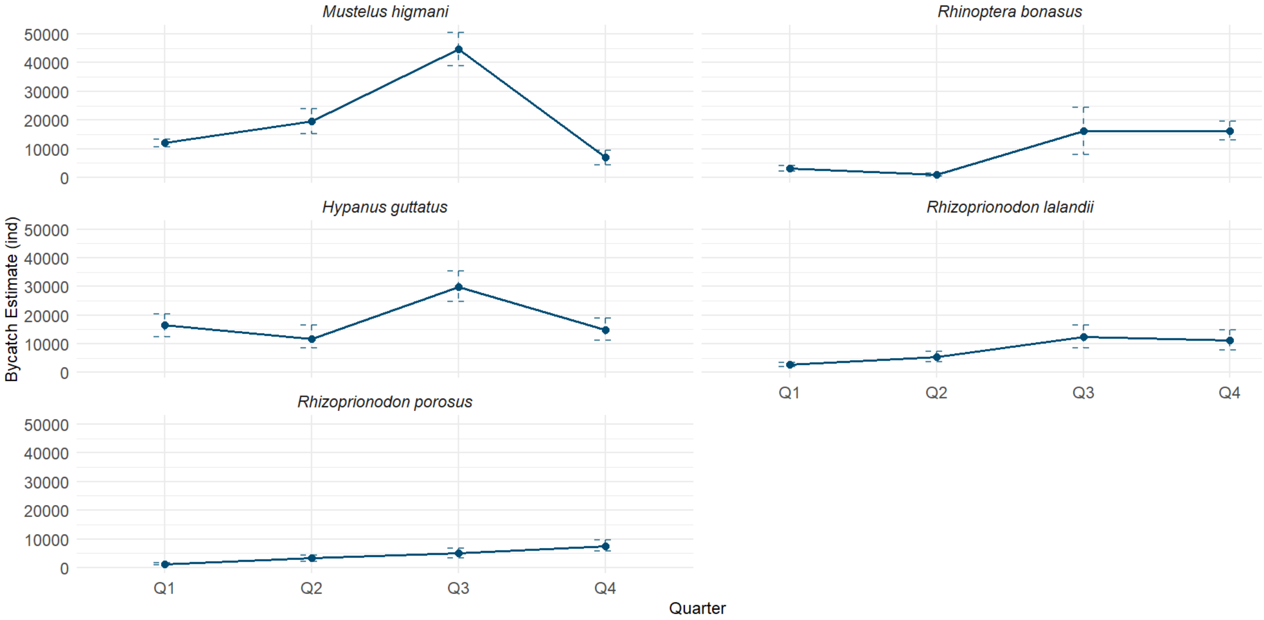


Figure 12. Quarterly variation in the scaled up bycatch estimates (observer x VMS effort) with 95% confidence intervals for the top 5 endangered, threatened, and protected species. Each panel shows seasonal patterns across four quarters (Q1-Q4) per species.

Discussion

This study provided the first spatio-temporal assessment of ETP species bycatch in Suriname's demersal finfish trawl fishery. Despite the opportunistic nature of the observer programme with limited temporal coverage (1.6% of fishing effort), a strong correlation between observer-recorded points and fleet-wide VMS trawling points was found, validating that observer spatial coverage effectively captured the fleet's spatial fishing patterns. This spatial representativeness ensures that ratio-estimated fleet-wide bycatch estimates are unbiased. Bycatch levels of the five most frequently caught ETP species were estimated, with *Mustelus higmani* identified as species of highest priority. Hotspots were concentrated in grid cells 5 and 31, and seasonal peaks occurred in Q3 (July to September), providing a foundation for targeted mitigation strategies in this data-limited fishery.

Scale and Species Composition of ETP Bycatch

Current fishing practices in Suriname's demersal trawl fishery may pose a significant threat to local populations of elasmobranchs and other ETP species. This study documented substantial ETP bycatch, with batoid fishes dominating in abundance and sharks contributing the highest species diversity. Such elasmobranch-rich bycatch in trawl fisheries has been reported previously globally (Oliver et al., 2015) and particularly in Suriname (De Getrouwe, unpublished data, 2018; Kalpoe and Willems, unpublished data, 2025; Willems et al., 2016).

A particularly concerning finding was the high capture rate of Critically Endangered species, notably the Wingfin stingray (*Fontitrygon geijskesi*), which comprised the majority of individuals in this category. The 2019 IUCN assessment reported a >80% population decline over the past three generations, driven by unmanaged fishing pressure and the species' low productivity (Pollom et al., 2020). Despite this, there are currently no species-specific protections in place, and further research is recommended. Our study recorded 977 individuals of *F. geijskesi*, based on limited temporal coverage (1.6% of fishing effort) but broadly representative spatial coverage across the fishing grounds—one of the first quantified bycatch estimates for this species. This finding provides valuable input for future IUCN population and threat assessments and raises urgent concerns about the species' vulnerability to bottom trawling, particularly in data-poor regions where baselines remain unknown.

The five most dominant species — *H. guttatus*, *M. higmani*, *R. bonasus*, *R. lalandii*, and *R. porosus* — together represented the majority of recorded ETP bycatch. All five species are currently listed as 'Near-Threatened' to 'Endangered' on the IUCN Red List, with *Mustelus higmani* identified as species of highest priority for having the highest bycatch rates and widest spatial distribution (See Appendix I. Species-Specific Analysis Summary). This composition mirrors patterns documented in other Surinamese trawl fishery studies (De Getrouwe, unpublished data, 2018; Willems et al., 2016) and in the neighboring Guyanese fishery (Garstin & Oxenford, 2018), suggesting a shared regional assemblage susceptible to trawl gear. The dominance of small shark species in the bycatch reflects the common pattern in bottom trawling, where large quantities of these species are frequently captured and discarded (Sacchi, 2021), likely due to habitat overlap and size-selective vulnerability to trawl gear.

In 2023 alone, the entire fleet of Suriname's demersal finfish trawl fishery is estimated to have captured approximately 241,746 individuals of ETP species as bycatch. Bycatch rates for the five dominant species ranged from 2.7 to 6.0 individuals h^{-1}, substantially higher than the elasmobranch bycatch rates reported from the neighboring Guyanese trawl fishery (2.3 individuals h^{-1}; Garstin & Oxenford, 2018) and other tropical trawl fisheries (1.7 individuals h^{-1} in Papua New Guinea; White et al., 2019). Similarly high bycatch rates were reported from Suriname's seabob shrimp trawl fishery, with an overall mean catch rate of 23.9 rays h^{-1} across all species (Willems et al., 2016). The persistence of elevated ray bycatch rates across different trawl fisheries and over more than a decade (2012-2023) suggests that Suriname's continental shelf waters represent important ray habitat or critical areas such as nursery grounds. While population abundance data are lacking, the magnitude of these removals relative to limited spatial and temporal coverage suggests substantial fleet-level impacts that warrant immediate attention for conservation management.

Spatial Distribution of Bycatch and Implications for Management

The spatial analysis revealed that bycatch is not uniformly distributed but concentrated in specific areas. Willems et al. (2015a,b) demonstrated that demersal fish and epibenthic communities on the Suriname continental shelf exhibit distinct spatial patterns driven by environmental factors such as depth gradients, sediment characteristics, and the influence of Amazon-derived waters. The location of the trawling grounds (27–64 m) falls within the zone where diverse epibenthic offshore assemblages were found, which include echinoderms, crustaceans, mollusks, and cephalopods (Willems et al., 2015b) — important food sources for small shark species and rays. While environmental variables were not examined in this study, the observed spatial hotspots in grid cells 23, 27, 30, and 76 with high bycatch rates may reflect habitat characteristics influencing species distribution. These particular areas might represent feeding grounds where abundant food sources attract more elasmobranchs. Implementing area closures or mandatory bycatch reduction devices in these high-impact hotspots could provide notable conservation benefits.

In the fleet-wide bycatch estimates, despite having low BPUEs, grid cells 5 and 31 emerged as prominent hotspots, reflecting the influence and magnitude of fishing effort. In these areas, fishing effort is the major driver of bycatch estimates rather than species abundance or habitat suitability. These effort-driven hotspots require effort-based management approaches such as fleet capacity limits or spatial-temporal effort redistribution to reduce total bycatch.

