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Comparison of Natural and Artificial Reefs and Their Relationship with the Abundance of *Chaetodontida*e Indicator Fish in Sental Nusa Penida, Bali

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Abstract

Coral reefs are vital ecosystems that support marine biodiversity, but face increasing threats from human activities and climate change. Artificial reefs (ARs) are proposed as a mitigation strategy to replicate the function of natural reefs (NRs). This study compared the effectiveness of ARs and NRs in supporting Chaetodontidae indicator fish abundance in Sental Village, Nusa Penida. A quantitative approach was applied using the Underwater Photo Transect (UPT) method to analyze coral cover and Underwater Visual Census (UVC) to measure Chaetodontidae abundance. Data were collected from ARs, NRs, and Rubble Fields (RFs), which represent degraded reef areas. Results showed that ARs had the highest coral cover (36%), followed by NRs (32%) and RFs (5%). Moderate fish species diversity was observed in ARs (H' = 1.210), while NRs (H' = 0.970) and RFs (H' = 0.702) showed low diversity. ARs supported the highest abundance of Chaetodontidae (0.34-0.57 ind/m²), indicating healthier coral conditions compared to NRs and RFs. Regression analysis showed a strong positive relationship between coral cover and Chaetodontidae abundance, with a coefficient of determination of R^2 = 0.9932. This study concludes that ARs effectively support Chaetodontidae biodiversity and abundance, although they do not fully mimic the ecological complexity of NRs. Chaetodon kleinii was identified as the dominant species in all reef types due to its high ecological flexibility

Keywords: Artificial Reefs, *Chaetodontidae*, Coral Covers

1. INTRODUCTION

Coral reefs are among the most diverse and valuable ecosystems on Earth [1]. Although they cover only 0.1% of the planet's surface, coral reefs support approximately 25% of marine life, including a wide variety of fish species [2]. These ecosystems are crucial for preserving marine biodiversity, offering coastal protection, and supporting industries such as tourism and fisheries [3]. However, despite their immense value, coral reefs are increasingly threatened by human activities, climate change, and natural disasters. [3].

In response to the decline of natural reefs (NRs), artificial reefs (ARs) have been proposed as a potential mitigation strategy. ARs can enhance coral cover, attract fouling organisms, and increase fish abundance and diversity [4]. However, the extent to which ARs can replicate the complexity and function of NRs remains debated. Meta-analyses have shown that ARs often differ from NRs in species composition, suggesting that factors beyond reef type itself may influence the effectiveness of ARs[5].

Fish from the *Chaetodontidae* family, commonly known as butterflyfish, are important indicators of coral reef health [6]. Their presence and abundance offer valuable insights into the condition of coral reefs, serving as bioindicators of ecosystem stability and vitality [7]. As these fish are highly dependent on coral reefs for habitat, spawning, and food sources, their population dynamics are closely linked to the health of reef ecosystems [8].

Sental Village, located in southeastern Bali, was selected for this study due to its rich biodiversity, ongoing marine conservation efforts, unique ecological characteristics, and its significance as a hub for marine biodiversity, including vital coral reefs, aquaculture, fisheries, and tourism [9]. Nusa Penida, where Sental Village is situated, is part of the Marine Protected Area (MPA), which integrates conservation with economic growth through zoning to preserve ecosystems while supporting development. Since its establishment in 2010, this MPA has positively impacted ecosystem health, including both coral reefs and fish biomass [9], [10]. The presence of coral reef restoration projects within the MPA offers a unique opportunity to study restoration efforts in a well-managed environment, making Nusa Penida an ideal location to assess the impact of restoration on biodiversity and local economies [11].

This research takes an innovative approach by utilizing three distinct research stations: NRs, ARs, and Rubble Fields (RFs). By including RFs, which represent degraded areas of coral ecosystems, the study offers a broader perspective on various conditions within the marine environment. This additional station provides a more comprehensive comparison of how different reef structures, both intact and degraded, influence the abundance and distribution of *Chaetodontidae* indicator fish. This approach enables a deeper understanding of the effectiveness of ARs in replicating natural ecosystems and their role in supporting marine biodiversity, particularly in areas undergoing restoration.The aim of this study is to compare NRs and ARs in Sental Village, Nusa Penida, based on coral cover and the presence of *Chaetodontidae* fish as indicators of coral health. The results are expected to offer valuable insights into the extent to which ARs can mimic NRs and support key indicator species.

