



Spirobranchus sp. Density as a Biological Indicator of Coral Health Under Environmental Stress in Beurawang Waters (SDG 14: Life Below Water)

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Abstract: This study examines the relationship between the Christmas tree worm (*Spirobranchus* sp.) and coral health in tropical reef ecosystems. Field observations and statistical analyses were conducted to evaluate worm abundance and its association with coral condition. The results showed a strong association (Phi coefficient = 0.79) between high worm density and degraded coral health. Juvenile *Spirobranchus* sp. preferentially settle on healthy coral substrates, while adult individuals may contribute to surface abrasion and localized lesions through opercular movement. Exposed worm tubes can facilitate turf algae colonization, inhibiting coral recovery. Environmental parameters, including temperature, pH, salinity, visibility, and current velocity, influence coral condition and worm distribution. Elevated and localized temperature anomalies and reduced water flow were associated with increased coral stress and algal growth. These findings indicate that *Spirobranchus* sp. may contribute to coral degradation under high population density. This study supports Sustainable Development Goal 14 (Life Below Water) by highlighting the potential of *Spirobranchus* sp. density as a practical indicator for coral reef monitoring and conservation.

Keywords: Bioindicator; Coral; Environmental stress; *Spirobranchus* sp.; Turf algae

Introduction

Sabang City is a marine tourism destination known for its rich biodiversity. The region encompasses mangrove ecosystems and coral reefs that host various species of ornamental reef fish and other marine biota (Aziz & Murtisal, 2019; Subiyati et al., 2024). The beauty and ecological wealth of Sabang make it a high-value economic area, attracting both domestic and international tourists. This aligns with the Indonesian Law that designates Sabang as a zone for integrated economic development, free trade, and a free port (Republik Indonesia, 2014; Afkar et al., 2024).

Preliminary studies conducted in Beurawang waters, one of Sabang's marine zones, revealed the presence of coral species from the genera *Acropora*, *Montipora*, *Porites*, and *Heliopora*. These findings support previous research indicating that Beurawang waters are

predominantly inhabited by corals from the genera *Acropora*, *Montipora*, and *Porites*, with variations in coral cover and associated reef fish communities reported in previous studies (Aldyza et al., 2022a, 2022b). Coral reef growth and development are influenced by environmental factors such as water temperature, salinity, and overall water quality (Muttaqin et al., 2014; Pakpahan et al., 2023; Thirukanthan et al., 2023). When water temperature remains within the optimal tolerance range, coral reefs can thrive and maintain healthy growth (Mulya et al., 2023).

The coral reefs in Beurawang, Weh Island, serve as a vital ecosystem supporting marine biodiversity in the region (Aldyza et al., 2024), biodiversity in coastal ecosystems can also be utilized as a contextual learning resource in biology education (Noviyanti et al., 2025). However, these reefs are currently under considerable pressure from both natural and anthropogenic factors,

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which threaten coral health and survival (Brandão & Brasil, 2020; Karnan, 2022; Afkar et al., 2023) often leading to coral reef degradation due to unsustainable marine exploitation practices (Irrubai & Subki, 2024). One organism playing a role in this ecosystem is the marine worm from the genus *Spirobranchus* sp., commonly known as the Christmas tree worm. *Spirobranchus* sp., a polychaete that forms symbiotic relationships with corals, exhibits ambivalent interactions with its coral hosts.

On one hand, the presence of *Spirobranchus* sp. is associated with increased bioerosion in coral structures, particularly in *Porites* sp. species, suggesting potential parasitic or detrimental effects on coral integrity. On the other hand, this symbiotic relationship may offer ecological benefits, such as enhanced water circulation around coral bodies and protection from predators, which could improve coral resilience to environmental stressors (Isdianto et al., 2024; Hoeksema et al., 2019b). Research conducted in Beurawang indicates that *Spirobranchus* sp. abundance tends to be higher on damaged corals, with a strong correlation coefficient of 0.611 between worm presence and coral degradation (Mardani et al., 2021). Conversely, studies in other locations, such as Sempu Island, have found that *Spirobranchus* sp. engages in mutualistic relationships that bolster coral resistance to environmental stress (Aldyza et al., 2022a). These contrasting findings raise fundamental questions about whether *Spirobranchus* sp. dominance in Beurawang represents a parasitic or adaptive response within the context of coral reef degradation.

