

# Reef fish resilience following a significant earthquake disaster in the Nias Islands, Indonesia

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**Abstract.** Putra RD, Siringoringo RM, Abrar M, Puranamasari NW, Bengen DG, Zamani NP, Subhan B, Aji LP, Giyanto, Almanar IP, Dollu EA. 2025. Reef fish resilience following a significant earthquake disaster in the Nias Islands, Indonesia. *Biodiversitas* 26: 1836-1845. The geological upheaval of the Nias Islands, Indonesia, due to a major earthquake in 2005, resulted in lithospheric shifts, causing a sea floor uplift of approximately 1-2 meters. This uplift led to localized coral mortality, posing a threat to certain reefs and consequently impacting the composition of coral reef fishes. This study aims to explore the enduring changes in coral reef fish composition before and after the earthquake. Underwater Visual Census (UVC) transect surveys were conducted using standard SCUBA diving equipment to quantify fish abundance and biomass in benthic substrate transect locations. The reef fish assemblages categorized into corallivores (Chaetodontidae), herbivores (Acanthuridae, Scaridae, and Siganidae), and carnivores (Haemulidae, Lethrinidae, Lutjanidae, and Serranidae), were studied from eight fish families, with species identification conducted at the individual level. Analysis of corallivorous fish abundance during the pre-earthquake period (2004), earthquake event (2005), and post-earthquake recovery (2007-2010) revealed no significant differences (Kruskal-Wallis, p: 0.58). Corallivore abundance was lower in the pre-earthquake conditions, increased during the earthquake (Pairwise Wilcoxon test, p-value: 0.74), decreased in 2007 (Pairwise Wilcoxon test, p-value: 0.071) after the disturbance, but rebounded in 2008 (Pairwise Wilcoxon test, p-value: 0.23). Post the seismic event in 2005, ecological indices reflecting Shannon diversity ( $H'$ ) and Uniformity Index Evenness ( $J$ ) among reef fish, especially the corallivore group, consistently displayed a noticeable decline. However, recovery progress levels were exclusively regained by 2010.

**Keywords:** Coral, corallivore, disaster, herbivore, recovery

## INTRODUCTION

Since the onset of the Nias, Indonesia, earthquake in 2005, there has been a dynamic transformation in the coral reefs that has continued into subsequent years. Following a gradual recovery, the condition of coral reefs is now approaching their initial state. This study provides concise observations of the annual recovery process of the coral reef fishes community structure. The structure of coral reef communities, particularly that of stony corals, plays a crucial role in assessing the overall health of coral reefs (Hoegh-Guldberg et al. 2019; Pepe et al. 2025). Resilience, or the ability to withstand pressure and recover, serves as a key indicator confirming the health of coral reef ecosystems (McLeod et al. 2019; Sangaji et al. 2024). Additionally, healthy coral reefs contribute vital ecological services by supporting and maintaining biological resources, especially commercially targeted reef fish for fishing purposes (Hoegh-Guldberg et al. 2017; Obura et al. 2019). In tectonically active zones, earthquakes can induce vertical displacement of reefs (Sosdian et al. 2024). The

geological disaster of the Nias earthquake in 2005 involved lithospheric movement followed by seafloor uplift of about one to two meters (Sosdian et al. 2024). This uplift condition led to localized coral mortality, posing an ongoing threat to certain reefs. In some cases, large earthquakes can cause differential global uplift and subsidence across reef systems spanning over 1,000 km along tectonic plate boundaries, as observed in the 2004 earthquake between the Andaman and Nicobar Islands (Malik et al. 2015). While large earthquakes in the ocean floor are often followed by tsunami phenomena, as was the case during the 2005 earthquake disturbance in Nias Island, the direct effects of the tsunami on shallow attached corals were relatively minimal (Shao et al. 2019).

The damage to coral reefs resulting from the earthquake was more severe than that caused by the accompanying tsunami. Impact included uplifted reefs, shattered coral beds, and overturned coral colonies (Foster et al. 2016; Goto et al. 2019; Siringoringo et al. 2021). Islands like Simeulue and Nias experienced tilting, with one end rising by as much as 2 meters while the other end descended by a

similar amount (Siringoringo et al. 2021). Notably, the tsunami run-up height during the Nias earthquake was approximately 4 meters or less in areas near the epicenter (Suppasri et al. 2015). Although several coral species suffered damage during the significant earthquake disturbance on Nias Island, with (Siringoringo et al. 2021) reporting the absence of live *Acropora* colonies in April 2005, the earthquake's impact was felt more deeply than the tsunami. In Thailand, a substantial amount of seafloor sand, up to 2 meters deep, was displaced (Suppasri et al. 2015). Coral destruction was found at 27 meters depth, with 66% of live coral tables either overturned or broken, and 40% of live coral at 10-20 meters depth damaged by the tsunami (Siringoringo et al. 2021).

The earthquake had a profound effect on the plants and animals of Nias Island, particularly the coral reef population along its western coast (Siringoringo et al. 2021). It brought about changes in coral cover and composition, with branching corals suffering significant damage, while massive corals, though declining, proved to be more resilient and dominant in the subsequent years (Siringoringo et al. 2021). Previous research by (Siringoringo et al. 2021) extensively explored the alterations in coral reef ecosystems following the devastating earthquake in Nias Island, Indonesia. The findings revealed severe damage, leading to a decline in coral coverage from 48.5% in 2004 to 20.5% in 2005, accompanied by an increase in rubble coverage to 16.1%. Branching corals bore the brunt of the earthquake's impact. Despite the significant damage to coral reefs, the earthquake in Nias Island did not directly affect the composition of reef fishes.

