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# Influence of coral transplantation on fish abundance and functional group composition

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## ABSTRACT

Coral transplantation has been widely implemented as a restoration strategy to accelerate reef recovery and enhance associated fish communities. However, its ecological effectiveness in shaping fish functional group composition remains insufficiently understood. This study compared fish abundance and functional group distributions between transplantation (T) and non-transplantation (NT) coral reef sites to evaluate how restoration activities influence reef fish communities. Fish communities were surveyed using underwater visual census (UVC) techniques, and individuals were classified into functional groups including herbivores, grazers, scrapers, corallivores, planktivores, invertivores, and carnivores. Two-way ANOVA was applied to test for the main effects of site type and functional group, along with their interaction effect. Significant interaction effects were detected for most functional groups, indicating that the response of fish abundance varied depending on both site type and ecological role. In particular, herbivores, grazers, and planktivores were more abundant at transplantation sites, suggesting that coral restoration supports higher trophic diversity and habitat complexity. Conversely, corallivores and carnivores showed inconsistent patterns, likely reflecting differences in coral maturity and prey availability. These findings indicate that the coral transplantation program implemented by PT. Borneo Indobara since 2010 has not only contributed to increasing fish abundance but also altered the functional composition of coral reef communities, emphasizing its crucial role in supporting the recovery and enhancing the resistance of reef ecosystems.

**Keywords:** coral transplantation, coral fish communities, functional groups, habitat complexity, ecosystem resilience.

## INTRODUCTION

Coral reef ecosystems represent among the planet's most biologically diverse and highly productive marine ecosystems (Moberg and Folke, 1999; Spalding et al., 2001; Duarte et al., 2023). These ecosystems support complex ecological interactions and provide essential habitats for a remarkable variety of fish associated with coral reefs (Roberts et al., 2002; Hughes et al., 2017; Bellwood et al., 2019). The intricate three-dimensional architecture of coral reefs creates a mosaic of ecological niches that underpin trophic dynamics, species coexistence, and the functional diversity of reef fish assemblages (Graham and Nash, 2013; Richardson et al., 2022; Wilson et al., 2010).

Globally, coral reef health has been severely compromised by the combined effects of anthropogenic disturbances and climate-driven stressors, including coral bleaching, ocean acidification, and unsustainable fishing practices (Hughes et al., 2017; Sully et al., 2024). The decline in live coral cover reduces habitat complexity, resulting in diminished shelter and foraging opportunities for reef fauna. This degradation often triggers shifts in community composition, reductions in fish numbers along with biomass losses (Pratchett et al., 2020; Morais et al., 2023; Messmer et al., 2011).

In response to these challenges, coral reef restoration has emerged as a key strategy to mitigate habitat loss and enhance ecosystem resilience. Among various restoration approaches, coral transplantation—defined as the attachment of nursery-grown coral fragments or colonies to degraded reef areas—has demonstrated considerable potential to accelerate reef recovery (Nakamura et al., 2020; Chamberland et al., 2022; dela Cruz and Harrison, 2020). Transplanted corals contribute to the reestablishment of benthic structural complexity, which facilitates the return of reef-associated fauna through improved availability of shelter, substrate heterogeneity, and feeding resources (Suggett et al., 2023; dela Cruz et al., 2021; Hein et al., 2021). Several studies have reported significant increases in reef fish abundance and diversity within a few years after transplantation, particularly among species dependent on live coral habitat (Boström-Einarsson et al., 2020; Hein et al., 2021; Lindahl, 2003).

However, the ecological effectiveness of coral transplantation in restoring reef fish communities varies widely depending on factors such as restoration scale, coral species used, and conditions of local environment (Montoya-Maya et al., 2016; Ng et al., 2023; Shaver and Silliman, 2017). While most transplantation projects have primarily focused on coral survival and growth metrics, there is growing recognition of the need to evaluate broader ecological outcomes, including fish community responses and ecosystem functionality (Suggett et al., 2023; Nakamura et al., 2024; Tebbett and Bellwood, 2019). Understanding how coral transplantation influences reef fish abundance, species richness, and functional diversity is essential for assessing the ecological benefits of restoration efforts and their contribution to the long-term resilience of coral reef ecosystems.