This study aims to examine the role of *Spirobranchus* sp. in relation to coral structural integrity and health in Beurawang waters. Through quantitative observation and statistical analysis, this research seeks to identify the strength of association between worm abundance and coral condition. Additionally, environmental factors influencing this interaction are assessed to determine the extent to which seawater conditions affect *Spirobranchus* sp. populations. The findings are expected to provide a comprehensive basis for understanding coral-symbiont interactions under environmental stress.

In a broader context, coral reef degradation represents a major global environmental issue aligned with Sustainable Development Goal 14 (Life Below Water), which emphasizes the conservation and sustainable use of marine resources. Understanding biological indicators such as *Spirobranchus* sp. and their relationship with coral health is therefore essential for developing effective monitoring and management strategies to support sustainable marine ecosystems (Ninasafitri et al., 2023).

Method

This research was conducted in August 2025 in the waters of Beurawang, Sabang, Weh Island. Beurawang is an open-access marine area not located within a conservation zone, making it a suitable site for studying the symbiotic impact of the Christmas tree worm (*Spirobranchus* sp.) on coral structural integrity and health. Observations were carried out at two depths: three meters and seven meters.

Data collection on *Spirobranchus* sp. and coral genera was conducted at six transect points laid parallel to the coastline, spanning coordinates from 95°20'12.59"E and 5°46'39.040"N to 95°20'22.52"E and 5°46'53.757"N. A purposive sampling approach was used to determine transect placement in areas with a high occurrence of *Spirobranchus* sp. *Spirobranchus* sp. data were collected using a belt transect method, with each of the six transects measuring 100 m in length and a sampling width of 3 m on either side of the transect line (total width of 6 m). Along each transect, six sampling plots measuring 5 × 6 m (30 m²) (Hoeksema et al., 2019a) were systematically established, with the 5 m side oriented parallel to the transect line and a 2 m interval between consecutive plots, resulting in a total of 36 plots (Figure 1). Plots were restricted to coral substrates. Within each plot, all *Spirobranchus* sp. individuals encountered were counted to estimate density, expressed as the number of individuals per unit area (ind/m²). Coral genera within the observation plots were identified using the Point Intercept Transect (PIT) method (Hoeksema et al., 2019a; van der Schoot & Hoeksema, 2024). In addition, environmental parameters, including temperature, pH, salinity, current velocity, and visibility, were measured at each transect location.

Spirobranchus sp. Density

Within each plot, all *Spirobranchus* sp. individuals encountered were counted to estimate density per unit area (ind/m²). Density was calculated using the following formula:

$$\text{Density of X} = \frac{\text{Number of individuals of } \textit{Spirobranchus} \textit{ sp.}}{\text{Area of transect (m}^2\text{)}} \quad (1)$$

Percentage of Coral Cover

Coral cover density was calculated using the following formula:

$$\% \text{ Component cover} = \frac{\text{Number of component}}{\text{Total component}} \times 100\% \quad (2)$$

Statistical Analysis

Statistical analysis was performed using SPSS version 25. The association between *Spirobranchus* sp.

and coral condition was examined using a 2x2 contingency table. Ludwig et al. (1988) stated that this table helps systematically understand the relationship or association between two variables (Krebs, 1999; Ludwig & Reynolds, 1988). To determine whether a significant association exists between *Spirobranchus* sp. and coral condition, the Chi-Square test was applied. The Chi-Square test with Yates' Continuity Correction was applied for the 2x2 contingency table to reduce overestimation of the χ^2 value due to small sample size (N = 36). The critical value for the Chi-Square test with one degree of freedom (df) at a 5% probability level is 3.84. If the calculated Chi-Square value exceeds 3.84, a significant association between the two variables is indicated.