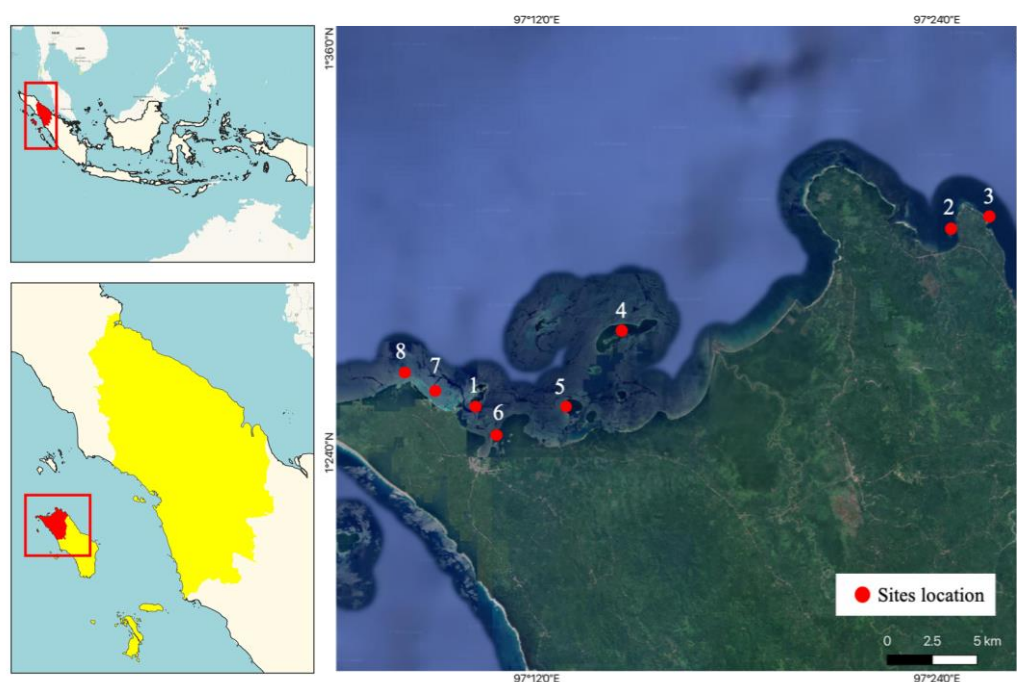
The repercussions of the Nias disaster extended beyond

coral reefs, affecting various biotas in coastal areas, including coral reef fish. Coral reef fish are intimately linked to corals (Brooker et al. 2016; González-Rivero et al. 2017; Harvey et al. 2018; Woodhead et al. 2019; DeVantier et al. 2020). Thus, several groups of reef fish can offer precise insights into the health of the coral reef ecosystem. Moreover, reef fish populations play a crucial role in determining whether a coral ecosystem affected by a disaster can survive and recover. Unfortunately, there is still a lack of comprehensive information regarding changes in reef fish composition before and during the recovery process after the Nias earthquake. This study aims to fill this gap by providing thorough data on changes in reef fish composition before and after the seismic event on Nias Island.

## MATERIALS AND METHODS

### Study sites location

The research investigations were carried out on Nias Island, situated along the western coast of Sumatra, Indonesia. As one of the outermost small islands in the Indonesian region, Nias Island is part of the COREMAP monitoring program (Figure 1, Table 1). Geographically facing the Indian Ocean, the island experiences substantial waves and high currents. Its formation results from tectonic processes, positioned in the collision zone between the Indo-Australian Plate and the Eurasian Plate, leading to elevated tectonic activity along the coast of Nias Island. Over a decade, the Research Centre for Oceanography, within the COREMAP Program, conducted extensive studies of the coral ecosystem on Nias Island.



**Figure 1.** Study area and survey location the significant earthquake disturbance impact in northern Nias Island, Indonesia. 1. NIAC01; 2. NIAC02; 3. NIAC03; 4. NIAC04; 5. NIAC05; 6. NIAC06; 7. NIAC07; 8. NIAC08

**Table 1.** The sites location coordinate

Station	Site code	Location	Longitude	Latitude
1	NIAC01	Baohi Island, Lahewa	97°10'14.18 E	1°25'21.35 N
2	NIAC02	Uge Sandsbar, Sawo	97°24'23.34 E	1°30'40.33 N
3	NIAC03	Bengkuang Bay, Sawo	97°25'30.67 E	1°30'53.80 N
4	NIAC04	Panjang Islands, Lahewa	97°14'33.90 E	1°27'33.34 N
5	NIAC05	Lafau Island, Lahewa	97°12'47.09 E	1°25'23.22 N
6	NIAC06	Balefadorotuhu village, Lahewa	97°10'41.25 E	1°24'39.20 N
7	NIAC07	Balefadorotuhu village, Lahewa	97°09'0.338 E	1°25'46.19 N
8	NIAC08	Panjang Islands, Lahewa	97°10'14.18 E	1°26'10.86 N

The primary data source for this investigation is derived from our long-term research, spanning over 15 years, in North Nias. This research was conducted under the National Coral Reef Rehabilitation and Management Program (COREMAP). The initial assessment of the coral reef ecosystem was conducted in 2004 (pre-earthquake), with eight permanent monitoring stations established along transects in North Nias. The permanent monitoring transects were strategically established in two key regions: the Lahewa location (covering Baohi Island, Panjang Island, Lafau Island, and Balefadorotuhu Village) and the Sawo location (comprising Uge Sandsbar and Bengkuang Bay) (Table 1). Unfortunately, in 2005 (earthquake), a geological phenomenon struck Nias Island, resulting in severe damage to the marine, coastal, and terrestrial ecosystems, particularly impacting the coral reef ecosystem. The damage was particularly noticeable in several coral species, with *Acropora* coral being significantly affected. Two years after the earthquake in 2007 (post-earthquake), evaluation studies were conducted to assess the recovery process of the coral reef ecosystems on Nias Island. These studies highlighted the substantial development and growth of the coral ecosystem. The assessment considered three key conditions of coral and fish populations on Nias Island: pre-earthquake (2004), during the large earthquake (2005), and post-earthquake (2007 to 2010). This evaluation covered six sites in Northern Nias Island (Figure 1; Table 1).

