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ORIGINAL RESEARCH ARTICLE

The role of marine protected areas in enhancing coral cover and reef fish communities

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ABSTRACT

BACKGROUND AND OBJECTIVES: Coral reefs are vital ecosystems that support a diverse array of marine species and provide essential services such as coastal protection, fisheries, and tourism. Nevertheless, these ecosystems face growing threats from human-induced pressures, including overfishing, pollution, and the impacts of climate change. No-take zones within marine protected areas have proven to be valuable instruments for the protection of coral reefs and the enhancement of biodiversity. The study objectives were to evaluates the role of no-take zones in promoting coral cover, reducing coral degradation, and supporting the diversity and abundance of reef fish communities in the Tapanuli Tengah Marine Conservation area, North Sumatra, Indonesia.
METHODS: Field surveys were conducted in three no-take zones and adjacent non-protected areas. Coral cover was assessed using the underwater photo transect method, while reef fish communities were surveyed using the underwater visual census technique. The analysis focused on comparing coral health, fish populations, and species diversity in both protected and unprotected zones. Statistical analyses were used to evaluate correlations between coral cover and fish communities and the effectiveness of no-take zones in supporting biodiversity.
FINDINGS: Analysis demonstrated that no-take zones had a significantly higher percentage of hard coral cover and a lower level of macroalgal growth when compared to non-protected areas. Fish species richness and abundance were also substantially more significant in no-take zones. Prominent families of reef fish, such as Pomacentridae, Apogonidae, and Caesionidae, showed a strong connection to vibrant coral habitats. Conversely, disturbed regions were characterized by algae-dominated substrates and species that can withstand such conditions, including Acanthuridae and Lethrinidae.
CONCLUSION: This study highlights the effectiveness of no-take zones in improving coral reef health and enhancing reef fish biodiversity. The findings support expanding and strictly enforcing no-take zones to mitigate the impacts of overfishing and environmental degradation. It is essential to pursue further research to identify site-specific influences and long-term ecological results, thereby guaranteeing sustainable benefits for both marine ecosystems and coastal communities.

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INTRODUCTION

Coral reefs represent some of the most expansive and ecologically varied ecosystems on Earth; coral reefs support a wide range of life, from tiny plankton to large fish. This astonishing range of biodiversity plays a vital role in sustaining the balance of ocean ecosystems and greatly influences human communities (Awak *et al.,* 2016; Azra *et al.,* 2023; Bellwood and Tebbett, 2024). Despite occupying less than 1 percent (%) of the ocean's surface, coral reefs sustain approximately 25% of all marine species, offering critical habitats for fish, mollusks, crustaceans, and numerous other organisms that depend on these ecosystems for protection, feeding, and reproduction (Kembrey *et al.,* 2024). Coral reefs, while ecologically significant, also deliver vital services to human communities, including protection against coastal erosion, support for fishing industries, and tourism opportunities, which together sustain millions of livelihoods globally. The extraordinary biodiversity and multifaceted benefits of coral reefs highlight the urgent need for protection amidst escalating environmental pressures (Burdett *et al.,* 2024; Hughes *et al.,* 2017). The "Coral Triangle", comprising Solomon Islands, Timor-Leste, Papua New Guinea, Malaysia, Philippines, and eastern Indonesia, is identified as the primary center of coral reef biodiversity worldwide (Green, 2008; Sobha *et al.,* 2023). Located in the Coral Triangle, Indonesia is known for its exceptional diversity of marine biodiversity. This area is home to approximately 569 species and 83 genera of stony corals, accounting for roughly 69% of the global species and 76% of the genera of stony corals worldwide (Hadi *et al.,* 2020). Recognized globally for their ecological diversity, the nation's coral reefs are home to over 70% of all species of reef-building corals, as well as a substantial variety of fish species that inhabit these ecosystems (De Clippele *et al.,* 2023). Recent studies underscore a significant decline in marine biodiversity, with coral reefs enduring substantial impacts from human activities (Camp *et al.,* 2024; Edgar *et al.,* 2023; L. Huang *et al.,* 2024; Obura *et al.,* 2022). These ecosystems are crucial not only for the survival of diverse marine species but also for the economic well-being of human communities through sectors such as fisheries, tourism, and coastal defense. Nevertheless, these essential habitats are facing growing challenges from a combination of overfishing, pollution, and the effects of climate change. Overfishing has led to the reduction of vital fish stocks, pollution has degraded water quality, and climate change has resulted in coral bleaching and increased ocean acidity, all of which threaten the structural and ecological integrity of coral reefs (Good and Bahr, 2021; O'Leary *et al.,* 2020). Globally, coral reefs face a range of complex challenges. Critical challenges involve the repercussions of overfishing, pollution, and especially the significant ramifications of climate change, such as higher sea temperatures, ocean acidification, and a rise in both the frequency and intensity of extreme weather phenomena. The intrinsic fragility and sensitivity of coral reef systems mean that even slight environmental fluctuations—like minor temperature or salinity changes—can have disastrous effects. These changes can trigger extensive coral mortality and lead to the degradation of the associated fish communities that rely on these habitats for survival and reproduction. The interaction between coral reefs and the fish populations that depend on them is one of the most thoroughly examined relationships within marine ecosystems. Coral reefs, particularly those dominated by Acropora and Millepora corals, provide critical habitat for a wide variety of fish species (Coker *et al.,* 2014), and their loss can have significant implications for fish biodiversity. Protecting coral habitats and the fish populations that rely on them is crucial, making conservation initiatives vital. Ecological disruption not only reduces biodiversity but also undermines the resilience of these ecosystems, complicating efforts towards their recovery and conservation (Hughes *et al.,* 2017; Selig and Bruno, 2010). The heightened exploitation of natural resources and the intensifying repercussions of global warming have brought to light the urgent need for comprehensive management strategies that bolster ecosystem resilience and enhance their ability to withstand and recover from various disturbances. In marine environments, no-take zone (NTZ) and marine protected areas (MPAs) have emerged as effective tools for conserving biodiversity and increasing the biomass of exploited species, as a key conservation strategy to protect and restore coral reef ecosystems and associated fish communities (Caughman *et al.,* 2024; Lusiana *et al.,* 2024). In-depth study indicates that properly enforced MPAs can markedly boost the diversity, abundance, size of individual organisms, and reproductive rates of fishes and invertebrates,

resulting in advantageous spillover effects to nearby unprotected zones (Benedetti-Cecchi *et al.,* 2024). However, it is important to note that the specific mechanisms and outcomes of MPAs in enhancing coral reef ecosystems can vary considerably across different regions, management contexts, and environmental conditions (Strain *et al.,* 2019). Among marine environments, coral reef ecosystems are some of the richest in biodiversity; however, they face growing threats from human impact and changes in the environment. NTZs can help fisheries recover and boost ecotourism by protecting coral reefs. However, they may cause short-term income loss for fishers and require investment in management. Involving local communities in decision-making can help balance these impacts and ensure long-term benefits. Since 2008, the waters of Tapanuli Tengah have been designated as a regional marine protected area. In 2020, this status was elevated with the issuance of Decree Number 87/KEPMEN-KP/2020 by the Minister of Marine and Fisheries of the Republic of Indonesia, officially recognizing it as a conservation area of coastal and small islands in Tapanuli Tengah and Adjacent Waters (MMAF, 2020). Nonetheless, the extent of community engagement in its management is markedly insufficient, which has limited the impact of conservation strategies. Depending on marine resources for their livelihoods, local communities have not been fully involved in managing the no-take zones. When communities are not involved, it often results in misunderstandings and pushback against conservation policies. Therefore, it is essential to actively involve these communities in the management process to secure long-term success. This study seeks to address two critical objectives. The first objective is to examine the relationship between coral cover and reef fish communities, focusing on their abundance and species diversity within the MPAs of Tapanuli Tengah. Understanding these dynamics is crucial to identifying the ecological linkages that sustain biodiversity in these systems. The second objective is to evaluate the effectiveness of MPAs in enhancing the health and resilience of coral reef and the fish species that are part of these environments. The study seeks to deliver practical insights into how MPAs contribute to the conservation of coral reef biodiversity and uphold the ecological balance necessary for their enduring sustainability by meeting these objectives. The study was conducted within the Tapanuli Tengah Marine Conservation area in North Sumatra, Indonesia. Data collection was executed in two distinct phases: initially, in 2021, observations were conducted outside NTZs, while in 2024, observations were undertaken at three specific locations of NTZs. This study has been carried out in the Tapanuli Tengah Marine Conservation Area in North Sumatra, Indonesia, in 2024.

MATERIALS AND METHODS

Study area

This study was conducted in the Tapanuli Tengah Marine Conservation Area in North Sumatra, Indonesia, focusing on coral reefs and reef fish. Three no-take zones were the focus of observations, including Mursala Island, where fishing and other disruptive activities are strictly prohibited. These areas were compared with locations outside the no-take zones to evaluate the conservation effectiveness of these protected areas. The specific sites for coral observations are shown in Fig. 1. This figure illustrates the geographic layout of the study sites, highlighting both the protected and non-protected areas, which enables a clear visual comparison of the ecological contexts within which the observations were made. Understanding the effects of conservation strategies on marine biodiversity relies heavily on this spatial separation.

Coral reef observation

The observational survey commenced from the mainland or coastal areas and extended into the adjacent waters. Designated stations were systematically monitored, employing self-contained underwater breathing apparatus (SCUBA) to facilitate underwater observations and capture photographic documentation (Hill and Wilkinson, 2004). The underwater photo transect (UPT) technique was employed to assess benthic reef cover, ensuring precision and reproducibility (Kohler and Gill, 2006). In this study, 50 photos were systematically analyzed, each annotated with 30 random points, using coral point count with excel extensions (CPCe) software for detailed analysis (Abrar *et al.,* 2024; Kohler and Gill, 2006). This strategy allowed for the assessment of multiple metrics, including the percentage of coral coverage, the diversity of benthic biota, and various substrate categories (Dumas *et al.,* 2009; Kornder *et al.,* 2021). The UPT method enables high-resolution