Result and Discussion

Impact of *Spirobranchus* sp. Abundance on Coral Condition

Spirobranchus sp. belongs to the family Serpulidae and is characterized by a calcareous operculum. Other distinctive features include terminal spines and lateral wing-like projections on its body. This species possesses

lower radiolar lobes that are longer than the upper lobes, giving it a shape reminiscent of a fir tree or Christmas tree (Brandão & Brasil, 2020). These morphological traits serve as key identifiers and play important roles in protection and ecological interaction within coral reef habitats. In this study, a total of 854 individuals of *Spirobranchus* sp. were recorded in Beurawang waters, with 446 individuals found at a depth of 3 meters and 408 individuals at 7 meters, indicating an increase compared to previous findings (Afkar et al., 2023).

Observations revealed that juvenile *Spirobranchus* sp. preferentially settle on healthy coral substrates during the planktonic larval phase, as living coral tissue is required to support tube formation and integration. Upon attachment, larvae undergo metamorphosis, producing mucus tubes that later calcify and become embedded within coral tissue. Over time, these calcareous tubes are enveloped by coral growth, contributing to structural thickening and forming integrated reef microstructures. This interaction reflects a complex symbiotic relationship in which *Spirobranchus* sp. not only occupies coral surfaces but also modifies coral morphology and microhabitat structure (Figure 2).

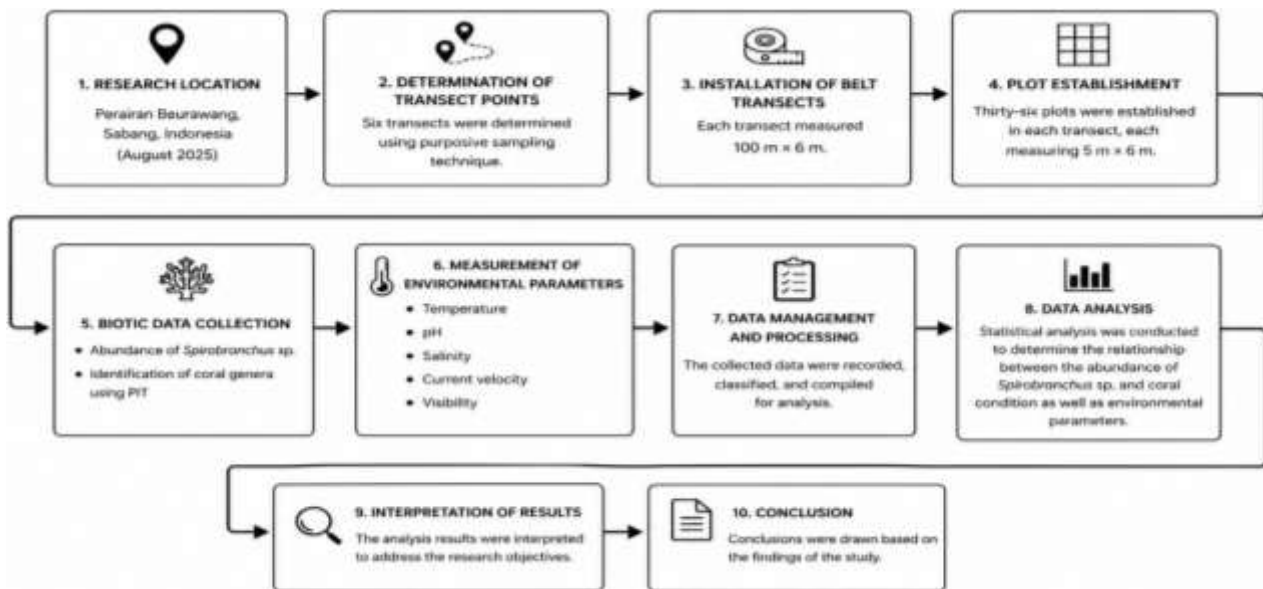


Figure 1. Research methodology flowchart



Figure 2. Structural alterations in coral morphology associated with the presence of *Spirobranchus* sp.