This study investigates the effects of coral transplantation conducted at the Batu Anjir patch reef about the numbers and community composition of reef-associated fishes in a previously degraded area. Specifically, we assess whether restored reef habitats support higher fish abundance and diversity compared to adjacent non-restored areas, thereby evaluating the ecological effectiveness of coral transplantation as a tool for promoting coral reef recovery and resilience.

## MATERIAL AND METHODS

### Research location

This study was conducted at the Batu Anjir coral reef, which forms part of the Angsana Marine Protected Area in Angsana District, South Kalimantan, Indonesia (Figure 1). The site comprises shallow reef habitats with depths of less than 10 meters and has undergone degradation due to anthropogenic pressures and coral bleaching events over the past two decades. The area is characterized by a combination of sandy substrates and remnant coral structures, exhibiting low live coral cover prior to restoration efforts. The coral transplantation activity carried out since 2012 is a coral reef ecosystem restoration activity initiated by PT Borneo Indobara. The research was conducted from July to November 2024.

### Fish community survey

Reef fish data were collected using the underwater visual census (UVC) method and belt transects (Samoilys and Carlos 2000; RCI 2015; Wilson et al. 2018). The observation area for reef fish was 250 m² (5 × 50 m) at each station. Fish were identified, and their abundance was recorded based on fish groups and species. Fish were classified into trophic or functional groups (herbivores, grazers, scrapers, corallivores, planktivores, invertivores, and carnivores). Fish abundance (N) was calculated following Odum (1971):

$$N = \frac{Xi}{A} \quad (1)$$

where: $X_i$ – number of individuals of species; $i$, and $A$ – area of the transect (250 m²).