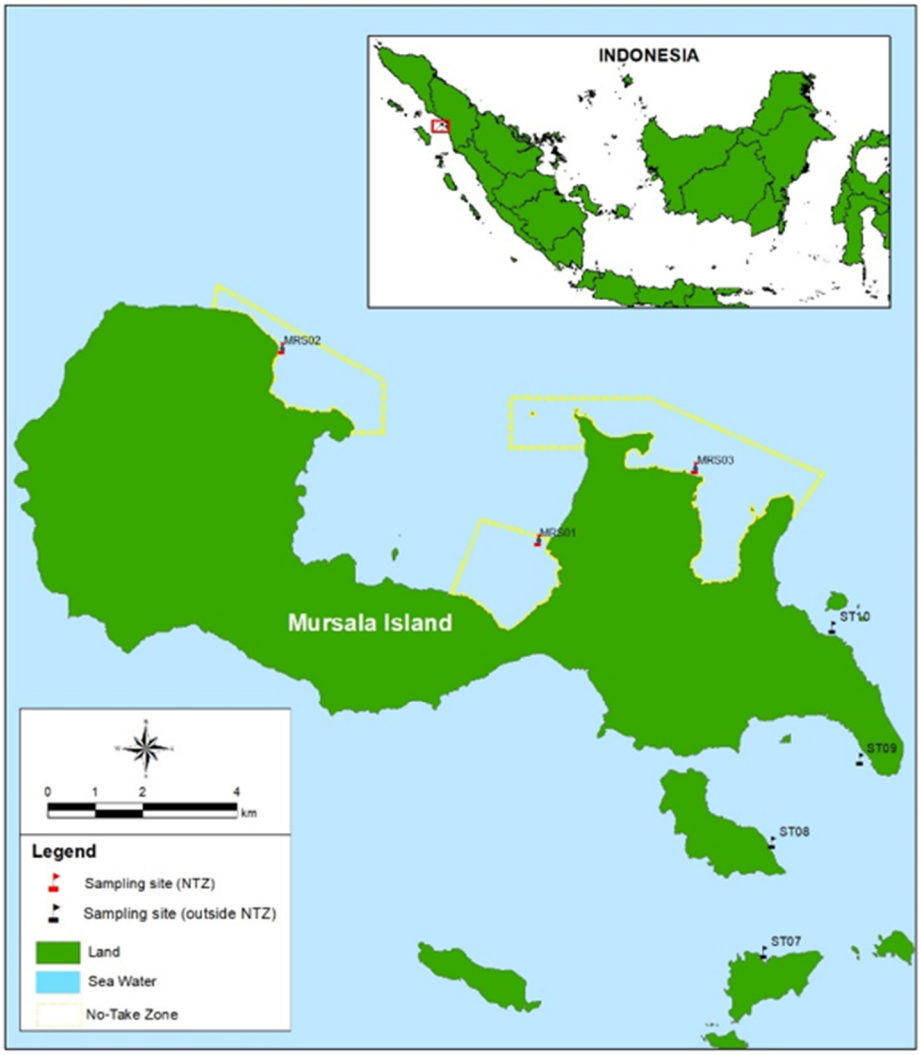


Fig. 1: Geographical location of the study area in Tapanuli Tengah Marine Conservation area, Indonesia

documentation of benthic ecosystems, facilitating detailed and consistent long-term monitoring of coral reef health while allowing for efficient quantification of coral cover and benthic composition across spatial and temporal scales (Prasetya and Santoso, 2022).

Coral cover

The evaluation of coral cover seeks to establish the status and categorization of coral reef areas, which is essential for assessing the ecological health and overall condition of the reef ecosystem. Percent cover of a lifeform category, using Eq. 1 (English *et al.,* 1997):

$$N_i = \frac{L_i}{N} x100\% \quad (1)$$

Where; Li : percent cover (%); Li : Total length of category; N : Length of transect

In many regions of Southeast Asia, coral reefs are assessed using a linear scale based on the percentage of live coral cover, as outlined by Bachtiar *et al.* (2019). According to this scale, reefs exhibiting more than 75% live coral cover are classified as being in "excellent" condition. Reefs with coral cover between 50% and 75% are categorized as being in "good"

condition, while those with coral cover ranging from 25% to 50% are deemed to be in "fair" condition. A reef is deemed to be in "poor" condition if it has less than 25% of its surface covered by live coral (Edinger and Risk, 2000).

Coral reef fish observation

Reef fish data were obtained through the underwater visual census (UVC) method along a 50-meter transect, with a field of view extending 2.5 meters on either side of the transect line (English *et al.,* 1997). At every specified data collection location, transects were set up, and fish data were documented through underwater video recordings taken during the day within the no-take zone reef. Divers utilized underwater video cameras to document the presence and behaviour of coral reef fish in shallow waters, capturing random yet comprehensive footage of fish communities (Kang *et al.,* 2022). The identification of species and the estimation of their abundance were conducted utilizing video image data. Observed fish were cross-referenced with identification guides, including (Frose and Pauly, 2024) and (Allen, 2003), to ensure accuracy. During dives, fish data were initially recorded on underwater slates and subsequently transferred to a Microsoft Excel datasheet for further processing and analysis. This strategy offered a comprehensive framework for the assessment of reef fish communities by combining visual census techniques with video documentation and rigorous data validation processes.

Community structure of coral reef fish

To characterize the community structure of reef fish, underwater visual surveys were conducted using SCUBA within designated survey plots. Throughout these surveys, the composition of species, their abundance, and the total length of all individuals measuring at least 15 centimeters (cm) were meticulously documented (Helder *et al.,* 2022). The identification of reef fish was guided by authoritative references, including Allen and Erdmann (2012), (Kuiter and Tonozuka, 2001), and FishBase online data (Froese and Pauly, 2024), which provide essential taxonomic, ecological, and distributional information. These resources, when combined, create a vital framework for studies related to biodiversity and ecology. The structure of coral reef fish communities was analyzed by calculating diversity indices, including Margalef richness index (D), Shannon-Wiener diversity index (H), Pielou's Evenness index (E), and Simpson dominance species index (C) (Fedor and Zvaríková, 2019; Gaertner *et al.,* 2008). The use of biodiversity metrics, including species richness, diversity, evenness, and dominance, is vital for analyzing the community structure and the general health of fish populations in coral reefs. These indices are instrumental in the monitoring, evaluation, and conservation of coral reef ecosystems, offering vital insights into biodiversity, ecosystem resilience, and functional processes. Furthermore, they are vital in monitoring alterations in fish community dynamics, identifying potential stressors, and shaping management and conservation strategies aimed at preserving the integrity and sustainability of reef ecosystems (Loiseau and Gaertner, 2015).

Statistical analysis

Correspondency analysis performed to investigate the correlation between reef fish family abundance and the percent cover of coral lifeforms (Chabanet *et al.,* 1997). This multivariate approach is often utilized to detect patterns and connections in categorical data, which makes it particularly adept at explaining the relationships between ecological variables. The analysis utilized a statistical computing environment that supports robust data visualization and interpretation. By employing this approach, the study intended to identify potential relationships or trends within the data that could shed light on the ecological dynamics between reef fish communities and the configuration of coral habitats.

RESULTS AND DISCUSSION

Coral cover

This study conducted an analysis of coral reef lifeforms both within and outside designated no-take zones in the Tapanuli Tengah Marine Conservation Area. The NTZs examined included MRS01, MRS02, and MRS03, while the non-protected areas comprised ST07, ST08, ST09, and ST10. The data presented in Fig. 2 reveal significant variations in coral composition between NTZs and adjacent unprotected areas, thereby substantiating the efficacy of conservation measures in preserving coral reef ecosystems (Wright, 2022). Within the NTZs, which are safeguarded from direct human disturbances such as fishing and boating, hard coral coverage is substantially higher

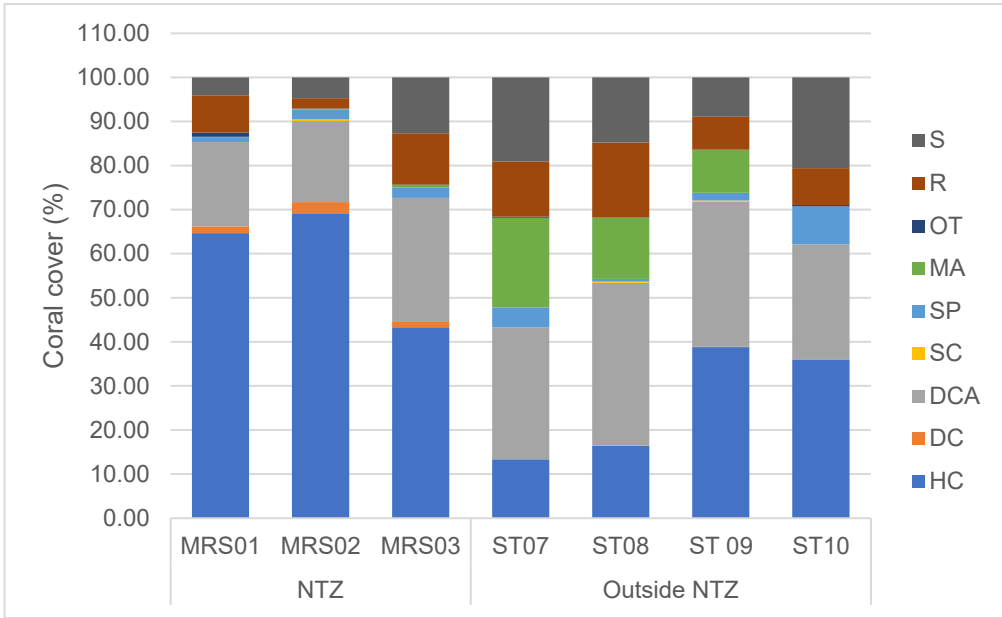


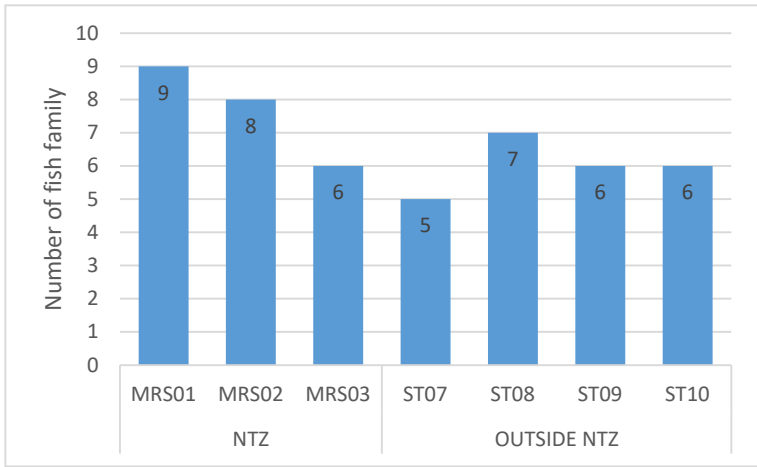
Fig. 2: Comparison of coral lifeforms in NTZ and outside NTZ