Table 1. Case Processing Summary

	N	Valid percent	N	Missing percent	N	Cases Total Percent
<i>Spirobranchus sp.</i> abundance*	36	100%	0	0.0%	36	100%
Coral conditions						

The distribution of *Spirobranchus sp.* on coral surfaces varies depending on coral size and spatial availability. On larger coral colonies, individuals tend to cluster in specific areas, whereas on smaller colonies, distribution appears more uniform. This pattern is likely influenced by space competition, substrate suitability, and local environmental conditions.

An increase in *Spirobranchus sp.* populations within coral ecosystems has measurable ecological implications. At high densities, these organisms may exert mechanical stress on coral tissue through opercular movement and space competition, while also facilitating

the accumulation of organic material and epibiotic organisms. Under balanced conditions, however, they may contribute positively to benthic dynamics by enhancing micro-scale water circulation.

The distribution of *Spirobranchus sp.* abundance across coral conditions shows a clear pattern. A total of 12 plots with low worm abundance were associated with healthy corals, while no low-abundance cases were observed in unhealthy corals. In contrast, high worm abundance was recorded in 4 plots with healthy corals and 20 plots with unhealthy corals (Table 2).

Table 2. *Spirobranchus sp.* Abundance* Coral Conditions Crosstabulation

			Healthy coral	Unhealthy coral	Coral conditions Total
<i>Spirobranchus sp.</i> abundance	Low	Count	12	0	12
		Expected count	5.3	6.7	12.0
	High	Count	4	20	24
		Expected count	10.7	13.3	24.0
	Total	Count	16	20	36
		Expected count	16.0	20.0	36.0

Table 3. Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	22.500a	1	.000		
Continuity correction ^b	19.25	1	.000		
Likelihood ratio	27.83	1	.000		
Fisher's exact test				.000	.000
Linear-by-linear association	21.87	1	.000		
N of valid cases	36				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 5.33

b. Computed only for a 2x2 table

Table 4. Symmetric Measures

		Value	Approximate Significance
Nominal by nominal	Phi	.79	.000
	Cramer's V	.79	.000
	Contingency Coefficient	.62	.000
N of Valid Cases		36	

The Chi-Square test with Yates' continuity correction revealed a significant association between *Spirobranchus sp.* abundance and coral condition ($\chi^2 = 19.25$, $df = 1$, $p < 0.05$) (Table 3). This indicates that worm abundance is not randomly distributed but strongly linked to coral health status. Furthermore, the strength of this association was categorized as strong based on the Phi coefficient ($\Phi = 0.79$, $p < 0.05$) (Table 4),

indicating that higher densities of *Spirobranchus sp.* are predominantly found in degraded coral conditions.

This pattern suggests that high densities of *Spirobranchus sp.* are closely associated with degraded coral conditions and may exacerbate coral damage through continuous physical interaction and the facilitation of turf algae colonization. Rather than indicating post-settlement movement, this finding

implies that coral degradation may occur after worm establishment or that worm-colonized corals are more susceptible to environmental stress.

Figure 3a shows coral surface erosion around worm tube openings, likely caused by repeated opercular movement, while Figure 3b illustrates turf algae growth surrounding *Spirobranchus sp.* tubes. In some cases, these tubes remain partially uncovered by coral tissue, providing a substrate for turf algae colonization. The presence of turf algae is particularly concerning, as it can inhibit coral regeneration, compete for space, and interfere with photosynthetic processes.

The increase in algal cover is often associated with reduced ecological control mechanisms, where herbivorous organisms play a key role in suppressing algal growth (Rani et al., 2023). Previous studies have shown that turf algae colonization on worm tubes can intensify coral damage, slow healing processes, and degrade coral structure (Hoeksema et al., 2019b; van der Schoot & Hoeksema, 2024; Afkar et al., 2024). Therefore, the interaction between *Spirobranchus sp.*, coral hosts, and turf algae represents a critical mechanism influencing coral reef degradation in Beurawang waters.