2. METHODS

This study employs a quantitative approach, using numerical data and statistical analysis to examine the relationship between coral reef species and the abundance of *Chaetodontidae* indicator fish. This method is well-suited for studying specific populations or samples and provides a strong framework for statistical evaluation [12].

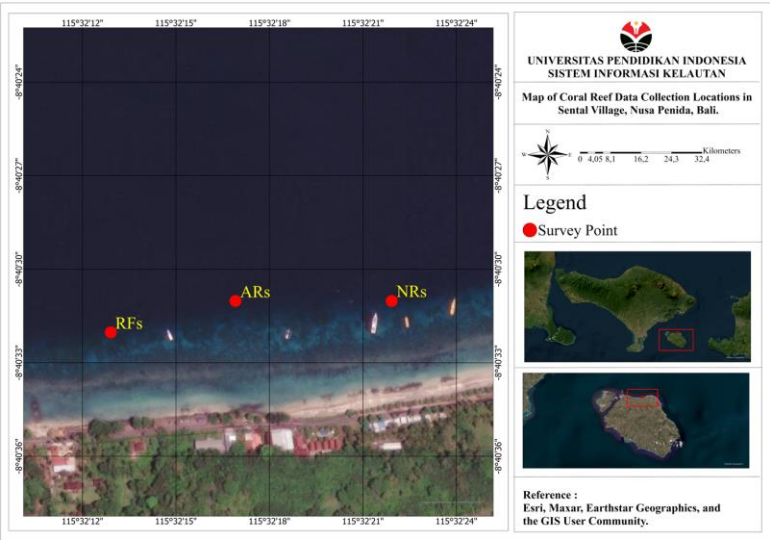

Figure 1. Map of Coral Reefs Survey Locations

The study, conducted between August to September 2024 at Blue Corner Marine Research at the Sental Village, Nusa Penida, involved data collection from three research stations at depths of 8 to 10 meters. This depth range was selected to align with the coral transplant activities conducted by Blue Corner Marine Research, making it ideal for assessing both ARs and NRs. To facilitate a comprehensive comparison, three distinct research stations were established :

1. ARs: Designed to replicate the structure of NRs [13], hese ARs provide habitat complexity and serve as a means to evaluate the effectiveness of ARs installations in supporting marine life..
2. NRs: Representing the baseline of coral reef ecosystems, these areas provide valuable insights into the ecological dynamics and fish abundance under natural conditions.
3. RFs: These stations serve as comparative references and calibration points, enabling the assessment of coral reef degradation's impact on fish populations and providing context for understanding the observed differences between ARs and NRs.

2.1. Coral Covers

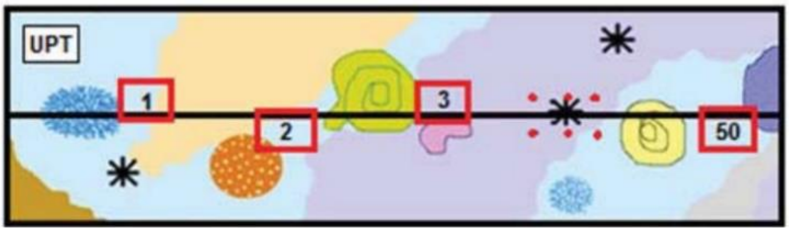

Figure 2. Underwater Photo Transect Survey

Coral data were collected using the Underwater Photo Transect (UPT) method and analyzed with Coral Point Count for Excel (CPCe) software, version 4.1. A total of 50 photos were analyzed, with 30 random points selected per photo according to the coral reef health monitoring guidebook from the Oceanographic Research Center of the Indonesian Institute of Sciences [7]. This method involved capturing images of coral reefs using an underwater camera (Olympus TG-6) along a designated transect. Each point was identified based on codes corresponding to different biota and substrate categories. The formula to calculate the percentage of cover of each category of biota and substrate per photo frame is as follows.

$$Percentage\ cover\ of\ category = \frac{Number\ of\ points\ in\ that\ category}{Total\ number\ of\ random\ points} \times 100 \quad (1)$$

The assessment of coral reef ecosystems is based on the percentage of live coral cover, as outlined by the Ministry of Environment (2001), which categorizes the condition of coral reefs into several ranges :

