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Christmas tree worm *Spirobranchus* spp. (Annelida: Serpulidae) as indicators of coral health at Weh Island, Aceh Province, Indonesia

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Abstract. *Afkar, Barus TA, John AH, Sarong MA. 2024. Christmas tree worm* Spirobranchus *spp. (Annelida: Serpulidae) as indicators of coral health at Weh Island, Aceh Province, Indonesia. Biodiversitas 25: 1743-1753.* The research was conducted along 300-m long transects at 3 and 7 m depth in Beurawang Waters, Weh Island, Aceh Province, Indonesia, which aimed to analyze the association of christmas tree worms (Polychaeta: Serpulidae: *Spirobranchus*) with coral health conditions and determine the impact of their presence on the coral reef ecosystem. On average, *Spirobranchus* individuals were more commonly found at 3 m than at 7 m depth. *Spirobranchus* was found to be most associated with massive corals of the genus *Porites*. *Spirobranchus* tends to be most abundant in damaged coral reef colonies, which suggests that coral conditions could worsen if the abundance of *Spirobranchus* worms increases. Statistical analysis also shows an association between the abundance of *Spirobranchus* and the condition of coral reefs, with a 'strong' relationship value of 0.611. Therefore, it is necessary to consider coral transplantation as an effort to repair damaged coral substrates in Beurawang Waters.

Keywords: Association, coral reef, operculum, tube worm

INTRODUCTION

Weh Island, Indonesia is an island characterized by a diverse coral reef ecosystem. Over the last few decades, the condition of coral reefs has declined globally due to natural disturbances and human activities (Utama and Hadi 2018). Coral damage can occur due to anthropogenic factors, including bleaching, algae overgrowth, and health problems, thus having a negative impact on coral growth (Aldyza and Afkar 2015). The impact of human activities mostly results in sedimentation, nutrient enrichment, and habitat loss due to fishing with fishing gear that damages coral. Coral damage in the form of bleaching on Weh Island was reported to have occurred in 2010 and 2016 (Rudi et al. 2012; Ampou et al. 2017; Mulya et al. 2023), so many corals experienced degradation and death. Coral bleaching is a condition where Zooxanthellae are lost in the body of coral polyps, resulting in reduced production of energy and color pigments, ultimately resulting in the coral becoming white/transparent (Plass-Johnson et al. 2015).

Beurawang Waters constitute one of the unrestricted access areas in the southeastern part of Weh Island. Unlike the eastern part of Weh Island, which is designated as a conservation area, Beurawang Waters are open for access, leading to a significant presence of fishermen involved in fishing activities. The Beurawang area is supervised by Panglima Laot Lhok Beurawang, whose responsibilities include maintaining maritime security and regulating the activities of the local community, particularly fishermen, and concerning the use of permitted fishing gear. This monitoring is carried out to minimize damage to corals after bleaching. The impact of bleaching peaked in 2022, which is marked by the absence of substrate and low variation in coral genera, especially in the waters of the Beurawang, Weh Island.

The preliminary survey results indicate that post-2016 bleaching, the coral ecosystem in the waters of Beurawang has experienced severe damage, suffered from health disturbances, and faced stiff competition from turf algae growth. The existence of turf algae that exceeds the coral cover is very worrying because turf algae that dominate the substrate can make it difficult for corals to regenerate. The breeding turf algae cover can form a thick and dense matrix and inhibit the formation of coral larvae (O'Brien and Scheibling 2018). The degradation of coral reef was generally associated with a reduction in coral cover and diversity and an increase in algal communities. The ability of turf algae that grow quickly has a negative impact on corals that are slow growing, then the loss or destruction of a coral colony can increase macroalgae cover by about 20% (Fricke et al. 2014; Reverter et al. 2020; Ditzel et al. 2022). During initial observations, *Spirobranchus* were found on average on the coral reefs in Beurawang Waters.