### Reef fishes' assemblages

Data on coral reef fishes were collected using Underwater Visual Census (UVC) conducted with SCUBA diving equipment (Robinson et al. 2016; Ricart et al. 2018). UVC is a widely employed, non-destructive surveying method for detecting and quantifying reef fishes within communities (Figueroa-Pico et al. 2020). This method is particularly effective for quantifying the composition of coral reef fish, including measures of fish abundance and biomass. UVC is extensively utilized in marine studies, especially for dynamic population assessments of marine fauna, providing insights into abundance, biomass, and species richness (Jones et al. 2015). The UVC approach is well-suited for application within Marine Protected Areas (MPAs) and recovery areas post-disturbance (Davis and Smith 2017). It is worth noting that UVC may potentially lead to an underestimation of communities characterized by

a high abundance of fish (Figueroa-Pico et al. 2020). The selection of UVC for the monitoring program and long-term research studies is attributed to its environmentally friendly methodology, offering valuable resources for researchers and enhancing information for effective management decisions (Jones et al. 2015). In employing the UVC method, reef fish assemblages were surveyed using a modified belt transect covering a total area of 350 m<sup>2</sup> (70 m long x 5 m wide) (English et al. 1994). These assemblages were categorized into three groups from eight reef fish families, namely corallivores (*Chaetodontidae*), herbivores (*Acanthuridae*, *Scaridae*, and *Siganidae*), and carnivores (*Haemulidae*, *Lethrinidae*, *Lutjanidae*, and *Serranidae*). All fish categories within these eight families were identified at the species level, referencing authoritative sources from (Du et al. 2016) and FishBase (Froese and Pauly 2025).

### Data analysis

The reef fish composition under three distinct conditions, namely the pre-earthquake period (2004), the earthquake event (2005), and the post-earthquake recovery phase (2007-2010), was imported and analysed using the "ggplot2" package (Wickham 2020) in the R statistical software (R Core Team 2025). Subsequently, a non-parametric Kruskal-Wallis test was executed through the "ggstatsplot" package (Patil 2018) to compare and explore the dynamic changes in the composition of three coral reef fish categories during the aforementioned conditions (pre-earthquake in 2004, earthquake in 2005, and post-earthquake recovery from 2007 to 2010). Furthermore, an analysis of the correlation between coral reef fish composition and coral reef benthic structure was conducted over varying disturbance conditions (pre-earthquake, during the earthquake, and post-earthquake) within northern Nias Island using Multivariate Analysis from Correspondence Analysis (CA). The benthic structure data were obtained from annual reports of Reef Health Monitoring conducted by the COREMAP Program. To assess significant differences in the abundance of coral reef fishes within different community structures across various conditions, a non-parametric Kruskal-Wallis test with internal Pairwise Wilcoxon analysis was applied using the "ggstatsplot" package, with a significance level set at  $p$ -value < 0.05 (Patil 2018; Putra et al. 2020a).

## RESULTS AND DISCUSSION

### The abundance of coral reef fish

Our study findings uncovered a notable shift in the dominant corallivorous fish species in northern Nias Island. Prior to the 2005 earthquake, *H. singularis* held a prevalent position among corallivorous fish species. However, immediately following the earthquake, there was a significant change as *H. varius* took over as the dominant corallivorous species. Remarkably, in the post-recovery phase (2007-2010), *H. varius* maintained its dominance in the corallivorous fish category in Northern Nias Island (Table 2). The herbivorous and carnivorous fish groups also experienced shifts in species dominance across pre-earthquake, post-earthquake, and post-recovery conditions. While specific fish species dominated each group for every condition, such as *C. striatus* in the herbivorous fish group and *C. argus* in the carnivorous fish group, the dominance of certain species changed within both groups (Table 2).

### The abundance composition trend of coral reef fishes

The abundance of corallivore fishes in the pre-earthquake (2004), during the earthquake (2005), and post-earthquake recovery (2007-2010) periods showed non-

significant differences in abundance (Kruskal-Wallis,  $p$ : 0.58) (Figure 2). Corallivore abundance was lower in pre-earthquake conditions and increased during the earthquake (Pairwise Wilcoxon test,  $p$ -value: 0.74). Following the disturbance, there was a decline in corallivore fish abundance in 2007 (Pairwise Wilcoxon test,  $p$ -value: 0.071). However, by the subsequent year (2008), corallivore fish abundance exhibited recovery and an increase (Pairwise Wilcoxon test,  $p$ -value: 0.23).

A similar pattern was observed in the herbivore fish group, where the abundance did not vary significantly among different earthquake time conditions (Kruskal-Wallis,  $p$ : 0.11) (Figure 2). The abundance trend in the herbivorous group also indicated higher abundance during the earthquake (2005) compared to pre-earthquake (2004) conditions (Pairwise Wilcoxon test,  $p$ -value: 0.33) and post-earthquake recovery conditions (2007) (Pairwise Wilcoxon test,  $p$ -value: 0.24). The herbivorous group showed a recovery process in 2008, three years after the earthquake shake in Nias Island (Pairwise Wilcoxon test,  $p$ -value: 0.06). The guild of carnivorous fishes exhibited commonalities and similarities across different earthquake time conditions (Kruskal-Wallis,  $p$ : 0.98) (Figure 2).

