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Research article

Assessment of horseshoe crab [*Tachypleus tridentatus* (Leach, 1819)] by catch in artisanal fish corrals of Palawan, the Philippines

Dorkas Kaiser[a], Maria Mojena G. Plasus[b,*], Sabine Schoppe[a], Benjamin J. Gonzales[c]

[a] *Katala Foundation Incorporated Casuy Road, Purok El Rancho, Barangay Santa Monica Puerto Princesa City, Palawan 5300, the Philippines*
[b] *Faculty, College of Fisheries and Natural Sciences, Western Philippines University, Puerto Princesa Campus 5300, the Philippines*
[c] *Supervising Consultant, BGERMC, Casuy Road, Purok El Rancho, Barangay Santa Monica, Puerto Princesa City, Palawan 5300, the Philippines*

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Abstract

Importance of the work: Incidental capture in small-scale fisheries is an increasingly recognized threat to marine megafauna, yet quantitative assessments remain limited in data-poor tropical regions, particularly for stationary fishing gear. This study has provided the first fishery-wide baseline estimate of horseshoe crab bycatch in artisanal fish corrals in Palawan, the Philippines.

Objectives: to provide the first fishery-wide baseline assessment of horseshoe crab [*Tachypleus tridentatus* (Leach, 1819)] bycatch in artisanal fish corrals in Palawan, the Philippines.

Materials and Methods: A full census was conducted of fishers (n = 60) from nine coastal villages in Puerto Princesa City, complemented by spatial mapping of 155 fish corrals. Interview-derived catch per unit effort (CPUE) was used to estimate annual bycatch by scaling weekly catches across reported months of operation, with median values applied where data were unavailable.

Results: The weekly bycatch was in the range 0–20 individuals/trap/wk, with median values of 2–3 individuals/trap/wk. Annual bycatch was estimated at approximately 14,300–28,600 individuals. Bycatch hotspots were concentrated in Honda Bay and Ulugan Bay. Although spawning was reported throughout the year, observations were strongly associated with periods of active trap operation, suggesting observation bias rather than distinct seasonal spawning. No respondents reported intentional killing, consumption, or sale of horseshoe crabs.

Main finding: Artisanal fish corrals exert substantial incidental bycatch pressure on horseshoe crabs, despite the absence of targeted exploitation. These findings have established the first quantitative baseline for this fishery and have identified priority areas for spatially targeted management and community-based conservation.

* Corresponding author.
E-mail address: mojena.plasus@wpu.edu.ph (M. M. G. Plasus)

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Introduction

Incidental capture in small-scale fisheries is recognized increasingly as a major but under-quantified threat to marine megafauna, particularly in tropical, data-poor regions, where monitoring is limited and the use of stationary fishing gear is widespread (Moore et al., 2010; Wallace et al., 2013; Lewison et al., 2014). While traditionally bycatch research has focused on industrial trawl, longline and gillnet operations (Lewison et al., 2004; Wallace et al., 2010), fixed the effects of nearshore gear, such as fish corrals, remains comparatively understudied, despite their extensive footprint in shallow coastal habitats (Teh et al., 2013; McClanahan et al., 2015).

Fish corrals are stationary, passive types of fishing gear that catch organisms as they move, rather than by actively pursuing them. Passive gear with extended soak times is known to increase interactions with non-target species because they remain fixed in ecologically important nearshore habitats (Lewison et al., 2004; Shester and Micheli, 2011). When deployed across shallow embayment and intertidal zones, these structures may intersect movement pathways of organisms migrating along shorelines during tidal cycles, particularly in systems where connectivity between feeding, nursery and spawning habitats is critical (Gillanders et al., 2003; Nagelkerken et al., 2015). For benthic and slow-moving species, such as horseshoe crabs, stationary gear may increase the likelihood of repeated encounters and incidental capture (Lewison et al., 2004; Wallace et al., 2010).

The tri-spine horseshoe crab [*Tachypleus tridentatus* (Leach, 1819)] is distributed widely in the Indo-West Pacific including along the coast of Palawan, the Philippines (Kaiser, 2002; Schoppe, 2002; Almendral and Schoppe, 2005; Hsieh and Chen, 2009; Wada et al., 2016; Kwan et al., 2016; Kaiser and Schoppe, 2018). Despite its recognized ecological and biomedical importance and the increasing concern regarding its conservation (Li et al., 2021; Wang et al., 2022), its population status in the Philippines remains poorly understood, particularly in relation to fishery-related pressures. Incidental capture in artisanal fisheries is likely one of the most pervasive threats, yet its magnitude, spatial distribution and seasonal dynamics in Palawan have not been quantified systematically.

In the Philippines, approximately 85% of the rural population depends on small-scale fisheries (Monteclaro et al., 2017). Stationary fish corrals (known locally as ‘baklad ’) are deployed widely in subtidal areas and are designed to intercept fish movement driven by tidal currents (Gonzales, 1997; Gonzales and Plasus, 2023; Gonzales and Gonzales, 2025). In addition, this passive setup is known to capture non-target species (Gonzales, 2018) and may entangle adult horseshoe crabs or interfere with access to spawning habitats (Kaiser and Schoppe, 2018). However, empirical estimates are unavailable of horseshoe crab bycatch associated with fish corrals in Palawan and little is known about how these interactions vary across space and time.