Figure 3. (a) Coral surface area exhibiting bleaching due to abrasion from the operculum of *Spirobranchus sp.*; (b) Coral surface colonized by turf algae surrounding the *Spirobranchus sp.* tube. (c) *Spirobranchus sp.* tube overgrown by turf algae

Environmental Conditions of Beurawang Waters

Environmental parameter measurements in Beurawang waters were conducted at two depths with three repetitions. The recorded water temperature at 3 meters depth was $30.67 \pm 1.15^\circ\text{C}$, while at 7 meters depth it reached $32.00 \pm 1.00^\circ\text{C}$. This pattern indicates a localized thermal anomaly, where higher temperatures were observed at greater depth. This condition is likely associated with reduced current velocity at deeper layers, which limits vertical water mixing and promotes heat accumulation. As current velocity decreases, the efficiency of heat distribution is reduced, allowing warmer water to persist in localized zones. Therefore, the observed temperature inversion in Beurawang waters is more likely driven by weak hydrodynamic conditions rather than large-scale oceanographic processes.

Temperatures exceeding 30°C have been linked to disruptions in Zooxanthellae photosynthesis, the production of Reactive Oxygen Species (ROS), and coral bleaching (Pfab et al., 2024). Elevated temperatures can impair the photosynthetic mechanisms of symbiotic algae and trigger oxidative stress, leading to tissue bleaching. This is consistent with Berkelmans (2018), who identified elevated seawater temperature as a primary driver of coral mortality. In addition, prolonged exposure to elevated temperatures under low mixing conditions may increase thermal stress on corals.

Table 5. Physical parameters of Beurawang waters

Parameter	3 meters	Depth 7 meters
Temperature ($^\circ\text{C}$)	30.67 ± 1.15	32 ± 1.00
pH	7.93 ± 0.057	8.06 ± 0.05
Salinity (ppt)	31.67 ± 0.57	33.33 ± 0.57
Visibility (cm)	300 ± 0	566.67 ± 11.54
Flow velocity (m/s)	0.14 ± 0.012	0.09 ± 0.01

In this context, the presence of *Spirobranchus sp.* may play a dual role in coral reef ecosystems. On one hand, its prominent and brightly colored radiolar structures can enhance micro-scale water flow around coral surfaces, facilitating nutrient exchange and oxygen circulation, which may help reduce localized bleaching risk. On the other hand, *Spirobranchus sp.* may exert mechanical stress on coral tissue, particularly when population densities are high or when individuals attach to structurally fragile coral forms. Several studies suggest that associations with massive corals such as *Porites sp.* tend to be more stable and potentially beneficial, whereas on branching corals, the presence of *Spirobranchus sp.* may increase susceptibility to physical damage and breakage.

The slight increase in pH from 7.93 at 3 meters to 8.06 at 7 meters is also relevant to this symbiotic interaction. Coral calcification processes are strongly influenced by seawater pH, and even minor fluctuations

can affect substrate stability and skeletal formation. Allison et al. (2021) reported that stable pH conditions support coral calcification and the survival of benthic organisms dependent on carbonate structures. Therefore, *Spirobranchus sp.* is more likely to persist on coral substrates with stable pH and sufficient structural integrity.

Salinity levels in Beurawang waters ranged from 31.67 to 33.33 ppt, which fall within the tolerance range of most tropical coral species. However, elevated salinity may reduce coral resilience under environmental stress and slow tissue regeneration. Wang et al. (2025) demonstrated that salinity fluctuations can induce osmotic imbalance, reduce coral growth rates, and increase susceptibility to bleaching. For symbiotic organisms such as *Spirobranchus sp.*, stable salinity conditions are critical for larval settlement and long-term persistence. Hoeksema et al. (2019) also noted that *Spirobranchus sp.* is more frequently associated with reefs exhibiting stable physical conditions, whereas extreme salinity fluctuations may disrupt its spatial distribution.

