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Biodiversity and Depth-Related Species Distribution of Coral Reef Fish on the Seamounts of Tho Chu Archipelago, Vietnam

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Abstract

This study provides the first comprehensive assessment of the species composition and distribution of coral reef fish populations on the seamounts of Tho Chu Archipelago. Surveys were conducted during the Northeast monsoon (December 2023) and Southwest monsoon (July–August 2024) seasons across 24 transects spanning depths 11-30m. A total of 83 species from 45 genera, 23 families, and 13 orders were recorded. The most abundant families were damselfishes (Pomacentridae) with 19 species and wrasses (Labridae) with 15 species. Species richness was the highest in the shallow reef crest (11-15m; 70 species) and declined markedly toward the deeper reef foot (26-28m; 18 species). The overall diversity was high (H' = 4.93), with a relatively even species distribution (J' = 0.77). Mean fish density reached about 250 individuals per 500 m^2, dominated by small-size fishes (< 10cm in total length). The Bray-Curtis similarity index revealed distinct depth-related groupings, with strong overlap in mid-depth communities. The findings provide baseline ecological data on species composition, density, and depth-related distribution patterns, serving as scientific evidence for marine conservation planning and sustainable fisheries management in offshore waters.

Keywords

Fish populations, seamount, species composition, sustainable fisheries

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Introduction

Seamounts are unique marine ecosystems defined by abrupt topography and complex hydrodynamics. By driving localized upwelling and forming Taylor columns, circular currents that retain eggs and larvae, these features create nutrient-rich biodiversity hotspots (White & Mohn, 2004). Research across the Atlantic, Indian and Pacific Oceans confirms that seamounts support exceptional species richness, large fish biomass, and vulnerable endemic populations (Holland & Grubbs, 2007; Kaschner, 2007; White *et al.*, 2007; Lavelle & Mohn, 2010; Mohn & White, 2010; Rogers, 2012). While modern technologies like sonar and ROVs have expanded our understanding of these global habitats (Porteiro *et al.*, 2013; Pinheiro *et al.*, 2015; Shea *et al.*, 2017), comprehensive quantitative data remain scarce. The extreme depths and remoteness of seamounts continue to hinder ecological assessments, particularly regarding coral reef fish populations (Ellis & Sharron, 1998). Consequently, while their ecological and economic importance is well-documented, logistical constraints in deep-water environments limit the ability to fully monitor and manage these critical marine communities.

Coral reef fish are vital to tropical marine ecosystems, maintaining ecological balance and serving as sensitive bioindicators of habitat quality. While these communities are essential benchmarks for monitoring environmental stressors, research remains largely focused on shallow coastal reefs. This creates significant knowledge gaps regarding deeper offshore structures like seamounts. Currently, global quantitative data on the biomass and economic value of these deep-water fish populations are limited (Rogers, 2012), highlighting the need to expand research beyond shallow-water environments. Vietnam's seamount ecosystems, such as Tho Chu Archipelago, a high-biodiversity hotspot located in southwestern Vietnamese waters featuring a characteristic seamount, remain poorly studied and inadequately managed. These offshore features differ fundamentally from coastal habitats in geomorphology and depth. The lack of baseline data on fish community structure represents a significant scientific gap, especially since these seamounts likely serve as critical spawning and nursery grounds within Vietnam's Exclusive Economic Zone. Tho Chu Archipelago is a biodiversity hotspot hosting over 1,100 marine species. Despite this, research has primarily targeted shallow coastal reefs and specific fish descriptions (Do Thanh An *et al.*, 2014; Do Anh Duy *et al.*, 2017). The region's seamount ecosystems, which serve as crucial breeding grounds, remain without systematic investigation. This leaves a significant knowledge gap in species composition, biodiversity, and depth-related distribution of reef fishes in seamount ecosystems.

This study addressed a critical knowledge gap by providing the first integrated assessment of seamount coral reef fish in Tho Chu Archipelago. We aimed to: (i) characterize the seamount morphology and benthic structure using in situ observations; (ii) evaluate seasonal species composition, diversity, and size structure; and (iii) analyze distribution patterns along an 11-30m depth gradient. These findings will establish a vital baseline for comparing offshore seamounts with Vietnam's coastal reefs. Ultimately, this research will provide the scientific evidence necessary for biodiversity conservation, marine spatial planning, and sustainable fisheries management in Vietnam's offshore waters.

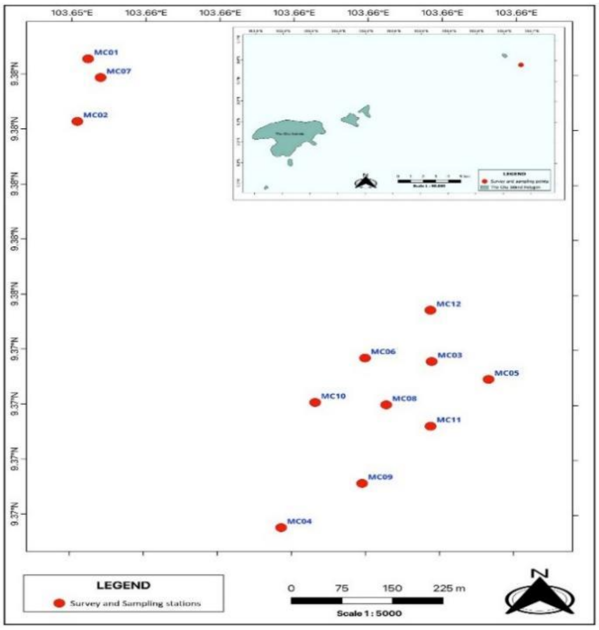
Materials and Methods

Study duration and location

The research aimed to evaluate coral reef fish populations across Tho Chu Archipelago, with surveys conducted at 12 stations and reaching depths of approximately 30 meters (**Figure 1**). Two separate survey periods were completed to account for seasonal variations, the first was carried out during the Northeast monsoon season from December 5 to December 16, 2023, and the second was conducted during the Southwest monsoon season from July 27 to August 7, 2024.