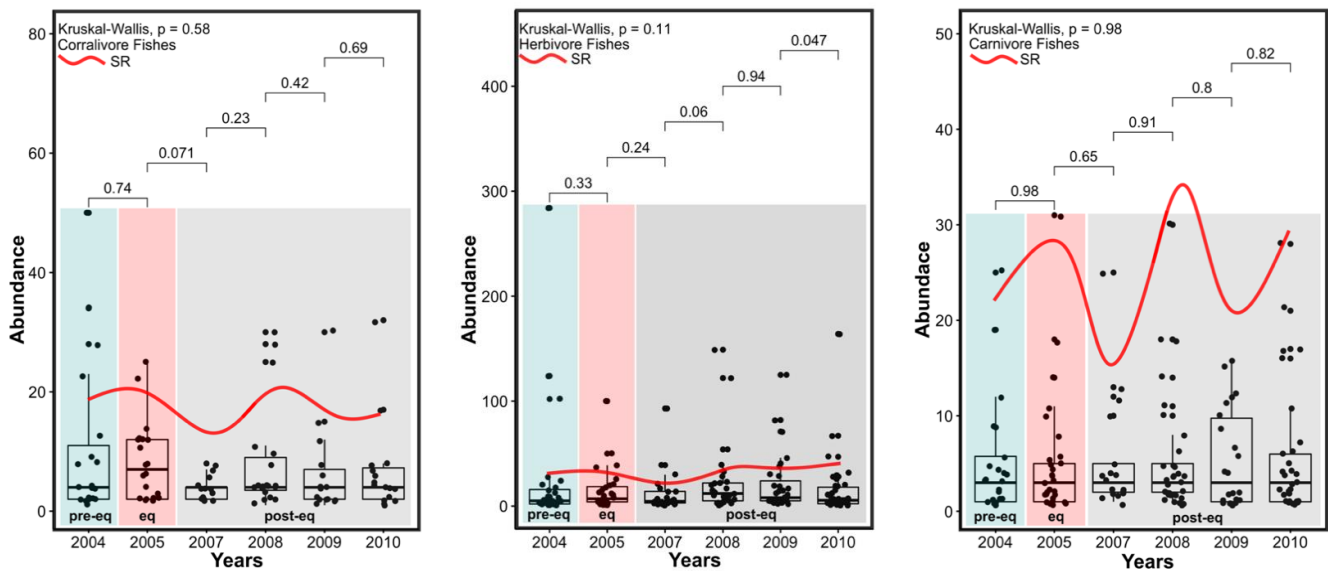
**Table 2.** Results of the analysis depicting the top five species consistently present in high abundance in each condition (pre-earthquake, earthquake, and post-recovery) related to the massive earthquake disaster in Nias Islands, Indonesia

Condition	Top 5 species corallivore	Square-meter abundance	Top 5 species herbivore	Square-meter abundance	Top 5 species carnivore	Square-meter abundance
pre-earthquake (2004)	<i>Heniochus singularis</i>	0.143	<i>Scarus rivulatus</i>	0.811	<i>Cephalopholis argus</i>	0.071
	<i>Heniochus pleurotaenia</i>	0.097	<i>Ctenochaetus striatus</i>	0.354	<i>Monotaxis grandoculis</i>	0.054
	<i>Heniochus acuminatus</i>	0.080	<i>Zebrasoma scopas</i>	0.291	<i>Lutjanus fulvus</i>	0.034
	<i>Heniochus chrysostomus</i>	0.066	<i>Scarus bleckeri</i>	0.080	<i>Plectorhinchus orientalis</i>	0.026
	<i>Heniochus monoceros</i>	0.037	<i>Acanthurus leucosternon</i>	0.069	<i>Lutjanus decussatus</i>	0.026
Earthquake (2005)	<i>Heniochus varius</i>	0.071	<i>Ctenochaetus striatus</i>	0.286	<i>Diploprion bifasciatus</i>	0.089
	<i>Heniochus singularis</i>	0.063	<i>Zebrasoma scopas</i>	0.143	<i>Lutjanus decussatus</i>	0.051
	<i>Forcipiger longirostris</i>	0.040	<i>Naso brevirostris</i>	0.111	<i>Monotaxis grandoculis</i>	0.040
	<i>Heniochus pleurotaenia</i>	0.034	<i>Scarus bleckeri</i>	0.106	<i>Cephalopholis argus</i>	0.031
	<i>Heniochus chrysostomus</i>	0.034	<i>Acanthurus nigricans</i>	0.074	<i>Gnathodentex sp.</i>	0.029
Post-recovery (2007)	<i>Heniochus monoceros</i>	0.023	<i>Zebrasoma djasdardini</i>	0.266	<i>Lethrinus harax</i>	0.071
	<i>Chaetodon trifascialis</i>	0.020	<i>Acanthurus leucosternon</i>	0.111	<i>Plectropoma maculatus</i>	0.037
	<i>Heniochus pleurotaenia</i>	0.017	<i>Ctenochaetus striatus</i>	0.086	<i>Cephalopholis argus</i>	0.034
	<i>Forcipiger longirostris</i>	0.011	<i>Acanthurus pyroferus</i>	0.060	<i>Cephalopholis urodeta</i>	0.029
	<i>Chaetodon vagabundus</i>	0.011	<i>Scarus frenatus</i>	0.049	<i>Lutjanus fulviflamma</i>	0.014
Post-recovery (2008)	<i>Heniochus pleurotaenia</i>	0.086	<i>Naso brevirostris</i>	0.426	<i>Lutjanus fulviflamma</i>	0.086
	<i>Heniochus varius</i>	0.080	<i>Acanthurus grammoptilus</i>	0.349	<i>Lutjanus decussatus</i>	0.051
	<i>Heniochus monoceros</i>	0.071	<i>Ctenochaetus striatus</i>	0.154	<i>Gnathodentex aurolineatus</i>	0.051
	<i>Chaetodon unicaudalis</i>	0.031	<i>Naso lituratus</i>	0.111	<i>Cephalopholis argus</i>	0.040
	<i>Heniochus singularis</i>	0.029	<i>Zebrasoma scopas</i>	0.094	<i>Lutjanus fulvus</i>	0.031
Post-recovery (2009)	<i>Heniochus varius</i>	0.086	<i>Naso hexacanthus</i>	0.357	<i>Cephalopholis argus</i>	0.046
	<i>Heniochus singularis</i>	0.043	<i>Ctenochaetus striatus</i>	0.234	<i>Monotaxis grandoculis</i>	0.043
	<i>Heniochus monoceros</i>	0.034	<i>Acanthurus tristis</i>	0.203	<i>Aetaloperca roghaa</i>	0.034
	<i>Forcipiger flavissimus</i>	0.023	<i>Zebrasoma scopas</i>	0.131	<i>Cephalopholis micropion</i>	0.034
	<i>Chaetodon ulietensis</i>	0.017	<i>Scarus niger</i>	0.117	<i>Lutjanus biguttatus</i>	0.031
Post-recovery (2010)	<i>Heniochus varius</i>	0.091	<i>Ctenochaetus binotatus</i>	0.469	<i>Lutjanus biguttatus</i>	0.080
	<i>Heniochus singularis</i>	0.049	<i>Ctenochaetus striatus</i>	0.191	<i>Cephalopholis argus</i>	0.060
	<i>Chaetodon ulietensis</i>	0.023	<i>Zebrasoma scopas</i>	0.134	<i>Monotaxis grandoculis</i>	0.049
	<i>Chaetodon raflesii</i>	0.023	<i>Scarus bleckeri</i>	0.091	<i>Cephalopholis micropion</i>	0.049
	<i>Forcipiger flavissimus</i>	0.020	<i>Naso hexagonathus</i>	0.083	<i>Gnathodentex aurolineatus</i>	0.046