The emergence of species-specific hotspots indicates distinct spatial preferences that likely reflect underlying life history traits and ecological requirements. Species-specific ecological traits from available literature provide insights into the observed spatial patterns. For example, the habitat preference of *Hypanus guttatus* to depths up to 70 m (Weigmann, 2016) could be a factor influencing its broad distribution across the fishing grounds, exhibiting greater mobility and less specialized habitat requirements. Such species might be more resilient to localized fishing pressure but require more extensive management approaches, including fleet-wide gear modifications and improved release protocols. In contrast, *Rhizoprionodon lalandii* and *Rhizoprionodon porosus* inhabit a wider range of depths (3–149 m and 0–500 m, respectively; Ebert et al., 2013; García, 2017), which may explain their sparser distribution patterns in the fishing grounds. Additionally, Yokota and Lessa (2006) reported that juveniles of *R. porosus* spend the first few months in shallow waters up to 20 m, then move to deeper waters as adults, suggesting that a substantial portion of the population may occur outside the main fishing zone. *Rhinoptera bonasus*, which prefers habitats between 0–60 m depth (Weigmann, 2016) overlapping with the fishing grounds, exhibited the most restricted distribution but the highest bycatch rates. This pattern may be linked to their behavior of migrating in large schools (Last et al., 2016), which likely concentrate in specific areas of preference. When these aggregations overlap with trawling activities, large numbers can be captured in a single event.

The pronounced spatial heterogeneity in bycatch patterns, combined with species-specific ecological requirements, demonstrates that a one-size-fits-all approach to bycatch mitigation would be ineffective. Instead, a portfolio of targeted management strategies is recommended. For habitat-driven hotspots (grid cells 23, 27, 30, 76), area-based measures such as seasonal closures during peak bycatch periods or enhanced gear restrictions could yield substantial conservation benefits. Effort-driven hotspots (grid cells 5, 31) require capacity-based management, including setting maximum allowable bycatch thresholds and fleet redistribution strategies. Species-specific variations need further study to understand the environmental drivers of the spatial patterns observed. In general, possible management approaches may include temporal or spatial closures of bycatch hotspots, gear modifications that allow certain species to escape, redistribution of fishing effort toward areas with lower ETP interaction, and adaptive catch limits where management actions are triggered once thresholds are exceeded. Implementation should prioritize cost-effective measures that address multiple species simultaneously, supported by enhanced monitoring in identified hotspots to enable adaptive management. This integrated approach, combining spatial management with species-specific strategies, provides a framework for reducing bycatch impacts while maintaining fishery productivity.

Temporal Patterns in Bycatch and Implications for Management

The temporal analysis reveals important ecological and management insights. The pronounced Q3 (Jul-Sep) peaks observed in both scaled estimates and BPUE for most species suggest potential seasonal aggregation behaviors or reproductive timing that increases vulnerability to fishing operations during this period. The abundance of elasmobranch in specific times can be linked to various factors including water temperature preference, prey availability, reproductive behaviour, or species-specific life-stage preference (Collins et al., 2008; Schlaff et al., 2014; Graf et al., 2025; Gong et al., 2023; Yokota and Lessa 2006).

However, discrepancies between BPUE and scaled estimates, such as in the case of *M. higmani*—which shows a BPUE peak in Q1 but a scaled estimate peak in Q3—highlight the need to interpret these metrics carefully. While BPUE reflects the relative temporal abundance patterns of species across quarters, scaled estimates incorporate the quarterly distribution of fishing effort and thus reflect when the fleet is most active (Campbell 2004; Ellis and Wang, 2007). This means that quarters with low BPUE can still contribute disproportionately to total bycatch if fishing effort is high during those periods, and vice versa (Hoyle et al., 2024; Walters, 2003). Such temporal mismatches suggest that seasonal fleet behavior patterns, rather than species seasonal abundance alone, play a crucial role in shaping bycatch impacts over time. This distinction is critical for designing effective temporal management strategies, such as seasonal closures during high-effort periods that coincide with species vulnerability.

These species-specific temporal patterns have important implications for adaptive management. The consistent Q3 peaks across multiple species indicate that this quarter represents a critical period, warranting further study to identify the underlying biotic and abiotic drivers of seasonal aggregations in elasmobranchs (Ferreira et al., 2023; Hopkins and Cech, 2003; Schlaff et al., 2014; Roskar et al., 2024). In contrast, the relatively stable patterns observed in *R. lalandii* and *R. porosus* may be explained by their broader depth ranges and partial use of habitats outside the main trawling grounds (Ebert et al., 2013; García, 2017), which reduces strong seasonal overlap with fishing. By comparison, the higher variability observed in *M. higmani* and *H. guttatus* could reflect more localized or seasonally driven habitat use—such as movements related to prey availability, or reproductive behavior (Schlaff et al., 2014)—that makes them more vulnerable to capture during certain periods. A deeper understanding of these species–environmental dynamics is crucial for developing effective, targeted management strategies. Overall, these findings highlight the need for enhanced monitoring during Q3 and consideration of mitigation measures such as seasonal closures.

The seasonal predictability of these patterns provides opportunities for implementing temporally-targeted management measures, such as seasonal effort restrictions during peak bycatch periods, enhanced observer coverage during high-risk quarters, or increased fishers' self-reporting programs during vulnerable periods to achieve greater monitoring coverage.

Potential Bycatch Mitigation Strategies

The fleet-wide spatial and temporal patterns identified in this study highlight the need for tailored mitigation measures based on each species' characteristics. For species with broad distributions and high bycatch rates such as *M. higmani* and *H. guttatus*, broad-scale strategies like gear modifications would be ideal. The combination of a bycatch reduction device (BRD) — specifically, a square-mesh escape panel — and a turtle excluder device (TED) using the Super Shooter sorting grid method has already been tested in Suriname's shrimp trawl fishery, resulting in a 36% reduction in ray catch rate, particularly for large-sized rays (Willems et al., 2016). Similarly, in the northern Australian prawn trawl fishery, the introduction of TEDs and BRDs reduced catches of sharks and rays by 17.7% and 36.3%, respectively (Brewer et al., 2006).

The use of TEDs in Suriname's fish trawl fishery is not yet mandated. However, a flexible 'cable' TED prototype, specifically designed for Surinamese fish trawling, has already been developed and tested. This device reduced ETP bycatch without significantly affecting target catch (LVV, 2021). The prototype was intended for further testing and eventual fleet-wide implementation (LVV, 2021). When appropriately adapted, this gear modification has the potential to significantly reduce trawl bycatch. Nevertheless, its application in multispecies trawl fisheries presents challenges and will require further investigation into ETP species' behaviour and escape responses. In designing or implementing such modifications, it is crucial to balance the escape of non-target species, such as sharks and rays, with minimizing economic losses from reduced target catch.

In situations where gear modifications are impractical or not yet feasible, changes in fishing behaviour can serve as an alternative. The same species — *M. higmani* and *H. guttatus* — also showed high bycatch estimates during Q1 and Q3. Thus, temporary closure of their shared hotspots (grid cells 3, 5, and 31) during these quarters are recommended. Restricting fishing effort in areas and periods with significant bycatch risk can be an effective tool for reducing bycatch of vulnerable species (Murray, Read and Solow, 2000; Smith et al., 2021; Van Beest et al., 2017). For *R. lalandii*, an area closure of grid cell 5 during Q3 and Q4 would be ideal.

Looking at the broader spatial patterns, grid cell 5 appears to be a consistent hotspot for all five studied species. This suggests that it is an ecologically important area supporting diverse species and should be prioritized for protection. However, further research into environmental, ecological, and biological factors is necessary to fully understand the drivers behind these high bycatch patterns before implementing any time-area closures.

As an alternative or complementary measure to time-area closures, the move-on rule—already applied in Suriname's seabob trawl fishery—offers a more dynamic management tool (Willems et al., 2016). Under this rule, vessels are required to move to a different location if bycatch levels exceed a certain threshold (Auster et al., 2011) or if ETP species such as rays and sharks are caught abundantly in the catch. This approach accounts for the spatial and temporal variability of bycatch occurrence and allows for real-time mitigation of impacts. Implementation and compliance could be monitored through electronic monitoring systems, such as onboard cameras, enabling more adaptive and responsive management in hotspot areas like grid cell 5.

Limitations and Future Research Directions

A key limitation of this analysis is the limited temporal coverage of observer data during the target year 2023, with observer BPUE values calculated from data collected between May 2023 and February 2025. While this approach is standard in data-limited fisheries, it assumes that bycatch rates remained relatively stable throughout 2023, potentially leading to under- or over-estimation if seasonal, operational, or behavioral factors influenced ETP encounter rates outside the sampled periods. Furthermore, operational variables such as fishing depth, trawl duration, and catch volume, as well as environmental factors and species-specific behavior, were not incorporated despite their potential influence on bycatch rates. Future studies should aim for more consistent and comprehensive temporal coverage of observer data while considering these biotic and abiotic factors to refine estimates and reduce uncertainty.