Data collection methods

Bathymetric data collection: In August 2024, bathymetric and benthic data were collected at the seamounts surrounding Tho Chu Archipelago. Using a Garmin GPSMAP 585 Plus single-beam sounder mounted on a vessel traveling at 2.5 m s^{-1}, we recorded vertical depth points along planned digital routes. Complementary benthic data (points and polygons) were gathered via SCUBA diving. Raw data were subsequently processed using QGIS and SAGA GIS for spatial interpolation.



Note: MC - Surveyed Station

Figure 1. Map of the surveyed areas and sampling stations on the seamounts of Tho Chu Archipelago

This methodological workflow established a precise geomorphological baseline for characterizing these remote offshore ecosystems.

Manta Tow Method: The distribution of the coral reef was surveyed using the manta tow method (Kenchington, 1982), while integrating GPS data for spatial correction and distribution map editing.

Quantitative Sampling: Quantitative sampling was conducted by SCUBA diving for direct observation, while simultaneously recording and taking underwater photos according to standard protocols (English *et al.*, 1997). At each survey station, a 100-m transect line was deployed along a fixed depth gradient, extending from the summit of the seamount (approximately 11-15m) to the base of the reef (approximately 25-30m). The transect was subdivided into twenty 5-m segments, with a 5-m buffer separating adjacent segments to ensure spatial independence and minimize observational bias.

Identification Method: Fish samples were collected directly at the surveyed area from local fishermen. The specimens were identified at the Marine Biology Laboratory, Institute of Marine Research, based on morphological analysis or identified through photos and videos (Tran Dinh & Nguyen Nhat Thi, 1985; Myers, 1991; Nguyen Huu Phung & Nguyen Nhat Thi, 1994; Nguyen Huu Phung & Tran Hoai Lan, 1994; Nguyen Huu Phung *et al.*, 1995; Lieske & Myers, 1996; English *et al.* , 1997; Nguyen Huu Phung *et al.*, 1997; Allen, 1999; Nguyen Nhat Thi & Nguyen Van Nguyen, 2005; Froese, 2025).

Data processing methods

Shannon's diversity index

The species diversity index is calculated by the formula of (Shannon & Wiener, 1963):

$$H' = -\sum_{i=1}^{n}\left(\frac{n_i}{N}\right) * log_2\left(\frac{n_i}{N}\right) \quad \textbf{(1)}$$

where n_i is the number of individuals of species 'i' and N is the total number of all individuals.

Coral reef fish density was calculated based on the number of individuals and by size group (total body length): < 10cm, from 10 ≤ 20cm, from 20 ≤ 30cm, and ≥ 30cm. Coral reef fish density data were converted to number of individuals per $500m^2$.

Similarity index

A Bray-Curtis similarity index chart was drawn using Primer 6 software.

Spatial analysis of seamount morphology

We employed interpolation using the inverse distance weighted (IDW) technique to compute a raster map of the depth factors into a GIS database in the SAGA GIS environment (Conrad *et al.*, 2015). As with many other spatial predictors, in the case of the inverse distance interpolation, the value of target variables at some new location can be derived as a weighted average:

$$\hat{z}(s_0) = \sum_{i=1}^{n} \lambda_i(s_0).z(s_i) \qquad \mathbf{(2)}$$

where λ_i is the weight for neighbor i. The sum of weights needs to equal one to ensure an unbiased interpolation. Eq. (2) in matrix form is:

$$\hat{z}(s_0) = \lambda_0^{\mathrm{T}}.z \qquad \mathbf{(3)}$$

where $z(s_i)$ is the value of the depth at the measured station s_i and $z(s_0)$ is the depth value to be interpolated at station s_0.

Inverse distance interpolation is an exact and convex interpolation method that fits only the continuous model of spatial variation. For large datasets (exceed 10^3 points), it can be time-consuming, so it is often a good idea to set a distance threshold (search radius) to speed up the calculations (Hengl, 2007).

Assessing the accuracy of predictions

The prediction error is often referred to as the precision of prediction. The true quality of a map can be best assessed by comparing estimated values ($\hat{z}(s_j)$)with actual observations at validation points ($z^*(s_j)$). Commonly, two measures are most relevant here (4): the mean prediction error (ME):

$$ME = \frac{1}{l}.\sum_{j=1}^{l}\left[\hat{z}(s_j) - z^*(s_j)\right]; \qquad E\{ME\} = 0 \ \mathbf{(4)}$$

and (5) the root mean square prediction error (RMSE):

$$RMSE = \sqrt{\frac{1}{l}.\sum_{j=1}^{l}[\hat{z}(s_j) - z^*(s_j)]^2}; \qquad E\{RMSE\} = \sigma\,(\mathbf{h} = 0) \quad \mathbf{(5)}$$

where l is the number of validation points.

To compare the accuracy of predictions between variables of different types, the RMSE can also be normalized by the total variation:

$$RMSE_r = \frac{RMSE}{s_z} \qquad \mathbf{(6)}$$

As a rule of thumb, a value of $RMSE_r$ that is close to 40% means a fairly satisfactory accuracy of prediction (R^2 = 85%). Otherwise, if $RMSE_r$ > 71%, this means that the model accounted for less than 50% of the variability at the validation points.

Results

Morphological characteristics of Tho Chu Archipelago's seamounts

Bathymetric analysis of the Tho Chu seamounts had a depth range of 10m to 39m, averaging 26m. Focused IDW interpolation on two specific seamount areas identified shallower depths between 10m and 17m. Morphologically, the first area measured 367m x 466m, while the second extended 510m x 720m (**Figure 2A**). The IDW model demonstrated exceptional precision, yielding a root mean square error (RMSE) of 0.45 and a coefficient of determination (R^2) of 0.99 (**Figure 2B**). This indicates minimal deviation between the field measurements and interpolated values, aligning with established spatial analysis benchmarks. Ultimately, these results confirm the IDW technique's reliability in accurately modeling the complex benthic morphology of Tho Chu Archipelago.