The increase in water visibility from 300 cm (approximately 3.0 m) at 3 meters depth to 566.67 cm (approximately 5.67 m) at 7 meters depth indicates relatively clear water conditions that support photosynthetic activity of zooxanthellae within coral tissues. High visibility also benefits *Spirobranchus sp.*, particularly during its planktonic larval phase, as larvae exhibit positive phototactic responses to light (Marsden, 2021), influencing settlement patterns on illuminated coral substrates.

The decrease in current velocity from 0.14 ± 0.012 m/s to 0.09 ± 0.015 m/s with increasing depth may promote sediment accumulation and organic particle deposition on coral surfaces. Reduced water flow limits the natural cleaning mechanisms of corals, thereby increasing the likelihood of turf algae colonization and other opportunistic organisms. Rawat et al. (2024) highlighted that low hydrodynamic conditions can accelerate algal succession and disrupt coral-symbiont interactions, including those involving *Spirobranchus sp.*, whose exposed tubes are particularly vulnerable to epibiotic algae growth. Furthermore, changes in current dynamics and sedimentation patterns may alter the stability of mutualistic relationships within reef ecosystems (Muller-Parker et al., 2023).

Overall, the physical parameters of Beurawang waters—including temperature, pH, salinity, visibility, and current velocity—collectively influence coral health and the distribution patterns of *Spirobranchus sp.*, as water quality is a key determinant of aquatic ecosystem condition (Supardiono et al., 2023). Elevated temperatures exceeding optimal thresholds may induce thermal stress and bleaching, while stable pH supports calcification processes. Salinity within tolerance limits

provides suitable conditions, although fluctuations may reduce resilience under stress. High visibility enhances photosynthetic efficiency, whereas reduced current velocity may facilitate sediment accumulation and turf algae growth.

These interacting environmental factors create conditions that shape both coral physiological performance and the ecological role of *Spirobranchus sp.* within reef systems, as the distribution and abundance of marine organisms are closely influenced by environmental conditions and ecosystem interactions (Mardiati et al., 2025). Consequently, *Spirobranchus sp.* tends to persist in environments with relatively stable physical conditions and structurally suitable coral substrates. This understanding contributes to a more integrated view of coral-symbiont interactions and provides a scientific basis for coral reef monitoring and conservation strategies in Beurawang waters, highlighting the importance of adaptive and community-based approaches in coral reef management (Nurhayu et al., 2025).

Conclusion

This study demonstrates that *Spirobranchus sp.* abundance is significantly associated with coral health in Beurawang waters. A strong association (Φ coefficient = 0.79) indicates that high densities of *Spirobranchus sp.* are predominantly found on degraded coral substrates. The findings further show that environmental parameters, including temperature, pH, salinity, visibility, and current velocity, play an important role in shaping coral health and influencing the persistence of *Spirobranchus sp.* symbiosis, as water quality and oceanographic conditions are key drivers of coral distribution and ecosystem stability. Elevated and localized temperature anomalies at specific depths, along with reduced water flow, may contribute to coral stress and facilitate turf algae colonization around worm tubes. High densities of *Spirobranchus sp.* are closely associated with degraded coral conditions and may exacerbate coral damage through continuous physical interaction and the promotion of turf algae growth. Therefore, *Spirobranchus sp.* can be utilized as a practical ecological indicator for coral reef health assessment. Integrating its density into monitoring programs may support targeted conservation strategies in Beurawang waters.

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Author Contributions

Conceptualization, A. and N.A.; methodology, A. and N.A.; formal analysis, A. and N.A.; investigation, A. and N.A.; field observation, A. and N.A.; data curation, N.A.; resources, A.; writing-original draft preparation, N.A.; writing-review and editing, N.A.; visualization, N.A.; supervision, A.; project administration, A. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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