Ideally, observer coverage of at least 50% for rare species and 20% for common species is needed to generate reliable bycatch estimates under unbiased sampling conditions (Babcock et al., 2003). However, given the logistical constraints in Suriname's fishery, a more feasible starting point would be to achieve the OOP's minimum target of one observed trip per month, ensuring a more temporally balanced dataset.

Given the challenges in the traditional OOP, alternative monitoring approaches such as fishers' self-reporting and electronic monitoring (e.g., onboard cameras) are emerging as cost-effective and scalable solutions. No one is better positioned to monitor bycatch than the fishers themselves—the true "eyes on the water." Their direct observations will provide a more comprehensive understanding of bycatch composition, abundance, and distribution (Moore et al., 2010; Nogueira, et al., 2016; Peckham et al., 2007). A successful pilot trial of digital self-reporting forms has already been conducted in Suriname (Rañada, unpublished data, 2025; Appendix J. Project Summary). With continued support from the

Fisheries Department, collaboration with the trawling company, and further crew training, this initiative holds promise for enhancing long-term monitoring and informing adaptive management. As a complementary approach, electronic monitoring systems—such as onboard cameras—could also be considered to improve data accuracy, support compliance, and enable verification of self-reported records.

Identifying ETP bycatch hotspots, peak periods, and species of critical concern provides Suriname's fisheries managers with a foundation for targeted conservation strategies. Future research could explore the ecological and environmental drivers behind the observed spatial and temporal bycatch patterns. Understanding factors such as prey availability, reproductive cycles, migration patterns, and oceanographic conditions could support more precise predictions and mitigation strategies.

An additional strength of this study lies in the use of the R programming language to conduct all analyses. This approach ensures transparency and repeatability, allowing the entire workflow to be easily updated with new data or adapted for different species. By sharing the R scripts with the Fisheries Department, the analysis can be re-used to assess specific species of interest—such as turtles or other ETP taxa—supporting ongoing monitoring, capacity-building, and evidence-based management.

Furthermore, integrating socio-economic data with ecological bycatch data would be essential for developing management plans that are not only ecologically sound but also socio-economically viable. Finally, future work should assess the effectiveness of different bycatch reduction devices and evaluate the feasibility of temporary closures of critical areas in the Surinamese context—both of which would represent proactive steps toward effective conservation.

Conclusion

This study presents the first spatio-temporal analysis of bycatch involving Endangered, Threatened, and Protected (ETP) species in Suriname's demersal finfish trawl fishery. By integrating observer-derived data with fleet-wide VMS effort records, we estimated the scale of ETP bycatch, identified spatial and temporal bycatch hotspots, and assessed management priorities for the five most frequently captured species. An estimated 241,746 individuals from only five ETP species were caught as bycatch in 2023 alone, with *Mustelus higmani* and *Hypanus guttatus* accounting for the majority of the catch and demonstrating pronounced seasonal and spatial peaks. *M. higmani* emerged as the highest-priority species for mitigation due to its 'Endangered' status, high bycatch levels, and wide distribution.

Strong spatial heterogeneity in bycatch risk—including concentrated hotspots in grid cells 5 and 31—underscores the value of fine-scale spatial monitoring and localized management. Temporal analyses revealed consistent Q3 bycatch peaks across most species, highlighting critical seasonal windows where fishing pressure and species vulnerability overlap. These findings provide clear direction for implementing adaptive measures such as seasonal closures, gear modifications, and hotspot-based effort reductions.

Although the OOP provided spatially representative data, its limited temporal coverage (1.6% of fishing effort and irregular sampling periods) is a key limitation. Expanding the OOP to meet its intended frequency—at least one observed trip per month—is essential for reducing seasonal bias in future assessments. In parallel, fisher self-reporting offers a promising and scalable monitoring alternative. Initial pilot trials in Suriname demonstrate its feasibility (Rañada, unpublished data, 2025; Appendix J. Project Summary), and further training and institutional support can enhance its integration into long-term data collection.

This research provides a much-needed scientific foundation for evidence-based bycatch mitigation in a data-limited setting. The integrated methodology demonstrates a scalable framework for ETP bycatch assessment that can inform national fisheries policy and regional conservation efforts in Suriname and similar tropical data-limited fisheries. Moving forward, targeted management interventions—such as spatial closures in grid cells 5 and 31 and seasonal restrictions in Q3 for high-risk species—should be prioritized. Ultimately, success will depend on combining spatially and temporally informed decision-making with improved monitoring and active fisher participation. Future work should expand ETP species coverage, validate proposed mitigation strategies, and embed co-management approaches to ensure the long-term sustainability and resilience of Suriname's trawl fisheries and its vulnerable marine biodiversity.

References

Artigas,L.F., P.Vendeville, M.Leopold, D.Guiral, and J.F.Ternon. 2003. Marine biodiversity in French Guinana: estuarine, coastal, and shelf ecosystems under the influence of Amazonian waters. Gayana 67:302-326.

Auster, P. J., Gjerde, K., Heupel, E., Watling, L., Grehan, A., and Rogers, A. D. (2011). Definition and detection of vulnerable marine ecosystems on the high seas: problems with the "move-on" rule. – ICES Journal of Marine Science, 68: 254–264.

Babcock, E. A., Pikitch, E. K., and Hudson, C. (2003). How much observer coverage is enough to adequately estimate bycatch? Oceana. https://oceana.org/reports/how-much-observer-coverage-enough-adequately-estimate-bycatch/

Benaka, L.R., Chan, A.N., Kennelly, S.J. et al. Using a tier classification system to evaluate the quality of bycatch estimates from fisheries. Rev Fish Biol Fisheries 31, 737–752 (2021). https://doi.org/10.1007/s11160-021-09670-y

Brewer, D., Heales, D., Milton, D., Dell, Q., Fry, G., Venables, B., and Jones, P. (2006). The impact of turtle excluder devices and bycatch reduction devices on diverse tropical marine communities in Australia's northern prawn trawl fishery. Fisheries Research, 81(2–3), 176–188. https://doi.org/10.1016/j.fishres.2006.07.009

Cadée,G.C. 1975. Primary production off the Guyana coast. Netherlands Journal of Sea Research 9:128-143.

Casale, P., Abitsi, G., Aboro, M. P., Agamboue, P. D., Agbode, L., Allela, N. L., Angueko, D., Bibang Bi

Nguema, J. N., Boussamba, F., Cardiec, F., Chartrain, E., Ciofi, C., Emane, Y. A., Fay, J. M., Godley, B. J., Kouerey Oliwiwina, C. K., Lewembe, J. D. D., Leyoko, D., Mba Asseko, G., Mengue M'adzaba, P., Mve Beh, J. H., Natali, C., Nyama-Mouketou, C., Nzegoue, J., Ogandagas, C., Parnell, R. J., Rerambyath, G. A., Schummer Gnandji, M., Sounguet, G.-P., Tiwari, M., Verhage, B., Vilela, R., White, L., Witt, M. J., and Formia, A. (2017). A first estimate of sea turtle bycatch in the industrial trawling fishery of Gabon. Biodiversity and Conservation, 26(10), 2421–2433. https://doi.org/10.1007/s10531-017-1367-z

CeDePesca. (2023). Annex I: Suriname acoupa weakfish (Cynoscion acoupa) and corvina (Cynoscion virescens) driftnet and trawling Fisheries Improvement Project – Update to the Action Plan. https://cedepesca.net/wp-content/uploads/2025/02/Suriname-corvina-and-acoupa-weakfish-FIP_Specific-Agreement-N3_public.pdf. Accessed on [4 July 2025].

Collins, A.B., Heupel, M.R. & Simpfendorfer, C.A. (2008). Spatial Distribution and Long-term Movement Patterns of Cownose Rays Rhinoptera bonasus Within an Estuarine River. Estuaries and Coasts 31, 1174–1183. https://doi.org/10.1007/s12237-008-9100-5

Cox T.M., Lewison R.L., Sydelis R., Crowder L.B., Safina C., Read A.J. (2007). Comparing effectiveness of experimental and implemented bycatch reduction measures: The ideal and the real. Conserv Biol 21:1155–1164

Davies, R. W. D., Cripps, S. J., Nickson, A., and Porter, G. (2009). Defining and estimating global marine fisheries bycatch. *Marine Policy, 33*(4), 661–672. https://doi.org/10.1016/j.marpol.2009.01.003

De Getrouwe, T. (2018). A detailed analysis of the catch composition of the finfish trawl fishery in Suriname [Unpublished data]. Anton de Kom Universiteit van Suriname, Institute for Graduate Studies and Research.