The surveyed area exhibited clear vertical stratification across three geomorphological zones defined by depth and substrate. The reef summit, located between 11 and 15m, and the reef slope, extending from 16 to 25m, offered high structural complexity characterized by rocky substrates, robust coral assemblages, and natural crevices that provide essential shelter for fish. In contrast, the reef foot, situated between 26 and 28m, showed a marked decline in complexity as the seabed transitions to a flatter profile dominated by sand, gravel, and mud with sparse coral cover (**Figure 2A**). This zonation demonstrates how depth and benthic morphology directly influence habitat availability within the seamount ecosystem.

Species diversity

A total of 83 coral reef fish species were recorded from Tho Chu Archipelago's seamounts, distributed among 45 genera, 23 families, 13 orders, and one class (**Figure 3**). Blenniiformes, Acanthuriformes, and Labriformes were the most dominant groups, with 20 species (24.10%) recorded. Followed by Perciformes (9 species, 10.84%) and Gobiiformes (4 species, 4.82%). The remaining orders showed much lower diversity, containing only 1 to 2 species (**Table 1**).

Among the 23 fish families identified from Tho Chu Archipelago's seamounts, Pomacentridae (damselfishes) showed the highest species richness with 19 species (22.89%), followed closely by Labridae (wrasses) with 15 species (18.07%). Other prominent families included Serranidae and Lutjanidae (red snapper) (eight species, 9.64%)

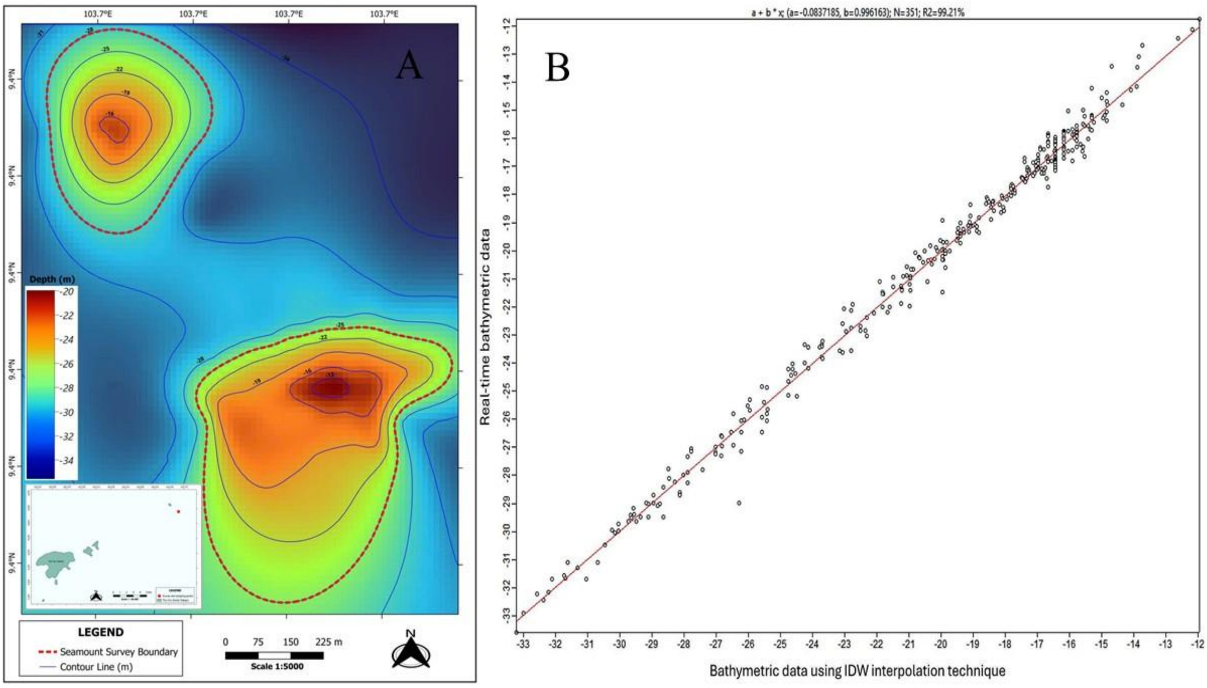


Figure 2. Map of depth-based seabed morphology of Tho Chu Archipelago's seamounts. (A): Map of the sea-bed terrain of Tho Chu Archipelago's seamounts; (B): Diagram showing the data correlation between the real-time bathymetric data with bathymetric data using the IDW interpolation technique

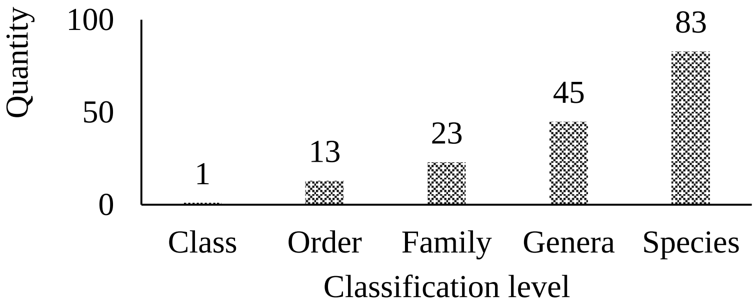


Figure 3. Species composition of coral reef fishes in Tho Chu Archipelago's seamounts

and Nemipteridae (four species, 4.82%). Three families, Apogonidae (cardinalfishes), Chaetodontidae (butterflyfishes), and Scaridae (parrotfishes), contributed three species each (3.61%). The remaining families were minimally represented, recording only one or two species each (**Table 1**).