In data-limited fisheries, structured interviews provide a practical and cost-effective approach for generating baseline information, despite the recognized limitations such as recall bias and potential underreporting (Carruthers and Neis, 2011; Lucchetti et al., 2017; Moore et al., 2021). When combined with spatial mapping, interview-based approaches can generate fishery-wide estimates of bycatch, identify spatial hotspots and describe temporal patterns of interaction (Gavin et al., 2009; Moore et al., 2010; Lin et al., 2023; Booth et al., 2023).

Against this backdrop, the present study has provided the first fishery-wide baseline assessment of horseshoe crab bycatch associated with artisanal fish corrals in Palawan. Specifically, the study aimed: 1) to estimate the magnitude of bycatch across fish corrals as a basis for evaluating whether year-round in situ monitoring is warranted; 2) to identify spatial patterns and potential hotspots of interaction; and 3) to examine temporal patterns of reported spawning observations in relation to trap operation, with the aim of assessing potential observation bias linked to variation in detection probability.

By shifting the focus from localized observations to fishery-wide interactions with stationary fishing gear, this study was expected to provide a quantitative baseline for understanding bycatch pressure on *T. tridentatus* in Palawan. The integration of interview-derived data and spatial mapping should offer practical insights to support targeted management strategies and conservation planning for this vulnerable species.

Materials and Methods

Study area

The study was conducted along the east and west coasts of Puerto Princesa City and the municipality of Aborlan, Palawan, the Philippines (Fig. 1). The surveyed coastline spanned approximately 114 km along the east coast (10.0198°N, 119.1549°E to 9.3554°N, 118.5503°E) and 136 km along the west coast (10.3111°N, 118.9640°E to 9.5590°N, 118.2854°E).

The region experiences a tropical monsoon climate, with a rainy season from June to November and a dry season from December to May. The mean annual temperature is approximately 27°C and the mean annual rainfall is about 1,700 mm (Philippine Atmospheric, Geophysical and Astronomical Services Administration, 2017). In 2025, El Niño conditions resulted in atypically high rainfall during the dry season.

Survey and spatial mapping of fish corrals

Georeferenced fish corral maps were prepared prior to interviews to enable linkage between spatial trap locations and interview-derived catch data.

Boat-based surveys were conducted in February 2025, during which the geographic coordinates of fish corrals were recorded using a global positioning system (GPS; 64csx handheld GPS unit; Garmin International, Inc.; Olathe, KS, USA). For each trap, photographic documentation and operational status (net installed or temporarily removed) were recorded. Additional surveys between August and October 2025 expanded coverage to previously unassessed coastal areas in Puerto Princesa City and Aborlan to ensure complete spatial coverage of fish corrals within Puerto Princesa City and Aborlan (Figs. 1–2).

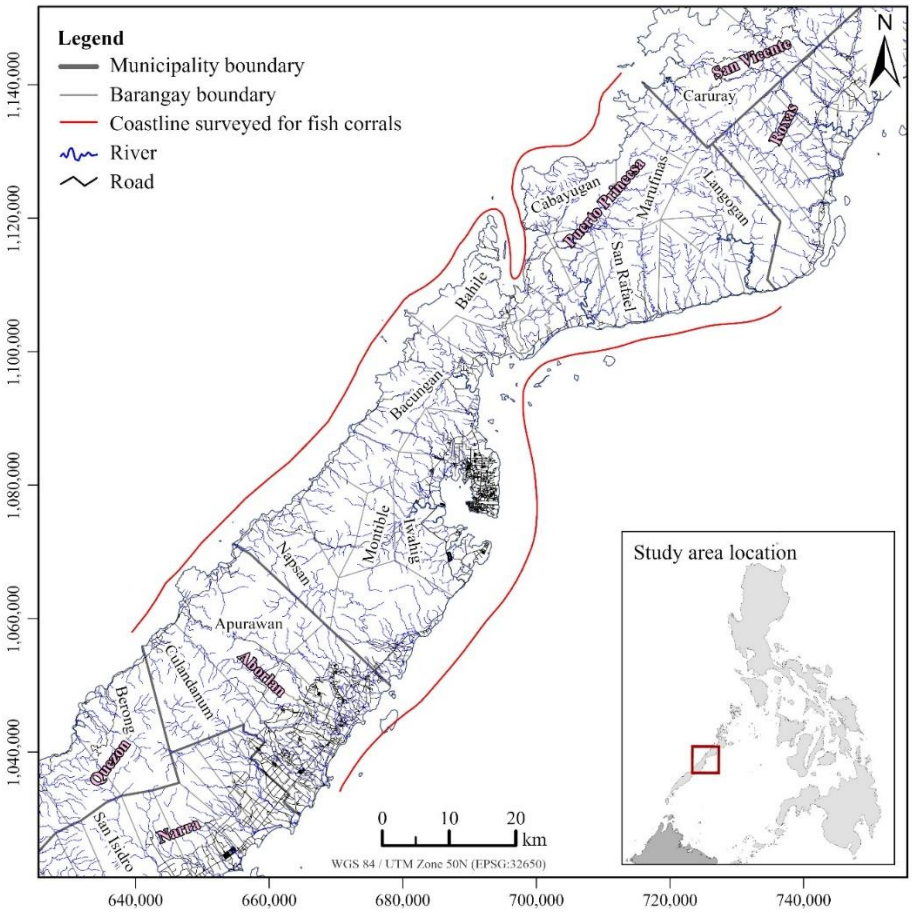


Fig. 1 Study area in Puerto Princesa City and Aborlan, Palawan, the Philippines, showing surveyed coastal waters and the extent of field assessments of active fish corrals (indicated by red lines), where inset map indicates study area location within Palawan and the Philippines.