Ebert, D.A., Fowler, S. and Compagno, L. (2013). Sharks of the World. Wild Nature Press, Plymouth.

Ellis, N., and Wang, Y-G. 2007. Effects of fish density distribution and effort distribution on catchability – ICES Journal of Marine Science, 64, 178–191.

Emery, T. J., Noriega, R., Williams, A. J., & Larcombe, J. (2019). Changes in logbook reporting by commercial fishers following the implementation of electronic monitoring in Australian Commonwealth fisheries. Marine Policy, 104, 135-145. https://doi.org/10.1016/j.marpol.2019.01.018

Dulvy, N. K., Sadovy, Y., & Reynolds, J. D. (2003). Extinction vulnerability in marine populations. *Fish and Fisheries, 4*(1), 25–64. https://doi.org/10.1046/j.1467-2979.2003.00105.x

FAO. (2021). Fishing operations. Guidelines to prevent and reduce bycatch of marine mammals in capture fisheries. FAO Technical Guidelines for Responsible Fisheries No.1, Suppl. 4. Rome. https://doi.org/10.4060/cb2887en

Ferreira JA, Alberts JA, Smith G, Bernard ATF, Pereira MJ, De Vos L. (2023) Seasonal changes characterise the shark and ray assemblages in a subtropical shallow sandy habitat in the iSimangaliso Wetland Park, South Africa. PeerJ. 2023 Jul 14;11:e15636. doi: 10.7717/peerj.15636. PMID: 37465155;
PMCID: PMC10351505.

Fishery Progress. (2024). Suriname corvina and acoupa weakfish – driftnet and trawl FIP. Fishery Improvement Project. https://cedepesca.net/prome/suriname-corvina-and-acoupa-weakfish-driftnet-and-trawl-fip/ Accessed on [4 July 2025].

Furqan, R., & Schlüter, A. (2024). Fishing logbook as stewardship action within turf management in Kepulauan Seribu Marine National Park, Indonesia. Ocean & Coastal Management, 252, 107114. https://doi.org/10.1016/j.ocecoaman.2024.107114

García, C.B. (2017). What do we know about soft-bottom elasmobranch species richness in the Colombian Caribbean and of its spatial distribution? Regional Studies in Marine Science 9: 62–68.

Garstin, A. and Oxenford, H. A. (2018). Reducing Elasmobranch Bycatch in the Atlantic Seabob (Xiphopenaeus kroyeri) Trawl Fishery of Guyana. Gulf and Caribbean Research 29 (1): GCFI 10-GCFI 20. https://aquila.usm.edu/gcr/vol29/iss1/4

Graf, L. G., Dalby, O., Whitmarsh, S., Ierodiaconou, D., & Young, M. A. (2025). Assessing the current and projected distributions of temperate sharks and rays in southeastern Australia. Regional Studies in Marine Science, 74, 104418. https://doi.org/10.1016/j.rsma.2025.104418

Gray, C.A and Kennelly, S.J. (2018). Bycatches of endangered, threatened and protected species in marine fisheries. Reviews in Fish Biology and Fisheries, 28(3): 521–541. https://doi.org/10.1007/s11160-018-9520-7

Heileman,S. 2008. North Brazil Shelf LME. pp. 701-710. in: K.Sherman, G.Hempel (Eds.), The UNEP Large Marine Ecosystems Report: A Perspective on Changing Conditions in LMEs of the World's Regional Seas., United Nations Environment Programme., United Nations Environment Programme.,
pp. 701-710.

Hellweger,F.L., andA.L.Gordon. 2002. Tracing Amazon River water into the Caribbean Sea. Journal of Marine Research 60:537-549.

Hopkins, T.E., Cech, J.J. (2003). The Influence of Environmental Variables on the Distribution and Abundance of Three Elasmobranchs in Tomales Bay, California. Environmental Biology of Fishes 66, 279–291. https://doi.org/10.1023/A:1023907121605

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. Fisheries Research, 269, 106860. https://doi.org/10.1016/j.fishres.2023.106860

Huang, C., Rice, J., Richter, A., and Zhou, K. (2024). Effects of fishery bycatch-mitigation measures on vulnerable marine fauna and target catch. *Nature Sustainability, 7*(11), 1535–1545. https://doi.org/10.1038/s41893-024-01422-7

Isaac, V. J., & Ferrari, S. F. (2017). Assessment and management of the North Brazil Shelf Large Marine Ecosystem. Environmental Development, 22, 97–110. https://doi.org/10.1016/j.envdev.2016.11.004

IUCN. (2025). The IUCN Red List of Threatened Species. Version 2025-1. https://www.iucnredlist.org. Accessed on [4 July 2025].

Johns,W.E., T.N.Lee, R.C.Beardsley, J.Candela, R.Limeburner, and B.Castro. 1998. Annual cycle and variability of the North Brazil Current. Journal of Physical Oceanography 28:103-128.

Kalpoe, N., & Willems, T. (2025). On-board observer program in the Suriname demersal finfish trawl fishery: Preliminary report – June 2025 [Unpublished data]. Suriname Fisheries Department.

Kennelly, S. J. (1995). The issue of by-catch in Australia's demersal trawl fisheries. *Reviews in Fish Biology and Fisheries, 5 (2), 213-234. https://doi.org/10.1007/BF00043001

Kerstetter D.W., Graves J.E. (2006) Effects of circle versus J-style hooks on target and non-target species in a pelagic longline fishery. Fish Res 80:239–25

Last, P., White, W., de Carvalho, M., Séret, B., Stehmann, M. and Naylor, G. 2016. Rays of the World. CSIRO Publishing, Clayton.

Lowe-McConnell,R.H. 1962. The fishes of the British Guiana continental shelf, Atlantic coast of South America, with notes on their natural history. Zoological Journal of the Linnean Society 44:669-700.

LVV. (2021). Fisheries management plan for Suriname 2021 – 2025 (Part A, B and C). Fisheries Department, Ministry of Agriculture, Animal Husbandry and Fisheries. March 2021. https://fisheryprogress.org/sites/default/files/indicators-documents/Fisheries%20Management%20Plan%20Suriname%202021-2025_v1_March-2021_%28Google%20translation%20into%20ENG%29_0.pdf

LVV. (2023). Observer protocol for fish trawl fisheries in Suriname [Unpublished internal document]. Fisheries Department, Ministry of Agriculture, Animal Husbandry and Fisheries.

LVV. (2024). Decision No. 253/24, establishing the number of fishing permits, fishing permit conditions, and the amount of fishing permit fees for the 2024 financial year. Official Gazette of the Republic of Suriname. Accessed on [4 July 2025].

Merrifield, M., Gleason, M., Bellquist, L., Kauer, K., Oberhof, D., Burt, C., Reinecke, S., & Bell, M. (2019). eCatch: Enabling collaborative fisheries management with technology. Ecological Informatics, 52 , 82-93. https://doi.org/10.1016/j.ecoinf.2019.05.010

Moilanen, A., Wilson, K. A., & Possingham, H. P. (Eds.). (2009). Spatial conservation prioritization: Quantitative methods and computational tools. Oxford University Press. https://doi.org/10.1093/oso/9780199547760.001.0001

Moore, J. E., Cox, T. M., Lewison, R. L., Read, A. J., Bjorkland, R., McDonald, S. L., Crowder, L. B., Aruna, E., Ayissi, I., Espeut, P., Joynson-Hicks, C., Pilcher, N., Poonian, C. N. S., Solarin, B., & Kiszka, J. (2010). An interview-based approach to assess marine mammal and sea turtle captures in artisanal fisheries. Biological Conservation, 143 (3), 795-805. https://doi.org/10.1016/j.biocon.2009.12.023

Moore, J. E., Heinemann, D., Francis, T. B., Hammond, P. S., Long, K. J., Punt, A. E., Reeves, R. R., Sepúlveda, M., Sigurðsson, G. M., Siple, M. C., Víkingsson, G. A., Wade, P. R., Williams, R., and Zerbini, A. N. (2021). Estimating bycatch mortality for marine mammals: Concepts and best practices. *Frontiers in Marine Science*, *8*, 752356. https://doi.org/10.3389/fmars.2021.752356

Murray, K.T., Read, A.J. and Solow, A.R. (2000). The use of time/area closures to reduce bycatch of harbour porpoises: lessons from the Gulf of Maine sink gillnet fishery. Journal of Cetacean Research and Management, 2(2): 135–141. https://doi.org/10.47536/jcrm.v2i2.497

Oliver, S., Braccini, M., Newman, S. J., and Harvey, E. S. (2015). Global patterns in the bycatch of sharks and rays. Marine Policy, 54, 86–97. https://doi.org/10.1016/j.marpol.2014.12.017

Pérez Roda, M.A. (ed.), Gilman, E., Huntington, T., Kennelly, S.J., Suuronen, P., Chaloupka, M. and Medley, P. (2019). A third assessment of global marine fisheries discards. FAO Fisheries and Aquaculture Technical Paper No. 633. Rome, FAO. 78 pp. Licence: CC BY-NC-SA 3.0 IGO.