(MRS01: 64.64%, MRS02: 69.16%, MRS03: 43.30%) compared to sites outside these zones (ST07: 13.33%, ST08: 16.40%, ST09: 38.80%, ST10: 36.00%). Hard corals are fundamental to the formation of reef structures and are integral to marine biodiversity. They deliver important ecosystem services, including protection for coastlines and habitats for various fish species (Angkotasan *et al.,* 2023; Darling *et al.,* 2017). According to Edinger and Risk (2000), NTZs are categorized as having good conditions based on live coral cover, while non-protected areas are in fair condition. Live coral cover is considered a primary indicator of reef health (Gudka *et al.,* 2023). Conversely, the elevated levels of dead corals covered with algae outside the NTZs (ranging from 26.13% to 36.93%) indicate ecological degradation. When corals die and are overtaken by algae, coral reef ecosystems display symptoms of distress. This rampant algal proliferation hinders the development of new coral colonies, worsening the decline of the reef system (Shah, 2021). Algae-covered dead corals signify not only the mortality of reef-building organisms but also a shift in ecological balance, often precipitated by overfishing, which reduces herbivorous fish populations that control algal growth, and nutrient pollution from land-based sources (Zaneveld *et al.,* 2016). Such disruptions can weaken the resilience of coral reefs, increasing their susceptibility to further challenges such as climate change and ocean acidification (Stier and Osenberg, 2014). Moreover, the notable presence of macroalgae (20.33% at ST07 outside the NTZ) starkly contrasts with its minimal occurrence within protected zones (maximum 0.53%). The growth of macroalgae often occurs as a result of nutrient enrichment, which can impede coral health by blocking sunlight and suffocating young coral recruits, ultimately leading to a destabilization of the reef structure (D'Angelo and Wiedenmann, 2014). This study underscores the necessity for expanded and strictly enforced NTZs as a critical measure in maintaining coral health, which is vital for environmental conservation and the socio-economic stability of communities that rely on these ecosystems. Serving as rich biological resources, coral reefs play a critical role in providing essential services like food security, tourism prospects, and natural coastal protection. Therefore, maintaining their health is a key concern that impacts both ecological balance and human welfare, as well as economic resilience (Cinner *et al.,* 2016; Hughes *et al.,* 2017; Moberg and Folke, 1999). Additionally, integrating these protective zones with comprehensive strategies aimed at

mitigating anthropogenic impacts like nutrient runoff and overfishing in adjacent areas is crucial. A holistic approach to marine conservation can help preserve these vital ecosystems for future generations, while promoting sustainable economic practices that rely on healthy reefs (Halpern *et al.,* 2013; Kusumawati and Huang, 2015). The data highlights that while NTZs maintain healthier coral populations and lower incidences of environmental stress indicators like macroalgae and sedimentation, challenges such as coral mortality and algal overgrowth broadly affect coral reefs. This emphasizes the critical need for holistic environmental management approaches that go beyond NTZ limits to address the pervasive environmental stressors impacting coral reefs. Statistical analysis of 95% confidence intervals was employed as an indicator to estimate the range within which the population parameters are likely to fall. The live coral cover (hard coral) in NTZs was statistically greater than that in areas outside NTZs. The confidence interval values for the NTZ indicated that coral cover varied from (59.03±15.63%), whereas outside NTZs, it ranged from (26.13±12.85%). This evidence points to the conclusion that NTZs are superior in safeguarding or encouraging coral growth. The overlap in ranges implies that, although NTZs generally exhibit better coral cover, variability may still exist both within and outside NTZ areas.

Reef fish communities

The analysis of marine reserve sites within and adjacent to NTZs demonstrates significant differences in ecological metrics, as shown in the presented data (Fig. 3). In Fig. 3a, a thorough analysis of the fish families identified at various marine sites is illustrated, with a clear distinction made between those located inside and outside NTZs. The sites within the NTZs—MRS01, MRS02, and MRS03—exhibit a greater diversity of fish families, with counts ranging from 6 to 9. Conversely, at sites beyond the NTZs—namely ST07 to ST10—the number of fish families consistently falls between 6 and 7, which is notably lower. This observation suggests that NTZs play a significant role in enhancing or at least sustaining marine biodiversity. Fig. 3b explores the total species count per site, further supporting the positive impact of NTZs on marine life diversity. Notably, species richness within NTZs, particularly at sites MRS02 and MRS03, significantly exceeds that observed in areas outside the NTZs, with counts as high as 29 species compared to a maximum of 22 species outside the NTZs. Furthermore, the disparity in species richness emphasizes the ability of NTZs to function as biodiversity hotspots, which play a crucial role in boosting the productivity and ecological equilibrium of marine habitats. Studies have shown that areas with higher biodiversity often exhibit greater stability and productivity, as diverse species interactions can enhance resource utilization and energy transfer efficiency within the ecosystem (Erm *et al.,* 2024; Russ and Alcala, 2011). Additionally, other opinions have been expressed by (Stuart-Smith *et al.,* 2013) that higher species abundance and functional traits offer a clearer understanding of biodiversity and its role in ecosystem functions. In temperate climates, the even distribution of species allows each one to contribute significantly to ecological functions, resulting in increased stability and productivity. In contrast, tropical regions have higher species richness, but individual species contribute less to the overall ecosystem functions. Thus, functional diversity and evenness in species abundance provide better ecosystem stability and efficiency indicators. Finally, Fig. 3c quantifies the reef fish abundance in individuals per hectare, highlighting a stark contrast in population density. Sites within NTZs, especially MRS02, show a remarkably high abundance of 19,440 individuals per hectare, whereas the highest abundance outside the NTZs is considerably lower at 4,600 individuals at ST09. The data presented in Fig. 3 strongly supports the notion that no-take zones are effective in boosting both biodiversity and the numbers of reef fish. The observed patterns align with established ecological theories that protected areas, by restricting extractive activities like fishing, create refuges for marine life, thereby allowing for greater biodiversity and biomass accumulation (Hollitzer *et al.,* 2023). The considerable disparity in fish family diversity and species richness observed between NTZs and non-NTZ regions can be explained by the decrease in fishing pressure. This pressure typically removes certain key species, thereby modifying the natural composition of the community (Salema *et al.,* 2022). Moreover, the increased abundance of individuals within NTZs, as shown in Fig. 3c, may be indicative of successful reproductive and recruitment processes, suggesting that NTZs provide not only refuge but also suitable conditions for the growth



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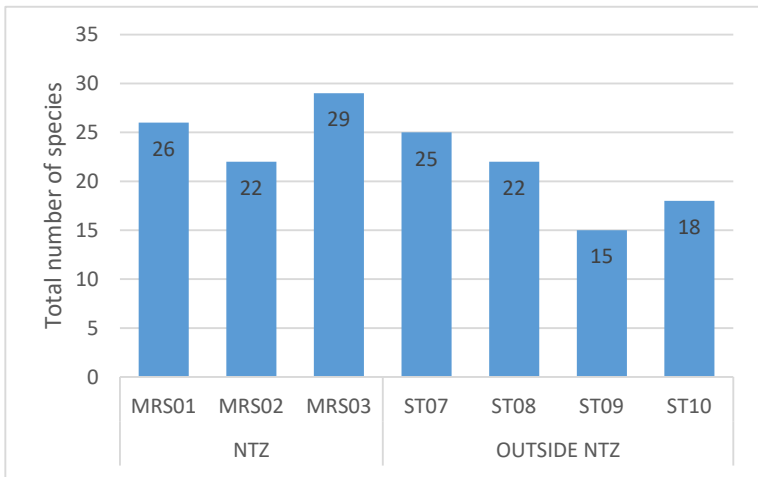

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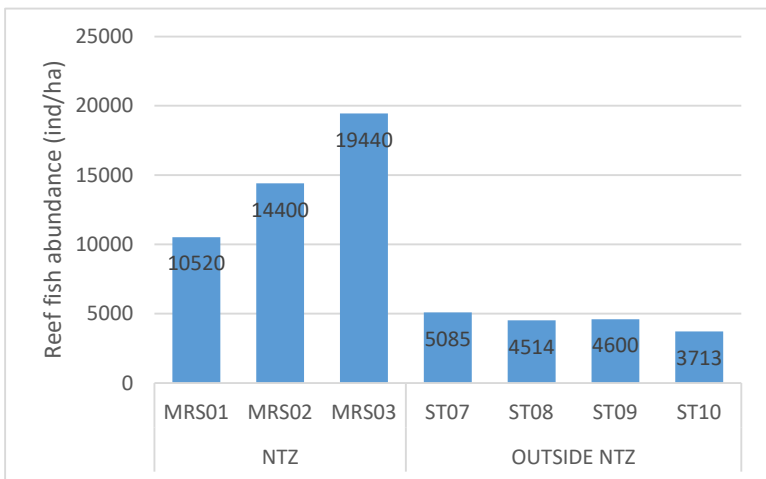

(c

Fig. 3: Comparative number of coral reef fish in NTZs and outside NTZs (a) family (b) Total number of species (c) fish abundance (individuals/ha)

and reproduction of various fish species (Bostedt *et al.,* 2020). Maintaining sustainable fish populations is particularly essential, as they significantly bolster the resilience of coral reef ecosystems against environmental shifts and disturbances. Additionally, the data underscores the need for continued support and potentially expanding NTZs as a conservation strategy. While NTZs are effective, the variability in results across differences in abundance at various sites implies that site-specific factors also play a crucial role in determining the success of these zones. The effectiveness of these protected areas may be influenced by various factors, including the quality of the habitat, closeness to pollution sources, and the enforcement of NTZ regulations (Ferreira *et al.,* 2022; Rodríguez-Rodríguez and Martínez-Vega, 2022). This study demonstrates that NTZs significantly enhance biodiversity and fish populations on coral reefs. The quantitative evidence supports expanding NTZs as an effective marine conservation strategy. The study underscores the necessity of implementing no-take zones in at-risk marine environments to facilitate the conservation and recovery of global biodiversity. Furthermore, confidence intervals serve to evaluate the reliability and validity of sample data employed in making estimates, clearly indicating that NTZs support significantly higher fish abundance and species richness compared to areas outside NTZs. Within NTZs, fish abundance is observed to range from 14,800 ± 5,059.19 ind/ha, with 95% confidence intervals offering a reliable estimate of the fish population within this range. In NTZs, the range of species richness is 25.67 ± 3.97 species, with confidence intervals supporting the precision of the diversity measurementsConversely, outside NTZs, fish abundance ranges from 4,478 ± 557.20 ind/ha, and species richness varies between 20 ± 4.31 species, with wider confidence intervals indicating greater variability (Fig. 3).