Spirobranchus is a mesofauna characteristic of rocky beaches (Kočí and Jäger 2015). The existence of *Spirobranchus* is an attraction for tourists who want to see see this worm in the water because it has beautiful colors of radioles that resembles a crown (Dávila-Jiménez 2017). The distribution of this worm genus has been reported in tropical and subtropical waters and is associated with certain types of coral (Skinner et al. 2012; Hoeksema and ten Hove 2017; Perry et al. 2018b). The presence of *Spirobranchus* in the coral ecosystem is mutually beneficial (mutualism). Coral serves as a permanent host for *Spirobranchus* which will grow covering the surface of *Spirobranchus* tubes, while Spirobranchus acts as a protector for the coral, as the two branchial crowns of *Spirobranchus* can provide protection by repelling coral polyp-eating predators (Perry et al. 2018a). However, the presence of Spirobranchus tends to be found on coral reefs with poor conditions and covered by turf algae, then the aim of this research is to analyze the association of Spirobranchus with coral health conditions and determine the impact of *Spirobranchus* presence on the coral reef ecosystem in the Beurawang Waters.

MATERIALS AND METHODS

Study area

The research was conducted in the Beurawang Waters, Weh Island, Aceh Province, Indonesia (Figure 1), in May-June 2022. The transect placement location was at coordinates 5°46'39.0"N; 95°20'12.6"E. The research was carried out at two depths, namely 3 m and 7 m. The waters of Beurawang represent one of the open-access locations in Weh Island, yet they hold potential for conservation due to the low coral cover in this area. Despite the suboptimal coral conditions, fish abundance in the waters of Beurawang tends to be high. The average fish species found in this area belong to the herbivore group, attributed to the abundance of food sources such as turf algae and articulated coralline algae. The abundance of fish in this area benefits the coastal communities of Beurawang, where fishing is a primary livelihood. Despite not being a protected area, the awareness of the Beurawang community in preserving coral ecosystems is high. Consequently, fishing activities are conducted using environmentally friendly methods such as rod and reel fishing from boats, and cast nets, rather than destructive methods like trawling nets and potassium fishing.

Data collection of *Spirobranchus* and coral reef

Spirobranchus data research was carried out using the belt transect method, with a transect length of 300 m at each depth and a transect width of 1 m each side. On the transect, there are plots with an area of 30 m^2 (Hoeksema et al. 2019a), which are placed parallel to the middle of the transect at intervals of 2 m so that the total sampling plots for *Spirobranchus* data are 36 plots (18 plots at 3 m depth and 18 at 7 m depth). *Spirobranchus* worms were collected based on their presence within plots laid along transect lines in the waters of Beurawang (Figure 2). *Spirobranchus* was counted when the species was on the reef surface and when it entered or was in the hole. Worms found outside the reef plots were not included in the count, and empty holes no longer occupied by Christmas tree worms are not counted. Data collection was conducted through SCUBA diving, followed by direct observation and aided by underwater cameras. *Spirobranchus* specimens were identified based on morphology, specifically the arrangement and shape of operculum spines, following the methods outlined in Willette et al. (2015): Figure 2, and Perry et al. (2018a): Figure 5.

Coral cover data were collected using the Point Intercept Transect (PIT) method, with transect lengths of 100 m repeated three times, resulting in a total transect length of 300 m. During transect line deployment, the transect position was on the left side of the diver. Three horizontal transects were laid along the coastline at depths of 3 m and 7 m, totaling 6 transects per station. Transects intersecting coral reefs were noted, with recordings taken every 50 cm (Figure 3). Subsequently, analysis was conducted at each point to identify and observe life forms.