Piasente, M., Stanley, B., Timmiss, T., McElderry, H., Pria, M., & Dyas, M. (2012). Electronic onboard monitoring pilot project for the Eastern Tuna and Billfish Fishery (FRDC Project 2009/048). Australian Fisheries Management Authority.

Pollom, R., Charvet, P., Faria, V., Herman, K., Lasso-Alcalá, O., Marcante, F., Nunes, J. & Rincon, G. 2020. Fontitrygon geijskesi. The IUCN Red List of Threatened Species 2020: e.T60153A104172152. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T60153A104172152.en. Accessed on 13 August 2025.

Rañada, M. 2025. Modern tools for fishers' self-reporting: How smartphone biodiversity observations of rare species can make a conservation difference in the Corvina and Acoupa weakfish trawl fishery in Suriname [Unpublished data]

Read, A. J., Drinker, P. and Northridge, S. (2006). Bycatch of marine mammals in U.S. and global fisheries. Conserv. Biol. 20, 163–169. DOI: 10.1111/j.1523-1739.2006.00338.x

Roskar, G., Morley, J. W., & Buckel, J. A. (2024). Seasonality and relative abundance within an elasmobranch assemblage near a major biogeographic divide. PLOS ONE, 19(6), e0300697. https://doi.org/10.1371/journal.pone.0300697

Sacchi, J. (2021). Overview of mitigation measures to reduce the incidental catch of vulnerable species in fisheries. Studies and Reviews No. 100 (General Fisheries Commission for the Mediterranean). Rome, FAO. https://doi.org/10.4060/cb5049en

Schlaff, A. M., Heupel, M. R., & Simpfendorfer, C. A. (2014). Influence of environmental factors on shark and ray movement, behaviour and habitat use: A review. Reviews in Fish Biology and Fisheries, 24(4), 1089–1103. https://doi.org/10.1007/s11160-014-9364-8

Senko, J. F., & Nalovic, M. A. (2021). Addressing sea turtle bycatch in developing countries: A global challenge that requires adaptive solutions for the 21st century. In K. L. Eckert, L. Sarti Martínez, A. B. Meylan, & B. P. Wallace (Eds.), *Sea turtle research and conservation: Lessons from working in the field* (pp. 151–165). Academic Press. https://doi.org/10.1016/B978-0-12-821029-1.00016-7

Slooten, E. (2013). Effectiveness of area-based management in reducing bycatch of the New Zealand dolphin. Endangered Species Research, 20: 121–130. doi: 10.3354/esr00483

Smith, J. A., Tommasi, D., Welch, H., Hazen, E. L., Sweeney, J., Brodie, S., Muhling, B., Stohs, S. M., and Jacox, M. G. (2021). Comparing dynamic and static time-area closures for bycatch mitigation: A management strategy evaluation of a swordfish fishery. Frontiers in Marine Science, 8, 630607. https://doi.org/10.3389/fmars.2021.630607

Soykan, C., Moore, J. E., Žydelis, R., and Crowder, L. B. (2008). Why study bycatch? An introduction to the Theme Section on fisheries bycatch. Endangered Species Research, 5(2), 91–102. https://doi.org/10.3354/esr00175

Spalding,M.D., H.E.Fox, B.S.Halpern, M.A.McManus, J.Molnar, G.R.Allen, N.Davidson, Z.A.Jorge, A.L.Lombana, S.A.Lourie, K.D.Martin, E.McManus, J.Molnar, C.A.Recchia, and J.Robertson. 2007. Marine ecoregions of the world: A bioregionalization of coastal and shelf areas. Bioscience 57:573-583.

Sys, K. (2019). Sea turtle bycatch assessment in the artisanal fisheries of Suriname [Conference presentation]. WIDECAST Annual General Meeting, Paramaribo, Suriname. https://www.widecast.org/What/AnnualMeeting/2019/2019%20Sys,%20Bycatch%20Assessment%20of%20Artisanal%20Fisheries%20in%20Suriname.pdf Accessed on [4 July 2025].

Van Beest, F.M., Kindt-Larsen, L., Bastardie, F., Bartolino, V. and Nabe-Nielsen, J. (2017). Predicting the population-level impact of mitigating harbor porpoise bycatch with pingers and time-area fishing closures. Ecosphere, 8(4): e 01785 [online]. https://doi.org/10.1002/ecs2.1785

Wakefield, C. B., Hesp, S. A., Blight, S., Molony, B. W., Newman, S. J., and Hall, N. G. (2018). Uncertainty associated with total bycatch estimates for rarely-encountered species varies substantially with observer coverage levels: Informing minimum requirements for statutory logbook validation. Marine Policy, 95, 273–282. https://doi.org/10.1016/j.marpol.2018.05.018

Wallace, B.P., Lewison, R.L., McDonald, S.L., McDonald, R.K., Kot, C.Y., Kelez, S., Bjorkland, R.K., Finkbeiner, E.M., Helmbrecht, S. & Crowder, L.B. (2010). Global patterns of marine turtle bycatch. Conservation Letters, 3(3), 131–142. https://doi.org/10.1111/j.1755-263X.2010.00105.x

Walters, C. 2003. Folly and fantasy in the analysis of spatial catch rate data. Canadian Journal of Fisheries and Aquatic Sciences. 60(12): 1433-1436. https://doi.org/10.1139/f03-152

Weigmann, S. 2016. Annotated checklist of the living sharks, batoids and chimaeras (Chondrichthyes) of the world, with a focus on biogeographical diversity. Journal of Fish Biology 88(3): 837-1037.

White, W.T., Baje, L., Simpfendorfer, C.A., Appleyard, S.A., Chin, A., Sabub, B., Rochel, E., and Naylor, G.J.P. (2019). Elasmobranch bycatch in the demersal prawn trawl fishery in the Gulf of Papua, Papua New Guinea. Sci Rep 9, 9254. https://doi.org/10.1038/s41598-019-45715-w

Willems, T., De Backer, A., Wan Tong You, K., Vincx, M., & Hostens, K. (2015a). Spatio-temporal distribution patterns of the epibenthic community in the coastal waters of Suriname. Continental Shelf Research, 108, 25–40. https://doi.org/10.1016/j.csr.2015.08.006

Willems, T., De Backer, A., Mol, J. H., Vincx, M., & Hostens, K. (2015b). Distribution patterns of the demersal fish fauna on the inner continental shelf of Suriname. Regional Studies in Marine Science, 2, 177–188. https://doi.org/10.1016/j.rsma.2015.10.008

Willems, T., Depestele, J., De Backer, A., and Hostens, K. (2016). Ray bycatch in a tropical shrimp fishery: Do Bycatch Reduction Devices and Turtle Excluder Devices effectively exclude rays? Fisheries Research, 175, 35–42. https://doi.org/10.1016/j.fishres.2015.11.009

Wilson, K. A., McBride, M. F., Bode, M., & Possingham, H. P. (2006). Prioritizing global conservation efforts. Nature, 440(7082), 337–340. https://doi.org/10.1038/nature04366

Worm, B., Davis, B., Kettemer, L., Ward-Paige, C. A., Chapman, D., Heithaus, M. R., Kessel, S. T., &

Gruber, S. H. (2013). Global catches, exploitation rates, and rebuilding options for sharks. Marine Policy, 40, 194–204. https://doi.org/10.1016/j.marpol.2012.12.034

Yokota, L., & Lessa, R. P. (2006). A nursery area for sharks and rays in Northeastern Brazil. Environmental Biology of Fishes, 75(3), 349–360. https://doi.org/10.1007/s10641-006-0038-9

Zhu, W., Lu, Z., Dai, Q., Lu, K., Li, Z., Zhou, Y., Zhang, Y., Sun, M., Li, Y., & Li, W. (2021). Transition to timely and accurate reporting: An evaluation of monitoring programs for China's first total allowable catch (TAC) pilot fishery. Marine Policy, 129 , 104503. https://doi.org/10.1016/j.marpol.2021.104503

Żydelis, R., Small, C. & French, G.(2013) The incidental catch of seabirds in gillnet fisheries: a global review. Biol. Conserv. 162, 76–88 . https://doi.org/10.1016/j.biocon.2013.04.002

Appendices

Appendix A. List of the Endangered, Threatened, and Protected (ETP) species bycaught from trawl fishing in Suriname as recorded by the observer programme from May 2023 – February 2025.

