RESEARCH ARTICLE
Journal of Biometry Studies (2026) 6(1): 1-15
DOI: 10.61326/jofbs.v6i1.01
www.biometrystudies.com

Journal of Biometry Studies
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Reef fish community structure and biomass in a fish sanctuary and a proposed marine protected area in Ilocos Sur, Philippines

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Received: 27/03/2026, Accepted: 09/05/2026

Abstract

This study assessed reef fish community structure and biomass in an established fish sanctuary and a proposed marine protected area (MPA) in Sto. Domingo, Ilocos Sur, northwestern Philippines. Underwater fish visual census (FVC) was conducted along belt transects in established Calay-Ab fish sanctuary and the proposed MPA (Calay-Ab-Sived reef), supplemented by assessments of artificial reef structures within the sanctuary. Diversity, evenness, and biomass were estimated using species-specific length–weight relationships. A total of 1562 individuals representing 43 species from 18 families were recorded. The established Calay-Ab fish sanctuary supported 28 species from 13 families, while the proposed MPA harbored 30 species from 16 families. Species diversity was moderate in the established Calay-Ab fish sanctuary (H' = 2.719) and low in the proposed MPA (H' = 2.485), with very low evenness at both sites ($J' \approx 0.11$), indicating dominance by a few species. Fish biomass values were relatively higher in the sanctuary (26.289 MT/km²) than in the proposed MPA (21.849 MT/km²) during the assessment period. Of the 86 AR units deployed, 59 (69%) remained intact and were colonized by macroalgae, gorgonians, reef fishes, and an endangered green sea turtle (*Chelonia mydas*), underscoring their ecological value. The findings provide baseline ecological information that may support future MPA management, monitoring, and conservation planning in Sto. Domingo, Ilocos Sur, Philippines.

Keywords: ARs, Biomass, Diversity, MPAs, Reef fish structure, Sto. Domingo, Ilocos Sur

Please cite this article as follows:
Allayban, M. T., Ragutero, F. C., Dagdagan, J. V. P., Dela Peña, G. G., & Soliven, C. B. (2026). Reef fish community structure and biomass in a fish sanctuary and a proposed marine protected area in Ilocos Sur, Philippines. *Journal of Biometry Studies*, *6*(1), 1-15. https://doi.org/10.61326/jofbs.v6i1.01

1. Introduction

The Philippines is an archipelagic country in Southeast Asia with 7641 islands (Tahiluddin & Sarri, 2022). It is bordered by seas and oceans, with maritime boundaries shared with neighboring Southeast Asian countries. Its marine waters extend approximately 2.2 million km², including its Exclusive Economic Zone (EEZ), and constitute a central part of the Coral Triangle—supporting one of the world's most diverse fish faunas and serving as a biodiversity hotspot (Allen, 2008; BFAR, 2025; Carpenter & Springer, 2005). This unique geographic and ecological setting underpins the country's critical role in global marine biodiversity conservation and regional food security, as its coastal and reef ecosystem sustains millions of livelihoods, supports fisheries production, and serves as vital reservoirs of marine life that contribute to ecological resilience and sustainable resource management (Barut et al., 2004; BFAR, 2025; Novilla & Fabinyi, 2025).

Coral reef ecosystems provide goods and services to a large number of people. These communities depend on them for daily sustenance, income, and other necessities, contributing to the social and economic development of coastal areas (Hoegh-Guldberg et al., 2019). However, these ecosystems are under severe threat. In the Philippines, overfishing, destructive fishing methods, overexploitation, and sedimentation are among the leading threats that have destroyed coral reef areas (Gomez et al., 1994; White et al., 2000; White & Vogt, 2000). These pressures are still escalating and expanding. For instance, Licuanan et al. (2019) reported a decline in coral cover in the major areas identified. They emphasized that Philippine reefs are no longer what they once were in terms of hard coral cover. Reefs are no longer categorized as 'excellent', reinforcing earlier findings that the coral reefs of the country are generally in poor condition (Alcala & Russ, 2002).

Owing to the current condition of the coral reef ecosystem and the goods and services it provides, Novilla and Fabinyi (2025) stressed that careful reconfiguration of governance regarding the conditions of use and access to coral reef areas must be undertaken. To maintain the integrity of coral reef areas, much effort is still needed (Alcala & Russ, 2002). The development of sustainable management regimes, including the establishment of marine reserves, regulation of harvest, enhancement of natural productivity, reef restoration efforts, and other integrated management approaches, is essential to mitigate the decline of coral reefs (Alcala & Russ, 2002; White et al., 2000; White & Vogt, 2000). The dynamics of these strategies must not undermine the livelihood adaptation mechanisms employed, especially for small-scale fishers, while rigid governance shifts are implemented (Hoegh-Guldberg et al., 2019; Novilla & Fabinyi, 2025), particularly in marine waters, which are increasingly viewed as a lucrative frontier for economic development (Bennett et al., 2021). White et al. (2000) and White and Vogt (2000) further highlight that reef management strategies must be a multisectoral effort involving various stakeholders, such as local fishing communities, local government units (LGUs), and other concerned organizations.

Although preserving the reefs is challenging due to social factors (e.g., population growth, poverty) that worsen reef protection and management, saving the Philippine reefs depends on strong political will and societal cooperation through various integrated programs (Alcala & Russ, 2002; White et al., 2000; White & Vogt, 2000). In the country, Marine Protected Areas (MPAs), are among the highlighted devolution of authority transferred under LGUs (White et al., 2002) due to their wider recognition as a key tool for conserving biodiversity and rebuilding fish stocks (Galveia & Macusi, 2025; Halpern, 2003; Muallil et al., 2019; Russ et al., 2004; White et al., 2002) after addressing highlighted drawbacks (Edgar et al., 2014; Galveia & Macusi, 2025) towards the MPA holistic approach. This study aims to provide science-based data on reef fish communities and habitat quality to support marine spatial planning, local fisheries management, and potential MPA expansion at the municipality of Sto. Domingo in the province of Ilocos Sur, northwestern Philippines. Specifically, this study aims to assess reef fish communities by examining their abundance, species diversity, and biomass within existing and proposed MPAs. It also evaluates the condition of artificial reef (AR) structures through the number of intact units and the marine organisms colonizing them and seeks to develop science-based recommendations for the LGU to aid in formulating management plans and policies for coastal fisheries and marine habitat conservation.