According to Eschmeyer's Catalog of Fishes (California Academy of Sciences, 2026), over 50% of the recorded fish species hold commercial significance. Fisheries represent the primary sector, with 57 species (68.67%) providing value, including high-market taxa like *Lethrinus lentjan* and *Lutjanus lutjanus*. The aquarium trade was also prominent, involving 39 species (46.98%), with an additional seven species (8.43%) suitable for public exhibition. These metrics underscore the region's dual role in supporting industrial food systems and the global ornamental market. Ultimately, this diversity serves as a vital economic pillar, extending far beyond the ecosystem's inherent ecological value.

The characteristics of coral reef fish species distribution in Tho Chu Archipelago's seamounts

Season-based specieces distribution

Based on the two surveys conducted during the Northeast monsoon season (December, 2023) and the Southwest monsoon season (July-August 2024), coral reef fish species diversity exhibited minor seasonal variation. The Northeast monsoon season showed greater richness, recording 69 species across 40 genera, compared to 58 species across 37 genera found during the Southwest monsoon season (**Figure 4**).

Transect-based species distribution

Analysis of the 12 survey transects revealed distinctly different species distributions in coral reef fish species composition across stations. The highest species richness was found at MC01 (2023) and MC03 (2024), both recording 29 species. Slightly lower richness was observed at MC02 and MC04 (2024), each with 26 species. Conversely, MC06 (2023) recorded the lowest species richness, with only 14 species, similar to the below-average diversity values observed at MC01 and MC10 in 2024 (**Figure 5A, Figure 5B**).

Depth-based species distribution

The survey analyzed reef fish distribution across depths from 11 to 28m, categorized into four five-meter intervals. The results indicated a clear inverse relationship between depth and biodiversity; species richness declined as depth increased. The shallowest zone (11-15m) exhibited the highest diversity with 70 recorded species. In contrast, the deepest interval (26-28m) supported only 18 species. This vertical stratification indicates that the seamount's upper layers serve as primary biodiversity hotspots, with species counts tapering significantly as the habitat transitions toward the deeper reef foot (**Figure 6A, Figure 6B**).

The indices of similarity and diversity

The Bray-Curtis analysis revealed three distinct clusters with overall similarity exceeding 30%. The middle depth range (16-25m) showed high stability, reaching 80% similarity due to significant species overlap. In contrast, the 26-30m range recorded the lowest similarity (~ 30%), signaling a major community shift (**Figure 7**). This transition is likely driven by environmental changes, specifically the move from coral-rich habitats to sandy-gravel substrates with sparse coral growth.

To assess biodiversity, our team used the Shannon-Wiener diversity index (H') and the Pielou's evenness index (J'). The results indicated high diversity (H' = 4.93, well exceeding the benchmark of H' ≥ 3.5) (Baliton *et al.*, 2020). With 83 species (S = 83), the Pielou evenness index (J' = H'/log S) was approximately 0.77. Despite a lower total species count than coastal reefs, these metrics confirm a stable, well-structured seamount ecosystem.

The density of coral reef fish species

Coral reef fish density at Tho Chu Archipelago's seamounts averaged 250.46 ± 111.83 individuals per 500m². Small fishes (< 10cm) clearly dominated the community, representing an average of 50.10 ± 15.07%. Conversely, large fish (≥ 30cm) accounted for a

Table 1. List of coral reef fish species at Tho Chu Archipelago's seamounts (arranged according to California Academy of sciences (2026))

No	SPECIES COMPOSITION	Time in years		Human uses [25]	
		2023	2024	Fisheries	Aquarium
I	Blenniiformes				
	Blenniidae				
1	*Ecsenius bicolor* (Day, 1888)	+		Commercial	Commercial
	Pomacentridae				
2	*Amblyglyphidodon aureus* (Cuvier, 1830)	+		Commercial	Commercial
3	*Amblyglyphidodon ternatensis* (Bleeker, 1853)	+		*N/A*	*N/A*
4	*Chromis fumea* (Tanaka, 1917)		+		
5	*Chromis* sp.		+	----	----
6	*Chromis westaustralis* (Allen, 1976)	+		Commercial	Commercial
7	*Chrysiptera hemicyanea* (Weber, 1913)	+	+		
8	Chrysiptera parasema (Fowler, 1918)	+	+	*N/A*	*N/A*
9	*Dascyllus trimaculatus* (Rüppell, 1829)	+	+	Minor commercial	Commercial
10	*Neoglyphidodon melas* (Cuvier, 1830)	+		of no interest	Public aquariums
11	*Neoglyphidodon oxyodon* (Bleeker, 1858)	+		Commercial	Commercial
12	*Neopomacentrus bankieri* (Richardson, 1846)		+	*N/A*	*N/A*
13	*Neopomacentrus cyanomos* (Bleeker, 1856)	+	+	of no interest	
14	*Plectroglyphidodon lacrymatus* (Quoy & Gaimard, 1825)		+		Commercial
15	*Pomacentrus auriventris* (Allen, 1991)		+	*N/A*	*N/A*
16	*Pomacentrus coelestis* (Jordan & Starks, 1901)	+	+	Commercial	Commercial
17	*Pomacentrus grammorhynchus* (Fowler, 1918)	+		of no interest	*N/A*
18	*Pomacentrus moluccensis* (Bleeker, 1853)	+		Commercial	Commercial
19	*Pomacentrus* sp.	+	+	----	----
20	*Stegastes* sp.		+	----	----
II	Acanthuriformes				
	Chaetodontidae				
21	*Chaetodon octofasciatus* (Bloch, 1787)	+	+	Commercial	Commercial
22	Chaetodon sp.	+		----	----
23	*Chelmon rostratus* (Linnaeus, 1758)	+	+	Minor commercial	Commercial
	Lethrinidae				
24	*Lethrinus lentjan* (Lacepède, 1802)	+	+	Highly commercial	
	Lutjanidae				
25	*Caesio caerulaurea* (Lacepède, 1801)	+	+	Commercial	*N/A*
26	*Caesio cuning* (Bloch, 1791)	+	+		
27	*Caesio teres* (Seale, 1906)	+	+	Minor commercial	
28	*Lutjanus ehrenbergii* (Peters, 1869)	+			
29	*Lutjanus lutjanus* (Bloch, 1790)	+	+	Highly commercial	
30	*Lutjanus vitta* (Quoy & Gaimard, 1824)	+	+	Commercial	Public aquariums
31	*Pterocaesio chrysozona* (Cuvier, 1830)		+		*N/A*