FAO Code	**Common Name**	**Scientific Name**	**Species Group**	**Total Count**
RDU	Longnose stingray	*Hypanus guttatus*	Batoid Fish	6073
CTJ	Smalleye smooth-hound	*Mustelus higmani*	Shark	5310
MRB	Cownose ray	*Rhinoptera bonasus*	Batoid Fish	2267
RHL	Brazilian sharpnose shark	*Rhizoprionodon lalandii*	Shark	1890
RHR	Caribbean sharpnose shark	*Rhizoprionodon porosus*	Shark	1101
RDJ	Wingfin stingray	*Fontitrygon geijskesi*	Batoid Fish	977
GUD	Chola guitarfish	*Pseudobatos percellens*	Batoid Fish	674
RGI	Smooth butterfly ray	*Gymnura micrura*	Batoid Fish	654
CCL	Blacktip shark	*Carcharhinus limbatus*	Shark	139
CCR	Smalltail shark	*Carcharhinus porosus*	Shark	85
CCN	Blacknose shark	*Carcharhinus acronotus*	Shark	66
TZB	Caribbean Electric Ray	*Narcine bancroftii*	Batoid Fish	38
SPL	Scalloped hammerhead	*Sphyrna lewini*	Shark	33
RMB	Giant manta ray	*Mobula birostris*	Batoid Fish	18

JUM	Smalleyed round stingray	*Urotrygon microphthalmum*	Batoid Fish	15
LKV	Olive Ridley	*Lepidochelys olivacea*	Sea Turtle	11
SPE	Scoophead shark	*Sphyrna media*	Shark	9
GNC	Nurse shark	*Ginglymostoma cirratum*	Shark	8
DHH	Chupare stingray	*Styracura schmardae*	Batoid Fish	8
TUG	Green Turtle	*Chelonia mydas*	Sea Turtle	5
FHJ	Southern stingray	*Hypanus americanus*	Batoid Fish	5
TIG	Tiger Shark	*Galeocerdo cuvier*	Shark	4
MAE	Spotted eagle ray	*Aetobatus narinari*	Batoid Fish	3
CCV	Caribbean Reef Shark	*Carcharhinus perezi*	Shark	2
TTL	Loggerhead Turtle	*Caretta caretta*	Sea Turtle	2
SPK	Great hammerhead	*Sphyrna mokarran*	Shark	2
CCB	Spinner Shark	*Carcharhinus brevipinna*	Shark	1
DUS	Dusky shark	*Carcharhinus obscurus*	Shark	1
RTD	Rough-toothed Dolphin	*Steno bredanensis*	Marine mammal	1

Appendix B. Summary table of the packages used in R Studio for data analysis.

R Packages	**Function**	**Citation**
boot	Provides functions for nonparametric bootstrapping, including confidence intervals for statistics like the mean.	Canty, A., Ripley, B., & Brazzale, A. R. (2024). boot: Bootstrap functions (originally by Angelo Canty for S) (Version 1.3-31) [R package]. https://doi.org/10.32614/CRAN.package.boot
dplyr	Data manipulation for filtering, grouping, summarizing, mutating, and joining datasets.	Wickham H, François R, Henry L, Müller K, Vaughan D (2025). dplyr: A Grammar of Data Manipulation. R package version 1.1.4, https://dplyr.tidyverse.org.
ggplot2	Visualizing spatial and non-spatial data	H. Wickham. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York, 2016.
lubridate	Handling date-time operations (month(), year(), tz())	Garrett Grolemund, Hadley Wickham (2011). Dates and Times Made Easy with lubridate. Journal of Statistical Software, 40(3), 1-25.

		URL https://www.jstatsoft.org/v40/i03/.
nortest	To assess the distribution of dataset using the Lilliefors test	Gross, J., & Ligges, U. (2015). nortest: Tests for Normality. R package version 1.0-4. https://CRAN.R-project.org/package=nortest Lilliefors, H. W. (1967). On the Kolmogorov–Smirnov test for normality with mean and variance unknown. Journal of the American Statistical Association, 62(318), 399–402. https://doi.org/10.2307/2283970
readxl	Reading Excel sheets	Wickham H, Bryan J (2025). readxl: Read Excel Files. R package version 1.4.5, https://github.com/tidyverse/readxl, https://readxl.tidyverse.org.
rcompanion	Effect size calculation after Kruskal–Wallis tests	Mangiafico, S. S. (2024). rcompanion: Functions to Support Extension Education Program Evaluation. R package version 2.4.35. https://CRAN.R-project.org/package=rcompanion
sf	Spatial data operations (bounding box, projections, grids, spatial joins)	Pebesma, E., & Bivand, R. (2023). Spatial Data Science: With Applications in R. Chapman and Hall/CRC. https://doi.org/10.1201/9780429459016 Pebesma, E., 2018. Simple Features for R: Standardized Support for Spatial Vector Data. The R Journal 10 (1), 439-446, https://doi.org/10.32614/RJ-2018-009
stringr	String manipulation for formatting labels and IDs.	Wickham, H., & Posit Software, PBC. (2023). stringr: Simple, consistent wrappers for common string operations (Version 1.5.1) [R package]. https://CRAN.R-project.org/package=stringr
tidyr	Handling missing data and reshaping data frames.	Wickham H, Vaughan D, Girlich M (2025). tidyr: Tidy Messy Data. R package version 1.3.1, https://tidyr.tidyverse.org.

Appendix C. Results of the Kruskal–Wallis tests and epsilon squared effect sizes for spatial variation in BPUE across grid cells for the five most observed endangered, threatened, and protected species. Significant variation indicates differences in mean BPUE across spatial locations. Effect sizes (ε^2) are interpreted as: weak (< 0.06), moderate (0.06–0.14), and strong (> 0.14).

Species Code	Chi-squared (χ^2)	p-value	Epsilon squared (ε^2)	Strength
MRB	58.53	0.00017	0.523	Strongest
RHL	65.93	0.00083	0.485	Very Strong
CTJ	130.37	<0.001	0.464	Very Strong
RHR	53.73	0.00687	0.444	Very Strong
RDU	124.47	<0.001	0.366	Strong

Appendix D. Results of the Kruskal–Wallis tests and epsilon squared effect sizes for temporal variation in BPUE across quarters for the five most observed endangered, threatened, and protected species. Significant variation indicates differences in mean BPUE across quarterly periods. Effect sizes (ε^2) are interpreted as: weak (< 0.06), moderate (0.06–0.14), and strong (> 0.14).

Species Code	Chi-squared (χ^2)	p-value	Epsilon squared (ε^2)	Strength
CTJ	65.811	3.36e-14	0.234	Strong
RDU	48.246	1.89e-10	0.142	Moderate
RHR	13.894	0.00305	0.115	Moderate
RHL	13.841	0.00313	0.102	Moderate
MRB	5.4582	0.1412	0.049	Weak/Not Significant

Appendix E. Spatial variation in the scaled up bycatch estimates (observer x VMS effort) with 95% confidence intervals for the combined most frequently caught endangered, threatened, and protected species.