Reef fish diversity across marine reserves and surrounding areas

The entire dataset is presented in Fig. 4, which offers a comprehensive comparison of reef fish diversity and functional group abundance across both NTZs (MRS01, MRS02, MRS03) and areas outside these protected zones (ST07, ST08, ST09, ST10). This illustration distinctly highlights the significant variations in species richness, population densities, and the distribution of important fish families, offering essential insights into the ecological impacts of NTZs on marine biodiversity and the interactions within functional groups. Within NTZs, MRS03 exhibits the highest species richness with 29 species and the highest individual density at 19,440 individuals per hectare. These metrics contrast markedly with the sites outside NTZs, where species richness and individual density are significantly lower; for example, ST09 supports only 15 species and 4,600 individuals per hectare. Further investigation demonstrates that the improved biodiversity in NTZs can be largely credited to the existence and abundance of vital functional groups, particularly those consisting of herbivorous and coralivorous species. The Pomacentridae family, which includes many coralivorous species, is notably abundant in NTZs, with counts of 169, 261, and 410 individuals at MRS01, MRS02, and MRS03, respectively. In contrast, this family is entirely absent from unprotected sites. The absence of Pomacentridae outside NTZs highlights the susceptibility of coralivorous species to fishing pressures, which may significantly disrupt coral-algal dynamics and, by extension, the health of the coral reef itself. The role of coralivorous fish is vital in sustaining the balance within coral-dominated ecosystems. By selectively grazing on both coral and algae, they help avert algal overgrowth that could potentially overwhelm and damage coral structures (Knoester *et al.,* 2023). Herbivorous reef fish are the primary grazers of macroalgae on coral reefs (Cheal *et al.,* 2010; Cook *et al.,* 2025), such as those in the Scaridae family (e.g., parrotfish), are also significantly more abundant in NTZs. These species are essential for managing algal populations, preventing them from overtaking coral reefs. The distribution of Scaridae, however, shows variability between sites. For instance, while sites within NTZs exhibit higher numbers, the non-NTZ site ST07 supports a notable 99 individuals. This variation implies that specific environmental conditions, such as the accessibility of algal resources or targeted fishing activities, might play a role in determining the density of herbivorous species in unprotected areas (Altman-Kurosaki *et al.,* 2021). Carnivorous species, particularly those in the Serranidae family (e.g., groupers and basses), are also more abundant within NTZs. By regulating the numbers of smaller fish and invertebrates, these predators play a crucial role in maintaining the

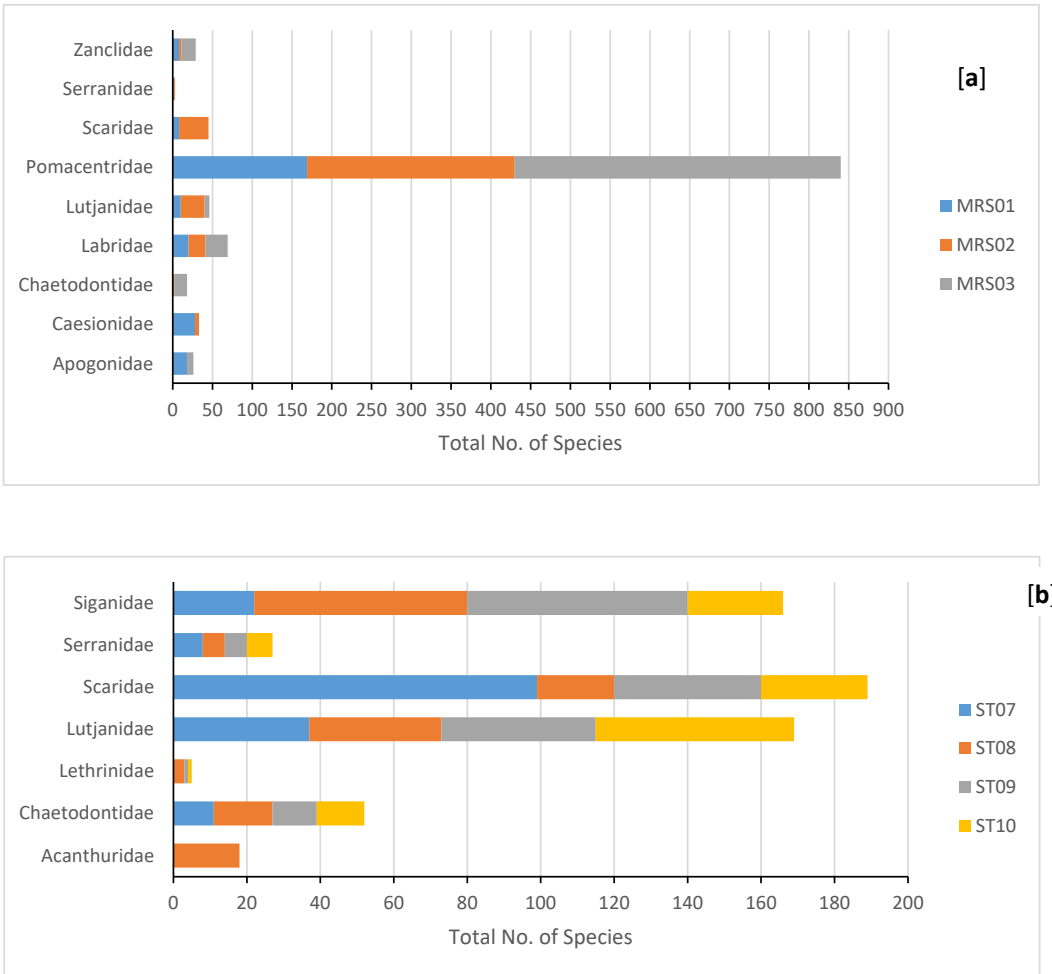

Fig. 4: Comparative abundance of fish families [a] no-take zone and [b] outside no-take zone

balance of the food web and fostering ecosystem stability (Boaden and Kingsford, 2015). In NTZs, the absence of fishing pressure allows these apex predators to thrive, which, in turn, helps control the abundance of herbivorous and coralivorous species and mitigates overgrazing and overgrazing-induced coral degradation. Apex predators play a vital role in preserving the structure and dynamics of marine ecosystems by ensuring the continuity of trophic cascades (Estes *et al.,* 2011). In contrast, the scarcity of both herbivorous and coralivorous fish in non-NTZ areas, alongside lower densities of carnivores, suggests that fishing pressures and habitat degradation may disrupt trophic interactions and reduce the ecological resilience of coral reef ecosystems. In the absence of adequate herbivorous and coral-eating species to manage algal proliferation and safeguard coral populations, these ecosystems could be at a higher risk of transitioning to algal-dominated conditions, which tend to be less diverse and more vulnerable to environmental fluctuations (Cook *et al.,* 2024). These findings underscore the crucial role of NTZs in sustaining marine biodiversity and maintaining the ecological functionality of coral reef ecosystems. The significantly higher abundance of herbivores, carnivores, and coralivores within NTZs highlights the protective benefits these areas provide in terms of maintaining healthy fish populations that fulfill essential ecological roles. Thus, the expansion and strict enforcement of NTZs ought to be seen as a

Table 1: Ecological diversity indices for reef fish in NTZs and outside NTZs of marine protected area

Indices	MRS01	MRS02	MRS03	ST07	ST08	ST09	ST10	P-value
Species Richness	26	29	22	25	22	15	18	0.13
Shannon-wiener (H')	2.61	1.89	1.85	1.37	1.80	1.49	1.55	0.06
Evenness (E)	0.80	0.56	0.60	0.43	0.58	0.55	0.54	0.14
Dominance (C)	0.11	0.25	0.26	0.37	0.22	0.27	0.27	0.23

crucial strategy for advancing biodiversity, improving the resilience of coral reefs to climate change, and fostering sustainable marine ecosystems that support both ecological integrity and the livelihoods of coastal populations.

Ecology indices

The ecological diversity indices for reef fish communities in NTZs (MRS01-MRS03) and areas outside NTZs (ST07-ST10) within the marine protected areas exhibit notable variations in species richness, diversity, evenness, and dominance. The total number of species, known as species richness, was typically greater in the NTZ, with MRS02 documenting the highest count at 29 species. In contrast, ST09 showed the lowest species richness, with only 15 species identified among the sites surveyed outside the protected area. These findings are consistent with earlier studies conducted by Kelaher (2014) who found that NTZs support higher species richness due to reduced fishing pressure and habitat protection. Although NTZs demonstrated slightly higher species richness, statistical analysis ($p = 0.127$) indicated that this difference was not statistically significant, suggesting that additional factors such as habitat complexity, recruitment dynamics (Moustaka *et al.,* 2024) and regional oceanographic conditions (Ceccarelli *et al.,* 2023) may also influence species composition. The Shannon-Wiener Diversity Index (H'), which measures species variety and abundance, was also higher inside NTZs, with MRS01 (H' = 2.61) recording the highest value, while ST07 had the lowest (H' = 1.37). This pattern indicates that NTZs have the potential to promote more resilient and diverse fish communities (Kembrey *et al.,* 2024). The difference was close to significance ($p = 0.0598$), indicating that marine protection plays a role in diversity but may not be the only factor (Sanchez *et al.,* 2024). Evenness (E), which shows how evenly species are distributed, was highest in MRS01 (0.80) and lowest in ST07 (0.43). When evenness is high, nearing a value of 1, it signifies that no particular species is overly dominant and that there is a more balanced distribution of species in NTZs. This condition typically reflects a more resilient ecosystem that can better withstand changes. Conversely, lower evenness in areas outside NTZs may point to an ecosystem that is more fragile, making it more prone to disturbances and slower in its recovery process. However, the difference was not statistically significant ($p = 0.140$), suggesting that competition and habitat differences influence evenness (Pereira *et al.,* 2024). Similarly, the Dominance Index (C), which measures whether a few species dominate, was lowest in MRS01 (0.11), indicating a balanced ecosystem, and highest in ST07 (0.37), showing dominance by a few species. This trend matches findings that overfishing in unprotected areas often leads to a few species dominating (Martin *et al.,* 2023). However, statistical tests ($p = 0.226$) did not confirm a significant difference between NTZs and outside NTZs. The lack of statistically significant differences in NTZs, as measured by diversity indices (species richness, H, E, and C) can be attributed to a combination of methodological limitations, NTZ characteristics, taxonomic variability, and broader environmental influences. To accurately evaluate the effectiveness of NTZs, it is crucial to adopt a multi-faceted strategy that integrates additional metrics, including phylogenetic and functional diversity (Matten *et al*., 2023), and takes into account external factors such as climate change and changes in land use (Häkkilä *et al.,* 2017). This comprehensive strategy will provide a more accurate understanding of the role of NTZs in biodiversity conservation.

The findings indicate that NTZs help maintain biodiversity by supporting more species, higher diversity, and a balanced ecosystem, but the differences observed were not consistently statistically significant. Moreovere, a range of factors like the structure of habitats, levels of fishing

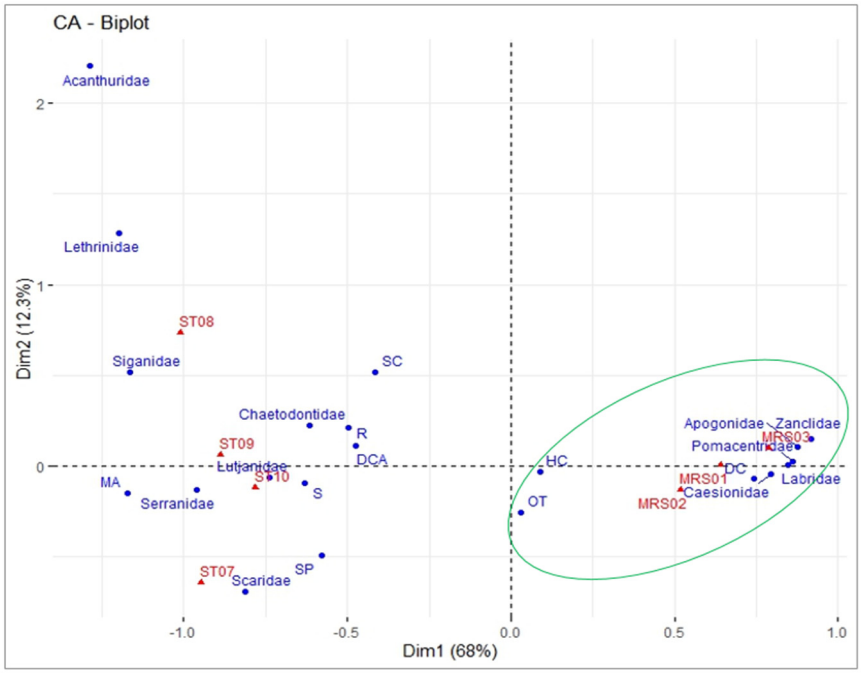

Fig. 5: Biplot graph of correspondence analysis across all sites with reef fish families and coral life forms

pressure, and changes in the environment may affect fish populations (Hernández-Andreu *et al.,* 2024; Hopf *et al.,* 2024; Varnes and Olsen, 2023). Future research should include long-term monitoring and habitat analysis to fully understand the benefits of no-take zones.