Table 1. Coral Reef Ecosystems According to the Ministry of Environment (2001)

Category	Coral Cover	Criterion
1	75 -100 %	High
2	50 -74,9%	Medium
3	25 – 49,9%	Low
4	0 – 24,95	Very low

2.2. Abundance of *Chaetodontidae*

Data were collected between 09:00-11:00 am to study the influence of habitat on the abundance of *Chaetodontidae* indicator fish. This time frame ensures consistent environmental conditions, which is crucial for observing fish behavior and coral reef dynamics. Data collection during this period is also supported by the fact that coral reef fish groups generally show higher abundance and diversity during the day compared to the night, with *Chaetodontidae* fish being diurnal species [15]. Data collection often faces uncertainty due to environmental factors and low measurement repetition [14]. To address this, the research included three repetitions to ensure reliability.

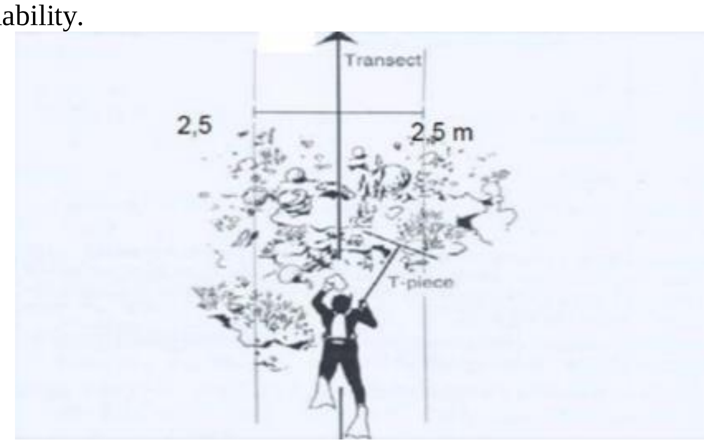

Figure 3. Underwater Visual Census Surveys [7]

The abundance data of reef fish was determined using the method developed by [16]. The Underwater Visual Census (UVC) method employs a belt transect for data collection. A 50-meter long transect was deployed with a monitoring width of 5 meters—2.5 meters on each side [7]. This process was repeated three times at the same location and during the same time to minimize errors and ensure accurate documentation of fish presence and distribution [14]. The abundance and diversity of *Chaetodontidae* indicator fish were assessed by recording the number of species and their distribution across each study site. The abundance of *Chaetodontidae* per unit of observed area was calculated using the formula provided by [17]:

$$K = \frac{Total\ number\ of\ fish}{Area\ of\ sampling\ (250m^2)} \quad (2)$$

2.3. Ecological Index

The ecological index is used to assess water quality at the research site, offering a comprehensive overview of the ecosystem's condition [18]. Data were analyzed to calculate the diversity index, which reflects the community structure and ecosystem stability [19], [20]. The composition of corals in the area can influence the ecological index, while the diversity index (H') indicates the abundance of biota and species balance. The evenness index (E) measures the distribution of individuals within the community, and the dominance index (C) quantifies the degree of dominance of certain biota within the ecosystem [21]. The following formula is used for analysis :

Diversity Index (H') Shanon – Winner [19]:

$$H' = -\sum_{i=1}^{n} p_i \cdot ln(p_i); p_i = \frac{ni}{N} \quad (3)$$

Descriptions :

1. H': Diversity index
2. ni: Number of individuals of species i
3. N: Total number of individuals
4. Interpretation:
   a. H' < 1: Low biodiversity
   b. 1 < H' < 3: Medium biodiversity
   c. H' ≥ 3: High biodiversity

Uniformity Index (E) [22] as follow :

$$E = \frac{H'}{H'_{max}};\ H'_{max} = ln(S) \quad (4)$$

Descriptions :

1. E: Uniformity index
2. H': Diversity index
3. S: Number of species found
4. Interpretation:
   a. 0 < E < 0.4: Low uniformity, distressed communities
   b. 0.4 < E < 0.6: Moderate uniformity, labile community
   c. 0.6 < E < 1.0: High uniformity, stable community

Index of Dominance (C) [17] :

$$C = \sum_{i=1}^{n} p_i^2 \quad (5)$$

Description :