2. Material and Method

2.1. Study site

Figure 1 illustrates the locations of the two reef sampling sites in Sto. Domingo, Ilocos Sur: Calay-Ab, an established fish sanctuary, and Calay-Ab-Sived, a proposed MPA. The sites were mapped using a Global Positioning System (GPS). The coral reefs surveyed ranged in depth from 9.14 to 13.75 m in both reef areas. The distance between the Calay-Ab and Calay-Ab-Sived reefs was approximately 500-700 m from each other. A 100-m transect line was laid, with two transects were deployed within the Calay-Ab fish sanctuary, while three transects were laid across the proposed MPA reef area to evaluate fish abundance, diversity, and biomass. The assessment was conducted during a single survey period and therefore represents a rapid ecological assessment or temporal snapshot of the reef fish community structure within the surveyed reef areas.

In addition to the fish visual census (FVC), the monitoring also included an assessment of the AR structures installed at established Calay-Ab fish sanctuary. This involved (1) counting the number of intact AR units, (2) observing and identifying marine organisms attached to the structures, and (3) documenting the presence and types of fish species associated with the ARs. These observations contribute to understanding the ecological performance of ARs in enhancing local biodiversity and supporting fish habitats.

2.2. Reef fish community

The reef fish community was assessed using the fish visual census (FVC) method (Figure 2). The FVC technique is widely used to estimate the diversity, abundance, and size distribution of common, observable reef fishes in areas with good underwater visibility, as described by Eballe (2014) and English et al. (1997). These data provide important indicators of the status and

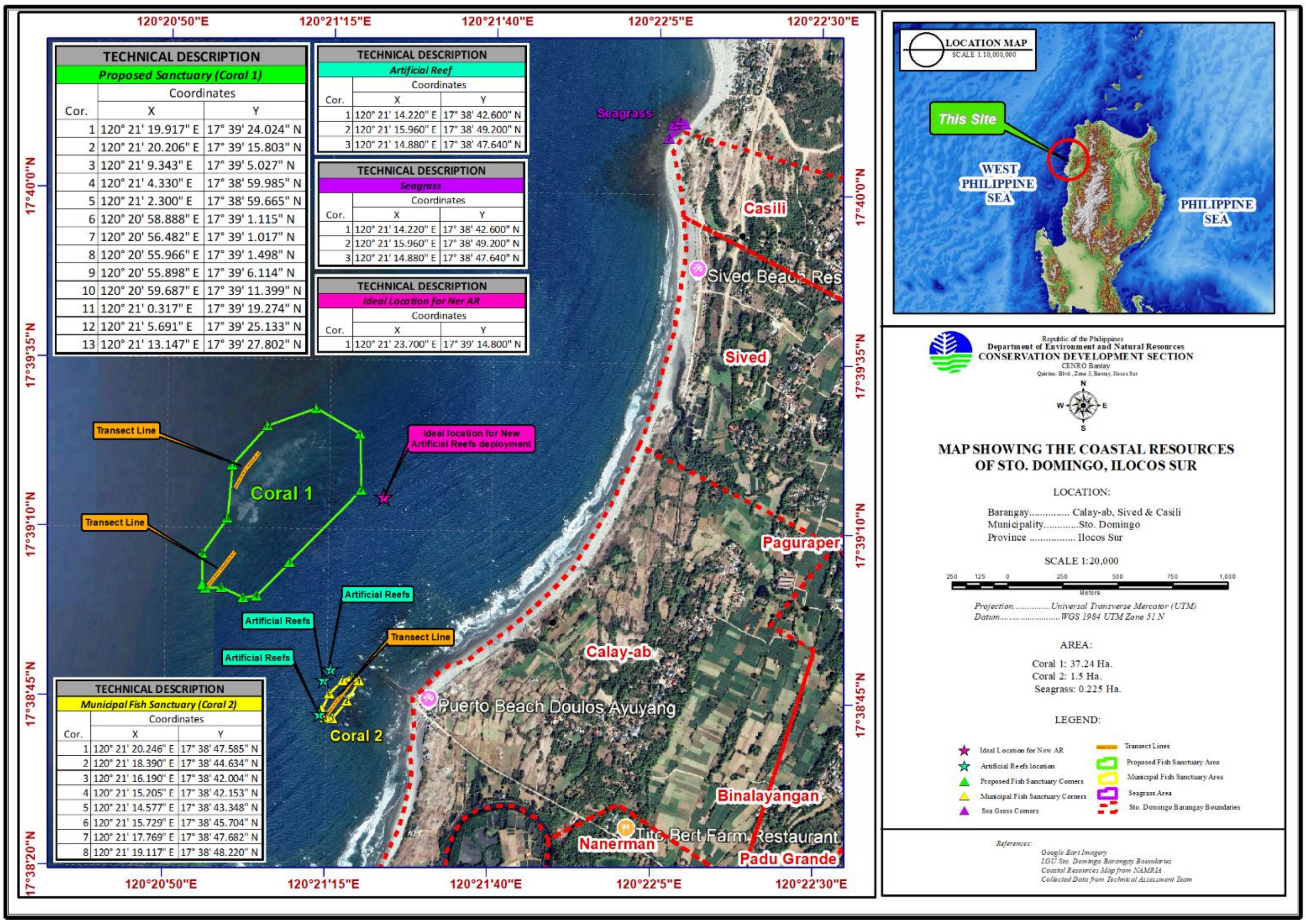

Figure 1. Map showing the assessment site in the municipality of Sto. Domingo, Ilocos Sur, Philippines