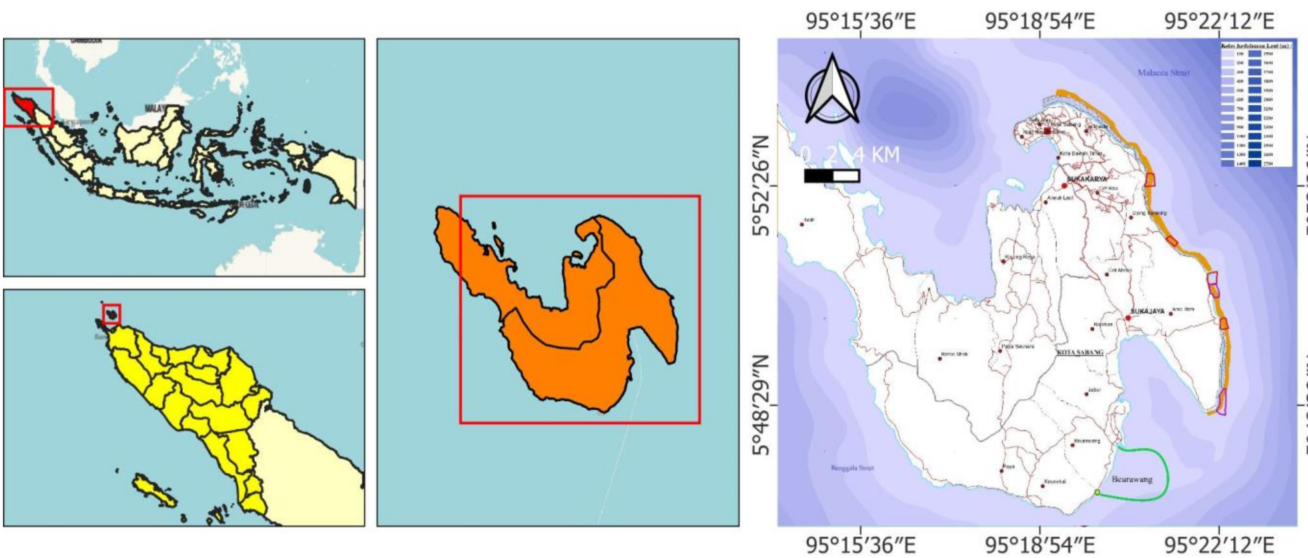

Figure 1. Research location map in Beurawang Waters, Weh Island, Aceh Province, Indonesia (on the green line)

Measurements

In conjunction with *Spirobranchus* and coral data collection, physical water measurements including sea water temperature, pH, salinity, visibility, and current speed were also carried out in situ. These measurements aimed to assess the water conditions which could potentially fluctuate and impact the development of coral reef ecosystems in Beurawang. The observed coral reef ecosystem did not appear to be in good condition. In this case, the condition of coral cover is divided into two categories, namely the categories of healthy and unhealthy. The condition of corals experiencing damage is seen based on health problems experienced by corals, including being covered by turf algae, response pigmentation, and several other disorders, which refer to the book Underwater Cards for Assessing Coral Health on Indo-Pacific Reefs (Beeden et al. 2008), while corals those that are not damaged are coral colonies that are still good/healthy without experiencing health problems.

Data analysis

The association between *Spirobranchus* and coral health conditions was analyzed using the Chi Test -Square, with a 2x2 contingency table, so that significant values will be seen in the continuity correction section. The significance level (α) used is 0.05. Categorization of data on the observed variables was carried out by assigning codes 1: Low and 2: High for the *Spirobranchus* abundance variable, with details of the abundance value is $\leq$ 0.50 ind/m^2 then it is grouped as 'Low,' and the abundance value > 0.50 ind/m^2 is grouped into 'High.' Then, the coral condition variable is coded 1: Healthy and 2: Unhealthy. Analysis was carried out with the help of IBM SPSS Statistics version 23 and Excel 2013. Recording results the percentage of coral points in each plot is calculated using an equation (1) (Jokiel et al. 2015), as follows:

$$\% \text{ coral cover } = \frac{\text{Number of points}}{\text{Total number of points}} \text{x } 100\% \qquad (1)$$

In order to measure the abundance of *Spirobranchus* was calculated using an equation (2) (Somma et al. 2017), where K is the abundance of *Spirobranchus* (ind.), ni is the number of *Spirobranchus* spp. at the *i*th observation plot and L is the area of the observation plot (2 x 15 m^2).

$$K = \frac{ni}{L} \qquad (2)$$

RESULTS AND DISCUSSION

***Spirobranchus* spp.**

Operculum

Morphological characteristics were described for all *Spirobranchus* species found in the waters of Beurawang (n=566), with 291 individuals at a depth of 3 m and 275 individuals at a depth of 7 m. All *Spirobranchus* worms have two spines located at the front of the operculum, with some having secondary spines (Willette et al. 2015). Species *S. gaymardi* is characterized by two small short spines that widen and blunt at the tip, often with short basal teeth (tine) on each spine (Figure 7.F). In *S. corniculatus*, all operculum spines are small and have closely spaced teeth (tine), while *S. cruciger* has long horn-like spines, with branched and pointed tips at a distance, and a long and branched spine in the middle.