1. C: Dominance index
2. n: Number of individuals of species i
3. N: Total individuals
4. Interpretation:
   a. 0 < C < 0.5: Low dominance
   b. 0.5 < C < 0.75: Medium dominance
   c. 0.75 < C ≤ 1: High dominance

2.4. Linear Regression

The relationship between the percentage of coral cover and the abundance of *Chaetodontidae* indicator fish was analyzed using simple linear regression. This method aims to derive a mathematical relationship in the form of an equation between the dependent variable (fish abundance) and the independent variable (coral cover) [23]. Simple linear regression involves only one regression line for a population. Data processing was carried out using Jupyter Notebook version 7.0.6 as the primary tool. A positive relationship is indicated when an increase in coral cover (x) results in an increase in fish abundance (y), while a negative relationship occurs when an increase in coral cover leads to a decrease in fish abundance [7]. The equation is represented by the following equation :

$$y = a + bx \quad (6)$$

Description :

1. y = *Chaetodontidae* (ind/m^2)
2. x = Coral cover (%)
3. a = Intercept
4. b = Slope

$$R^2 = 1 - \frac{\sum_{i=1}^{m}(x_i - y_i)^2}{\sum_{i=1}^{m}(\bar{y} - y_i)^2} \quad (7)$$

Description :

1. R^2 = Coefficient of determination
2. y = *Chaetontidae* (ind/m^2)
3. x = Coral cover (%)

The determination coefficient (R-squared) is a statistical measure that indicates how well the independent variables explain the variability of the dependent variable in a regression model [24]. Values close to 1 signify a strong fit, meaning that most of the variance in the dependent variable can be predicted by the independent variable [25]. Conversely, lower R-squared values suggest a poor fit, indicating that the independent variable explains only a small portion of the variance in the dependent variable [25]. Therefore, the closer the R-squared value to 1, the more effective the model is in making predictions.

3. RESULTS AND DISCUSSION

3.1. Corals Cover

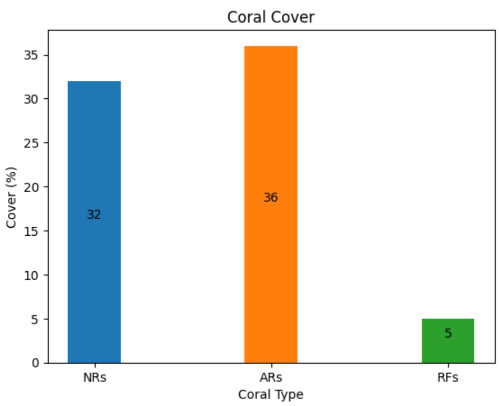

Figure 4 Coral Covers Results

The coral cover analysis, as illustrated in the graph, shows that NRs have a coral cover of 32%, while ARs exhibit a slightly higher cover at 36%. In contrast, RFs show significantly lower coral cover at only 5%. Based on the Ministry of Environment's (2001) classification criteria, both NRs and ARs fall into the "low" category, while RFs are categorized as "very low." The observed low coral cover can be attributed to multiple contributing factors. Previous studies have demonstrated that climate change, particularly rising ocean temperatures, has led to widespread coral bleaching and a decline in overall reef health [26]. Additionally, anthropogenic activities in Nusa Penida, such as destructive fishing practices, pollution, and the lack of a well-defined zoning system to regulate coastal activities, have further exacerbated the degradation of coral reef ecosystems [24], [26]. These findings emphasize the potential of ARs in supporting coral restoration efforts while simultaneously highlighting the critical degradation of RFs. This underscores the urgent need for targeted restoration interventions to mitigate further decline and promote reef recovery.