Relationship between coral cover and coral reef fish

The correspondence biplot visualizes the relationship between the abundance of reef fish families and coral lifeforms at NTZs and sites outside the NTZs (Fig. 5). Two principal dimensions are utilized in the biplot to represent the variability within the data: Dim1 (68%), which accounts for the greatest proportion of variation, and Dim2 (12.3%), capturing secondary gradients of association.

Fig. 5 demonstrates a clear distinction between the ecological conditions of NTZs and outside NTZs, highlighting how these areas differ in both fish family composition and the types of coral life forms present. The presence of fish families like Acanthuridae, Lethrinidae, and Sigannidae on the negative side of Dim1 indicates that they are more closely linked to degraded coral habitats located beyond the NTZs (ST07, ST08, ST09, ST10). These sites are dominated by dead coral (DC), dead coral with algae (DCA), and rubble (R). Acanthuridae feed on detritus and algae, which are abundant in degraded environments, as they are detritivorous (Russ *et al.,* 2018). Their abundance in such areas is strongly linked to the availability of dead substrate, which provides both food and shelter. Similarly, Lethrinidae and Sigannidae are known to exploit algae and detritus, making them well-suited to degraded coral environments (McCormick *et al.,* 2017). The fish families found here, such as Chaetodontidae and Scaridae, are often associated with more disturbed ecosystems where they may rely on macroalgae and detritus, their ability to adapt to disturbed ecosystems by altering their diet suggests a potential resilience to environmental changes (Russ and Leahy, 2017). These results support the concept that fish communities in impaired habitats tend to be less diverse and increasingly dependent on opportunistic resources (Rogers *et al.,* 2017). In contrast, Pomacentridae, Apogonidae, Zanclidae, and Caesionidae, found on the positive side of Dim1, are strongly associated with sites in the NTZs (MRS01, MRS02, MRS03), where hard coral (HC) is

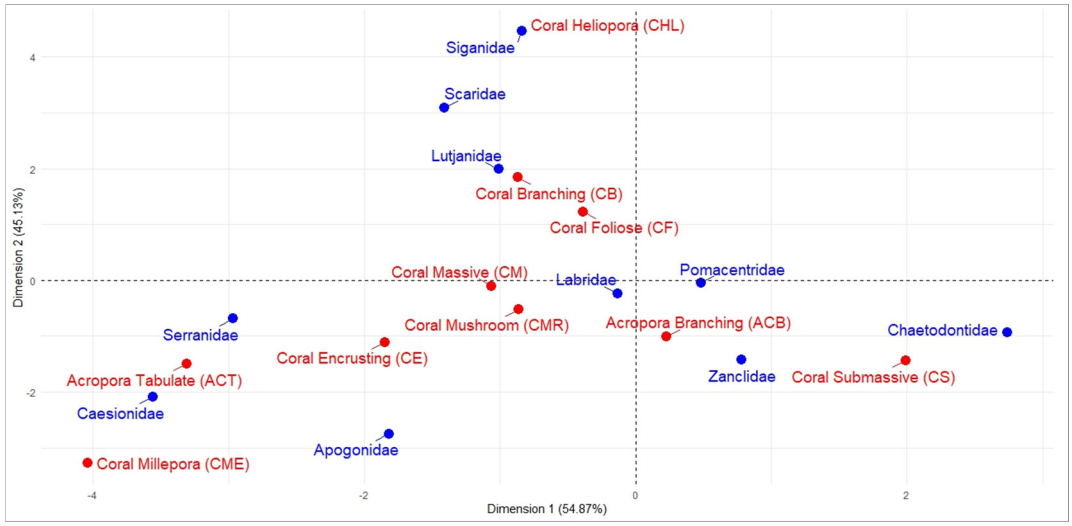

Fig. 6: Analysis of the correlation between fish family abundance and hard coral cover in NTZs

more abundant. The proximity of these fish families to hard coral indicates their reliance on complex reef habitats for shelter, food, and breeding sites (Coker *et al.,* 2014; Hall and Kingsford, 2021). NTZs, through the prohibition of fishing, create healthier and more diverse coral environments, thereby supporting a larger array of fish species, especially those that are reliant on live coral (Kembrey *et al.,* 2024). The dominance of hard coral in NTZs further enhances the habitat's ability to support high biodiversity, as healthy reefs are essential for maintaining ecosystem function and structure (Harvey *et al.,* 2018). Additionally, sand (S) and sponge (SP) life forms are located closer to the fish families found outside the NTZs, further highlighting the degraded conditions of these sites. Outside of NTZs, macroalgae (MA) is more commonly found, often flourishing due to less competition from coral. This phenomenon is intensified by factors such as overfishing and habitat degradation (Seemann *et al.,* 2018). Fish families associated with macroalgae, such as Scaridae, may dominate in these disturbed areas, as they can graze on algae that thrive in coral-depleted environments (Wilson *et al.,* 2022). Overall, this correspondence analysis underscores the importance of NTZs in preserving reef biodiversity, where healthier, coral-dominated ecosystems support a more diverse range of fish families. The graph visually reinforces the concept that NTZs play a critical role in maintaining biodiversity by offering refuges for coral and associated fish species threatened by anthropogenic disturbances outside these protected areas. However, the efficacy of NTZs is often influenced by effective enforcement and community engagement, which are essential for optimizing conservation outcomes (Espinosa-Andrade *et al.,* 2020). Furthermore, long-term monitoring is vital for assessing coral reef ecosystems' ecological condition, evaluating conservation efforts' success, and adapting management strategies. Monitoring provides essential data on the health and trends of coral reefs, which are under significant pressure from both anthropogenic and natural factors (Obura *et al.,* 2019). By integrating these elements, NTZs can function as a potent mechanism for the preservation of coral reef ecosystems.

This correspondence analysis offers a visual tool to assess variations in fish family composition between protected and non-protected areas, highlighting the role of NTZs in supporting biodiversity and ecosystem health. In Fig. 6, the method is shown to analyze the habitat preferences of reef fish in relation to different hard coral species. Fish families such as Serranidae, Caesionidae, and Apogonidae exhibit a strong spatial association with coral species like Acropora Tabulate (ACT) and Coral Millepora (CME), as evidenced by their close proximity on the correspondence analysis biplot. The connections between coral structures and reef fish are not limited to basic habitat use; they include sophisticated functional relationships that are mutually beneficial. Corals provide critical

shelter from predation pressure for fish families, particularly for juvenile individuals. Research has documented by Leal *et al.* (2013) that juvenile fish comprise approximately 65% of individuals observed in association with Millepora coral colonies. The ecological interactions between reef fish families such as Serranidae, Caesionidae, and Apogonidae and coral species like Acropora Tabulate and Millepora represent intricate relationships crucial for coral reef ecosystems' biodiversity and ecological processes. These relationships include overall association trends and targeted habitat preferences, demonstrating the adaptations of fish species to the unique structural attributes of different coral varieties. The complex architecture of the Acropora Tabulate and Millepora colonies creates a variety of microhabitats that upport different life stages and ecological functions of the associated fish species. On the other hand, fish species like Lutjanidae, Pomacentridae, and Chaetodontidae appear further apart from certain coral types such as Coral Submassive (CS) and Coral Heliopora (CHL), possibly indicating that these fish families are associated with different coral structures, either for feeding or sheltering purposes (González-Rivero *et al.,* 2017; Harsindhi *et al.,* 2020). According to Hernández *et al*. (2023), various fish families display specific preferences for certain coral types; however, these preferences are not exclusively determined by the availability of coral. Instead, factors such as predator avoidance, metabolic changes, and ontogenetic vertical migration play significant roles in shaping the distribution patterns of these species. These behavioral elements can impact larval dispersal and connectivity, highlighting a sophisticated interaction between preferences for different coral types and the larger ecological framework. The biplot reveals some notable trends in how coral species and fish families are distributed across the plot. For instance, the Acropora Branching (ACB) coral species is located near fish families such as Labriidae, which may suggest a functional relationship between these coral structures and the fish's feeding or shelter needs (Floros and Schleyer, 2017). Likewise, the Coral Foliose (CF) and Coral Encrusting (CE) types show a closer relationship to species like Zanclidae and Scaridae, indicating potential ecological interactions. According to the biplot analysis, the no-take zone supports specific ecological connections between particular fish families and hard coral species. Some fish species appear to preferentially associate with particular coral structures, which likely offer critical resources such as feeding, spawning, and nursery grounds (Bonaldo *et al.,* 2017; Kembrey *et al.,* 2024). The insights gained from this research are vital for shaping future conservation strategies that aim to protect the critical interactions between coral and fish in designated conservation zones.

CONCLUSION

This study underscores the critical role of MPAs, particularly NTZs, in conserving and enhancing coral reef ecosystems. The results from the Tapanuli Tengah Marine Conservation Area provide robust evidence that well-enforced NTZs can significantly improve coral cover and biodiversity, particularly by increasing the abundance and diversity of reef fish communities. Sites within NTZs exhibited significantly higher hard coral coverage, lower incidence of macroalgal overgrowth, and greater fish abundance compared to adjacent non-protected areas, demonstrating the efficacy of these protected areas in fostering ecological resilience. Moreover, the results of the correspondence analysis indicated a specific relationship between the abundance of different fish families and coral lifeforms, underscoring the structural dependencies of reef fish on coral ecosystems. Fish families such as Pomacentridae, Apogonidae, and Caesionidae, which are closely associated with healthy coral environments, were more abundant in NTZs, where hard corals were prevalent. Conversely, non-protected regions, characterized by dead coral and macroalgae, exhibited a greater presence of fish families like Acanthuridae, Lethrinidae, and Siganidae, which are generally linked to deteriorated coral environments. These findings substantiate the hypothesis that MPAs, and specifically NTZs, play a pivotal role in maintaining habitat quality and enhancing biodiversity by providing refuges for species reliant on live coral structures. The positive relationship observed between coral cover and reef fish populations underscores the essential connection between the vitality of coral reefs and the structure of the fish communities that rely on them. These results align with extensive global research indicating that NTZs provide effective refuges for marine species, contributing to the recovery and maintenance of ecosystem services such as biodiversity preservation, habitat provisioning,

and trophic stability. These findings emphasize the critical need to enhance and rigorously enforce NTZs in the study region and globally, serving as an essential strategy to combat the detrimental effects of overfishing, habitat destruction, and climate change on marine environments. Although this study offers significant insights into the ecological benefits of NTZs, further research is required to assess the influence of additional site-specific factors such as habitat complexity, local enforcement strength, and anthropogenic pressures on the success of these conservation areas. Furthermore, continuous monitoring programs play a key role in determining the resilience and adaptability of these ecosystems over time. It is essential to integrate multi-scale monitoring and management approaches to guarantee the lasting ecological benefits provided by NTZs. As the world faces escalating environmental challenges, the growth and proper management of MPAs, particularly (NTZs, are vital for the conservation of coral reefs and the protection of marine biodiversity. This approach has profound implications for ecosystem-based management and the resilience of coastal areas.