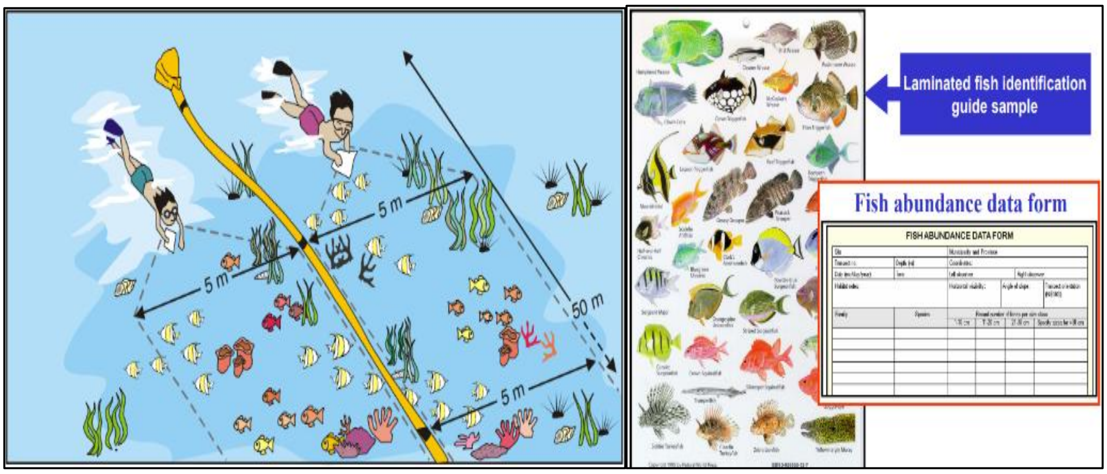

Figure 2. Fish visual census (FVC) method and fish identification materials used during reef assessment

health of fish stocks within the surveyed reef areas. A 100-m transect line was deployed as the survey area, with observations conducted within a 5-m belt on either side, covering a total area of 500 m² per transect. Fish species encountered along the transect were recorded, including counts and estimated lengths (in cm). Fish data were grouped and summarized by species and families to evaluate species diversity and abundance. Mean fish abundance was calculated as the number of individuals observed per 500 m². Biomass estimates were derived using species-specific length-weight relationships, enabling an assessment of total fish biomass within each transect. Dominant fish families and species were identified to reflect the current ecological status of the coral reef habitats.

2.3. Diversity, relative abundance, and frequency

All calculations for relative abundance, Shannon-Wiener diversity index (*H'*), Pielou's evenness index (*J'*), and fish biomass were computed using Microsoft Excel 2021 following standard ecological formulas described by Odum and Barrett (2004) and Pielou (1966).

Relative abundance (*K*) of each fish species was calculated using Odum and Barrett (2004) formula, as:

$$K = \frac{\text{The amount of species (i)}}{\text{The number of individuals of all species}} \text{x100} \quad (1)$$

The Shannon-Wiener Index method was used to measure biodiversity in a community, including fish species in aquatic ecosystems using this formula:

$$H' = -\sum (P_i * \ln(P_i)) \quad (2)$$

Where, H' is the Shannon-Wiener Index; Σ is the sum over all species; Pi is the proportion of individuals belonging to the *i*-th species in the community; and ln is the natural logarithm.

To describe the index, the criteria given by Gervaňa and Pampilona (2009) in Table 1 are used.

Meanwhile, Pielou's evenness index is used to measure the equitability among species in reef-associated fishes (Pielou, 1966). The evenness index (*J*) indicates the relative abundance of each species. An index value close to 1 signifies that the individuals are relatively evenly distributed; furthermore, if it is close to 0, it means that the numbers of individuals across species are unevenly distributed.

$$J' = \frac{H'}{\ln S} \quad (3)$$

Where, *J'* is the evenness index, *H'* is the diversity index, and *S* is the number of species. For the evenness criteria, Table 2 is used.

2.5. Data analysis

The study employed a descriptive ecological assessment approach. Data interpretation was based on observed numerical values of fish abundance, diversity indices, evenness, and biomass. No inferential statistical analyses (e.g., Mann–Whitney U test, ANOSIM, or PERMANOVA) were applied because the assessment was intended to provide baseline descriptive information from a single survey period. In addition, the number of transects and sampling replicates was limited, which may not be sufficient to support robust statistical comparisons between reef areas.

Table 1. Diversity index classification scale (Gervaňa & Pampilona, 2009)

Category	H' values
Very high	≥3.5000
High	3.0000-3.4999
Moderate	2.5000-2.9999
Low	2.0000-2.4999
Very low	≤1.9999

Table 2. Evenness index classification scale

Evenness value	Condition of community structures	Category
>0.81	Very equally	Very good
0.61-0.80	More equally	Good
0.41-0.60	Equally	Medium
0.21-0.40	Fairly equally	Poor
<0.20	Not equally	Very Poor

2.4. Biomass

Biomass of fish is commonly computed using a standard length-weight relationship formula in fisheries science, as:

$$W = f(a \text{ x } L^b) \quad (4)$$

Where, *W* is an estimated weight of the fish (in grams); *L* is the length of the fish (cm); *a* and *b* are the species-specific constants; and *f* is the number of counts of fish species. Table 3 presents the fish density and biomass scale.

Table 3. Fish density and biomass metrics (Nañola et al., 2004)

Category	Fish Density (species/1000 m²)	Fish Biomass (MT/km²)
Very high	>7592	≥41
High	2268-7592	21-40
Moderate	677-2267	11-20
Poor	202-676	6-10
Very poor	<202	≤5

3. Results and Discussion

3.1. Fish abundance and diversity

The FVC identified a total of 43 species and 18 families of reef fishes commonly associated with corals at the study sites (Table 4). Within the Clay-Ab municipal fish sanctuary, a total of 28 species across 13 families were identified. The predominant ten fish families recorded are the Pomacentridae (damselfishes), Mullidae (goatfishes), Lutjanidae (snappers), Labridae

Table 4. Reef fishes identified and their IUCN Red List status in the study sites