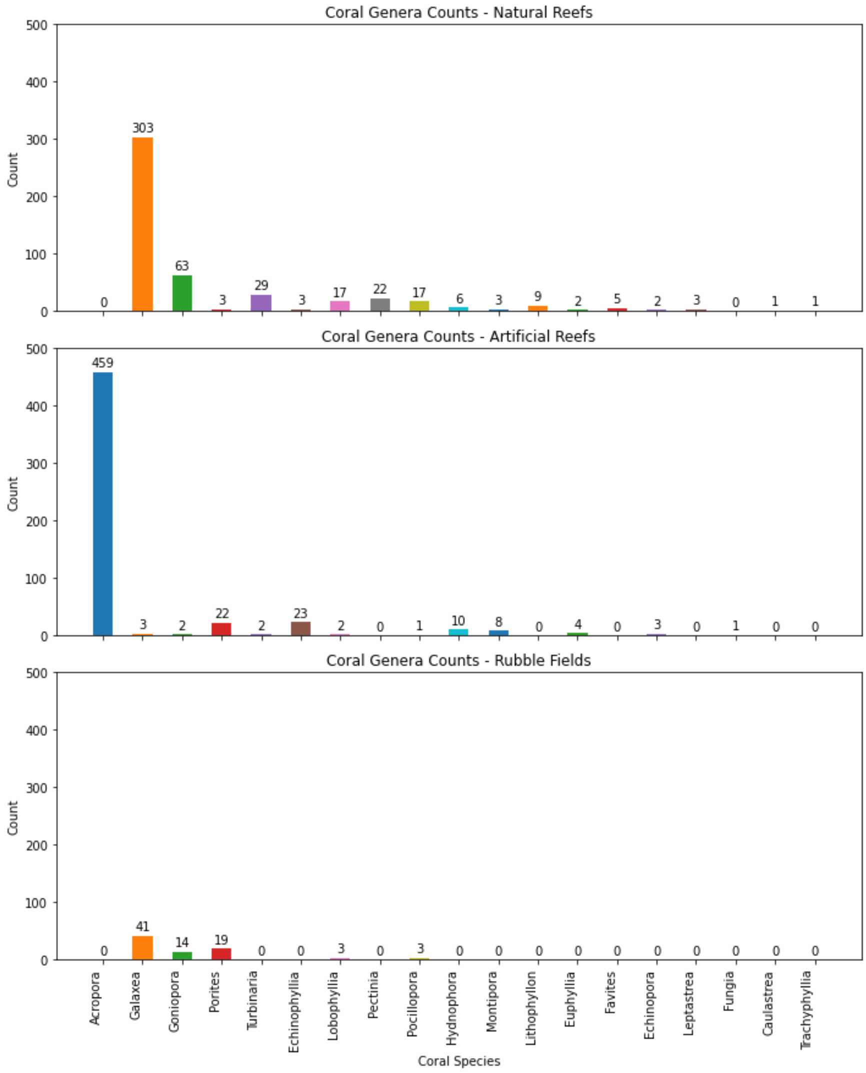

Figure 5. Abudance of Coral Reefs by Genera

Abundance data, described in the attached graph, reveal distinct patterns between NRs, ARs, and RFs. NRs, with a total of 14 genera, show significant diversity, with dominant genera such as *Galaxea* (303). ARs, which include 10 genera, are characterized by the significant presence of *Acropora* (459). In contrast, RFs, which represent only 5 genera, have a much lower abundance, with *Galaxea* (41) being the most dominant. The dominance of *Galaxea* in NRs reflects its strong ecological adaptation to natural habitats and highlights its role as a provider of complex microhabitat structures that support other reef organisms [27]. Additionally, the presence of *Galaxea* in RFs demonstrates its resilience under stress, with its ability to increase particle feeding during elevated seawater temperatures [28]. This flexibility in feeding strategies enhances its survival and adaptability to environmental changes.

The high abundance of *Acropora* in ARs reflects its rapid growth and strong resistance to environmental disturbances. According to [29], *Acropora* exhibits exceptional survival during coral bleaching events, with approximately 94% of colonies surviving. This resilience is attributed to the genetic stability and connectivity of the *Acropora* population, which facilitate recovery from disturbances [30]. These results highlight the potential of ARs to promote coral reef diversity and accelerate ecosystem recovery. Meanwhile, the limited coral diversity in RFs emphasizes the urgent need for restoration interventions to rehabilitate degraded reef areas.

3.2. Ecological Index of Coral Reefs

The ecological assessment of coral reef stations, represented by the Diversity Index (H'), Uniformity Index (E), and Dominance Index (C), provides valuable insights into both the biodiversity and ecological status of the analyzed sites [21].

Table 2 Ecological Index of Coral Reefs

No	Stations	C	E	H
1	NRs	0,497	0,384	1,110
2	ARs	0,503	0,345	0,912
2	RFs	0,897	0,152	0,2741

The calculated diversity index showed that station NRs, with an H' value of 1.110, indicated moderate diversity, while station ARs, with an H' of 0.912, also indicated moderate diversity. In contrast, station RFs, which was dominated by 95% dead coral fragments and only 5% live corals, showed a low H' value of 0.2741, reflecting low diversity and potential ecological pressures affecting the community.