Spatial data were compiled and analyzed in ArcGIS Pro v3.5.4 (Esri; Redlands; CA, USA) based on WGS 84/UTM Zone 50N. Maps were generated to illustrate: 1) the distribution of fish corrals in the study area; 2) maximum reported weekly catch per unit effort (CPUE) of *T. tridentatus* per trap; and 3) spatial clusters of bycatches using the density-based spatial clustering of applications with noise (DBSCAN) algorithm with a 1,000 m search radius. Within each cluster, maximum weekly CPUE values were summed to identify potential hotspots.

Fieldwork preparation and fisher interviews

A fishery-dependent census approach was applied within the mapped study area to obtain bycatch and operational data from fish corral operators. Based on prior mapping and local validation, all active operators in nine coastal villages were interviewed between February and June 2025.

Semi-structured interviews were conducted in Filipino and later translated into English for analysis. In the absence of standardized logbook data in small-scale artisanal fisheries in Palawan, interview-based approaches provide a widely accepted and practical method for generating baseline CPUE estimates in data-limited contexts (O'Donnell et al., 2012). The questionnaire collected information on the demographic characteristics of the interviewed fishers, as well as on: 1) fishing effort and operational practices, including months of operation; 2) weekly CPUE, reported as minimum and maximum numbers of *T. tridentatus* captured per trap per week; and 3) months during which spawning pairs or gravid females were observed.

Interview responses were coded into a structured dataset and verified prior to analysis. Statistical analyses were conducted using IBM SPSS Statistics v29 (IBM Corp.; Armonk, New York, NY, USA). Metadata and the full questionnaire are available upon request.

Annual bycatch estimation

Normality of CPUE values was assessed using the Shapiro-Wilk test. As data were non-normal ($p < 0.05$), median values were used to summarize central tendency and for substitution of missing data in traps lacking both CPUE and information on months of operation.

Due to the absence of temporally resolved catch data, CPUE per trap was assumed to be constant over the reported months of operation, providing a simplified baseline estimate of annual bycatch. The

median reported number of months of operation was 12, indicating year-round operation for most traps.

For each trap with complete data (n = 75), annual horseshoe crab bycatch was estimated individually using fisher-reported weekly CPUE values and reported months of operation in an effort-expansion model based on Equation 1:

$$\text{Annual bycatch} = \text{Weekly CPUE} \times 4 \times \text{Months of operation} \quad (1)$$

where CPUE is the catch per unit effort.

Notably, 4 wk/mth were used (instead of 4.3 wk). Furthermore, lower- and upper-bound estimates were calculated because CPUE was reported as minimum and maximum weekly values.

Subsequently, the trap-level estimates were aggregated based on the coastal stratum (east or west coast). For traps lacking both CPUE and information on months of operation, missing values were imputed using coast-specific median substitution. This approach preserved observed variability among traps, while allowing for complete coverage of all mapped fish corrals.

The resulting estimates were intended to provide an order-of-magnitude baseline of annual bycatch and should not be interpreted as temporally resolved estimates.

Seasonal patterns in spawning activity

Seasonal patterns in spawning observations were evaluated based on fisher-reported months of observed spawning pairs or gravid females and months of trap operation. The analysis aimed to assess whether reported spawning observations were associated with periods of active trap operation (as a means of identifying potential observation bias linked to increased detection probability during fishing activity) and was not intended to imply a causal relationship between fishing activity and spawning behavior. Fish corral operation referred to the months during which the fish corral was installed in the water and functioning as active fishing gear, regardless of the number of fishing days within the month.

Statistical analyses

Associations between spawning observations (yes/no) and fish-coral operation (yes/no) were tested using chi-squared analysis. The null hypothesis (H_0) was that spawning observations were independent of fish-corral operation, whereas the alternative hypothesis (H_1) was that spawning observations were associated with fish-corral operation. This association was interpreted as reflecting differences in observation likelihood, not a causal relationship. Effect sizes were quantified using phi (ϕ) coefficients following Cohen (1988). Then, logistic regression was used for additional evaluation of the relationship, with spawning observation as the dependent variable and trap operation as the primary predictor. Month and village (known locally as 'barangay') were included as covariates to account for temporal and spatial variation in observation likelihood.

Cases with missing responses were excluded from inferential analyses.

Resuts

Respondent characteristics

In total, 60 fish corral operators were interviewed, representing 75 operated traps across 9 coastal villages in Puerto Princesa City. Respondents were clustered spatially, reflecting the concentration of fish corral operations. The highest proportions were recorded in Kamuning (21.7%) and Inagawan Sub (20.0%), followed by Tagabinet (16.7%), Macarascas (15.0%), Bahile (11.7%), Bacungan (6.7%), Babuyan (3.3%), Sta. Cruz (3.3%) and Luzviminda (1.7%). The respondents were long-term residents who relied primarily on fishing with fish corrals as their main livelihood and the majority had completed only elementary or high school education (Fig. 2). All respondents were married males aged 24–67 yr, with 2–11 children and the respondents had fishing experience in the range 4–50 yr (median = 30 yr). Reported monthly income from fishing was low, in the range USD 45–360 (median = USD 99), as shown in Fig. 2.