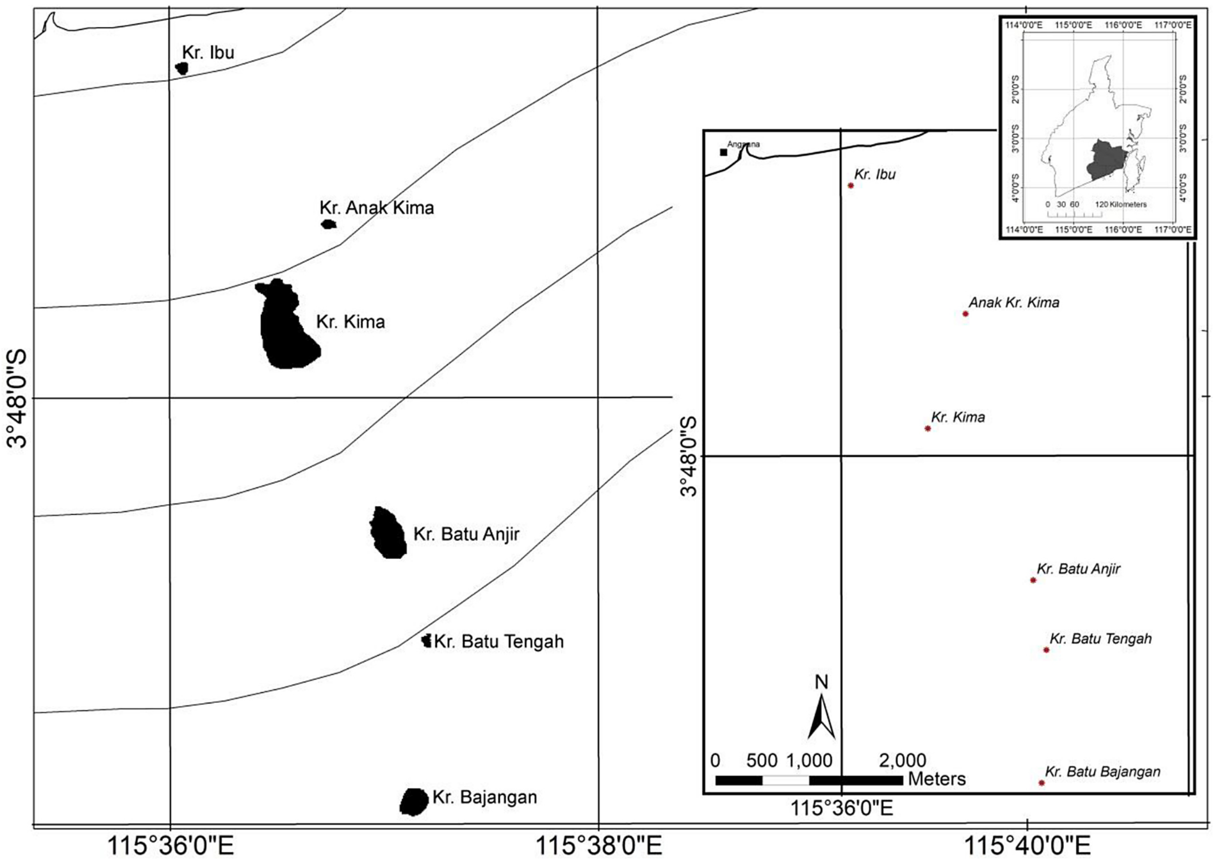



**Figure 1.** Location of patch reefs within the Angsana Marine Protected Area, Tanah Bumbu Regency, South Kalimantan

Species composition and abundance data were then analyzed to determine dominant and indicator species among the six patch reefs.

## Data analysis

A two-way ANOVA with replication was applied to assess the main and interaction effects between coral site conditions (non-transplantation, NT; and transplantation, T) and fish functional groups as fixed factors. Fish abundance was used as the response variable and categorized according to trophic functional groups. Count data were log-transformed using ln(x + 1) prior to analysis to improve normality and variance homogeneity. ANOVA assumptions were verified using the Shapiro–Wilk test for normality and Levene's test for homogeneity of variance. When significant effects were detected, Tukey's honest significant difference (HSD) test was used for pairwise mean comparisons among functional groups and between site–functional group interactions.

To further explore group differentiation between NT and T sites based on functional composition, Linear Discriminant Analysis (LDA) was performed. All statistical analyses were carried out in R version 4.3.2 (R Core Team, 2024) using the following packages: emmeans for post hoc comparisons (Lenth, 2025), car for ANOVA assumption diagnostics (Fox and Weisberg, 2019), dplyr and tidyr for data wrangling (Wickham et al., 2023; Wickham et al., 2024), MASS for LDA (Venables and Ripley, 2002), and ggplot2 and ggord for data visualization (Wickham, 2016, Beck, 2024).