**The ecological indices of coral reef fish group**

The ecological indices of coral reef fish groups (corallivores, herbivores, and carnivores) were examined to assess the impacts of the 2005 earthquake and subsequent recovery phases in Nias Islands, Indonesia (Table 3). Our result showed pre-earthquake (2004), earthquake (2005), and post-recovery periods (2007–2010) revealed significant changes in diversity, species richness, and community structure for each coral reef fish groups. For corallivores, Shannon Diversity (H) increased from 2.349 pre-earthquake to 2.705 during the earthquake, then slightly declined to 2.444 in 2007, with small fluctuations through 2010. The Uniformity Index Evenness (J) showed an increase from 0.798 pre-earthquake to 0.953 in 2007, stabilizing at 0.839 by 2010, while the Dominance Index Simpson (D) was lowest during the earthquake (0.081) and

gradually increased post-recovery. Herbivores exhibited a substantial increase in Shannon Diversity (H) from 2.055 pre-earthquake to 2.743 during the earthquake, with a subsequent decrease to 2.448 in 2007, before rising to 2.882 by 2010. The Uniformity Index Evenness (J) for herbivores also increased, peaking at 0.824 in 2009, while the Dominance Index Simpson (D) dropped significantly from 0.224 pre-earthquake to 0.087 in 2009, maintaining a low level thereafter. For carnivores, Shannon Diversity (H) increased from 2.576 pre-earthquake to 2.846 during the earthquake, peaking at 3.017 in 2008, before slightly decreasing to 2.842 by 2010. The Uniformity Index Evenness (J) remained relatively stable, and the Dominance Index Simpson (D) showed a decrease from 0.106 pre-earthquake to 0.071 in 2008, followed by a slight increase in 2010.



**Figure 2.** Depicts the Kruskal-Wallis test with internal Pairwise Wilcoxon tests illustrating the composition structure of three reef fish groups (corallivore, herbivore, and carnivore) and the abundance trend of reef fishes (individuals per 350 m<sup>2</sup>) from before the earthquake to the post-earthquake recovery process in northern Nias Island. The pink color indicates the earthquake condition (2005), while the grey color represents the post-earthquake condition (2007-2010)

**Table 3.** Ecological indices of coral reef fish groups (corallivore, herbivore, and carnivore) in each condition (pre-earthquake, earthquake, and post-recovery) related to the massive earthquake disaster in Nias Islands, Indonesia

Reef fishes group	Ecological index	Pre-earthquake (2004)	Earthquake (2005)	Post-recovery (2007)	Post-recovery (2008)	Post-recovery (2009)	Post-recovery (2010)
Corallivore	Shannon Diversity (H)	2.349	2.705	2.444	2.481	2.223	2.326
	Uniformity Index Evenness (J)	0.798	0.903	0.953	0.843	0.821	0.839
	Dominance Index Simpson (D)	0.133	0.081	0.097	0.116	0.156	0.142
	Effective Number of Species (ENS)	10	15	12	12	9	10
Herbivore	Shannon Diversity (H)	2.055	2.743	2.448	2.689	2.831	2.882
	Uniformity Index Evenness (J)	0.617	0.823	0.770	0.799	0.824	0.771
	Dominance Index Simpson (D)	0.224	0.098	0.146	0.109	0.087	0.103
	Effective Number of Species (ENS)	8	16	12	15	17	18
Carnivore	Shannon Diversity (H)	2.576	2.846	2.384	3.017	2.676	2.842
	Uniformity Index Evenness (J)	0.846	0.845	0.842	0.863	0.866	0.844
	Dominance Index Simpson (D)	0.106	0.087	0.130	0.071	0.084	0.080
	Effective Number of Species (ENS)	13	17	11	20	15	17