Distribution of fish corrals

In total, 155 active fish corrals were mapped along the east and west coasts of Puerto Princesa City and Aborlan during the surveys conducted during 2025. The spatial distribution of the corrals was heterogeneous, with clear clustering in specific coastal areas (rather than uniform coverage along the coastline), occurring within approximately 70 km of the east coast and a 55 km stretch of the west coast (Fig. 3). No fish corrals were observed along the exposed coastline sections or within areas where their installation is restricted, including urban coastal waters and zones adjacent to the Puerto Princesa City Subterranean River National Park.

This clustered distribution reflected the actual spatial configuration of the active fishing grounds within the study area that had been s shaped by habitat suitability, coastal geomorphology and local permitting regulations, rather than a limitation of the sampling design (Fig. 2).

Catch per unit effort

All interviewed fishers (n = 60) reported at least occasional weekly encounters with *T. tridentatus* in their fish corrals. Reported values for weekly CPUE of *T. tridentatus* varied widely among respondents (0–20 individuals/trap/wk (Fig. 4). The median minimum CPUE was 2 individuals/trap/wk, while the median maximum CPUE was 3 individuals/trap/wk, indicating a relatively consistent central tendency despite variability in reported ranges. The median reported number of months of operation was 12.

Commonly, the fishers reported the capture of both solitary individuals and paired horseshoe crabs. In addition, gravid females were reported from multiple locations, indicating that fish corrals intercepted reproductively active individuals.

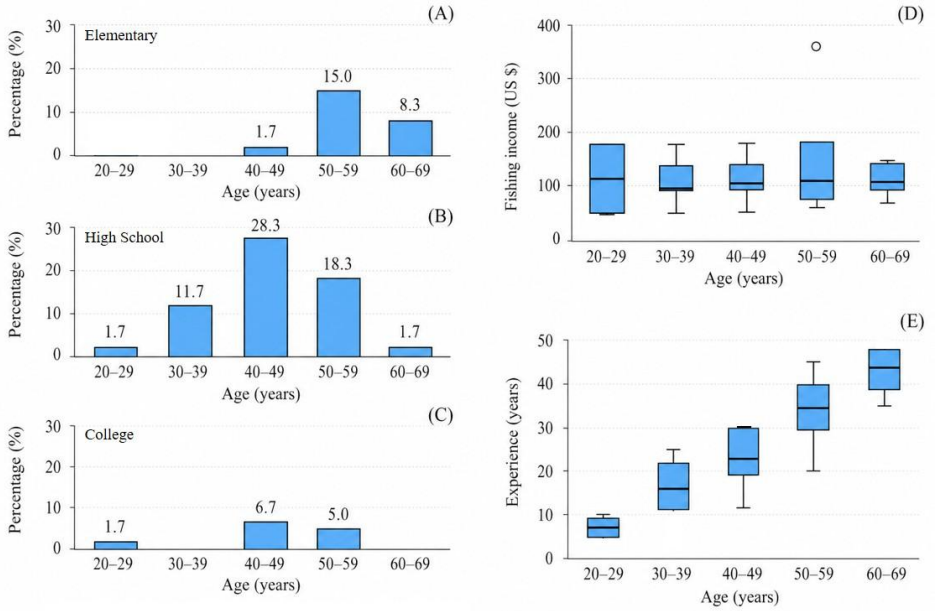


Fig. 2 Demographic age distribution information of interviewed fishers (n = 60) by: (A) elementary school as highest education level; (B) high school as highest education level; (C) college as highest education level; (D) monthly fishing income; (E) years of fishing experience. In (D) and (E), boxes represent the interquartile range (IQR), bold horizontal lines indicate medians, whiskers extend to the most extreme values within 1.5 × IQR, and circles indicate outliers.

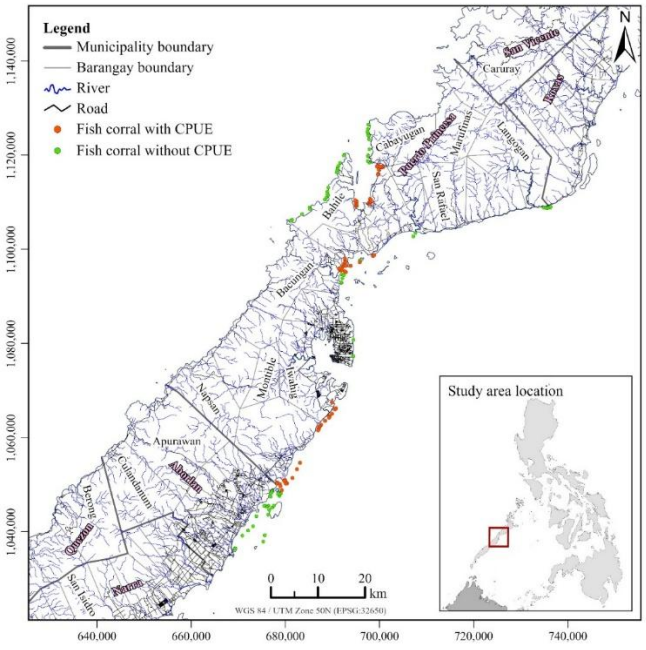


Fig. 3 Spatial distribution of surveyed fish corrals in Puerto Princesa City and Aborlan, Palawan, where each point represents a georeferenced fish corral documented during field assessments in 2025, with red points indicating corrals for which catch per unit effort (CPUE) data were obtained through fisher interviews, whereas green points represent corrals without associated CPUE data and the spatial clustering of fish corrals reflects distribution of active fishing grounds, as influenced by habitat suitability and existing regulatory constraints.