The Kerbs uniformity index (E) at all three stations showed low uniformity, indicating stress on the community, in line with the low coral cover found. Uniformity values at NRs (0.384) and ARs (0.345) were not significantly different, reflecting a more stable community structure. Meanwhile, RFs had a lower uniformity value (0.152), indicating greater stress on the community as well as significant species imbalance due to the dominance of dead coral fragments.

The Dominance Index (C) at station RFs showed a very high value of 0.897, indicating strong dominance by dead coral fragments. This strong dominance negatively impacts genus diversity, impeding coral recruitment and recovery processes [31]. The movement of dead coral fragments can exacerbate physical abrasion and smother live corals, further reducing biodiversity and ecological resilience [32]. In contrast, NRs and ARs stations showed lower dominance values of 0,497 and 0,503, respectively, reflecting a more balanced community structure that supports greater ecological stability and resilience.

3.3. *Chaetodontidae* Abudance

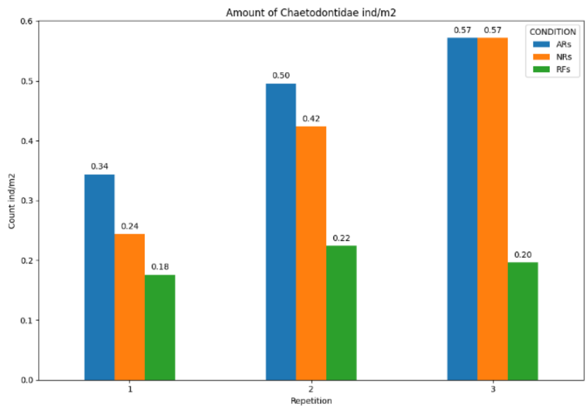

Figure 6. *Chaetodontidae* fish abundance per unit area

This graph reveals a clear pattern in the abundance of *Chaetodontidae* fish across the three types of coral reefs observed. ARs consistently showed the highest abundance in the first and second repetitions, with densities of 0.34 ind/m² and 0.50 ind/m², respectively, equivalent to 86 and 124 individuals. NRs followed ARs, while RFs consistently recorded the lowest number of individuals. In the third iteration, both ARs and NRs reached peak abundance, with densities of 0.57 ind/m² (equivalent to 143 individuals), while RFs remained at much lower abundance, with densities ranging from 0.18 to 0.20 ind/m². This trend suggests that ARs are able to support *Chaetodontidae* fish populations, whereas the degraded RFs show limitations in sustaining these fish populations. The abundance of *Chaetodontidae* is likely influenced by their preference for massive and branched corals, which provide suitable habitats for their survival [33]. This is consistent with the finding that the genus Galaxea, dominant in NRs, and Acropora in ARs, which are massive and branching corals, are closely related in supporting the abundance of *Chaetodontidae* species.