32	*Pterocaesio lativittata* (Carpenter, 1987)	+		Subsistence fisheries	
	Nemipteridae				
33	*Scolopsis affinis* (Peters, 1877)	+			*N/A*
34	*Scolopsis bilineata* (Bloch, 1793)	+	+	Subsistence fisheries	Commercial
35	*Scolopsis margaritifera* (Cuvier, 1830)	+			*N/A*
36	*Scolopsis monogramma* (Cuvier, 1830)		+	Minor commercial	
	Priacanthidae				
37	*Priacanthus blochii* (Bleeker, 1853)	+	+	Commercial	Commercial
38	*Priacanthus tayenus* (Richardson, 1846)	+	+	Minor commercial	*N/A*
	Siganidae				
39	*Siganus javus* (Linnaeus, 1766)	+	+	Commercial	Commercial
40	*Siganus virgatus* (Valenciennes, 1835)	+		Minor commercial	
III	Acropomatiformes				
	Pempheridae				
41	*Pempheris oualensis* (Cuvier, 1831)	+	+	Minor commercial	Commercial
IV	Anguilliformes				
	Muraenidae				
42	*Gymnothorax thyrsoideus* (Richardson, 1845)	+	+	Minor commercial	*N/A*
V	Aulopiformes				
	Synodontidae				
43	*Trachinocephalus myops* (Forster, 1801)	+	+	Minor commercial	*N/A*
VI	Beryciformes				
	Holocentridae				
44	*Sargocentron rubrum* (Forsskål, 1775)	+	+	Minor commercial	Public aquariums
45	*Sargocentron spiniferum* (Forsskål, 1775)	+	+		
VII	Carangiformes				
	Sphyraenidae				
46	*Sphyraena flavicauda* (Rüppell, 1838)		+	Commercial	*N/A*
VIII	Gobiiformes				
	Apogonidae				
47	*Cheilodipterus isostigmus* (Schultz, 1940)	+	+	*N/A*	*N/A*
48	*Cheilodipterus macrodon* (Lacepède, 1802)	+	+		
49	*Cheilodipterus quinquelineatus* (Cuvier, 1828)	+	+	Minor commercial	Public aquariums
	Gobiidae				
50	*Amblyeleotris* sp.	+		----	----
IX	Labriformes				
	Labridae				
51	*Cheilinus trilobatus* (Lacepède, 1801)	+	+	Minor commercial	Commercial
52	*Coris gaimard* (Quoy & Gaimard, 1824)	+		Commercial	Public aquariums
53	*Diproctacanthus xanthurus* (Bleeker, 1856)	+			Commercial
54	*Halichoeres binotopsis* (Bleeker, 1849)	+			

55	*Halichoeres chloropterus* (Bloch, 1791)		+	Minor commercial	
56	*Halichoeres hortulanus* (Lacepède 1801)	+	+		
57	*Halichoeres melanochir* (Fowler & Bean, 1928)	+	+	Commercial	
58	*Halichoeres melanurus* (Bleeker, 1851)	+	+		Public aquariums
59	*Halichoeres nigrescens* (Bloch & Schneider, 1801)		+	*N/A*	*N/A*
60	*Halichoeres scapularis* (Bennett, 1832)	+	+	Minor commercial	
61	*Halichoeres* sp.	+			
62	*Labroides dimidiatus* (Valenciennes, 1839)	+	+	of no interest	Commercial
63	*Leptojulis cyanopleura* (Bleeker, 1853)	+			
64	*Oxycheilinus digramma* (Lacepède, 1801)	+	+	Minor commercial	
65	*Thalassoma lunare* (Linnaeus, 1758)	+	+		
	Pinguipedidae				
66	*Parapercis snyderi* (Jordan & Starks, 1905)		+	*N/A*	*N/A*
67	*Parapercis* sp.	+			
	Scaridae				
68	*Scarus ghobban* (Forsskål, 1775)	+			
69	*Scarus globiceps* (Valenciennes, 1840)	+	+	Commercial	Commercial
70	*Scarus* sp.	+	+		
X	Perciformes				
	Scorpaenidae				
71	*Scorpaenopsis diabolus* (Cuvier, 1829)		+	Commercial	Commercial
	Serranidae				
72	*Cephalopholis boenak* (Bloch, 1790)	+	+	Subsistence fisheries	Commercial
73	*Cephalopholis microprion* (Bleeker, 1852)	+		Minor commercial	*N/A*
74	*Cephalopholis formosa* (Shaw, 1812)	+	+	Subsistence fisheries	
75	*Diploprion bifasciatum* (Cuvier, 1828)	+			
76	*Epinephelus awoara* (Temminck & Schlegel, 1842)	+			Commercial
77	*Epinephelus fasciatus* (Forsskål, 1775)	+	+	Commercial	
78	*Epinephelus quoyanus* (Valenciennes, 1830)	+	+		
79	*Plectropomus maculatus* (Bloch, 1790)	+	+		Commercial
XI	Siluriformes				
	Plotosidae				
80	*Plotosus lineatus* (Thunberg, 1787)	+	+	Commercial	Commercial
XII	Syngnathiformes				
	Mullidae				
81	*Upeneus tragula* (Richardson, 1846)	+	+	Commercial	Commercial
XIII	Tetraodontiformes				
	Monacanthidae				
82	*Aluterus monoceros* (Linnaeus, 1758)		+	Commercial	*N/A*
83	*Monacanthus chinensis* (Osbeck, 1765)	+		Minor commercial	
		69	58		

Note: (----): Unknown; N/A: not available.