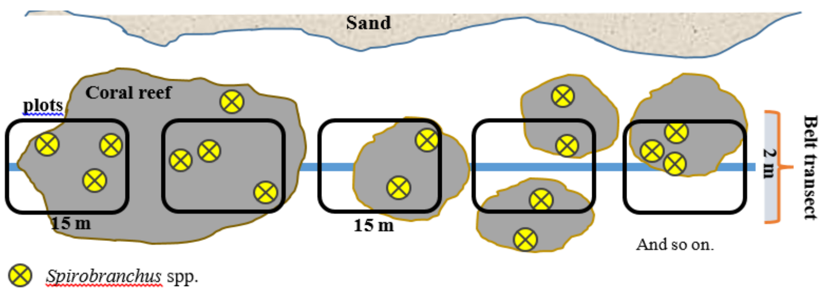

Figure 2. Schematic illustration of transects and plots (2 x 15 m^2) for observing *Spirobranchus* spp. using the Belt Transect method

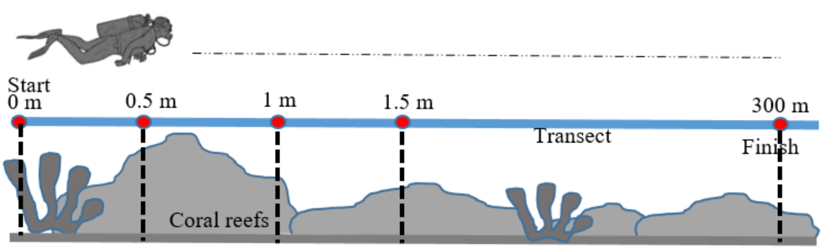

Figure 3. Sampling illustration for live corals and basic coral reef substrate by a PIT method

Tube

The tubes adhere to the coral surface and become embedded in the coral over time. The tubes are triangular-rounded in shape, with the inner part of the tube being white and some found to be pinkish-red. Observations indicate that in the juvenile phase, the tube opening is circular, while in the adolescent phase, the circular part of the tube opening develops a pointed orange structure (see arrow, Figure 5.D) with a pinkish-red ring, and in the adult phase, the entire circular part of the tube opening turns yellow/orange (Figure 5.B). Based on observations, the length of the tubes in the juvenile phase when attached to the coral surface ranges from 7 mm to 2 cm, with the diameter of the *Spirobranchus* tube opening ranging from 8-9 mm. This is consistent with the statement by Perry et al. (2018a) that the diameter of the tube opening reaches 9 mm, and the outer width up to 12 mm.

Radiolar crown

The arrangement of the radiola resembles a pair of cones consisting of two lobes. The research findings indicate that almost all adult worms have approximately 5-6 spiral turns in each lobe (Figure 7.C). The color of the radiolar varies, with the observed findings tending to have combinations of two colors such as black-white, brown-white, or maroon-yellow.

Abundance of *Spirobranchus*

The abundance of *Spirobranchus* in Beurawang Waters at two depths showed slightly different results and was found more frequently at a depth of 3 m. The abundance value at a depth of 3 m is 9.70 ind/m^2, while at a depth of 7 m, it is 9.17 ind/m^2 (Table 1, Figure 4). The average value for the number of *Spirobranchus* individuals per depth is 16.17 individuals (3 m) and 15.28 individuals (7 m).

Association of *Spirobranchus* spp. with coral conditions

The statistical results in the Crosstabulation table show that the Chi-Square Test requirements have been met because there are no data cells that contain zero (0) (Table 2), and none of the expected count values are < 5 (Table 3). Therefore, testing can continue. Based on the results of statistical analysis, there were 19 plots healthy corals with a low abundance of *Spirobranchus*. In contrast, 13 plots unhealthy corals with a high abundance of *Spirobranchus* were found. This illustrates that corals infested with Christmas tree worms tend to experience health problems.

From the Chi-square test results, a p-value or Asymp.Sig value of 0.00 was obtained. Using an alpha of 0.5, the p-value < 0.05 (Tables 3 and 4), thus it can be concluded that there is an influence of *Spirobranchus* spp. abundance on the condition of the coral reef ecosystem.