**The composition of benthic substrate**

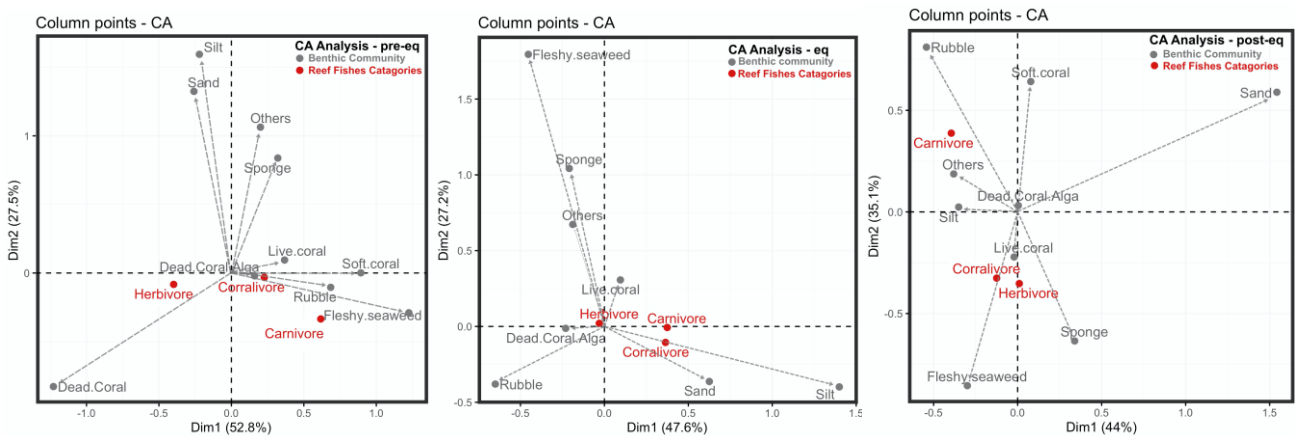
Our analysis revealed significant temporal dynamics in benthic community composition (Table 4). Of the ten benthic categories identified, two dominant components emerged live coral and dead coral with algae (DCA). Longitudinal data demonstrated substantial fluctuations in these key indicators, particularly following seismic disturbance. Pre-earthquake baseline measurements (2004) recorded live coral coverage at  $48.45\% \pm 3.62$  (fair condition category). The 2005 seismic event precipitated dramatic ecosystem degradation, with live coral cover declining by  $>50\%$  to  $20.45\% \pm 3.64$  (poor condition) by 2005, reaching a nadir of  $17.20\% \pm 4.30$  in 2007. Subsequent recovery initiated in 2008 ( $19.82\% \pm 5.75$ ), progressing to  $29.83\% \pm 7.01$  (2009) and  $32.04\% \pm 6.59$  (2010). Conversely, DCA coverage exhibited an inverse trajectory, peaking at  $53.68\% \pm 8.76$  in 2009 before declining to  $22.48\% \pm 6.30$  in 2010. This countercyclical pattern between live coral and DCA suggests competitive dynamics during post-disturbance succession.

**Multivariate analysis from CA in the structure of the coral reef ecosystem (benthos and reef fishes)**

Multivariate Analysis using Correspondence Analysis (CA) was conducted to assess the structure of the coral reef ecosystem, considering both benthic components and reef fishes, across different disturbance conditions (pre-earthquake, during the earthquake, and post-earthquake) within northern Nias Island. The analysis revealed substantial variability in the ecosystem's structure over time (Figure 3). Before the earthquake in 2004, corallivore fishes were distinctly associated with live coral cover, while herbivore fishes were linked to the condition of dead coral-algae. The period of earthquake disturbance in 2005 exhibited a shifting variability in the coral reef ecosystem, with corallivore fishes now associated with sand and silt, while the herbivorous group was linked to dead coral-algae and rubble (Figure 3). Finally, the post-earthquake condition showed a repatterning of the corallivore fishes' group, reverting to a configuration reminiscent of the pre-earthquake condition. This analysis highlights the dynamic changes in the coral reef ecosystem structure during and after the earthquake events, emphasizing the impact of such disturbances on both benthic components and reef fish composition within the studied region.

**Table 4.** Interannual variation in benthic cover percentages was derived from surveys conducted in 2004, 2005, and biennially from 2007 to 2010