Family name	Scientific name	English name	Local name	Study sites		IUCN Status
				Established Calay-Ab Fish Sanctuary	Proposed MPA	
Acanthuridae	*Acanthurus lineatus*	Lined surgeonfish	Pugpugot	✓		LC
	Acanthurus pyroferus	Chocolate surgeon fish	Pugpugot		✓	LC
	Ctenochaetus strigosus	Fivelined bristletooth	Pugpugot	✓	✓	LC
	Naso unicornis	Bluespine unicornfish	Sungayan	✓		LC
Apogonidae	*Fibramia amboinensis*	Amboina cardinal fish	Bagsang-bakes	✓		DD
Balistidae	*Rhinecanthus verrucosus*	Blackbelly triggerfish	Papakol		✓	LC
Chaetodontidae	*Chaetodon unimaculatus*	Teardrop butterfly fish	Par-parya	✓	✓	LC
	Chaetodon punctatofasciatus	Spotbond butterfly fish	Par-parya	✓	✓	LC
	Chaetodon rafflesii	Latticed butterflyfish	Par-parya	✓		LC
	Chaetodon vagabandus	Vagabond butterfly fish	Par-parya		✓	LC
	Chaetodon xanthurus	Pearlscale butterfly fish	Par-parya		✓	LC
	Ostorhinchus bryx	Offshore cardinalfish	Bagsang-bakes	✓		LC
Cirrhitidae	*Cirrhitichthys falco*	Dwarf hawkfish	Angrat		✓	LC
Epinephelidae	*Cephalopholis urodeta*	Darkfin hind	Lapu-lapu	✓	✓	LC
Holocentridae	*Myripristis murdjan*	Pinecone soldierfish	Baratiktik	✓	✓	LC
Labridae	*Bodianus mesothorax*	Splitlevel hogfish	Mol-mol		✓	LC
	Cheilio inermis	Cigar wrasse	Mol-mol	✓		LC
	Gomphosus varius	Bird wrasse	Mol-mol		✓	LC
	Halichoeres hortulanus	Checkerboard wrasse	Mol-mol		✓	LC
	Halichoeres nebulosus	Nebulous wrasse	Mol-mol	✓		LC
	Hemigynus fasciatos	Barred thicklip wrasse	Mol-mol		✓	LC
	Labroides dimidiatus	Bluestreak cleaner wrasse	Mol-mol	✓	✓	LC
Lutjanidae	*Lutjanus lutjanus*	Big-eye snapper	Baratiktik	✓	✓	LC
	Lutjanus russelli	Russell's snapper	Baratiktik	✓	✓	LC
	Lutjanus timorensis	Timor snapper	Bugbugsi	✓	✓	LC
Mullidae	*Parupeneus barberinus*	Dash-and-dot goatfish	Balaki	✓	✓	LC
	Upeneus quadrilineatus	Fourstripe goatfish	Balaki	✓		NE
Pomacanthidae	*Chaetodonplus mesoleucus*	Vermiculated angelfish	Bibiran		✓	LC
	Pomacanthus imperator	Emperor angelfish	Bibiran	✓	✓	LC
Pomacentridae	*Abudefduf vaigiensis*	Indopacific sergeant	Ar-aro	✓	✓	LC
	Neopomacentrus azysron	Yellowtail demoiselle	Ar-aro	✓		LC
	Pomacentrus philippinus	Philippine damsel	Ar-aro	✓	✓	LC
	Pycnochromis caudalis	Blue axil chromis	Ar-aro	✓	✓	LC
	Pygoplites diacanthus	Royal angelfish	Bibiran		✓	LC
Scaridae	*Chlorurus bowersi*	Bower's parotfish	Mol-mol		✓	NT
Scorpaenidae	*Pterois volitans*	Red lionfish	*		✓	LC
Siganidae	*Siganus puellus*	Masked spinefoot	Malaga	✓		LC
	Siganus spinus	little spinefoot	Malaga	✓		LC
	Siganus sutor	Shoemaker spinefoot	Malaga	✓		LC
	Siganus vulpinus	Fox face	Malaga		✓	LC
Tetraodontidae	*Arothron nigropunctatus*	Blackspotted puffer	Butete		✓	LC
Terapontidae	*Terapon puta*	Small-scaled terapon	Baraungan	✓		NE
Zanclidae	*Zanclus cornutus*	Moorish idol	Bayang bayang	✓	✓	LC

** for verification.*
IUCN red list: LC – Least Concerned; VU -Vulnerable; NT – Non-Threatened; DD -Data Deficient; NE – Not Evaluated.

(wrasses), Apogonidae (cardinalfish), Acanthuridae (surgeonfishes), Siganidae (spinefoot fishes), Pomacanthidae (angelfish), Holocentridae (squirrelfishes), and Chaetodontidae (butterflyfishes). The three least represented families are Epinephelidae, Zanclidae, and Terapontidae. The FVC also showed that most species are listed as Least Concern (LC), three as Not Evaluated (NE), and one as Data Deficient (DD) on the IUCN Red List.

Meanwhile, in the proposed MPA, FVC results indicated that 30 species from 16 families were initially observed. The top ten fish families recorded are the Acanthuridae (surgeonfishes), Pomacentridae (damselfishes), Lutjanidae (snapper), Labridae (wrasses), Pomacanthidae (angelfish), Chaetodontidae (butterflyfishes), Epinephelidae (groupers), Mullidae (goatfishes), Balistidae (triggerfish), and Cirrhitidae (hawkfishes). The least are Holocentridae, Zanclidae, Siganidae, Scaridae, Scorpaenidae, and Tetraodontidae families. The FVC also showed that most species are categorized as Least Concerned (LC), with one species classified as Non-Threatened (NT) category based on the IUCN Red List.

For fish counts and abundance, established Calay-Ab fish sanctuary recorded a total of 658 fish individuals across 28 species from 13 families (Table 5). The dominant species were Timor snapper (*L. timorensis*, 13.68%), blue Axil chromis (*P. caudalis*, 12.92%), dash-and-dot goatfish (*P. barberinus*, 9.73%), bluestreak cleaner wrasse (*L. dimidiatus*, 8.05%), and yellowtail demoiselle (*N. azysron*, 7.60%). Species with the lowest abundance included small-scaled terapon (*T. puta*, 0.15%) and lined surgeonfish (*A. lineatus*, 0.15%). These results align with studies by Russ et al. (2004), who found that protected reefs tend to harbor higher abundances of commercially important species such as snappers and goatfishes, reflecting effective management in fish sanctuaries.