AUTHOR CONTRIBUTIONS

Z.A. Harahap contributed to crafting the research proposal, executing field sampling, performing data analysis and interpretation, and drafting the manuscript. D.G. Bengen performed the conception and design, critical revision of the manuscript, and supervision. I.W. Nurjaya performed a critical revision of the manuscript and supervision. S.A. Bahri performed the conception and design, critical revision of the manuscript, and supervision. Y. Naulita performed the conception and design, critical revision of the manuscript, and supervision. R.M. Siringoringo performed data collection and tabulation.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the authors have completely observed the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

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ABBREVIATIONS

%	Percent
ACB	Acropora branching
ACT	Acropora tabulate
C	Dominance species index
CB	Coral branching
CE	Coral encrusting
CF	Coral foliose
CHL	Coral heliopore
cm	Centimeter
CM	Coral massive
CME	Coral millepora
CMR	Coral mushroom
CS	Coral submassive
CPCe	Coral point count with excel extension
D	Richness index
DC	Dead coral
DCA	Dead coral with algae
E	Evennes index
H	Diversity index
HC	Hard coral
ind/ha	Individual per hectare
MA	Macroalgae
MPA	Marine protected area
NTZ	No-take zone
OT	Others
R	Rubble
R^2	Determinant
r	Correlation
S	Sand
SCUBA	Self-contained underwater breathing apparatus
SP	Sponge
UPT	Underwater photo transect
UVC	Underwater visual census

REFERENCES

Abrar, M.; Bengen, D.G.; Zamani, N.P.; Suharsono; Giyanto; Putra, R.D.; Ni, N.W.; Siringoringo, R.M.; Hadi, T.A.; Utama, R.S.; Hermanto, B.; Arbi, U.Y.; Hukom, F.D.; Alifatri, L.O.; Wouthuyzen, S.; Harrison, P., (2024). Spatial distribution of juvenile corals (Scleractinia) in the coastal and small islands of Sumatra, Indonesia. Reg. Stud. Mar. Sci., 80: 1-11 **(10 pages)**.

Allen, G.R., (2003). Reef Fish Identification: Tropical Pacific. New World Publications. **(457 pages).**

Allen, G.R.; Erdmann, M.V., (2012). Reef fishes of the East Indies. Vols. I–III. Tropical Reef Research, Perth, Australia. **(1292 pages).**

Altman-Kurosaki, N.T.; Smith, C.M.; Franklin, E.C., (2021). O'ahu's marine protected areas have limited success in protecting coral reef herbivores. Coral Reefs. 40(2): 305–322 **(17 pages).**

Awak, D.S.H.L.M.K.; Gaol, J.L.; Subhan, B.; Madduppa, H.H.; Arafat, D., (2016). Coral reef ecosystem monitoring using remote sensing data: case study in Owi Island, Biak, Papua. Procedia Environ. Sci., 33: 600–606 **(7 pages).**

Azra, M.N.; Aouissi, H.A.; Hamma, W.; Guerzou, M.; Noor, M.I.M.; Petrişor, A.I., (2023). A scientometric macroanalysis of coral reef research in the world. Ecosyst. Evol., 42(2): 108–116 **(9 pages).**

Bachtiar, I.; Suharsono, Damar, A.; Zamani, N.P., (2019). Practical resilience index for coral reef assessment. Ecosyst. Serv., 54(1): 117–127 **(11 pages).**

Bellwood, D.R.; Tebbett, S.B., (2024). Habitat trumps biogeography in structuring coral reef fishes. Coral Reefs, 43(6): 1599–1609 **(11 pages).**

Benedetti-Cecchi, L.; Bates, A.E.; Strona, G.; Bulleri, F.; Horta e Costa, B.; Edgar, G.J.; Hereu, B.; Reed, D.C.; Stuart-Smith, R.D.; Barrett, N.S.; Kushner, D.J.; Emslie, M.J.; García-Charton, J.A.; Gonçalves, E.J.; Aspillaga, E., (2024). Marine protected areas promote stability of reef fish communities under climate warming. Nat. Commun., 15(1): 1–14 **(14 pages)**.

Boaden, A.E.; Kingsford, M.J., (2015). Predators drive community structure in coral reef fish assemblages. Ecol. Soc. Am., 6(4): 1–33 **(33 pages)**.

Bonaldo, R.M.; Pires, M.M.; Guimarães Junior, P.R.; Hoey, A.S.; Hay, M.E., (2017). Small marine protected areas in Fiji provide refuge for reef fish assemblages, feeding groups, and corals. PLoS One. 12(1): 1-26 **(26 pages)**.

Bostedt, G.; Berkström, C.; Brännlund, R.; Carlén, O.; Florin, A.B.; Persson, L.; Bergström, U., (2020). Benefits and costs of two temporary no-take zones. Mar. Policy, 117(2020): 1-13 **(13 pages)**.

Burdett, H.L.; Albright, R.; Foster, G.L.; Mass, T.; Page, T.M.; Rinkevich, B.; Schoepf, V.; Silverman, J.; Kamenos, N.A., (2024). Including environmental and climatic considerations for sustainable coral reef restoration. PLoS Biol., 22(3): 1–17 **(17 pages)**.

Camp, E.F.; Braverman, I.; Wilkinson, G.; Voolstra, C.R., (2024). Coral reef protection is fundamental to human rights. Global

Change Biol., 30(9): 1–4 **(4 pages)**.
Caughman, A.M.; Gaines, S.D.; Bradley, D., (2024). Climate change reduces long-term population benefits from no-take marine protected areas through selective pressures on species movement. Glob. Chang. Biol., 30(3): 1–15 **(15 pages)**.
Ceccarelli, D.M.; Evans, R.D.; Logan, M.; Jones, G.P.; Puotinen, M.; Petus, C.; Russ, G.R.; Srinivasan, M.; Williamson, D.H., (2023). Physical, biological and anthropogenic drivers of spatial patterns of coral reef fish assemblages at regional and local scales. Sci. Total Environ., 904(2023): 2–23 **(24 pages)**.
Chabanet, P.; Ralambondrainy, H.; Amanieu, M.; Faure, G.; Galzin, R., (1997). Relationships between coral reef substrata and fish. Mar. Ecol. Prog. Ser., 16(2): 93–102 **(9 pages)**.
Cheal, A.J.; MacNeil, M.A.; Cripps, E.; Emslie, M.J.; Jonker, M.; Schaffelke, B.; Sweatman, H., (2010). Coral-macroalgal phase shifts or reef resilience: Links with diversity and functional roles of herbivorous fishes on the Great Barrier Reef. Coral Reefs, 29(4): 1005–1015 **(11 pages)**.
Cinner, J.E.; Pratchett, M.S.; Graham, N.A.J.; Messmer, V.; Fuentes, M.M.P.B.; Ainsworth, T.; Ban, N.; Bay, L.K.; Blythe, J.; Dissard, D.; Dunn, S.; Evans, L.; Fabinyi, M.; Fidelman, P.; Figueiredo, J.; Frisch, A.J.; Fulton, C.J.; Hicks, C.C.; Lukoschek, V.; Mallela, J.; Moya, A.; Penin, L.; Rummer, J.L.; Walker, S.; Williamson, D.H., (2016). A framework for understanding climate change impacts on coral reef social–ecological systems. Reg. Environ. Change, 16(4): 1133–1146 **(14 pages)**.
Coker, D.J.; Wilson, S.K.; Pratchett, M.S., (2014). Importance of live coral habitat for reef fishes. Rev. Fish Biol. Fish, 24(1): 89–126 **(37 pages)**.
Cook, D.T.; Schmitt, R.J.; Holbrook, S.J.; Moeller, H.V., (2024). Modeling the effects of selectively fishing key functional groups of herbivores on coral resilience. Ecol. Soc. Am., 15(1): 1–14 **(14 pages)**.
D'Angelo, C.; Wiedenmann, J., (2014). Impacts of nutrient enrichment on coral reefs: New perspectives and implications for coastal management and reef survival. Curr. Opin. Environ. Sustain., 7: 82–93 **(12 pages)**.
De Clippele, L.H.; Díaz, L.A.; Andradi-Brown, D.A.; Lazuardi, M.E.; Iqbal, M.; Zainudin, I.M.; Prabuning, D.; van Hooidonk, R.; Hakim, A.; Agung, F.; Dermawan, A.; Hennige, S.J., (2023). Evaluating annual severe coral bleaching risk for marine protected areas across Indonesia. Mar. Policy. 148: 1-11 **(11 Pages)**.
Dumas, P.; Bertaud, A.; Peignon, C.; Léopold, M.; Pelletier, D., (2009). A "quick and clean" photographic method for the description of coral reef habitats. J. Exp. Mar. Biol. Ecol., 368(2): 161–168 **(8 pages)**.
Edgar, G.J.; Stuart-Smith, R.D.; Heather, F.J.; Barrett, N.S.; Turak, E.; Sweatman, H.; Emslie, M.J.; Brock, D.J.; Hicks, J.; French, B.; Baker, S.C.; Howe, S.A.; Jordan, A.; Knott, N.A.; Mooney, P.; Cooper, A.T.; Oh, E.S.; Soler, G.A.; Mellin, C.; Ling, S.D.; Dunic, J.C.; Turnbull, J.W.; Day, P.B.; Larkin, M.F.; Seroussi, Y.; Stuart-Smith, J.; Clausius, E.; Davis, T.R.; Shields, J.; Shields, D.; Johnson, O.J.; Fuchs, Y.H.; Denis-Roy, L.; Jones, T.; Bates, A.E., (2023). Continent-wide declines in shallow reef life over a decade of ocean warming. Nature, 615(7954): 858–865 **(8 pages)**.
Edgar, G.J.; Stuart-Smith, R.D.; Heather, F.J.; Barrett, N.S.; Turak, E.; Sweatman, H.; Emslie, M.J.; Brock, D.J.; Hicks, J.; French, B.; Baker, S.C.; Howe, S.A.; Jordan, A.; Knott, N.A.; Mooney, P.; Cooper, A.T.; Oh, E.S.; Soler, G.A.; Mellin, C.; Ling, S.D.; Dunic, J.C.; Turnbull, J.W.; Day, P.B.; Larkin, M.F.; Seroussi, Y.; Stuart-Smith, J.; Clausius, E.; Davis, T.R.; Shields, J.; Shields, D.; Johnson, O.J.; Fuchs, Y.H.; Denis-Roy, L.; Jones, T.; Bates, A.E., (2023). Continent-wide declines in shallow reef life over a decade of ocean warming. Nature, 615(7954): 858–865 **(8 pages)**.
Edinger, E.N.; Risk, M.J., (2000). Reef classification by coral morphology predicts coral reef conservation value. Biol. Conserv., 92(1): 1-13 **(13 pages)**.
English, S.; Wilkinson, C.; Baker, V., (1997). Survey manual for tropical marine sources (2nd Edition) **(385 pages)**.
Erm, P.; Balmford, A.; Krueck, N.C.; Takashina, N.; Holden, M.H., (2024). Marine protected areas can benefit biodiversity even when bycatch species only partially overlap fisheries. J. Appl. Ecol., 61: 621–632 **(12 pages)**.
Espinosa-Andrade, N.; Suchley, A.; Reyes-Bonilla, H.; Alvarez-Filip, L., (2020).The no-take zone network of the Mexican Caribbean: assessing design and management for the protection of coral reef fish communities. Biodivers. Conserv., 29: 2069–2087 **(19 pages)**.
Estes, J. A.; Terborgh, J.; Brashares, J.S.; Power, M.E.; Berger, J.; Bond, W.J.; Carpenter, S.R.; Essington, T.E.; Holt, R.D.; Jackson, J.B.C.; Marquis, R.J.; Oksanen, L.; Oksanen, T.; Robert, T.P.; Pikitch, E.K.; Ripple, W.J.; Sandin, S.A.; Scheffer, M.; Schoner, T.W.; Shurin, J.B.; Sinclair, A.R.E.; Soulé, M.E.; Vistanen, R.; Wardle, D.A., (2011). Trophic downgrading of planet earth. Science. 333(6040): 301–307 **(7 pages)**.
Fedor, P.; Zvaríková, M., (2019). Biodiversity indices. Encyclopedia of Ecology: Volume 1-4, Second Edition 1: 337–346 **(10 pages)**.
Ferreira, H.M.; Magris, R.A.; Floeter, S.R.; Ferreira, C.E.L., (2022). Drivers of ecological effectiveness of marine protected areas: A meta-analytic approach from the Southwestern Atlantic Ocean (Brazil). J. Environ. Manage., 301: 113889 **(1 page)**.
Floros, C.; Schleyer, M.H., (2017). The functional importance of Acropora austera as nursery areas for juvenile reef fish on South African coral reefs. Coral Reefs, 36(1): 139–149 **(11 pages)**.
Froese, R.; Pauly, D. (Eds.), 2024. FishBase. World Wide Web electronic publication. www.fishbase.org., version (10/2024).
Gaertner, J.C.; Taquet, M.; Dagorn, L.; Mérigot, B.; Aumeeruddy, R.; Sancho, G.; Itano, D., (2008). Visual censuses around drifting fish aggregating devices (FADs): A new approach for assessing the diversity of fish in open-ocean waters. Mar. Ecol. Prog. Ser., 366: 175–186 **(12 pages)**.
González-Rivero, M.; Harborne, A.R.; Herrera-Reveles, A.; Bozec, Y.M.; Rogers, A.; Friedman, A.; Ganase, A.; Hoegh-Guldberg, O., (2017). Linking fishes to multiple metrics of coral reef structural complexity using three-dimensional technology. Sci. Rep., 7(1): 1-17 **(17 pages)**.
Good, A.M.; Bahr, K.D., (2021). The coral conservation crisis: Interacting local and global stressors reduce reef resiliency and create challenges for conservation solutions. SN Appl. Sci., 3(3):1-14 **(14 pages)**.
Green, A.; M.P.J., (2008). Delineating the coral triangle, its ecoregions and functional seascapes. Version 5.0. TNC coral triangle program report 1/08 **(44 pages)**.
Gudka, M.; Aboud, S.; Obura, D., (2023). Historical coral reef