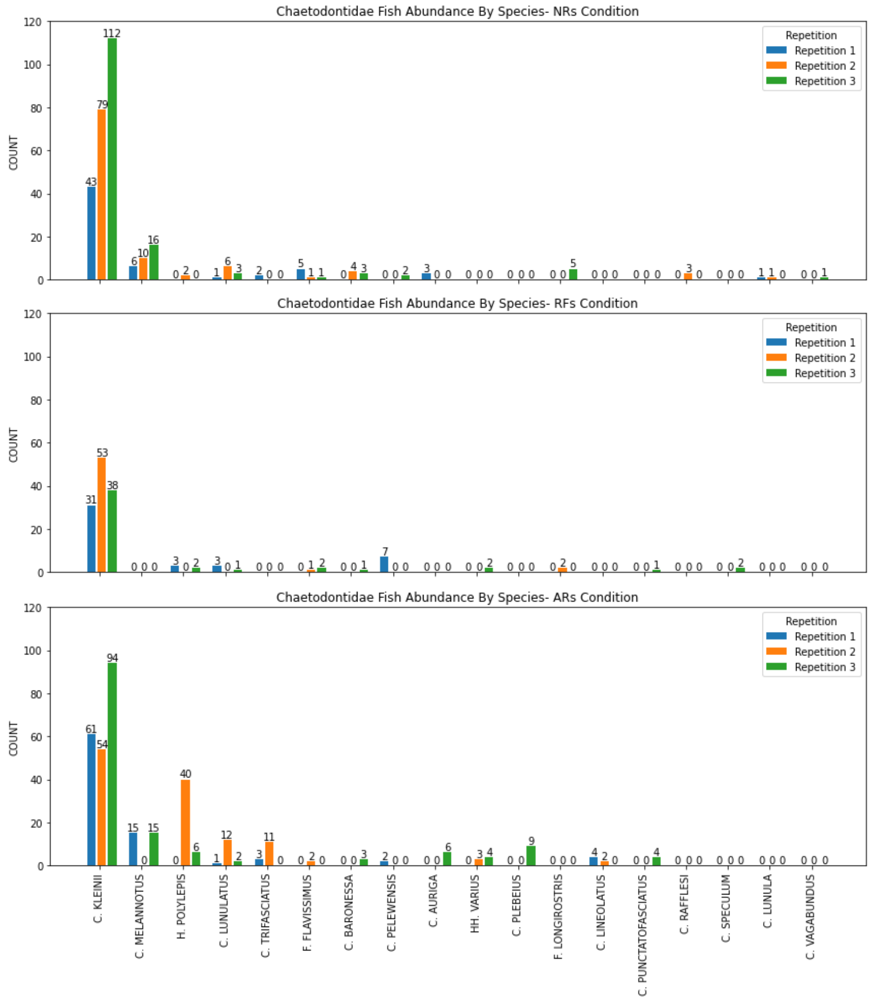

Figure 7 Abudance of Chetodontidae by Spesies

The abundance of *Chaetodontidae* species varied across NRs, ARs, and RFs. At all stations, *Chaetodon* kleinii (C. kleinii) emerged as the most dominant species, with the highest average count observed in the third repetition at NRs, where 112 individuals were recorded, and in ARs, with 94 individuals. In contrast, RFs recorded the lowest abundance of this species, with a peak count of 53 individuals in the second repetition. In NRs, C. melannotus ranked second after C. kleinii, though it was much less abundant. Meanwhile, in ARs, Hemitaurichthys polylepis (H. polylepis) ranked second, with 40 individuals recorded in the second repetition. Despite the presence of 10 *Chaetodontidae* species in RFs, their numbers were generally low, with C. kleinii showing significant dominance.

These results reflect ecological differences between stations and provide insights into the habitat preferences of *Chaetodontidae* species. *Chaetodontidae* are known for their species-specific distribution and feeding preferences on coral reefs [34]. The data highlight *C. kleinii* as the most abundant species across all reef types, which can be attributed to its ecological flexibility in utilizing various substrates, particularly massive corals, which are preferred feeding substrates [33]. This dominance is evident in both NRs and ARs. Even in RFs, despite the low coral cover, *C. kleinii* maintains its abundance, demonstrating its adaptability to less complex substrates [33]. Furthermore, *C. kleinii* shows the ability to utilize Acropora colonies in ARs for both habitat and feeding, although it does not significantly rely on branching Acropora [33], [35]. The success of *C. kleinii* in a variety of habitats emphasizes its important role in coral reef ecosystems and underscores the significance of coral conservation to support the survival and diversity of *Chaetodontidae* species, as indicated by [35].

3.4. Ecological Index

Table 3. Ecologycal Index of *Chaetodontidae*

No	Stations	C	E	H	Avarages		
					C	E	H
1	NRs	0,517	0,382	1,074			
		0,570	0,330	0,991	0,572	0,331	0,970
		0,628	0,281	0,844			
2	ARs	0,537	0,366	0,947			
		0,312	0,495	1,391	0,434	0,423	1,210
		0,452	0,408	1,293			
3	RFs	0,530	0,452	0,905			
		0,897	0,153	0,243	0,679	0,308	0,702
		0,609	0,319	0,957			

Based on the calculation of the ecological index, the Shannon diversity index (H') for NRs averaged 0.970, indicating a low level of diversity (H' < 1). In contrast, ARs had an average H' value of 1.21054, placing them in the medium diversity category (1 < H' < 3). ARs also recorded the highest species uniformity (E) value compared to NRs and RFs, with an average of 0.423. This suggests that species distribution in ARs is more even, whereas NRs are dominated by certain species. This trend is further reflected in the dominance index (C), where RFs and NRs had average values of 0.679 and 0.572, respectively. Both values fall within the moderate dominance category (0.5 < C < 0.75), indicating the presence of dominant species within the community. On the other hand, RFs had an average Shannon index (H') value of 0.702, which signifies the lowest level of diversity and places RFs in the low diversity category (H' < 1).