Table 5. Fish counts and relative abundance of recorded species in the established Calay-Ab fish sanctuary

Scientific name	English name	Count			Abundance (%)
		T1	T2	Total	
Lutjanus timorensis	Timor snapper	40	50	90	13.68
Pycnochromis caudalis	Blue axil chromis	50	35	85	12.92
Parupeneus barberinus	Dash-and-dot goatfish	60	4	64	9.73
Labroides dimidiatus	Bluestreak cleaner wrasse	38	15	53	8.05
Neopomacentrus azysron	Yellowtail demoiselle	40	10	50	7.60
Upeneus quadrilineatus	Fourstripe goatfish	15	20	35	5.32
Ctenochaetus strigosus	Fivelined bristletooth	20	13	33	5.01
Fibramia amboinensis	Amboina cardinal fish	20	10	30	4.56
Ostorhinchus bryx	Offshore cardinalfish	30	0	30	4.56
Pomacentrus philippinus	Philippine damsel	10	18	28	4.25
Pomacanthus imperator	Emperor angelfish	21	5	26	3.96
Halichoeres nebulosus	Nebulous wrasse	20	5	25	3.80
Siganus spinus	Little spinefoot	0	20	20	3.04
Siganus puellus	Masked spinefoot	8	5	13	1.98
Myripristis murdjan	Pinecone soldierfish	8	5	13	1.98
Cheilio inermis	Cigar wrasse	4	8	12	1.82
Abudefduf vaigiensis	Indopacific sergeant	8	2	10	1.52
Cephalopholis urodeta	Darkfin hind	5	2	7	1.06
Chaetodon unimaculatus	Teardrop butterfly fish	6	0	6	0.91
Naso unicornis	Bluespine unicornfish	3	3	6	0.91
Lutjanus russellii	Russell's snapper	2	3	5	0.76
Zanclus cornutus	Moorish idol	3	1	4	0.61
Chaetodon punctatofasciatus	Spotbond butterfly fish	4	0	4	0.61
Lutjanus lutjanus	Big-eye snapper	3	0	3	0.46
Siganus sutor	Shoemaker spinefoot	0	2	2	0.30
Chaetodon rafflesii	Latticed butterflyfish	0	2	2	0.30
Terapon puta	Small-scaled terapon	1	0	1	0.15
Acanthurus lineatus	Lined surgeonfish	1	0	1	0.15
	Total	420	238	658	100

Table 6. Fish counts and relative abundance of fish species recorded in the proposed MPA in the Calay-Ab-Sived reef area

Scientific name	English name	Count				Abundance (%)
		T1	T2	T3	Total	
Ctenochaetus strigosus	Fivelined bristletooth	109	75	0	184	20.35
Pycnochromis caudalis	Blue axil chromis	79	20	39	138	15.27
Pomacentrus philippinus	Philippine damsel	70	31	15	116	12.83
Acanthurus pyroferus	Chocolate surgeon fish	19	20	45	84	9.29
Lutjanus timorensis	Timor snapper	3	50	0	53	5.86
Lutjanus lutjanus	Big-eye snapper	18	0	18	36	3.98
Cephalopholis urodeta	Darkfin hind	7	3	15	25	2.77
Parupeneus barberinus	Dash-and -dot goatfish	15	4	4	23	2.54
Pomacanthus imperator	Emperor angelfish	13	0	8	21	2.32
Chaetodontoplus mesoleucus	Vermiculated angelfish	10	10	0	20	2.21
Gomphosus varius	Bird wrasse	8	2	10	20	2.21
Bodianus mesothorax	Splitlevel hogfish	10	10	0	20	2.21
Labroides dimidiatus	Bluestreak cleaner wrasse	4	4	8	16	1.77
Hemigymnus fasciatus	Barred thicklip wrasse	8	8	0	16	1.77
Halichoeres hortulanus	Checkerboard wrasse	0	0	16	16	1.77
Myripristis murdjan	Pinecone soldierfish	0	1	14	15	1.66
Cirrhitichthys falco	Dwarf hawkfish	2	2	11	15	1.66
Rhicanthus verrucosus	Blackbelly triggerfish	0	3	12	15	1.66
Zanclus cornutus	Moorish idol	3	3	7	13	1.44
Siganus vulpinus	Fox face	6	0	6	12	1.33
Chaetodon vagabandus	Vagabond butterfly fish	3	3	4	10	1.11
Chlorurus bowersi	Bower's parrotfish	1	0	8	9	1.00
Chaetodon unimaculatus	Teardrop butterfly fish	2	2	3	7	0.77
Abudefduf vaigiensis	Indopacific sergeant	5	0	0	5	0.55
Chaetodon punctatofasciatus	Spotbond butterfly fish	2	2	1	5	0.55
Chaetodon xanthurus	Pearlscale butterfly fish	1	1	2	4	0.44
Pygoplites diacanthus	Royal angelfish	3	0	0	3	0.33
Arothron nigropunctatus	Blackspotted puffer	1	0	0	1	0.11
Lutjanus ruselli	Russell's snapper	1	0	0	1	0.11
Pterrois volitans	Red lionfish	0	0	1	1	0.11
	Total	403	254	247	904	100

Meanwhile, in the proposed MPA in the Calay-Ab-Sived reef area, a total of 904 individuals from 30 species across 16 families were recorded (Table 6). The most abundant species were fivelined bristletooth (*C. strigosus*, 20.35%), blue Axil chromis (*P. caudalis*, 15.27%), Philippine damsel (*P. philippinus*, 12.83%), chocolate surgeonfish (*A. pyroferus*, 9.29%), and Timor snapper (*L. timorensis*, 5.86%). Less abundant species included blackspotted puffer (*A. nigropunctatus*, 0.11%) and Red lionfish (*P. volitans*, 0.11%). The prevalence of herbivorous fishes such as *C. strigosus* and *A. pyroferus* supports observations by Hoey and Bellwood (2009), who emphasized the critical role of herbivores in maintaining coral reef resilience by controlling algal overgrowth.

The common distribution of reef fishes across two reef areas was observed. This provides vital insights into the ecological structure and functioning of each site, as trophic structure reflects the stability of the food web, energy flow, and habitat quality. In the established Calay-Ab fish sanctuary, fish families such as Zanclidae (Moorish idol), Pomacentridae (damselfishes), Labridae (wrasses and hogfishes), Cirrhitidae (hawkfishes), and Scorpaenidae (lionfishes) were observed. These species generally function as herbivores, planktivores, and small invertivores—fulfilling critical roles in algae control, habitat maintenance, and nutrient cycling (Bellwood et al., 2004; Hoey and Bellwood, 2009). Their prevalence indicates that the reef provides an appropriate habitat structure and forage availability, signifying a moderate level of ecological stability. Meanwhile, the target fish group fish population, includes economically important species such as groupers (*Epinephelidae*), snappers (*Lutjanidae*), rabbitfishes (*Siganidae*), and parrotfishes (*Scaridae*). These species are often subject to fishing pressure due to their high commercial value (Cinner et al., 2009; Elston et al., 2020). Their abundance signals the area's importance to fisheries, though it may also indicate potential risks of overexploitation if not sustainably managed. Furthermore, indicator species such as angelfishes (*Pomacanthidae*) and butterflyfishes (*Chaetodontidae*), which are highly sensitive to coral degradation and depend on live coral for food and shelter (Hourigan et al., 1989; Pratchett, 2005; Pratchett et al., 2006).