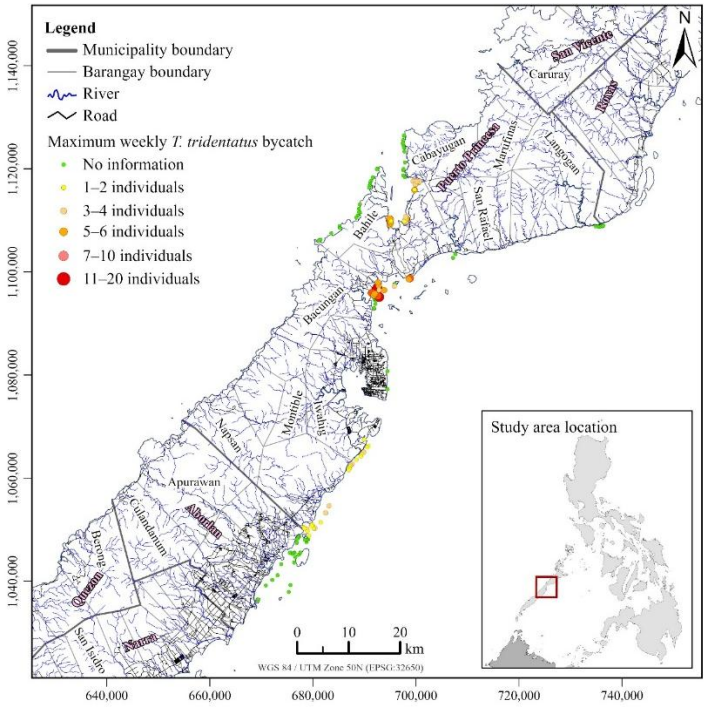


Fig. 4 Maximum weekly bycatch of *Tachypleus tridentatus* per active fish corral in Puerto Princesa City and Aborlan, Palawan, where circle size and color indicate highest weekly number of individuals reported during structured fisher interviews and green symbols represent assessed fish c orrals for which no interview data were available.

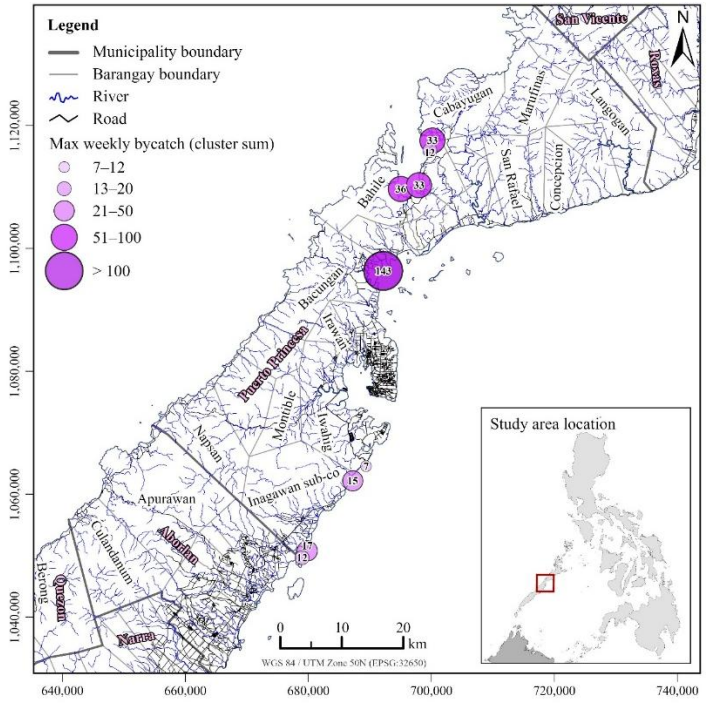


Fig. 5 Spatial clustering of active fish corrals based on interview-derived maximum weekly bycatch of *Tachypleus tridentatus* in Puerto Princesa City, Palawan, based on cluster identification using DBSCAN algorithm (1,000 m search radius; minimum of three corrals), where circles represent cluster centroids, with size proportional to the summed maximum weekly bycatch within each cluster.

Spatial patterns and bycatch hotspots

Mapping of the CPUE values revealed pronounced spatial heterogeneity in horseshoe crab bycatch (Fig. 4). When the maximum weekly CPUE values were spatially aggregated, distinct clusters of elevated bycatch became apparent, with hotspots concentrated primarily in Honda Bay and Ulugan Bay (Fig. 5). These hotspots corresponded to areas with both higher densities of fish corrals and higher reported CPUE values. These spatial patterns were consistent across the minimum and maximum CPUE scenarios and corresponded closely with areas of high fish corral density. Outside these areas, CPUE values were generally lower and more sporadic.