Table 1. Composition of *Spiroranchus* species in Beurawang Waters, Aceh Province, Indonesia

Spirobranchus	**Depth**		**Total**
	3 m	**7 m**	
S. gaymardi	117	105	222
S. corniculatus	70	59	129
S. cruciger	39	30	69
Undetected*	65	81	146
Total individuals	291	275	566
Abundance	9.70	9.17	

Note: * The operculum is covered by turf algae

Table 2. Crosstabulation of abundance of *Spirobranchus* and coral condition

			Coral condition		**Total**
			Healthy	**Unhealthy**	
Abudance of *Spirobranchus*	Low	Count	19	2	21
		Expected count	12.3	8.8	21
		% within abundance of *Spirobranchus*	90.5%	9.5%	100%
	High	Count	2	13	15
		Expected count	8.8	6.3	15
		% within abundance of *Spirobranchus*	13.3%	86.7%	100%
Total		Count	21	15	36
		Expected count	21.0	15.0	36.0
		% within Abundance of *Spirobranchus*	58.3%	41.7%	100%

Table 3. Chi-Square tests

	Value	**df**	**Asymptotic Sig. (2-sided)**	**Exact Sig. (2-sided)**	**Exact Sig. (1-sided)**
Pearson Chi-Square	21.424[a]	1	.000		
Continuity Correction[b]	18.367	1	.000		
Likelihood Ratio	23.913	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	20.829	1	.000		
N of Valid Cases	36				

Note: a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.25; b. Computed only for a 2x2 table

Table 4. Symmetric measures

		Value	**Approximate significance**
Nominal by Nominal	Contingency Coefficient	.611	.000
N of Valid Cases		36	

The research findings indicate severe damage in several coral colonies, with some still healthy but potentially vulnerable to damage, as depicted in Figure 5.A, where the coral surface condition is affected by the detachment of worm tubes from the coral. Tube detachment is presumed to occur due to initial attachment at closely spaced locations, resulting in overlapping as the tubes enlarge, causing unstable tubes to detach from the coral surface. This detachment results in scars that are feared to trigger the growth of turf algae, spreading extensively over the coral colony surface. This can be observed in areas where scars have appeared, leading to the growth of turf algae and crustose coralline algae. In Figure 5.B, coral conditions with scar marks from the in-and-out activity of the tubes are evident (see arrow). In some cases observed in the field, the scars appear white, while in others, they appear pinkish-red. These coral surface wounds can occur when *Spirobranchus* is still young, as these marine worms also engage in in-and-out activities from their tubes.

Observations reveal that some *Spirobranchus* living on coral surfaces are not encased by coral. As depicted in Figure 5.C, *Spirobranchus* still within calcareous tubes are attached to the coral but not covered by coral reef. If tube attachment is not secure, tubes may detach, leaving scars, as shown in Figure 5.A. In contrast, in Figure 5.D, juvenile Christmas tree worms are enveloped by new coral tissue. The growth of new coral that encases these *Spirobranchus* tubes still appears thin.

Physical conditions of water

The growth and development of coral ecosystems greatly influences environmental conditions, so water conditions are an important factor for coral reef health. The physical conditions of the water observed at the two depths showed values that were not much different (Table 5).

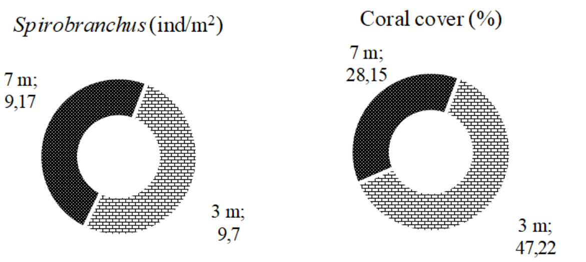

Figure 4. Composition of hard coral (%) and abundance of *Spirobranchus* spp. (ind/m^2)

Table 5. Physical condition of the water in Beurawang Waters, Aceh Province, Indonesia

Parameter	Depth	
	3 m	7 m
Temperature (°C)	33.3±0.57	32.3±1.15
Salinity (ppt)	33.3±1.15	39.3±1.15
pH	7.8±0.11	7.8±0.12
Visibility (m)	3±0	6.5±17.32
Flow velocity (m/s)	0.23±0.01	0.16±0.03