benthic cover for the Western Indian Ocean (1970-2008). West. Indian Ocean J. Mar. Sci., 22(1): 103–115 **(13 pages)**.

Hadi, T.A.; Abrar, M.; Giyanto, G.; Prayudha, B.; Johan, O.; Budiyanto, A.; Dzumalek, A.R.; Alifatri, L.O.; Sulha, S.; Suharsono, S., (2020). The status of Indonesian coral reefs 2019. Research Center for Oceanography (RCO). Jakarta: 1–86 **(86 pages)**.

Häkkilä M.; Le Tortorec, E.; Brotons, L.; Rajasärkkä, A.; Tornberg, R.; Monkkonen, M., (2017) Degradation in landscape matrix has diverse impacts on diversity in protected areas. PLOS ONE. 12(9): 1–17 **(17 pages)**.

Hall, A.E.; Kingsford, M.J., (2021). Habitat type and complexity drive fish assemblages in a tropical seascape. J. Fish Biol., 99(4): 1364–1379 **(16 pages)**.

Halpern, B.S.; Klein, C.J.; Brown, C.J.; Beger, M.; Grantham, H.S.; Mangubhai, S.; Ruckelshaus, M.; Tulloch, V.J.; Watts, M.; White, C.; Possingham, H.P., (2013). Achieving the triple bottom line in the face of inherent trade-offs among social equity, economic return, and conservation. Proc. Natl. Acad. Sci. U.S.A., 110(15): 6229–6234 **(6 pages)**.

Harsindhi, C.J.; Bengen, D.G.; Zamani, N.P.; Kurniawan, F., (2020). Abundance and spatial distribution of reef fish based on coral lifeforms at Tidung Island, Seribu Islands, Jakarta Bay. AACL Bioflux, 13(2): 736–745 **(10 pages)**.

Harvey, B.J.; Nash, K.L.; Blanchard, J.L.; Edwards, D.P., (2018). Ecosystem-based management of coral reefs under climate change. Ecol. Evol., 8(12): 6354–6368 **(15 pages)**.

Helder, N.K.; Burns, J.H.R.; Green, S.J., (2022). Intra-habitat structural complexity drives the distribution of fish trait groups on coral reefs. Ecol. Indic., 142(2022): 1-11 **(11 pages)**.

Hernández, C.M.; Paris, C.B.; Vaz, A.C.; Jones, B.T.; Kellner, J.B.; Richardson, D.E.; Sponaugle, S.; Cowen, R.K.; Llopiz, J.K., (2023). Diverse patterns of larval coral reef fish vertical distribution and consequences for dispersal and connectivity. Coral Reefs, 42(2): 453–465 **(13 pages)**.

Hernández-Andreu, R.; Félix-Hackradt, F.C.; Schiavetti, A.; Jessyca, J.L.; Hackradt, C.W., (2024). Marine protected areas are a useful tool to protect coral reef fishes but not representative to conserve their functional role. J. Environ. Manage., 351(2024): 1-13 **(13 pages)**.

Hill, J.; Wilkinson, C.R., (2004). Methods for ecological monitoring of coral reefs : a resource for managers. Australian Institute of Marine Science, Townsville, Version 1: 1–117 **(117 pages)**.

Hollitzer, H.A.L.; May, F.; Blowes, S.A., (2023). A meta-analysis examining how fish biodiversity varies with marine protected area size and age. Ecol. Soc., 14(12): 1–12 **(12 pages)**.

Hopf, J.K.; Quennessen, V.; Ridgway, J.; Barceló, C.; Caltabellotta, F.P.; Farnsworth Hayroyan, S.; Garcia, D.; McLeod, M.; Lester, S.E.; Nickols, K.; Yeager, M.; White, J.W., (2024). Ecological success of no-take marine protected areas: Using population dynamics theory to inform a global meta-analysis. Ecol. Appl., 34(7): 1–14 **(14 pages)**.

Huang, L.; McWilliam, M.; Liu, C.; Yu, X.; Jiang, L.; Zhang, C.; Luo, Y.; Yang, J.; Yuan, X.; Lian, J.; Huang, H., (2024). Loss of coral trait diversity and impacts on reef fish assemblages on recovering reefs. Ecol. Evol., 14(11):1–13 **(13 pages)**.

Hughes, T.P.; Barnes, M.L.; Bellwood, D.R.; Cinner, J.E.; Cumming, G.S.; Jackson, J.B.C.; Kleypas, J.; Van De Leemput, I.A.; Lough, J.M.; Morrison, T.H.; Palumbi, S.R.; Van Nes, E.H.; Scheffer, M., (2017). Coral reefs in the anthropocene. Nature, 546(7656): 82–90 **(9 pages)**.

Jiménez Bedoya, A.; Fuentes Gandara, F.; Paternina Uribe, R.; Pinedo Hernández, J., (2024). Perception and adaptation to climate change in vulnerable regions. Global J. Environ. Sci. Manage., 10(4): 1791-1808 **(18 pages).**

Kang, Y.; Zhang, R.; Yu, K.; Han, M.; Pei, J.; Chen, Z.; Wang, Y., (2022). Organochlorine pesticides (OCPs) in corals and plankton from a coastal coral reef ecosystem, South China Sea. Environ. Res., 214(2022): 1-9 **(9 pages)**.

Kelaher, B.P.; Coleman, M.A.; Broad, A.; Rees, M.J.; Jordan, A. Davis, A.R., (2014) Changes in Fish Assemblages following the establishment of a network of no-take marine reserves and partially-protected areas. Plos one. 9(1): 1–13 **(13 pages)**.

Kembrey, H.; Pittman, S.J.; Bejarano, I.; Blanco-Parra, M.del P.; Jabado, R.W.; Yaghmour, F.; Mateos-Molina, D., (2024). Fish-seascape associations within an offshore protected area in the Arabian Gulf. Marine Ecol., 45(6): 1-17 **(17 pages)**.

Knoester, E.G.; Rizzi, E.; Murk, A.J.; Osinga, R., (2023). Biomass of key grazing fishes is an important determinant of coral growth and fouling control in coral nurseries. Restor. Ecol., 31(8): 1–12 **(12 pages)**.

Kohler, K.E.; Gill, S.M., (2006). Coral point count with excel extensions (CPCe): a visual basic program for the determination of coral and substrate coverage using random point count methodology. Comput. Geosci., 32(9): 1259–1269 **(11 pages)**.

Kornder, N.A.; Cappelletto, Jose; Mueller, B.; Zalm, M.J.L.; Martinez, S.J.; Mark, Vermeij, J.A.; Huisman, J.; De Goeij, J.M., (2021). Implications of 2D versus 3D surveys to measure the abundance and composition of benthic coral reef communities. Coral Reefs, 40: 1137–1153 **(17 pages)**.

Kuiter, R.H.; Tonozuka, T., (2001). Pictorial Guide to Indonesian Reef Fishes. Zoonetics, Australia. **(318 pages)**.

Kusumawati, I.; Huang, H.W., (2015). Key factors for successful management of marine protected areas: A comparison of stakeholders' perception of two MPAs in Weh Island, Sabang, Aceh, Indonesia. Mar. Policy. 51: 465–475 **(11 pages)**.