Benthic categories	Percentage of mean benthic communities structure (%) $\pm$ SE					
	2004	2005	2007	2008	2009	2010
Live coral	48.45 $\pm$ 3.62	20.45 $\pm$ 3.64	17.20 $\pm$ 4.30	19.82 $\pm$ 5.75	29.83 $\pm$ 7.01	32.04 $\pm$ 6.59
Soft coral	0.76 $\pm$ 0.54	0.00 $\pm$ 0.00	0.17 $\pm$ 0.13	0.21 $\pm$ 0.15	0.17 $\pm$ 0.11	0.12 $\pm$ 0.07
Sponge	4.59 $\pm$ 1.35	1.86 $\pm$ 0.91	2.59 $\pm$ 1.18	0.87 $\pm$ 0.34	1.15 $\pm$ 0.59	3.66 $\pm$ 0.94
Dead coral	0.03 $\pm$ 0.03	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.08 $\pm$ 0.08	0.00 $\pm$ 0.00	0.52 $\pm$ 0.42
Dead coral alga	34.53 $\pm$ 4.59	50.56 $\pm$ 2.80	50.23 $\pm$ 5.15	49.45 $\pm$ 6.08	53.68 $\pm$ 8.76	22.48 $\pm$ 6.30
Fleshy seaweed	0.52 $\pm$ 0.19	0.99 $\pm$ 0.91	0.76 $\pm$ 0.68	4.22 $\pm$ 3.90	1.71 $\pm$ 1.12	4.79 $\pm$ 3.01
Rubble	1.73 $\pm$ 0.69	15.57 $\pm$ 4.70	15.55 $\pm$ 6.20	17.10 $\pm$ 5.50	1.12 $\pm$ 0.73	26.68 $\pm$ 13.19
Sand	5.99 $\pm$ 3.52	8.77 $\pm$ 3.84	10.32 $\pm$ 6.32	8.08 $\pm$ 3.81	8.56 $\pm$ 4.48	9.32 $\pm$ 5.35
Silt	0.96 $\pm$ 0.61	0.40 $\pm$ 0.40	2.65 $\pm$ 1.30	0.00 $\pm$ 0.00	3.15 $\pm$ 3.10	0.00 $\pm$ 0.00
Others	0.97 $\pm$ 0.46	1.41 $\pm$ 0.90	0.53 $\pm$ 0.24	0.15 $\pm$ 0.08	0.64 $\pm$ 0.25	0.40 $\pm$ 0.12



**Figure 3.** Multivariate analysis using Correspondence Analysis (CA) depicting the structure of the coral reef ecosystem (benthos and reef fishes) across different disturbance conditions (pre-earthquake, during the earthquake, and post-earthquake) within northern Nias Island, Indonesia

## Discussion

According to our findings presented in Table 2, the corallivorous fish group belonging to the genus *Heniochus* demonstrated the highest levels of dominance among fish species in the waters of Nias. Notably, this fish group maintained its dominant status even in the aftermath of the earthquake that struck Nias. Our study results, indicating that the *Heniochus* genus is the most dominant fish group in Nias waters, align with previous research highlighting the prevalence of *Heniochus* in coral reef systems that presence after disaster (Putra et al. 2022). The feeding habits of *Heniochus* species, primarily involving the consumption of live coral polyps and tissues, likely contribute to their high abundance and dominance in coral reef environments (Putra et al. 2024). Intriguingly, our study also demonstrated that the *Heniochus* genus sustained its dominance even after a massive earthquake in Nias, suggesting resilience possibly rooted in the adaptable feeding behavior of *Heniochus*, known to adjust to different coral species depending on availability.

The findings of our study further reveal that the herbivorous fish assemblage in Nias is predominantly composed of the Acanthuridae and Scaridae families. In contrast, the Siganidae family exhibits low occurrence in the seawaters of Nias (Table 2). Importantly, the Acanthuridae and Scaridae families maintained their population dominance both during and after the catastrophic earthquake. The resilience of these fish families to environmental disturbances may be attributed to their feeding habits, where both families are known to feed on a diverse range of algae and seagrasses, reducing their dependence on specific coral species for food and habitat (Clements et al. 2018). Following the massive earthquake disturbance, our study observed a dominance of roving herbivore fishes from Scaridae and Acanthuridae, such as *C. striatus*, *Z. scopas*, and *S. bleckeri*, in Nias Island. The majority of herbivore fish species (Acanthuridae and Scaridae) play a significant role in maintaining the Epilithic Algal Matrix (EAM), where *Diadema* Coating Algae (DCA) forms (Marshall and Mumby 2015; Rice et al. 2019). According to previous research by Putra et al. (2020b), the Acanthuridae family represented more than 70% of eroding EAM and removed nearly 70% of daily EAM productivity in the coral ecosystem. The presence of another macroalgae eroder (Siganidae family) does not support the competition between fleshy seaweed and live coral cover (Ditzel et al. 2022; Zarco-Perello et al. 2024).

Our results found the presence of herbivorous fish composition from Siganidae to be extremely low, impacting the increase in fleshy seaweed composition three years after the earthquake condition (Table 2). Fleshy seaweeds, a macroalgae group with larger forms than turf, are anatomically more complex and rigid (Khen et al. 2025). The significant increase in fleshy seaweed after the massive earthquake in Nias Island is abundant in the shallow intertidal reef, where massive damage to coral reef locations occurred. The recovery of the coral ecosystem in Nias Island depends on the presence and significant role of this herbivory group. It exerts pressure on seaweed to become a competitively dominant algal species in the coral

ecosystem (Roth et al. 2018; Adam et al. 2022). The low abundance of the Siganidae family in Nias Island after an earthquake, coupled with the standing biomass of seaweed, makes it challenging to prevent the coral-algal phase shift, as seaweed can overgrow and harm coral over the long term (Manangkalangi et al. 2022). Our study identified a decrease in fish density two years after the earthquake in Nias Island, which is associated with structural changes in the coral reef ecosystem (Figure 2). A pronounced shift in reef structure was observed with live coral cover decreasing by >3% across sites (Table 4).