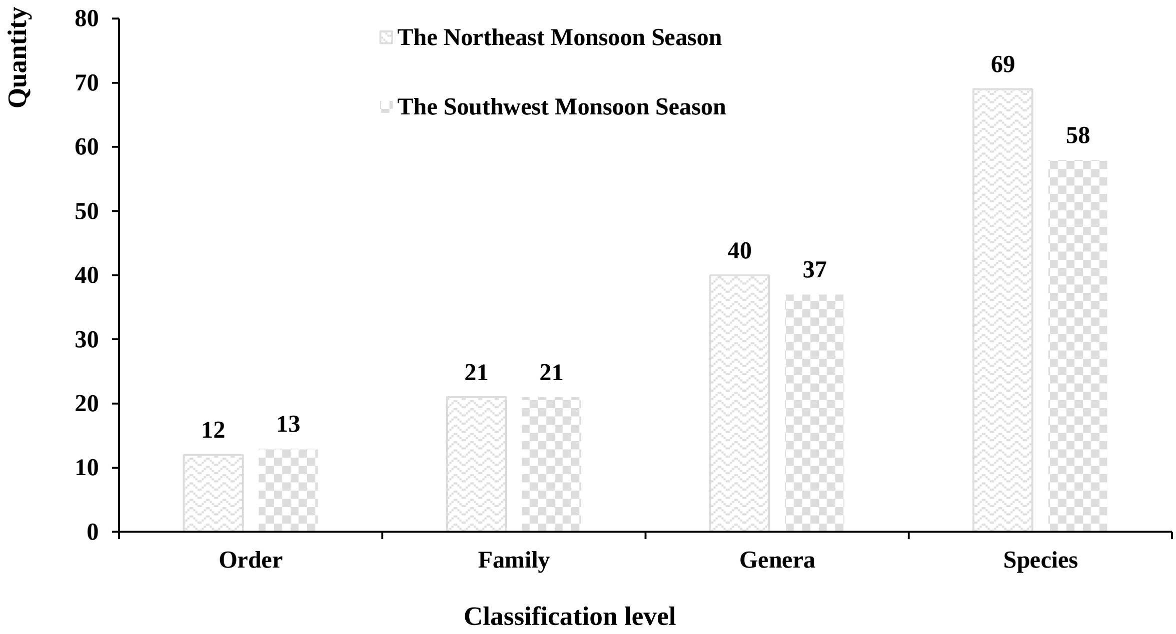


Figure 4. Season-based distribution of coral reef fish species composition

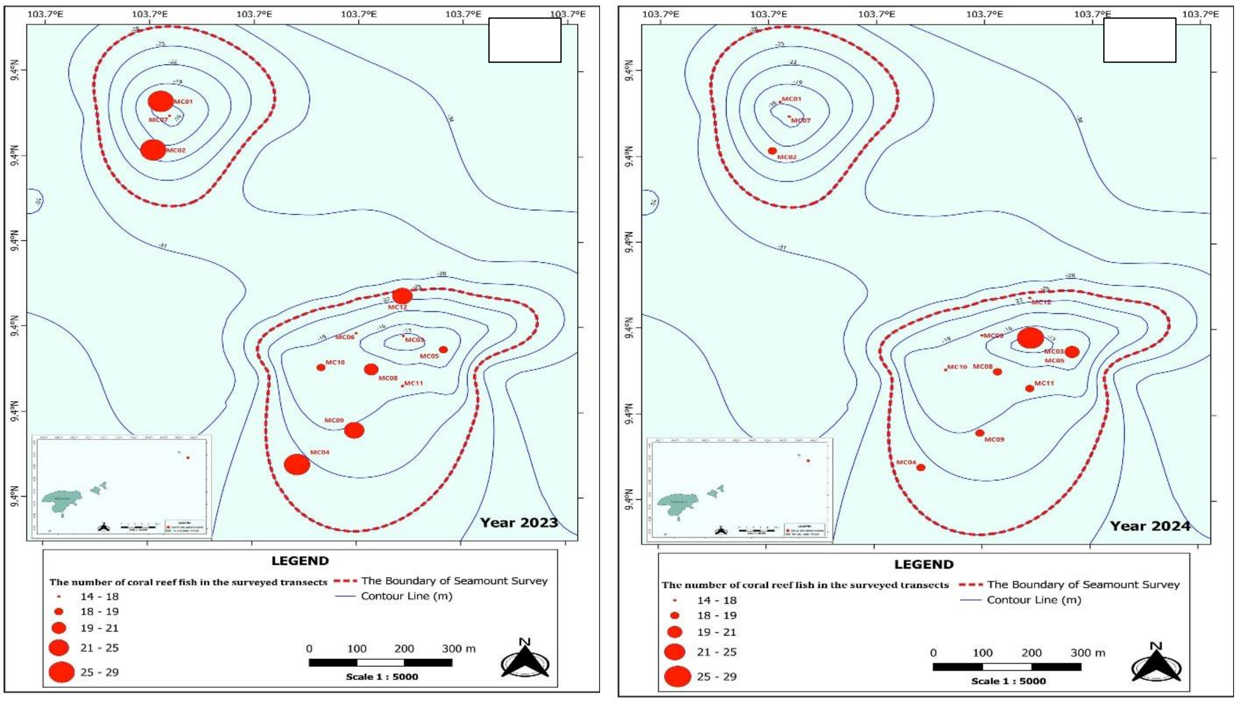


Figure 5. The number of reef fish species recorded across the surveyed transects at Tho Chu Archipelago's seamounts (A): Year 2023; (B): Year 2024

very low percentage (0.86 ± 3.24%), which may be linked to exploitation pressure or limited habitat suitability (e.g., few large burrows or shelters). Notably, specific cross-sections recorded schools of red snapper (*Lutjanus vitta*) exceeding 100 individuals per 500m², highlighting the seamounts' important role in supporting economically valuable fish populations.