Estimated annual bycatch

The annual bycatch of *Tachypleus tridentatus* was estimated at the trap level by scaling fisher-reported weekly CPUE values according to reported months of trap operation and subsequently aggregating across the study area. Coast-specific median substitution was applied for traps lacking CPUE and information on months of operation ($n = 80$). CPUE data were available for 75 of the 155 mapped fish corrals, with the remaining traps were estimated using median substitution.

Under the preferred coast-specific scenario, the estimated total annual bycatch across Puerto Princesa City and Aborlan ranged between approximately 14,300 and 28,600 individuals/yr (Table 1). An alternative overall-median scenario yielded a comparable range (≈ 15,400–27,000 individuals/yr), supporting the robustness of the regional estimate to alternative median substitution approaches (Table 1).

As the CPUE values were derived from recall-based data and not stratified by season, the estimates should be interpreted as indicative baseline approximations of the overall bycatch magnitude within the studied municipalities and should not be interpreted as temporally resolved measures.

Because fish corrals were spatially restricted to defined coastal stretches within the study area, these values represented a region-wide estimate of bycatch across all areas where fish corrals were legally and physically present. Regarding the life stages of bycaught horseshoe crabs, fishers reported individuals of varying sizes and approximately 30–40% of the reported bycatch was classified as large-sized based on fisher-reported size categories (small, medium, large).

Seasonal patterns in spawning observations

Reported spawning observations and fish-corral operation overlapped throughout the year, with the highest concurrence between August and October (Fig. 6). While 70% of respondents reported year-round trap operation, 36.7% reported year-round spawning observations.

Monthly chi-squared analyses demonstrated significant associations between trap operation and reported spawning observations in most months (Table 2), with effect sizes ranging from moderate to strong. Accordingly, the null hypothesis (H_0) of independence between spawning observations and fish-corral operation was rejected for months with significant associations, supporting the alternative hypothesis (H_1) that spawning observations were associated with fish-corral operation. Significant associations were particularly pronounced in January, February, March, April, May, October, November and December, whereas associations during June–September were weaker or not significant.

Logistic regression analysis further confirmed that spawning observations were strongly associated with active trap operation (Table 3). After controlling for month and village (barangay), active trap operation was strongly associated with reported spawning observations (odds ratio = 213.0; 95% confidence interval = 68.82–658.12; $p < 0.001$). The large odds ratio reflected the strong dependence of spawning observations on observation effort, as spawning was rarely reported during months without active trap operation. Although the confidence interval was wide, indicating uncertainty in the precise magnitude of the effect, the direction and strength of the association were consistent across analyses.

Collectively, these findings indicated that apparent seasonal peaks in spawning observations largely reflected variation in fishing effort rather than independent evidence of discrete biological spawning periods. Therefore, the reported seasonal pattern in spawning observations appeared to be driven primarily by variation in observation effort, suggesting that fisher-reported spawning observations were strongly influenced by periods of active trap operation.

Table 1 Estimated annual bycatch of *Tachypleus tridentatus* under coast-specific and overall-median scenarios, where annual estimates were scaled from weekly catch per unit effort (CPUE) on reported months of trap operation, missing CPUE, values were imputed using coast-specific median, with coast-specific scenario being the preferred estimate, with the overall-median scenario providing a robustness check.

Scenario	East coast		West coast		Total annual bycatch (individuals/yr)
	Reported CPUE	Imputed (median substitution)	Reported CPUE	Imputed (median substitution)	
Coast-specific minimum median	5,336	3,384	2,400	3,168	14,288
Coast-specific maximum median	6,768	10,404	5,128	6,336	28,636
Overall-median (verification)–minimum	–	–	–	–	15,416
Overall-median (verification)–maximum	–	–	–	–	27,052