Meanwhile, a comparable pattern is evident in the proposed MPA, where the target fish observed reinforces the reef's role as a key fishing ground. Species contributing to this group include *Terapontidae*, *Mullidae* (goatfishes), *Lutjanidae*, *Holocentridae* (soldierfishes), and *Acanthuridae* (surgeonfishes), many of which are known for their trophic versatility and ecological importance (Elston et al., 2020; Friedlander & Parrish, 1998). Other species also indicate that the reef is still capable of supporting a wide array of resident fish, including *Pomacentridae*, *Zanclidae*, *Labridae*, and *Apogonidae* (cardinalfishes). This indicates a functionally balanced ecosystem, though perhaps still facing localized stress. Meanwhile, an indicator group of fish is observed; their presence echoes the pattern at the sanctuary site and further suggests suboptimal coral habitat conditions (Bellwood et al., 2004; Green & Bellwood, 2014; Wainwright & Bellwood, 2002). This wide distribution of fish highlights the need for coral habitat restoration and management strategies that protect herbivores and coral-dependent species to maintain ecosystem resilience.

Among the top 20 species documented in Sto. Domingo, Ilocos Sur, data on FVC results from both sites revealed a total of 1562 fish individuals (Table 7). The predominant species include *P. caudalis*, *C. strigosus*, *P. philippinus*, *L. timorensis*, and *P. barberinus*, representing the major fish families Pomacentridae, Acanthuridae, Lutjanidae, and Mullidae. These findings align with the reef fish community structures documented in Philippine reefs (Alcala & Russ, 2006). This suggests a reef ecosystem characterized by a balanced composition of planktivores and herbivores, which are essential for sustaining ecological functions.

Table 7. Top 20 fish species recorded in Sto. Domingo, Ilocos Sur and its diversity indices

Rank	Scientific name	English name	Count		Total Count
			Established Calay-Ab Fish Sanctuary	Proposed MPA	
1	*Pycnochromis caudalis*	Blue Axil Chromis	85	138	223
2	*Ctenochaetus strigosus*	Fivelined bristletooth	33	184	217
3	*Pomacentrus philippinus*	Philippine Damsel	28	116	144
4	*Lutjanus timorensis*	Timor snapper	90	53	143
5	*Parupeneus barberinus*	Dash-and-dot goatfish	64	23	87
6	*Acanthurus pyroferus*	Chocolate Surgeon fish	0	84	84
7	*Labroides dimidiatus*	Bluestreak cleaner wrasse	53	16	69
8	*Neopomacentrus azysron*	Yellowtail demoiselle	50	0	50
9	*Pomacanthus imperator*	Emperor Angelfish	26	21	47
10	*Lutjanus lutjanus*	Big-eye snapper	3	36	39
11	*Upeneus quadrilineatus*	Fourstripe goatfish	35	0	35
12	*Cephalopholis urodeta*	Darkfin hind	7	25	32
13	*Fibramia amboinensis*	Amboina cardinal fish	30	0	30
14	*Ostorhinchus bryx*	Offshore cardinalfish	30	0	30
15	*Myripristis murdjan*	Pinecone soldierfish	13	15	28
16	*Halichoeres nebulosus*	Nebulous wrasse	25	0	25
17	*Bodianus mesothorax*	Splitlevel hogfish	0	20	20
18	*Chaetodonplus mesoleucus*	Vermiculated Angelfish	0	20	20
19	*Gomphosus varius*	Bird wrasse	0	20	20
20	*Siganus spinus*	Little spinefoot	20	0	20
21	Others		66	133	199
		Total	658	904	1562
		H' values	2.719	2.485	2.602 (ave.)
		J' values	0.109	0.108	0.108 (ave.)

For the species diversity index, the established Calay-Ab fish sanctuary exhibited a higher diversity index (*H'* = 2.719), categorized as moderate (2.5–2.99), whereas the proposed MPA site demonstrated a slightly lower diversity index (*H'* = 2.485), classified as low diversity (2.0–2.49). The average *H'* value for both locations is 2.602, which indicates a moderate level of species diversity overall. These observations indicate variation in fish community composition between the surveyed reef areas. Diversity is often linked to habitat complexity and protection status; protected reefs tend to recruit and host more species due to reduced disturbances and better ecological integrity (Alcala & Russ, 2006; Russ et al., 2004).

Meanwhile, in terms of species evenness, both sites exhibited exceptionally low *J'* values (Calay-Ab = 0.109; Calay-Ab–Sived = 0.108), signifying that fish populations are distributed unevenly, with a limited number of species numerically dominating the community. According to Pielou's classification, values below 0.3 indicate very poor evenness, suggesting ecological stress or imbalance within the system (Pielou, 1966). The low evenness is commonly associated with disturbed or overexploited ecosystems, where competitive exclusion, overfishing, or habitat simplification allows certain resilient or opportunistic species to dominate (McClanahan et al., 1999; Hughes et al., 2007). These conditions may reduce niche availability for less dominant species, leading to skewed community structures. Despite the low evenness, the dominance of commercially important species—such as fivelined bristletooth (*C. strigosus*), chocolate surgeonfish (*A. pyroferus*), Timor snapper (*L. timorensis*), and Dash-and-dot goatfish (*P. barberinus*)—is ecologically and economically significant. These species contribute to reef productivity and local fisheries, highlighting the potential for these reef areas to support sustainable fishery activities, if properly managed.

3.2. Fish biomass

The Fish biomass employs a length-weight relationship to estimate the weight of an individual fish based on its length measured during the FVC. Parameters ‘a’ and ‘b’ are specific to each fish species and are used to calculate the estimated weight for each species. The estimated weight, when multiplied by the number of fishes, produces the total fish biomass. Therefore, both fish size and abundance (number of individuals) are significant factors in overall fish biomass. Thus, Table 8 presents the total count and average length of fish species from the two assessed sites, utilizing the constants ‘a’ and ‘b’ obtained from Froese and Pauly (2025). The findings from the FVC indicate that the recorded fish species are typically smaller than the maximum lengths reported in FishBase, however, high biomass estimate was still recorded (Table 9). Observations on the established Calay-Ab fish sanctuary contained slightly larger reef fishes than the proposed MPA. In fisheries, it is often targeted at larger, commercially valuable fish, which reduces biomass and is often due to open access or the absence of regulation. Although reef fishes in the proposed MPA in Calay-Ab–Sived area were generally smaller, their high abundance still contributed considerably to total biomass.