# RESULTS AND DISCUSSION

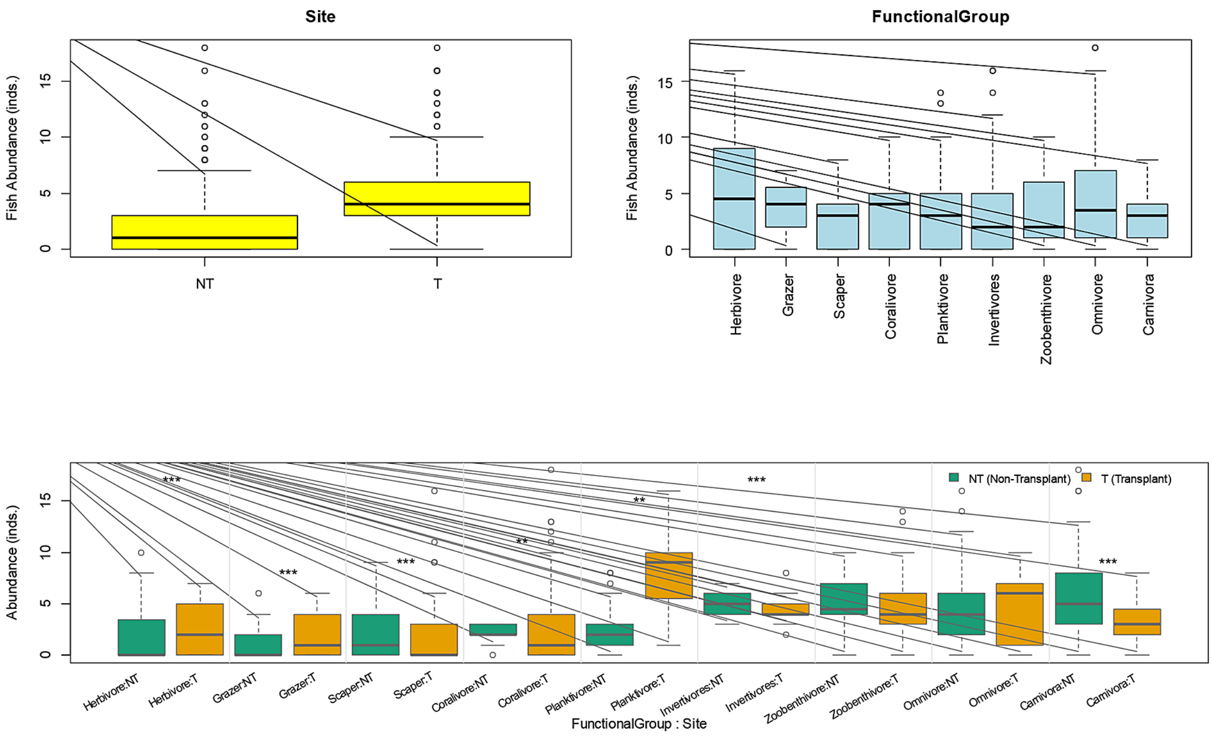
The two-way ANOVA revealed a highly significant effect of site on fish abundance ($F = 152.83$, $p < 0.001$), indicating that fish communities were generally more abundant in the transplanted coral sites (T) than in the non-transplanted ones (NT). A significant effect of functional group was also observed ($F = 2.65$, $p = 0.007$), suggesting that abundance varied across trophic guilds. Moreover, the significant Site × Functional Group interaction (F = 3.94, $p < 0.001$) indicated that the response to transplantation was not uniform among groups. Significant interaction effects were detected for Herbivores, Grazers, Scrapers, Corallivores, Planktivores, Invertivores, and Carnivores (Figure 2). Herbivores, grazers, planktivores and omnivores showed a strong increase in abundance at transplanted sites, while scaper, coralipore, and carnivores exhibited relatively higher non transplanted sites.

Fish abundance was significantly higher at transplantation sites (T) compared to non-transplantation sites (NT) (ANOVA, $p < 0.05$) as shown in Figure 3, but the response differed among functional groups as indicated by a significant site × functional group interaction (Figure 2). Herbivores, grazers and planktivores were notably more abundant at transplantation sites, whereas zoobenthivores and omnivores showed relatively similar abundances between site types, suggesting trophic-specific habitat responses to coral restoration.

These univariate results were further supported by linear discriminant analysis (LDA), which demonstrated a clear separation between fish assemblages across functional groups based on NT and T conditions. The first discriminant axis (LD1), accounting for 88.8% of the variance, was primarily driven by the transplantation variable, effectively distinguishing functional groups according to their habitat preference. This finding reinforces that coral transplantation significantly reshaped the functional composition of fish communities, highlighting its ecological influence on trophic structure.

The significant Site × Functional Group interaction from the two-way ANOVA indicates that the response of fish abundance to coral transplantation differs among functional groups. This result is further supported by LDA, which showed clear separation trends among groups along LD1, primarily driven by the T variable. Together, these analyses confirm that coral transplantation modifies fish functional structure, although with varying responses across trophic guilds (Figure 4).

Coralivorous fishes also showed a significant increase at transplanted sites, which may indicate improved coral availability and habitat suitability




Note: significance based on Tukey HSD post-hoc test (α = 0.05).