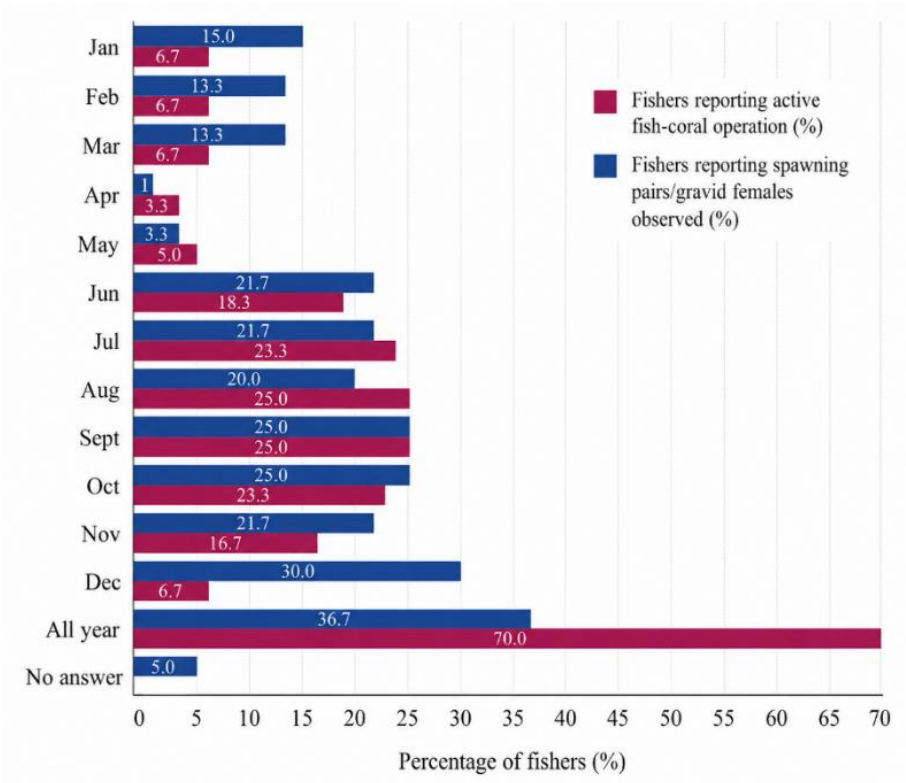


Fig. 6 Monthly distribution of fishers reporting spawning pairs or gravid females of *Tachypleus tridentatus* (blue) and active fish-corral operation (red) for n = 60, where percentages indicate respondents reporting each month, with multiple months allowed to be selected, "All year" responses shown separately and excluded from monthly bars to avoid double-counting, although they were coded as present in all months for inferential analyses and "No answer" indicates respondents unable to identify specific spawning months.

Table 2 Monthly association between trap operation period and reported spawning observations. Results of chi-squared (χ^2) tests of independence examining the association between trap operation and reported spawning observations for each month (n = 60 per month), where effect size reported as phi coefficient (ϕ) and significant associations indicate effort-related patterns in spawning observations.

Month	χ^2	*p*-value	Phi
January	16.91	<0.001	0.53
February	15.75	<0.001	0.51
March	15.75	<0.001	0.51
April	11.44	0.001	0.44
May	11.20	0.001	0.43
June	1.67	0.197	0.17
July	3.70	0.054	0.25
August	2.06	0.151	0.19
September	2.71	0.100	0.21
October	4.38	0.036	0.27
November	5.95	0.025	0.31
December	25.73	<0.001	0.65

Effect size (ϕ): weak (0.10–0.29), moderate (0.30–0.49), strong (0.50–0.69), very strong ($\geq$ 0.70).

Table 3 Logistic regression model predicting reported spawning observations based on results of logistic regression analysis assessing the association between active trap operation and reported spawning observations, where model adjusted for month and village (barangay) and presented based on regression coefficient (B), odds ratio, 95% confidence interval (CI) and *p*-value.

Predictor	B	Odds ratio	95% CI	*p*-value
Trap operation (adjusted for month and village)	5.36	213.0	68.82–658.12	< 0.001

Evidence of targeted use or trade

No respondent reported current intentional killing, consumption, or sale of horseshoe crabs, suggesting that targeted use of the species was currently limited or absent in the study area. Accordingly, interactions between fish corrals and horseshoe crabs appear to be predominantly incidental.

Discusssion

Regulatory change, reported use and conservation awareness

The recent enforcement of coastal regulations requiring permits for fish corrals represents a major institutional development in managing interactions between artisanal fisheries and vulnerable coastal species. Although the prohibition of fish corrals in urban waters had existed for several years, its effective implementation, beginning in 2024, appears to have reduced fishing pressure in ecologically sensitive nearshore areas, including habitats used by *T. tridentatus*. Comparable governance interventions are most effective when regulatory enforcement coincides with local acceptance and behavioral change among resource users (Cinner et al., 2012; Fulton et al., 2014).

Within this regulatory context, a notable finding of the present study was an apparent shift in reported practices relative to conditions documented two decades ago. Earlier work from Palawan documented widespread killing, consumption, or sale of horseshoe crabs entangled in fishing gear (Kaiser, 2002). In contrast, no respondent reported current intentional killing, consumption, or sale of horseshoe crabs. Although post-release survival remains unknown, these practices may reduce direct fishing mortality relative to the earlier reports from the region. Similar shifts away from consumptive or trade-related use following bycatch have been reported in other small-scale fisheries following increased awareness, stakeholder engagement and regulatory attention (Moore et al., 2010; Lewison et al., 2014).

This pattern was consistent with broader evidence indicating that effective bycatch mitigation in small-scale fisheries is shaped by governance context and perceived legitimacy of management measures (Ostrom, 2009; Gelcich et al., 2010; Dalpaz et al., 2024). Where conservation measures are viewed as fair and locally relevant, fishers are more likely to adopt and sustain conservation-oriented practices (Gelcich et al., 2005; Cinner et al., 2012).

Despite these encouraging developments, substantial knowledge gaps persist. Fishers demonstrated limited understanding of horseshoe crab biology and conservation status, with younger fishers having particularly low levels of ecological knowledge. This pattern mirrors findings from other small-scale fisheries, where erosion of intergenerational ecological knowledge can undermine long-term stewardship (Sáenz-Arroyo et al., 2005; Gelcich et al., 2014).

Spatial concentration of bycatch and implications for management

The identification of bycatch hotspots in Honda Bay and Ulugan Bay demonstrated that interactions between fish corrals and horseshoe crabs were spatially concentrated rather than uniformly distributed along the coastline. Such clustering is a common feature of bycatch dynamics, particularly where fixed fishing gear overlap with migratory pathways or critical habitats (Lewison et al., 2004; Wallace et al., 2013). In Aborlan, the exclusive placement of fish corrals along the east coast further underscored the role of geomorphology, coastal exposure and regulatory constraints in shaping risk patterns.