Another key finding from our study highlights significant changes in the composition of reef fish populations during the post-earthquake period. These changes are further evidenced by alterations in the ecological indices for each coral reef fish group, with particular emphasis on corallivorous species (Table 3). The regeneration of changes in fish composition was evident in the third year after the massive earthquake, accompanied by an increase in herbivorous fish density in Nias (Figure 2). Despite the substantial impact of the massive earthquake in Nias, our findings demonstrate the resilience and survival of coral reef fish populations, albeit with changes in the dominance of certain species. A general decrease in population was observed only in the corallivorous fish group, while the herbivorous and carnivorous fish groups did not experience a significant decline. The observed decline in corallivorous fish population aligns with the decrease in coral cover, as these fish heavily rely on corals for sustenance.

Multiple studies have documented that coral depletion, driven by both natural disturbances and anthropogenic stressors, exerts direct impacts on corallivorous fish assemblages (Pratchett et al. 2006; Russ and Leahy 2017; Keith et al. 2018). A study in French Polynesia revealed that obligate corallivores, such as butterflyfishes, experienced a 50% decline in density following a natural phenomenon mass bleaching event (Semmler et al. 2025). Similarly, in the central and western Indian Ocean, the abundance of obligate coral-feeding butterflyfishes significantly decreased in response to live coral mortality, with no further decline once the physical reef structure eroded (Graham et al. 2009). This underscores the immediate and severe impact of coral loss on specialized feeders. Corallivorous fish, exhibiting specialized feeding behaviors and mouth structures for consuming live corals (Bramasta et al. 2024), depend on corals as a critical habitat for shelter and territory establishment. The close interdependence between corallivorous fish and corals is well-established, and any reduction in coral populations may have a significant impact on corallivorous fish populations. The occurrence of a massive earthquake, such as the one in Nias, may contribute to a decrease in corallivorous fish populations (Aulia et al. 2021).

Based on the insights derived from the correspondence analysis presented in Figure 3, our study discerned a noteworthy correlation pattern before and after the 2005 earthquake in Nias Island. Pre-earthquake conditions indicated a significant correlation between the presence of live coral and the abundance of corallivorous fish, while

dead coral algae exhibited a positive correlation with the herbivorous fish group. However, post-earthquake, the presence of sand and mud showed a substantial positive correlation with corallivorous fish. Interestingly, in the post-earthquake conditions, live coral presence displayed a positive correlation with reef fishes, signifying ongoing recovery attempts and a return to pre-earthquake growth and development stages. Understanding the recovery of coral and reef fish populations post-catastrophic events, such as earthquakes, is pivotal for gauging the resilience of coral reef ecosystems (Steneck et al. 2019; Siringoringo et al. 2021). Our findings revealed a positive correlation between the presence of sand and mud and corallivorous fishes after the earthquake, indicating their adaptive response to altered habitat conditions. This aligns with other studies demonstrating the ability of corallivorous fish to modify feeding behavior and habitat use in response to environmental changes (MacDonald et al. 2021). The comprehensive results of this study, reinforced by multivariate analysis (Figure 3), underscore the significant impact of the high-magnitude Nias earthquake in 2005 on altering the coral ecosystem's structure. Notably, post-earthquake conditions in Nias Island offered an opportunity for ecosystem recovery, with an increase in herbivorous fishes playing a crucial role in expediting this rejuvenation process (Mumby et al. 2006; Graham et al. 2011). While the initial impact of the earthquake on the coral and reef fish populations was significant, the ecosystem showed resilience in its ability to recover.

Our study found that the presence of sand and mud was positively correlated with corallivorous fishes after the earthquake, which suggests that these fish were able to adapt to the altered habitat conditions caused by the earthquake. This finding is supported by other studies that have documented the ability of corallivorous fish to adjust their feeding behavior and habitat use in response to environmental changes (Feary et al. 2018; Rice et al. 2019; Gunn et al. 2022). The comprehensive results of this study are strengthened by the results of multivariate analysis (Figure 3), with showing the high moment magnitude of the Nias earthquake in 2005 had to change the structure of the coral ecosystem where the indicator corallivore fishes were changes in the group in sand and silt from before the pre-earthquake condition which is a closed group in live coral. The most interesting result, the conditions after the earthquake in Nias Island give a chance to the ecosystem to recover (Figure 3), and the increase of herbivorous fish's composition play an important role in accelerating this process. Herbivorous fish play a crucial role in the recovery of coral reef ecosystems by controlling algal growth and facilitating coral recruitment (Eynaud et al. 2016; Wu et al. 2022; Theo and Shanker 2023). Their feeding activities help maintain a balance between coral and algae, promoting coral health and resilience against environmental disturbances which is essential for the health of these ecosystems (Nash et al. 2016; Ruttenberg et al. 2019). The following sections outline the specific contributions of herbivorous fish to coral reef recovery.

Our study concludes that the condition of reef fish before the earthquake (2004), during the earthquake

(2005), and during the post-earthquake recovery (2007-2010) exhibited fluctuations in the two years following the seismic event. Reef fish abundance decreased two years after the earthquake, and by 2018, coral reefs began to recover, leading to an increase in reef fish abundance. Similar trends were observed in herbivorous fish groups, indicating their role in coral resilience, and in the economically important carnivorous fish group. Following the earthquake, the abundance of these fish groups also decreased, initiating a recovery process in 2008. This study underscores the resilience of coral and reef fish populations in the face of environmental disturbances such as earthquakes. The recovery observed in these populations can be attributed to various factors, including the adaptive capacity of corallivorous fish to altered habitat conditions, the presence of herbivorous fish groups, and effective governmental management measures to safeguard coral reef ecosystems. Understanding these factors is paramount for the proficient management and conservation of coral reef ecosystems. Despite fluctuations and declines in post-earthquake abundance, the changes in fish abundance did not exhibit significant differences.

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