**Figure 2.** Boxplots illustrating fish abundance at NT and transplantation (T) coral sites (upper left), across functional groups (upper right), and the interaction between site and functional group (bottom). Significant interaction effects were detected for Herbivores, Grazers, Scrapers, Corallivores, Planktivores, Invertivores, and Carnivores

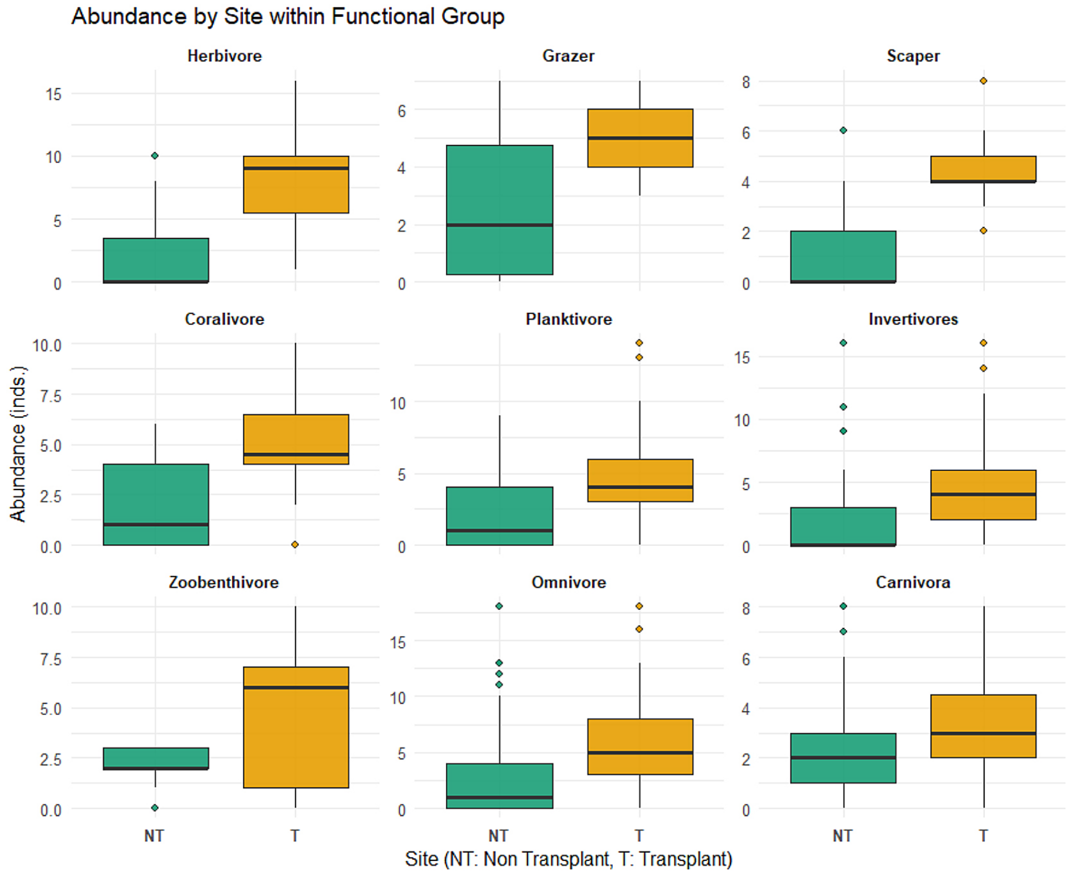



**Figure 3.** Boxplot showing fish abundance differed significantly between sites (ANOVA, $p < 0.05$), with higher abundance in T than non transplanted reef