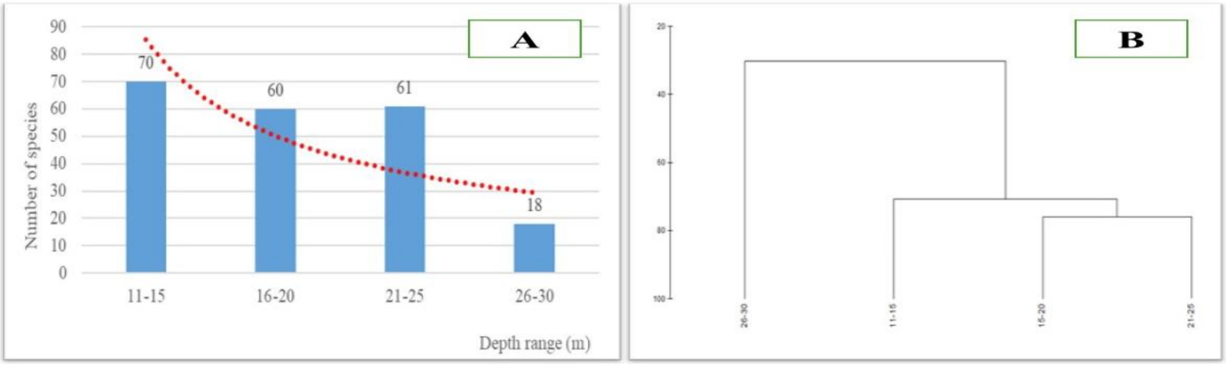


Figure 6. Distribution of coral reef fishes.

(A): According to the surveyed depth range; (B): Coral reef fish similarity index by depth range

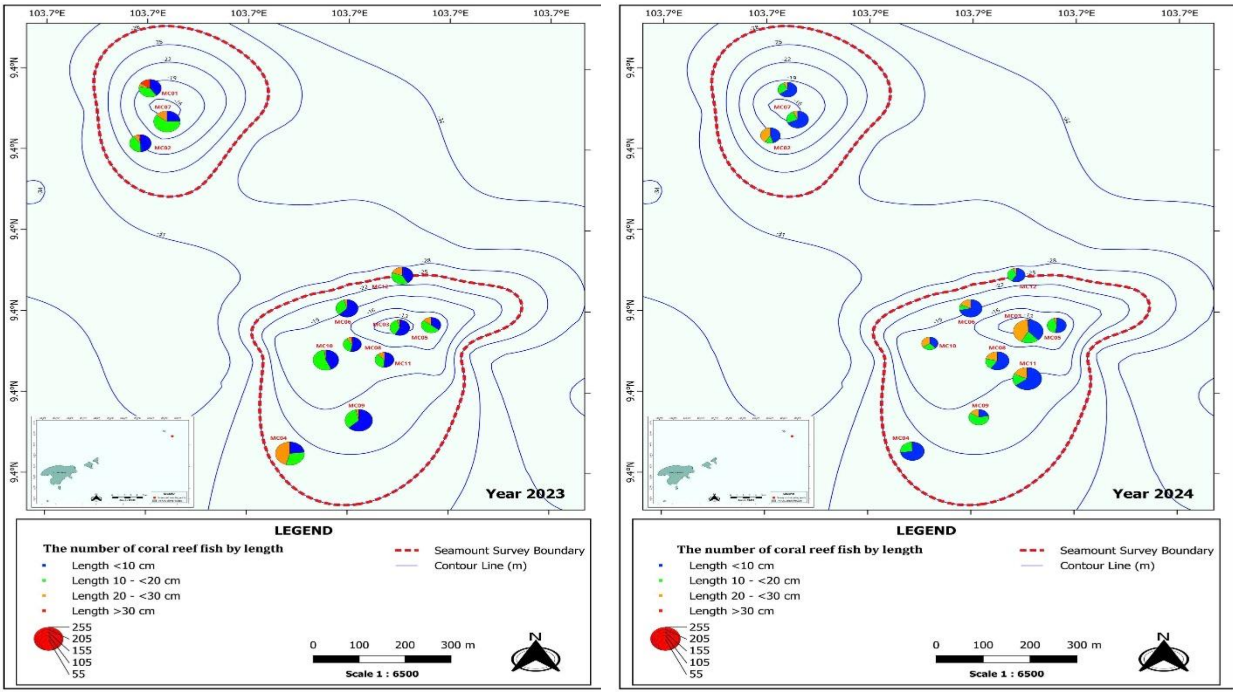


Figure 7. Density distribution of coral reef fish at the surveyed cross-section.

(A): Northeast monsoon season; (B): Southwest monsoon season

Discussion

This research presents the inaugural scientific documentation of coral reef fish ecology within Tho Chu Archipelago's offshore seamounts. A robust correlation between bathymetric geomorphology and fish assemblage patterns underscores how physical structure dictates population distribution across these unique features (**Figures 2A, 5 and 6**). The reef summit and upper slope provide exceptional structural complexity rich in rocky substrates, dense coral cover, and intricate natural cavities. These features create critical microhabitats for shelter, specialized foraging, and essential ontogenetic transitions, directly accounting for the peak species density and diversity observed in the shallower strata (**Figures 5 and 6**). In contrast, the reef foot (26-30m) transitions into a flatter, significantly less complex seabed environment. This pronounced depth-dependent shift aligns with global ecological models, where substrate complexity, light attenuation, and resource availability serve as the primary drivers of community structure. Ultimately, the study indicates that seamount topography is the fundamental architect of biodiversity within these vibrant, offshore marine ecosystems.

The 83 species documented across the surveyed depths represent a moderate yet ecologically significant level of biodiversity within the Vietnamese archipelago context. While this richness is lower than figures from Ly Son, Phu Quoc, Cu Lao Cham, or Con Dao, direct comparisons require caution (**Table 2**). Unlike those expansive, shallow coastal systems, this study specifically targeted compact offshore seamounts (≈ 52ha) with depth-limited reef development. Consequently, the lower species count reflects inherent geomorphological constraints and a smaller spatial scale rather than habitat degradation or poor ecological health. These findings suggest that the unique environmental conditions of seamount formations rather than research frequency or localized decline, are the primary drivers of the observed community structure, highlighting the distinct ecological niche these offshore formations occupy.