Grid ID	Bycatch Estimate *(ind)*	Lower 95% CI	Upper 95% CI
Grid_1	808	157	1244
Grid_10	0	0	0
Grid_18	0	0	0
Grid_19	0	0	0
Grid_2	11360	9422	13541
Grid_22	658	508	810
Grid_23	0	0	0
Grid_24	3576	2238	4932
Grid_25	319	288	338
Grid_26	1390	934	1849
Grid_27	0	0	0
Grid_28	0	0	0
Grid_29	8755	5313	13641
Grid_3	16106	13357	18853
Grid_30	15654	10794	20493
Grid_31	29349	22115	36674
Grid_32	10066	5296	14930
Grid_33	2095	1748	2450
Grid_34	8621	6498	11039
Grid_35	14228	11252	17448
Grid_36	10108	6812	13921

Grid_37	6198	3798	9253
Grid_38	1524	634	2436
Grid_39	13150	9995	16418
Grid_4	0	0	0
Grid_40	7195	5930	8486
Grid_44	734	699	753
Grid_48	0	0	0
Grid_49	1142	553	1727
Grid_5	41522	34446	49155
Grid_51	754	383	1311
Grid_52	1511	1234	1652
Grid_53	2044	1861	2229
Grid_54	1844	1335	2379
Grid_55	2356	1541	3233
Grid_56	2758	2137	3455
Grid_57	0	0	0
Grid_58	1294	728	1853
Grid_59	2092	1786	2362
Grid_6	0	0	0
Grid_60	0	0	0
Grid_67	0	0	0
Grid_69	0	0	0
Grid_7	4227	2986	5420
Grid_73	2738	2528	2931
Grid_74	4081	2546	5605

Grid_75	6820	4571	9292
Grid_76	0	0	0
Grid_77	4667	2367	7489
Grid_78	0	0	0
Grid_79	0	0	0
Grid_9	0	0	0
Grid_94	0	0	0

Appendix F. Quarterly variation in the scaled up bycatch estimates (observer x VMS effort) with 95% confidence intervals for the top 5 endangered, threatened, and protected species.

Quarter	Species Code	Bycatch Estimate *(ind)*	Lower 95% CI	Upper 95% CI
Q1	CTJ	12018	10726	13411
Q1	MRB	3103	2251	3998
Q1	RDU	16543	12547	20444
Q1	RHL	2676	2015	3379
Q1	RHR	1289	879	1703
Q2	CTJ	19658	15182	24037
Q2	MRB	1059	597	1520
Q2	RDU	11717	8535	16504
Q2	RHL	5445	3639	7422
Q2	RHR	3287	2225	4453
Q3	CTJ	44620	39016	50540
Q3	MRB	16189	8050	24384
Q3	RDU	29945	24736	35393

Q3	RHL	12453	8684	16476
Q3	RHR	4954	3253	6664
Q4	CTJ	7006	4437	9320
Q4	MRB	16136	13051	19528
Q4	RDU	14920	11344	19053
Q4	RHL	11147	7761	14860
Q4	RHR	7581	5817	9610

Appendix G. Spatial variation in the observer-derived BPUE with 95% confidence intervals for the combined five most frequently observed endangered, threatened, and protected species.

Grid ID	Mean BPUE *(ind/hr)*	Lower 95% CI	Upper 95% CI
Grid_1	2.09	0.49	4.13
Grid_2	7.32	5.51	9.37
Grid_3	8.73	4.78	13.31
Grid_4	5.09	0.61	9.69
Grid_5	7.77	6.60	8.99
Grid_6	5.85	1.65	10.36
Grid_7	4.79	2.75	7.43
Grid_8	0.00	0.00	0.00
Grid_9	2.32	1.56	3.03
Grid_10	9.83	3.20	16.40
Grid_11	0.00	0.00	0.00
Grid_12	0.00	0.00	0.00
Grid_13	0.00	0.00	0.00

Grid_14	0.00	0.00	0.00
Grid_15	0.00	0.00	0.00
Grid_16	0.00	0.00	0.00
Grid_17	0.00	0.00	0.00
Grid_18	2.15	0.32	4.22
Grid_19	2.01	1.00	3.00
Grid_20	0.00	0.00	0.00
Grid_21	0.00	0.00	0.00
Grid_22	5.22	3.90	6.51
Grid_23	14.15	1.74	26.16
Grid_24	4.33	2.57	7.04
Grid_25	3.49	1.39	6.37
Grid_26	3.14	1.91	5.03
Grid_27	12.57	9.60	15.60
Grid_28	6.59	2.00	12.84
Grid_29	7.57	4.45	11.01
Grid_30	13.03	7.54	19.30
Grid_31	8.56	5.47	12.09
Grid_32	8.63	5.45	12.26
Grid_33	3.64	1.31	6.99
Grid_34	2.05	1.53	2.66
Grid_35	2.66	2.16	3.22
Grid_36	2.86	1.94	3.92
Grid_37	4.35	2.62	6.53
Grid_38	4.12	2.48	5.91

Grid_39	7.54	5.12	10.33
Grid_40	7.42	5.68	9.31
Grid_41	0.00	0.00	0.00
Grid_42	0.00	0.00	0.00
Grid_43	0.00	0.00	0.00
Grid_44	4.14	1.86	7.35
Grid_45	0.00	0.00	0.00
Grid_46	0.00	0.00	0.00
Grid_47	0.00	0.00	0.00
Grid_48	6.00	4.09	7.82
Grid_49	9.63	1.06	20.82
Grid_50	0.00	0.00	0.00
Grid_51	2.91	1.53	5.04
Grid_52	3.47	1.93	5.06
Grid_53	4.54	2.49	6.93
Grid_54	2.12	1.60	2.72
Grid_55	2.88	2.14	3.72
Grid_56	3.48	2.37	4.65
Grid_57	1.35	0.34	2.71
Grid_58	5.74	2.67	9.71
Grid_59	9.94	6.28	13.15
Grid_60	1.34	1.00	1.67
Grid_61	0.00	0.00	0.00
Grid_62	0.00	0.00	0.00
Grid_63	0.00	0.00	0.00

Grid_64	0.00	0.00	0.00
Grid_65	0.00	0.00	0.00
Grid_66	0.00	0.00	0.00
Grid_67	4.99	3.33	6.67
Grid_68	0.00	0.00	0.00
Grid_69	1.25	0.31	2.19
Grid_70	0.00	0.00	0.00
Grid_71	0.00	0.00	0.00
Grid_72	0.00	0.00	0.00
Grid_73	7.76	3.63	11.79
Grid_74	8.75	3.98	13.94
Grid_75	2.45	1.56	3.47
Grid_76	14.08	1.26	26.84
Grid_77	5.87	2.94	9.59
Grid_78	10.29	0.67	28.00
Grid_79	2.16	1.33	3.00
Grid_80	0.00	0.00	0.00
Grid_81	0.00	0.00	0.00
Grid_82	0.00	0.00	0.00
Grid_83	0.00	0.00	0.00
Grid_84	0.00	0.00	0.00
Grid_85	0.00	0.00	0.00
Grid_86	0.00	0.00	0.00
Grid_87	0.00	0.00	0.00
Grid_88	0.00	0.00	0.00

Grid_89	0.00	0.00	0.00
Grid_90	0.00	0.00	0.00
Grid_91	0.00	0.00	0.00
Grid_92	0.00	0.00	0.00
Grid_93	0.00	0.00	0.00
Grid_94	5.60	2.64	8.57
Grid_95	0.00	0.00	0.00
Grid_96	0.00	0.00	0.00
Grid_97	0.00	0.00	0.00
Grid_98	0.00	0.00	0.00
Grid_99	0.00	0.00	0.00
Grid_100	0.00	0.00	0.00

Appendix H. Quarterly variation in observed mean BPUE with 95% confidence intervals for the five most frequently captured endangered, threatened, and protected species.

Quarter	Species Code	Mean BPUE *(ind/hr)*	Lower 95% CI	Upper 95% CI
Q1	CTJ	9.13	6.88	11.51
Q2	CTJ	3.61	3.12	4.17
Q3	CTJ	9.95	8.30	11.69
Q4	CTJ	4.36	1.65	7.52
Q1	MRB	5.07	3.19	7.20
Q2	MRB	3.60	1.90	5.55
Q3	MRB	12.04	6.60	18.03
Q4	MRB	5.11	3.68	6.80

Q1	RDU	8.11	6.32	9.98
Q2	RDU	3.05	2.25	4.04
Q3	RDU	7.71	6.17	9.34
Q4	RDU	6.01	4.32	7.84
Q1	RHL	3.87	2.47	5.46
Q2	RHL	2.07	1.54	2.69
Q3	RHL	4.81	3.31	6.66
Q4	RHL	6.11	3.65	9.10
Q1	RHR	2.58	1.69	3.68
Q2	RHR	1.80	1.16	2.56
Q3	RHR	4.38	2.72	6.22
Q4	RHR	2.58	2.00	3.26

Appendix I. Species-Specific Analysis and Management Priorities

Due to time constraints, the study focused on the five most frequently caught ETP species for further analysis. These species showed distinct patterns in abundance, spatial distribution, and temporal variation, which informed different management approaches.