3.5. Linear Regression

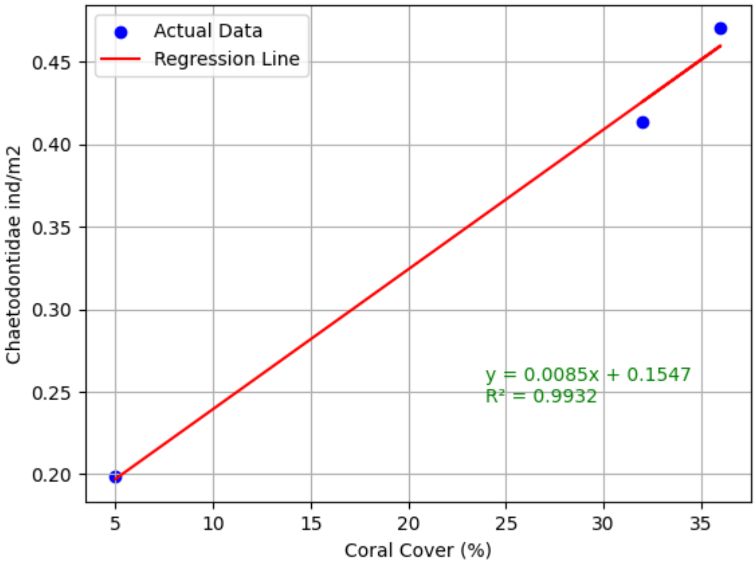

Figure 8. Linear Regression Result of Coral Cover and *Chaetodontide* Abundance

Using coral cover (%) as the independent variable (x) and *Chaetodontidae* abundance (ind/m²) as the dependent variable (y), linear regression analysis was performed. The R-squared value obtained from the analysis was 0.9932, indicating that 99.32% of the variance in *Chaetodontidae* abundance is explained by coral cover. This demonstrates a very strong positive correlation between coral cover and *Chaetodontidae* abundance, confirming the importance of coral health in sustaining *Chaetodontidae* populations.

Covariance and correlation are both essential for interpreting this relationship [36]. Covariance measures the directional relationship between two variables—in this case, coral cover and *Chaetodontidae* abundance. Positive covariances indicate that the variables tend to move in the same direction [37]. When one variable increases, the other also tends to increase, and when one decreases, the other typically decreases as well [38]. In this context, the positive covariance indicates that as coral cover increases, *Chaetodontidae* abundance also increases, which aligns with the regression analysis results. The equation derived from the analysis is (y

= 0.0085x + 0.1547), meaning that for every 1% increase in coral cover, the abundance of *Chaetodontidae* increases by 0.0085 individuals per square meter.

This statistical approach is crucial in confirming that *Chaetodontidae*, as biological indicators, increase in abundance with higher coral cover. Regression analysis, supported by covariance and correlation, underscores the ecological significance of using *Chaetodontidae* abundance as an indicator of coral reef health, reinforcing their role as an important species in monitoring reef conditions.

4. CONCLUSION

The condition of coral reefs in Sental Village, Nusa Penida, is generally in the low category based on coral cover levels, which is 32% in NRs, 36% in ARs, and only 5% in RFs, which is classified as very low according to the Ministry of Environment (2001). Based on the analysis of the ecological index *Chaetodontidae*, ARs in this study demonstrated an effective role as they were able to support higher abundance of *Chaetodontidae* indicator fish compared to NRs and RFs, demonstrating their potential to mimic natural ecosystem functions. However, the effectiveness of ARs remains dependent on ongoing management and evaluation to ensure their sustainability in supporting marine biodiversity.

Linear regression analysis showed a very strong positive relationship between coral cover and *Chaetodontidae* abundance ($R^2 = 0.9932$). The regression equation ($y = 0.0085x + 0.1547$) indicated that every 1% increase in coral cover increased *Chaetodontidae* abundance by 0.0085 individuals per square meter. These findings underscore the important role of coral cover in maintaining *Chaetodontidae* populations as a biological indicator of coral reef health.

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