The observed seasonal shifts in species richness, particularly the surge during the Northeast monsoon, underscore the critical interplay between oceanographic conditions, water clarity, and habitat structural integrity. This pattern aligns with findings from the Hai Tac Islands (Shannon & Wiener, 1963; Tran Van Huong *et al.*, 2021a), where the "wilder," high-complexity terrain of offshore seamounts provides superior refuge during turbulent weather (Tran Van Huong & Nguyen Khac Bat, 2020; Huong *et al.*, 2022). Conversely, the lower monsoon-season species counts in Nam Du and Phu Quoc may stem from intense marine tourism and habitat exploitation, which likely diminish the reefs' resilience. Consequently, these results clearly suggest that the Tho Chu seamounts function as vital ecological sanctuaries. By offering stable shelter and abundant resources during adverse environmental periods, these geomorphologically diverse formations play a fundamental role in maintaining regional fish populations and buffering against seasonal fluctuations.

Reef fish were documented across the entire seamount profile, from summit to foot, demonstrating spatial community continuity. However, a significant gradient in species richness emerged: the reef summit (11-15m) and reef slope (16-25m) hosted the highest concentrations, while the reef foot (26m to 28m in depth) showed a sharp decline (**Figures 6A and 6B**). This pattern underscores the vital link between depth and habitat complexity. In shallower zones, robust coral growth and intricate rocky structures provide optimal shelter and foraging grounds. Conversely, below 25m, the environment transitions to a flat, sediment-heavy seabed of sand and gravel. This loss of structural complexity and natural cavities restricts available niche space, directly limiting species distribution (**Figures 2 and 5**). Ultimately, these findings highlight that topographic complexity is the primary driver of biodiversity within these seamount ecosystems.

Table 2. Comparison of the number of coral reef fish species in islands/archipelagos in Vietnam

No.	Island/Archipelago	Number of species	Area (ha)	References
1	Tho Chu Archipelago's seamounts	83	52	This study
2	Long Chau	98	75	Tran Van Huong *et al.* (2021b)
3	Cat Ba	169	75	Tran Van Huong & Nguyen Van Hieu (2019)
4	Con Co	104	274	Tran Van Huong *et al.* (2020)
5	Cu Lao Cham	200	139	Nguyen Van Long *et al.* (2006)
6	Ly Son	232	1,704	Hoang Xuan Ben (2018); Hoang Xuan Ben *et al.* (2018)
7	Phu Quoc	152	220	Nguyen Van Long *et al.* (2007)
8	Con Dao	202	914	Vo Sy Tuan *et al.* (2005)
9	Tho Chu	261	128	Do Anh Duy *et al.* (2017)
10	Nam Du	108	145	Tran Van Huong & Nguyen Khac Bat (2020)

Although the diversity index (H') values suggest high biodiversity, this comparison remains symbolic. The unique geomorphology and composition of the Tho Chu seamounts differ fundamentally from coastal reefs (**Table 3**). To objectively define their ecological role, expanded research across more Vietnamese seamounts with increased survey frequency is essential. These findings underscore that seamount ecosystems require distinct benchmarks rather than direct coastal comparisons.

Average reef fish density at the Tho Chu seamounts was recorded as 250.46 ± 111.83 individuals per $500m^2$. While low compared to shallow coastal reefs (Nguyen Huu Phung *et al.*, 1995; Vo Dieu *et al.*, 2012; Do Anh Duy *et al.*, 2017; Huong *et al.*, 2022), this figure provides the first critical data regarding fish distribution within these offshore seamounts. Critically, the size distribution mirrors that of coastal coral reefs, with small fish (< 10cm) dominating (averaging 50.10 ± 15.07%). The seamount's dominance indicates a dual ecological function, serving as a critical breeding ground and nursery area for resource regeneration. The scarcity of large-bodied fish signals potential overexploitation, mirroring coastal reef trends. Consequently, the Tho Chu seamount ecosystem urgently requires a robust, long-term conservation and management framework.

The Tho Chu seamounts are ecologically vital habitats that complement Vietnam's coastal reef systems, serving as essential nurseries and biodiversity reservoirs. However, the scarcity of large fish and sensitivity to depth-related habitat changes signal significant vulnerability. These findings necessitate focused monitoring, stricter fisheries regulation, and the formal inclusion of offshore seamounts in national marine protected area networks and spatial planning frameworks.

Conclusions

This study provides the first baseline assessment of Tho Chu Archipelago's offshore seamounts, revealing depth-driven distribution patterns shaped by geomorphological complexity. While these habitats support diverse fish populations and serve as vital nurseries, evidenced by juvenile dominance, the scarcity of large-bodied individuals suggests emerging ecological pressures. These findings underscore the vulnerability of seamount ecosystems, necessitating targeted monitoring and improved management within Vietnam's offshore waters. Ultimately, this dataset establishes a critical foundation for integrating these unique formations into national conservation and marine spatial planning frameworks.

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Table 3. H' index of the seamounts of Tho Chu Archipelago compared with the coastal islands/archipelagos

No.	Island/Archipelago	H' index	References
1	Tho Chu Archipelago's seamounts	4.93	This study
2	Long Chau	3.08	Tran Van Huong *et al.* (2021b)
3	Hai Tac	2.25	Tran Van Huong *et al.* (2021a)
4	Ha Long Bay	0.74	
5	Da Tay	2.56	
6	Toc Tan	2.74	
7	Sinh Ton	3.09	Nguyen Van Quan (2005)
8	Da Nam	2.43	
9	Cu Lao Cham	1.23	
10	Cu Lao Cau	1.28	
11	Ly Son	1.46	Vo Dieu *et al.* (2012)
12	Nam Du	2.72	Tran Van Huong & Nguyen Khac Bat (2020)
13	Con Co	3.76	Tran Van Huong *et al.* (2020)

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