The established Calay-Ab municipal fish sanctuary recorded relatively higher fish biomass (26.289 MT/km²) than the proposed Calay-Ab–Sived reef area (21.849 MT/km²) during the assessment period. This observed variation may be associated with differences in protection status, habitat condition, or fishing pressure. However, since the study was based on a single survey event, the findings should be interpreted cautiously and primarily serve as baseline ecological information for future monitoring and management assessments. Numerous studies have shown that well-managed MPAs lead to increased fish biomass, size structure, and species richness due to reduced fishing mortality (Russ et al., 2005; Halpern, 2003). The absence of extractive activities allows larger-bodied and longer-lived species to flourish, enhancing reproductive output and ecological resilience (Mumby & Harborne, 2010). Conversely, proposed MPA, with a wider area than the established Calay-Ab fish sanctuary, has lower biomass and is not formally protected, reflecting continued exposure to fishing pressure, habitat disturbance, or other anthropogenic stressors that limit fish recovery (Jackson et al., 2001). Fishing in unprotected areas often targets top predators and large herbivores, leading to trophic downgrading and reduced ecological complexity (Dulvy et al., 2004). Moreover, habitat quality is dependent to the structurally complex reef features that offer refuge and foraging areas for reef-associated fish (McClanahan et al., 2007). A healthy fish biomass contributes to ecosystem services, such as nutrient cycling and reef maintenance, and provides spillover benefits to adjacent fished areas (Roberts et al., 2001; Russ & Alcala, 2010). Furthermore, a prior investigation also asserts that increased biomass was subjected to overfishing beyond the MPA. In their research, although the existing locally managed MPAs were not sufficiently effective for the management of coral reef fisheries, they were nonetheless superior to the absence of any MPA altogether (Muallil et al., 2019).

Table 8. Average length of reef fishes in Calay-Ab and Calay-Ab-Sived, Sto. Domingo, Ilocos Sur along with the maximum length obtained in FishBase

Scientific Name	English Name	Established Calay-Ab Fish Sanctuary		Proposed MPA		Total Count	Max. Length (cm)	a	b
		Count	Size Range (cm)	Count	Size Range (cm)				
Pycnochromis caudalis	Blue axil chromis	85	4-5	138	2-3	223	7.5	0.092	2.415
Ctenochaetus strigosus	Fivelined bristletooth	33	8-10	184	8-9	217	15	0.00222	3
Pomacentrus philippinus	Philippine damsel	28	7-8	116	4-5	144	10	0.0113	2.681
Lutjanus timorensis	Timor snapper	90	10-13	53	9-10	143	73.7	0.0382	2.95
Parupeneus barberinus	Dash-and-dot goatfish	64	9-10	23	9-10	87	60	0.00955	3.11
Acanthurus pyroferus	Chocolate surgeon fish	0	0	84	12-13	84	29	0.00179	3
Labroides dimidiatus	Bluestreak cleaner wrasse	53	4-5	16	2-3	69	14	0.0076	3.105
Neopomacentrus azysron	Yellowtail demoiselle	50	7-8	0	0	50	7.5	0.0297	2.868
Pomacanthus imperator	Emperor angelfish	26	8-10	21	9-10	47	40	0.0959	2.77
Lutjanus lutjanus	Big-eye snapper	3	9-10	36	15-16	39	35	0.0235	2.807
Upeneus quadrilineatus	Fourstripe goatfish	35	9-10	0	0	35	17	0.0063	3.593
Cephalopholis urodeta	Darkfin hind	7	13-15	25	9-10	32	28	0.02822	2.818
Fibramia amboinensis	Amboina cardinal fish	30	4-5	0	0	30	7	0.0255	2.857
Ostorhinchus bryx	Offshore cardinalfish	30	4-5	0	0	30	5.2	0.0087	3.36
Myripristis murdjan	Pinecone soldierfish	13	9-10	15	8-9	28	60	0.0231	3.267
Halichoeres nebulosus	Nebulous wrasse	25	8-10	0	0	25	12	0.021	3
Bodianus mesothorax	Splitlevel hogfish	0	0	20	4-5	20	25	0.0147	3
Chaetodonplus mesoleucus	Vermiculated angelfish	0	0	20	9-10	20	18	0.0601	2.692
Gomphosus varius	Bird wrasse	0	0	20	4-5	20	30	0.0147	3
Siganus spinus	little spinefoot	20	4-5	0	0	20	28	0.0264	3.122
Zanclus cornutus	Moorish idol	4	14-15	13	15-16	17	23	0.0172	3.171
Halichoeres hortulanus	Checkerboard wrasse	0	0	16	2-3	16	27	0.01485	3
Hemigynus fasciatos	Barred thicklip wrasse	0	0	16	3-4	16	30	0.0289	3
Abudefduf vaigiensis	Indopacific sergeant	10	6-7	5	10	15	20	0.0874	2.779
Cirrhitichthys falco	Dwarf hawkfish	0	0	15	2-3	15	8	0.0172	2.977
Rhicanthus verrucosus	Blackbelly triggerfish	0	0	15	9-10	15	23	0.012	3.08
Chaetodon unimaculatus	Teardrop butterfly fish	6	7-8	7	8-9	13	20	0.0533	2.833
Siganus puellus	Masked spinefoot	13	9-10	0	0	13	38	0.01761	3.028
Cheilio inermis	Cigar wrasse	12	6-7	0	0	12	50	0.004	3.01
Siganus vulpinus	Fox face	0	0	12	11-12	12	25	0.01616	3
Chaetodon vagabandus	Vagabond butterfly fish	0	0	10	6-7	10	23	0.0312	2.953
Chaetodon punctatofasciatus	Spotbond butterfly fish	4	7-8	5	9-10	9	12	0.0247	3.106
Chlorurus bowersi	Bower’s parotfish	0	0	9	11-12	9	40	0.0247	3.14
Lutjanus ruselli	Russell’s snapper	5	9-10	1	16	6	50	0.00708	3.234
Naso unicornis	Bluespine unicornfish	6	12-15	0	0	6	70	0.0314	3.037
Chaetodon xantharus	Pearlscale butterfly fish	0	0	4	8-9	4	14	0.0042	3.808
Pygoplites diacanthus	Royal angelfish	0	0	3	12	3	25	0.00514	3
Chaetodon rafflesii	Latticed butterflyfish	2	7-8	0	0	2	18	0.0533	2.833
Siganus sutor	Shoemaker spinefoot	2	8-9	0	0	2	45	0.0328	2.716
Acanthurus lineatus	Lined surgeonfish	1	15	0	0	1	38	0.0475	2.81
Arothron nigropunctatus	Blackspotted puffer	0	0	1	15	1	33	0.00534	3
Pterrois volitans	Red lionfish	0	0	1	11-12	1	45.7	0.0052	3.16
Terapon puta	Small-scaled terapon	1	8-9	0	0	1	30	0.01023	3
	Total	658		904		1562			