Although bycatch estimates for the west coast of Puerto Princesa City were derived from a limited number of fish corrals in Ulugan Bay, the consistency of the CPUE values within the surveyed areas suggested that the identified hotspots were robust at a management-relevant scale. Therefore, these locations represent priorities for targeted monitoring and mitigation. Repeatedly, spatially focused approaches have been shown to outperform uniform regulations in reducing bycatch while minimizing socioeconomic impacts (Dunn et al., 2019).

The spatial clustering observed here mirrored patterns reported for other vulnerable marine taxa, where bycatch risk was concentrated in predictable locations rather than evenly distributed across fishing grounds (Lewison et al., 2004; Wallace et al., 2010). Such patterns provide a strong rationale for place-based management strategies rather than broad coast-wide measures that may be less efficient and more socially costly (Pons et al., 2022; Bowlby et al., 2024).

Apparent year-round spawning and observation bias

Reports of spawning pairs and gravid females throughout the year may suggest prolonged reproductive activity in *T. tridentatus* in Palawan. Similar patterns have been reported from other tropical regions (Mohamad et al., 2019). However, the strong association between reported spawning observations and months of trap operation indicated a pronounced observation bias. Similar limitations of interview-based data have been documented where effort-driven detection has obscured true biological seasonality (Moore et al., 2010, 2021; Carruthers and Neis, 2011; Lucchetti et al., 2017). As such, the present results do not allow definitive conclusions regarding spawning phenology, underscoring the need for fishery-independent monitoring such as beach surveys or direct observation of spawning habitats.

Although uncertainty remains regarding the proportion of reproductively active adults in the bycatch, life-history theory predicts that even moderate additional mortality of large, slow-maturing

species can have disproportionate population-level effects (Heppell et al., 1999). Fixed fishing gear can further amplify these impacts by altering the habitat use and movement patterns of benthic and spawning species (Lewison et al., 2004; van Denderen et al., 2014). Furthermore, the systemic vulnerability of horseshoe crabs to small-scale nearshore gear is supported by recent records in the Andaman Sea, where *Tachypleus gigas* was documented as a persistent bycatch component in bottom-set artisanal nets deployed within nearshore seagrass beds (Arkronrat et al., 2025). This underscores a broader regional need to monitor chelicerate-gear interactions across shallow coastal ecosystems.

Annual bycatch estimates and potential implications for spawning success

The estimated annual bycatch of *T. tridentatus* in Puerto Princesa City and Aborlan ranged from approximately 14,300 to 28,600 individuals, with consistent values obtained using an alternative extrapolation approach. These estimates combined trap-specific, fisher-reported CPUE values with coast-specific, median substitution for corrals lacking interview data and have provided the first fishery-wide approximation of interaction frequency associated with fish corrals in the surveyed municipalities. They should be interpreted as indicative baseline approximations intended to characterize fishery-wide magnitude rather than as precise seasonal catch rates.

These estimates are neither direct measures of adult mortality nor population decline. Fishers reported that only 30–40% of captured individuals were large and uncertainty remains regarding the maturity of medium-sized crabs. Nevertheless, even conservative assumptions would suggest that substantial numbers of potentially reproductive individuals encounter fish corrals annually. Fixed gear intercepting spawning migrations has been shown to affect reproductive output in other benthic or migratory species, even when direct mortality was low (Heppell et al., 2005; van Denderen et al., 2014).

Encouragingly, existing spatial restrictions appear to have prevented fish corrals from being installed in front of the approximately 2 km nursery habitat in Puerto Princesa City. Protection of nursery and spawning areas is recognized widely as a cornerstone of effective conservation for long-lived marine species (Beck et al., 2001; Heupel et al., 2019), suggesting that current zoning measures may already be reducing pressure on critical habitats.

Conservation implications and priorities for future research

Overall, the present findings have highlighted both challenges and opportunities for horseshoe crab conservation in Palawan. While the scale of incidental bycatch underscores the importance of fish corrals as a key interface between artisanal fisheries and *T. tridentatus*, the reported absence of targeted use suggests that interactions were primarily incidental, providing a foundation for community-based conservation. In this context, peer-led communication and locally embedded outreach have been shown to be effective in sustaining conservation-positive behavior in small-scale fisheries (Ostrom, 2009; Gelcich et al., 2010).

Given the estimated magnitude of the annual bycatch, these results have highlighted the need for further targeted research to better quantify temporal variability, mortality and population-level impacts. Priority areas for future work include refining interview instruments, expanding assessments to the provincial scale, implementing year-round visual monitoring of bycatch, documenting interactions with fishing gear beyond fish corrals and quantifying injury, mortality and post-release survival. Furthermore, evidence-based management would be supported by evaluating the effectiveness of existing spatial restrictions, particularly near spawning and nursery habitats. By integrating fisher interviews, spatial mapping and CPUE-based extrapolation, this study has provided essential baseline information to inform adaptive management, targeted outreach and long-term conservation planning for *T. tridentatus* in Palawan.

In addition, the interview-based and spatial approaches applied here may be useful for assessing interactions between stationary fishing gear and other vulnerable coastal taxa, including sea turtles, dugongs and dolphins.

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