Mustelus higmani **(CTJ) - Highest Priority:** Listed as 'Endangered', *M. higmani* was identified from the observer dataset as the species of critical concern requiring the highest priority for bycatch reduction. Despite being the second most abundant species in the observer data (5,310 individuals), it showed the highest observed mean BPUE at 5.96 individuals per hour (95% CI = 5.30 - 6.73) and the widest spatial distribution (50 grid cells). The spatial variation in BPUE was highly significant and accompanied by a large effect size ($p < 0.001$, $\varepsilon^2 = 0.46$). It exhibited the most pronounced temporal variation, with a sharp decline from Q1 (9.13 ind/hr) to Q2 (3.61 ind/hr), peaking again in Q3 (9.95 ind/hr) before declining in Q4 (4.36 ind/hr). This pattern was also highly significant temporally ($p < 0.001$) and had the strongest temporal effect ($\varepsilon^2 = 0.234$). When scaled to fleet-wide estimates, *M. higmani* showed the highest estimated bycatch of 83,302 individuals (95% CI: 75,487 - 91,295) for the year 2023, along with the most extreme temporal variation, with Q3 estimates reaching 44,620 individuals. It also exhibited distinct spatial clustering, with high bycatch in grid cells 3, 5, 30, and 31 (8,100 to 10,398 individuals). Given its endangered status, high bycatch rates, and wide distribution, broad-scale management strategies such as gear modifications and seasonal closures during Q1 and Q3 peaks in high bycatch grid cells 3, 5, 30, and 31 could be considered to mitigate bycatch of *M. higmani.*

Hypanus guttatus **(RDU) - Second Priority:** The most abundant species in the bycatch from the observer dataset (6,073 individuals), *H. guttatus* showed a mean BPUE of 5.57 individuals per hour (95% CI = 4.90 - 6.35) across 49 grid cells. It exhibited strong spatial variation ($\varepsilon^2 = 0.366$, $p < 0.001$) and moderate temporal variation ($\varepsilon^2 = 0.142$, $p < 0.001$). The species followed a similar seasonal pattern to *M. higmani*, with peaks in Q1 (8.11 ind/hr) and Q3 (7.71 ind/hr), and lower rates in Q2 (3.05 ind/hr) and Q4 (6.01 ind/hr). Fleet-wide scaling estimated a total bycatch of 73,125 individuals (95% CI: 64,513 - 82,043) with moderate spatial aggregation in grid cells 3, 5, 31, and 39 (7,066 to 8,571 individuals) and seasonal peaks reaching 29,945 individuals in Q3. The broad distribution and high abundance suggest that broad-scale mitigation strategies, particularly gear modifications and seasonal restrictions during peak periods (Q1 and Q3) in grid cells 3, 5, 31, and 39, would be ideal.

Rhinoptera bonasus **(MRB) - Localized Management Candidate:** With 2,267 individuals captured based on the observer dataset, *R. bonasus* showed a mean BPUE of 5.76 individuals per hour (95% CI = 4.64 - 7.23) but was restricted to only 26 grid cells, indicating the most limited spatial coverage among the five species. Despite this restricted range, it exhibited the strongest spatial variation ($\varepsilon^2 = 0.52$, $p < 0.001$) but weak temporal variation ($\varepsilon^2 = 0.049$, $p = 0.141$, not significant). The species showed a dramatic Q3 peak (12.04 ind/hr) and wide confidence intervals, suggesting high variability. With 36,487 individuals (95% CI = 27,556 - 45,733) of fleet-wide bycatch estimate, *R. bonasus* showed a relatively sparse and scattered spatial pattern with highest concentrations in grid cells 5 and 31 (10,115 and 10,471 individuals, respectively). Moderate seasonal variation (1,059 - 16,189 individuals) was observed with highest estimates in Q3-Q4. The restricted spatial coverage but intense hotspots within preferred habitats make *R. bonasus* an excellent candidate for localized management interventions, such as spatial closures or effort reduction in specific high-risk zones (grid cells 5 and 31).

Rhizoprionodon lalandii **(RHL) - Moderate-Risk Species:** Based on the observer data, *R. lalandii* was captured in moderate numbers (1,890 individuals) with a mean BPUE of 4.07 individuals per hour (95% CI = 3.32 - 5.19) across 35 grid cells. It showed very strong spatial variation ($\varepsilon^2 = 0.49$, $p < 0.001$) and moderate temporal variation ($\varepsilon^2 = 0.102$, $p = 0.003$). Similar to the other five species, *R. lalandii* showed a slight dip in Q2 which is also the lowest bycatch rate recorded (2.07 ind/hr) then increases through Q3-Q4 (4.81-6.11 ind/hr). Fleet-wide estimates revealed a total bycatch of 25,807 individuals (95% CI = 20,784 - 31,145), with lowest estimates of 2,676 individuals in Q1 gradually increasing to 12,453 individuals in Q3 before slightly dropping to 11,147 individuals in Q4. Spatially, the highest bycatch estimate of 7,138 individuals was found in grid cell 5. Effort reduction in grid cell 5 during Q3–Q4 is therefore recommended.

Rhizoprionodon porosus **(RHR) - Lowest Impact** The least abundant of the five species from observer dataset (1,101 individuals), *R. porosus* showed the lowest mean BPUE of 2.70 individuals per hour (95% CI = 2.24 - 3.34) across 32 grid cells. It exhibited very strong spatial variation ($\varepsilon^2 = 0.44$, $p = 0.007$) and moderate temporal variation ($\varepsilon^2 = 0.115$, $p = 0.003$). The species showed the most stable version of the general seasonal pattern, with minimal variation across quarters (1.80 - 4.38 ind/hr) and consistently narrow confidence intervals. Fleet-wide estimates, with a total bycatch of 14,111 individuals, remained consistently low across all quarters (1,289 to 7,581 individuals) and a spatially hotspot in grid cell 5 (5,549 ind). Given its lower abundance and bycatch rates, R. porosus represents the lowest management priority among the five species, though it may benefit from the other management approaches mentioned previously such as the gear modification recommended to the same small-sized shark species *M. higmani*.

Appendix J. Fishers' Self-reporting Project Summary

"Modern tools for fishers' self-reporting: How smartphone biodiversity observations of rare species can make a conservation difference in the Corvina and Acoupa weakfish trawl fishery in Suriname"

The demersal trawl fishery targeting Corvina (*Cynoscion virescens*) and Acoupa weakfish (*Cynoscion acoupa*) on Suriname's continental shelf plays a significant role in the national seafood economy. However, this fishery faces challenges in documenting its interactions with Endangered, Threatened, and Protected (ETP) species—an issue highlighted during a 2020 Marine Stewardship Council (MSC) pre-assessment. In response, this pilot project aimed to design and test a cost-effective, auditable self-sampling programme that equips fishers with digital tools to collect ETP bycatch data, improving both the geographic scope and frequency of monitoring compared to traditional observer coverage.

The work contributes directly to the Fishery Improvement Program (FIP) led by CeDePesca and supports Action Plan 3 of the FIP, which focuses on better understanding and reducing ETP species interactions. By enabling the systematic collection of GPS-referenced records of ETP encounters—including species, fate, fishing context, photo documentation—the project provides a foundation for improved bycatch monitoring and the future development of evidence-based mitigation strategies.

In close collaboration with the Suriname Fisheries Department and one of the leading trawl fishing companies operating under the FIP, the project assessed and piloted two mobile data collection platforms—MOFI and KoboToolbox. This trawling company is operating over half of the active demersal trawl fleet in the country. Following field testing and fisher consultations during a one-month visit to Suriname, KoboToolbox was selected and fully customized into a digital logbook. This tool enables captains to record fishing effort, catch, and any ETP bycatch directly onboard using mobile devices. Training and user guides were developed in partnership with local authorities, who are now leading the rollout of the system.

The project also provides a baseline for validating fisher-reported data by conducting a complementary bycatch assessment using 2023–2025 observer data. This analysis supports future comparisons and helps establish a scalable framework for fleet-wide monitoring using both self-reported and independently observed data.

By equipping fishers with user-friendly mobile tools to digitally record ETP bycatch and GPS-referenced drag data during regular fishing operations, the project has demonstrated a practical model for scalable electronic monitoring that aligns with Suriname's national bycatch reporting and sustainability objectives. It offers a promising model for engaging industry actors in sustainable practices while enhancing the fishery's preparedness for potential MSC certification.