Leal, I.C.S.; Pereira, P.H.C.; Araújo, M.E.de., (2013). Coral reef fish association and behaviour on the fire coral Millepora spp. in north-east Brazil. J. Mar. Biol., 93(6): 1703–1711 **(9 pages)**.

Loiseau, N.; Gaertner, J.C., (2015). Indices for assessing coral reef fish biodiversity: The need for a change in habits. Ecol. Evol., 5(18): 4018–4027 **(10 pages)**.

Lusiana, E.D.; Astutik, S.; Nurjannah, N.; Sambah, A.B., (2023). Spatial delineation on marine environmental characteristics using fuzzy c-means clustering method. Global J. Environ. Sci. Manage., 9(3): 463-476 **(14 pages).**

Martin, C.A.; Watson, C.J.; de Grandpré, A.; Desrochers, L.; Deschamps, L.; Giacomazzo, M.; Loiselle, A.; Paquette, C.; Pépino, M.; Rainville, V.; Rheault, G.; Proulx, R., (2023). The dominance-diversity dilemma in animal conservation biology. PLoS One. 18(2023): 1–11 **(11 pages)**.

Matten, D.M.; Mienna, I.M.; Bieker, V.C.; Mishler, B.D.; Moen, V.S.; Nygaard, M.; Vuorinen, K.E.M.; Bendiksby, M.; Martin, M.D.; Speed, J.D.M., (2023). Spatial patterns of phylogenetic and species diversity of Fennoscandian vascular plants in protected areas. Biodivers. Conserv., 32: 4425–4443 **(19 pages).**

McCormick, M.I.; Barry, R.P.; Allan, B.J.M., (2017). Algae associated with coral degradation affects risk assessment in coral reef fishes. Sci. Rep., 7(1): 1–12 **(12 pages)**.

MMAF, (2020). Decree No. 87/KEPMEN-KP/2020 of 2020 concerning the Coastal and Small Island Conservation Area of Central Tapanuli and Its Surrounding Waters in North Sumatra Province. Ministry of Marine Affairs and Fisheries of the Republic of Indonesia **(13 pages)**.

Moberg, F.; Folke, C., (1999). Ecological goods and services of coral reef ecosystems. Ecol. Econ., 29(2): 215–233 **(18 pages)**.

Moustaka, M.; Evans, R.D.; Kendrick, G.A.; Hyndes, G.A.; Cuttler, M.V.W.; Bassett, T.J.; O'Leary, M.J.; Wilson, S.K., (2024). Local habitat composition and complexity outweigh seascape effects on fish distributions across a tropical seascape. Landsc. Ecol., 39(2): 1–26 **(26 pages)**.

Obura, D.; Gudka, M.; Samoilys, M.; Osuka, K.; Mbugua, J.; Keith, D.A.; Porter, S.; Roche, R.; van Hooidonk, R.; Ahamada, S.; Araman, A.; Karisa, J.; Komakoma, J.; Madi, M.; Ravinia, I.; Razafindrainibe, H.; Yahya, S.; Zivane, F., (2022). Vulnerability to collapse of coral reef ecosystems in the Western Indian Ocean. Nat. Sustain., 5(2022): 104–113 **(10 pages)**.

Obura, D.O; Aeby, G.; Amornthammarong, N.; Appeltans, W.; Bax, N.; Bishop, J.; Brainard, R.E; Chan, S.; Pamela Fletcher, P.; Gordon, T.A.C.; Gramer, L.; Gudka, M.; Halas, J.; Hendee, J.; Hodgson, G.; Huang, D.; Jankulak, M.; Jones, A.; Kimura, T.; Levy, J.; Miloslavich, P.; Chou, L.M.; Muller-Karger, F.; Osuka, K.; Samoilys, M.; Simpson, S.D.; Tun, K.; Wongbusarakum, K., (2019). Coral reef monitoring, reef assessment technologies, and ecosystem-based management. Front. Mar. Sci., 6(2019): 1-21 **(21 pages)**.

O'Leary, B.C.; Hoppit, G.; Townley, A.; Allen, H.L.; McIntyre, C.J.; Roberts, C.M., (2020). Options for managing human threats to high seas biodiversity. Ocean Coast. Manage., 187(2020): 1-12 **(12 pages)**.

Pereira, P.H.C.; de Lima, G.V.; da Silva, E.G.; de Farias Pontes, A.V.; Côrtes, L.G.F.; Sampaio, C.L.S.; Pinto, T.K.; da Silva Pinto Belluci, M.; Cardoso, A.T.C.; Normande, I.C., (2024). Spatial distribution, management zoning and depth effects on reef biodiversity and productivity at the largest Brazilian coastal marine protected area. Coral Reefs. 43(5): 1271–1283 **(13 pages)**.

Prasetya, J.D.; Santoso, D.H., (2022). Comparative study of point intercept transect (PIT) method and underwater photo transect (UPT) to calculate hard coral cover percentage. J. Ind. Mar. Sci., 14(2): 404–410 **(7 pages)**.

Rodríguez-Rodríguez, D.; Martínez-Vega, J., (2022). Ecological effectiveness of marine protected areas across the globe in the scientific literature. Adv. Mar. Biol., 92(2022): 129–153 **(24 pages)**.

Rogers, A.; Blanchard, J.L.; Mumby, P.J., (2018). Fisheries productivity under progressive coral reef degradation. J. Appl. Ecol., 55(3): 1041-1049 **(9 pages)**.

Russ, G.R.; Alcala, A.C., (2011), Enhanced biodiversity beyond marine reserve boundaries: The cup spillith over. Ecol. Appl., 21: 241-250 **(9 pages)**.

Russ, G.R.; Leahy, S.M., (2017). Rapid decline and decadal-scale recovery of corals and Chaetodon butterflyfish on Philippine coral reefs. Mar. Biol., 164(1): 29 **(8 pages)**.

Russ, G.R.; Payne, C.S.; Bergseth, B.J.; Rizzari, J.R.; Abesamis, R.A.; Alcala, A.C., (2018). Decadal-scale response of detritivorous surgeonfishes (family Acanthuridae) to no-take marine reserve protection and changes in benthic habitat. J. Fish Biol., 93(5): 887–900 **(14 pages)**.

Salema, F.G.; Mbije, N.E.; Mwakalapa, E.B.; Rija, A.A., (2022). Patterns of fish community structure in protected and non-protected marine areas of mainland Tanzania. West Indian Ocean J. Mar. Sci., 21(1): 91–101 **(11 pages)**.

Sanchez, L.; Loiseau, N.; Edgar, G.J.; Hautecoeur, Cxz.; Leprieur, F.; Manel, S.; McLean, M.; Stuart-Smith, R.D.; Velez, L.; Mouillot, D., (2024). Rarity mediates species-specific responses of tropical reef fishes to protection. Ecol. Lett., 27(3): 1–13 **(13 pages)**.

Seemann, J.; Yingst, A.; Stuart-Smith, R.D.; Edgar, G.J.; Altieri, A.H., (2018). The importance of sponges and mangroves in supporting fish communities on degraded coral reefs in Caribbean Panama. PeerJ, 6(2018):1-22 **(22 pages)**.

Selig, E.R.; Bruno, J.F., (2010). A global analysis of the effectiveness of marine protected areas in preventing coral loss. PLoS One. 5(2): 1-7 **(7 pages)**.

Shah, S.B., (2021). Heavy metals in the marine environment—an overview. Springer Nature, 1(2021): 1–14 **(14 pages)**.

Stier, A.C.; Osenberg, C.W., (2024). How fishes and invertebrates impact coral resilience. Cur. Biol., 34(13): 613-615 **(3 pages)**.

Sobha, T.R.; Vibija, C.P.; Fahima, P., (2023). Coral reef: a hot spot of marine biodiversity. In conservation and sustainable utilization of bioresources (Sukumaran, S.T; T R, K., Eds.); Springer Nature Singapore. 30: 171–194 **(24 pages)**.

Strain, E.M.A.; Edgar, G.J.; Ceccarelli, D.; Stuart-Smith, R.D.; Hosack, G.R.; Thomson, R.J., (2019). A global assessment of the direct and indirect benefits of marine protected areas for coral reef conservation. Divers. Distrib., 25(1): 9–20 **(12 pages)**.

Stuart-Smith, R.D.; Bates, A.E.; Lefcheck, J.S.; Duffy, J.E.; Baker, S.C.; Thomson, R.J.; Stuart-Smith, J.F.; Hill, N.A.; Kininmonth, S.J.; Airoldi, L.; Becerro, M.A.; Campbell, S.J.; Dawson, T.P.; Navarrete, S.A.; Soler, G.A.; Strain, E.M.A.; Willis, T.J.; Edgar, G.J., (2013). Integrating abundance and functional traits reveals new global hotspots of fish diversity. Nature, 501(7468): 539–542 **(4 pages)**.

Takarina, N.D.; Chuan, O.M.; Afifudin, M.I.; Tristan, L.; Arif, I.; Adiwibowo, A., (2023). Modeling the tropical fish community related to land uses and environmental determinants. Global J. Environ. Sci. Manage., 9(3): 515-530 **(16 pages).**

Varnes, B.K.; Olsen, E.M., (2023). Fish community dynamics in a coastal no-take marine protected area compared to a harvested area before and after protection from fishing. ICES J. Mar. Sci., 80(5): 1462–1471 **(10 pages)**.

Wilson, S.K.; Fulton, C.J.; Graham, N.A.J.; Abesamis, R.A.; Berkström, C.; Coker, D.J.; Depczynski, M.; Evans, R.D.; Fisher, R.; Goetze, J.; Hoey, A.; Holmes, T.H.; Kulbicki, M.; Noble, M.; Robinson, J.P.W.; Bradley, M.; Åkerlund, C.; Barrett, L.T.; Bucol, A.A.; Tinkler, P., (2022). The contribution of macroalgae-associated fishes to small-scale tropical reef fisheries. Fish. Aquat. Sci., 23(4): 847–861 **(15 pages)**.

Wright, L.S., (2022). Small no-take areas benefit hard corals more than regulation through fishing permits. Aquat. Conserv., 32(7): 1209–1216 **(8 pages)**.

Wu, P.; Wang, T.; Liu, Y.; Li, C.; Xiao, Y.; Xu, S.; Han, T.; Lin, L.; Quan, Q., (2022). Differences of macroalgal consumption by eight herbivorous coral reef fishes from the Xisha Islands, China. Front. Mar. Sci., 9(2022): 1–14 **(14 pages)**.

Zaneveld, J.R.; Burkepile, D.E.; Shantz, A.A.; Pritchard, C.E.; McMinds, R.; Payet, J.P.; Welsh, R.; Correa, A.M.S.; Lemoine,

N.P.; Rosales, S.; Fuchs, C.; Maynard, J.A.; Thurber, R.V., (2016). Overfishing and nutrient pollution interact with temperature to disrupt coral reefs down to microbial scales. Nat. Commun., 7(2016): 1–12 **(12 pages)**.

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