Table 9. Fish biomass of two reef areas in Sto. Domingo, Ilocos Sur, Philippines

Sampling Sites	Biomass (MT/km^2)	
	Established Calay-Ab Fish Sanctuary	Proposed MPA
Transect 1	16.088	8.909
Transect 2	10.201	5.646
Transect 3	-	7.294
Total	26.289	21.849

Collectively, the biomass results within the established Calay-Ab fish sanctuary may suggest improved habitat quality due to current regulations. Nonetheless, the effectiveness of these regulations should be consistently monitored and evaluated to ensure the preservation of fish diversity and the enhancement of fish biomass over time. Additionally, the proposed MPA should not be overlooked, given its promising biomass and potential for substantial spillover benefits when properly conserved and managed, owing to its higher coral cover. These findings strongly support the need for continued, more rigorous enforcement of laws, coupled with the LGU's advocacy for the whole community to encourage the expansion of sanctuary zones. Such measures are essential for maintaining biodiversity and promoting sustainable fisheries in Sto. Domingo and surrounding areas.

3.3. Physical characteristics of AR structure

A total of 86 ARs units were strategically deployed in 2016 off the coast of established Calay-Ab fish sanctuary in Sto. Domingo, Ilocos Sur. Subsequent monitoring revealed that 59 AR units are intact and visible, representing a retention rate of approximately 69% during the assessment. The observed colonization and biological activity around these units suggest that the ARs are performing their intended ecological and fisheries enhancement functions. During field assessments, a diverse range of sessile and mobile marine life was documented (Table 10). Early-stage colonizers included seaweeds such as *Halymenia* spp. and brown macroalgae (Ochrophyta), as well as soft corals, particularly presumptive Gorgonians. These pioneer organisms are well documented to contribute considerably to habitat complexity, thereby promoting successional reef development by providing food and shelter for various reef-associated species (Perkol-Finkel & Benayahu, 2005; Toledo et al., 2020). Their presence signifies the early to mid-successional stage of AR ecological maturation. Similar observations were reported by Toring-Farquerabao et al. (2021) in Tigbauan, Iloilo, Philippines, where deployed ARs were gradually colonized by benthic organisms such as soft corals and sponges and attracted reef fishes over time.

Table 10. Aquatic resources documented in the deployed fish ARs

Aquatic Resources Identified	Phylum/Family	Scientific Name	English/*Local* Name	IUCN Red List Status
Reef Associated-Fish	Lutjanidae	*Lutjanus timorensis*	Timor snapper/*Bugbugsi*	LC
	Zanclidae	*Zanclus cornutus*	*Bayang bayang*	LC
	Tetraodontidae	*Arothron nigropunctatus*	Blackspotted Puffer/*Butete*	LC
	Haemulidae	*Plectorhinchus* spp.	Sweetlips	LC/DD
Reptiles	Cheloniidae	*Chelonia mydas*	Green Sea Turtle	EN
Seaweed	Halymeniaceae	*Halymenia* spp.	Red Algae	DD
	Ochrophyta		Brown Algae	-
Soft corals	Gorgonians		*	-

**for verification*

One of its ecological importance was the sighting of an endangered sea turtle, a species listed under Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Observations of this highly mobile and habitat-sensitive species suggest that the AR site may now serve as a feeding ground or refuge, underscoring its conservation significance for many significant marine resources (Higgins et al., 2022). In addition, several economically and ecologically valuable reef fish species were recorded around the ARs. These include Timor snapper, moorish idol, blackspotted puffer, and Sweetlips. These species are associated with reef-dependent ecological functions such as predation, herbivory, and consumption of plankton, and they rely on structurally complex environments for feeding, shelter, and reproduction (Bohnsack & Sutherland, 1985). Their presence further highlights the role of ARs in enhancing local biodiversity, restoring fish habitats, and potentially boosting the productivity of artisanal fisheries in the long term (Seaman, 2000). Overall, the current biological profile of the ARs reflects positive ecological trends, although continued monitoring is essential to evaluate long-term reef development, structural stability, and fisheries yield. Maintaining these ARs can be a critical strategy for coral reef conservation, particularly in areas where natural reef recovery is limited by anthropogenic pressures.

4. Conclusion

This study provides baseline ecological information on reef fish diversity, abundance, biomass, and artificial reef conditions in Sto. Domingo, Ilocos Sur, Philippines. The assessment documented 1562 reef fish individuals representing 43 species from 18 families across the surveyed reef areas. The established Calay-Ab fish sanctuary recorded slightly higher diversity and biomass values than the proposed MPA area during the assessment period. However, since the study was conducted during a single survey period, the findings represent only a temporal snapshot and should therefore be interpreted cautiously. Furthermore, because the study employed limited sampling replication, the observed variations between reef areas should be regarded as descriptive observations rather than statistically significant differences. Continued long-term monitoring and strengthened coastal management are recommended to further evaluate reef condition, fish community dynamics, and the potential effectiveness of marine protection measures in the area.

Acknowledgement

We would like to acknowledge Community Environment and Natural Resources Office (CENRO) – Ilocos Sur, Philippines, for providing us the map.

Conflict of interest

The authors declare no conflict of interest.

Ethical Approval

This article does not require ethics committee approval.

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