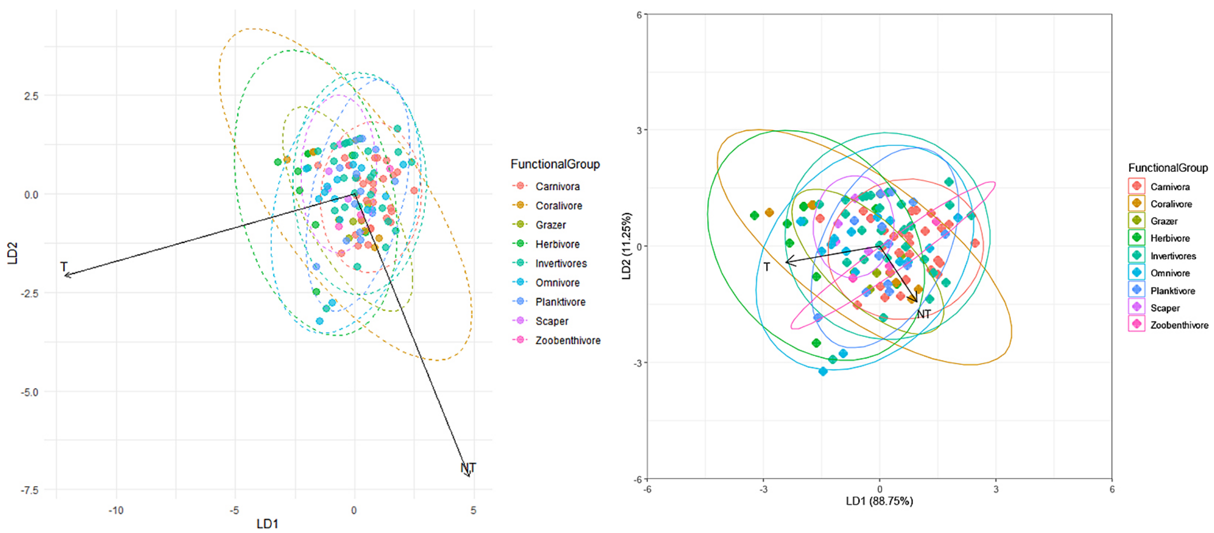



**Figure 4.** Fish distribution by fungsional group

for coral-dependent species (Coker et al., 2014; Pratchett et al., 2013). Since coralivores rely on live coral tissue as a primary food source, their presence is often associated with structurally complex and recovering reef habitats (Cole et al., 2008). However, although coralivores increased at transplanted sites in this study, their overall density remained substantially lower than herbivores, suggesting that the potential grazing pressure on coral tissue is still limited and unlikely to compromise the success of the transplantation effort at this stage. Even so, the ecological role of coralivores warrants attention in long-term monitoring, as excessive coral predation may eventually slow coral growth and rehabilitation (Rotjan and Lewis, 2008).

The strong response of herbivorous fishes to coral transplantation observed in this study suggests that restoration actions can enhance essential ecological processes on degraded reefs. Herbivores play a critical role in reducing algal overgrowth and maintaining substrate availability for coral recruitment (Bellwood et al., 2004; Hughes et al., 2007). The higher abundance of herbivores at transplanted sites indicates that restored coral structures may facilitate grazing activity by increasing habitat complexity and food availability through the development of turf algae and biofilm on artificial or restored substrates (Graham et al., 2015; Goatley and Bellwood, 2011). This functional recovery is in line with previous research where coral reef restoration efforts can promote the return of benthic associated fish guilds that depend on reef microhabitats (Komyakova et al., 2013; Sheppard et al., 2009). As herbivores are widely recognized as key drivers of reef resilience by preventing phase shifts to algal dominance (Mumby and Steneck, 2008), their increased abundance at transplanted sites highlights the ecological value of coral rehabilitation efforts. These findings support the view that restoration strategies can not only increase fish abundance but also re-establish functional integrity, which is crucial for long-term reef recovery.

## CONCLUSIONS

The results elucidated that coral transplantation significantly enhanced the abundance of reef fish and altered the functional configuration of the fish assemblage. Two-way ANOVA analysis showed that fish abundance was generally higher at transplanted sites than at non-transplanted sites, with a significant interaction between site type and functional group. Fish responses to transplantation varied across trophic groups: herbivores, grazers, and planktivores increased significantly at transplanted sites, while scrapers, corallivores, and carnivores showed more variable patterns. LDA results supported these findings by showing a clear separation between fish communities at transplanted and non-transplanted sites, indicating a shift in functional structure due to restoration. Increased herbivore abundance is important in the restoration of ecological processes by controlling algae and providing substrate for coral recruitment, which contribute to the resilience and sustainability of coral reef ecosystems. Thus, coral transplantation has been shown to not only increase fish abundance but also strengthen ecological functions and accelerate the recovery of degraded coral reef ecosystems.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