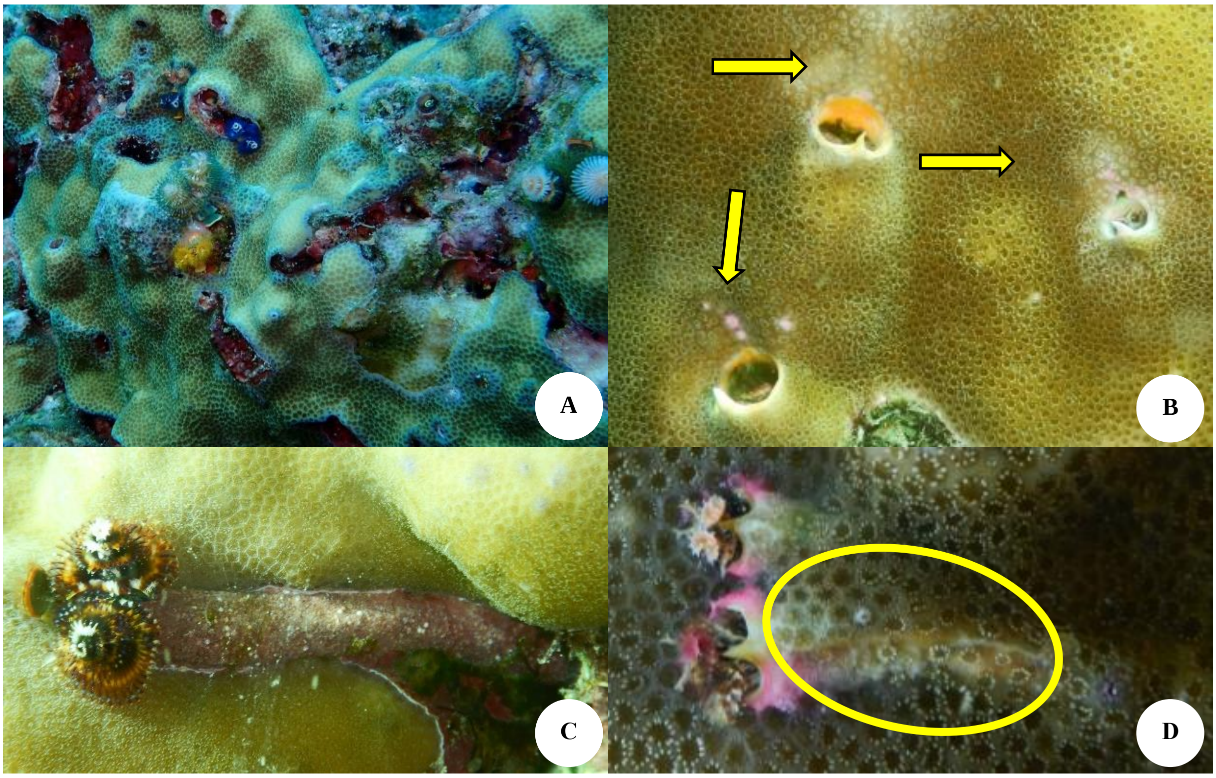

Figure 5. The condition of the coral inhabited by *Spirobranchus* spp.: A. Coral *Porites* sp. damaged, B. Wounds caused by erosion by the *Spirobranchus* operculum (see arrow), C. Adult *Spirobranchus* with calcareous tubes in visible condition, D. Young *Spirobranchus* with tubes covered by coral

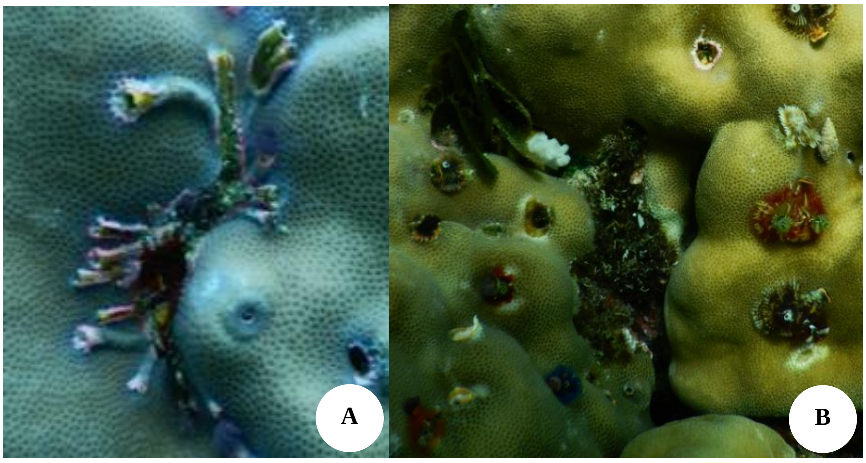

Figure 6. A. A group of young *Spirobranchus* attached to the same coral colony, B. Condition of coral reefs inhabited by a number of individuals of *Spirobranchus* spp.

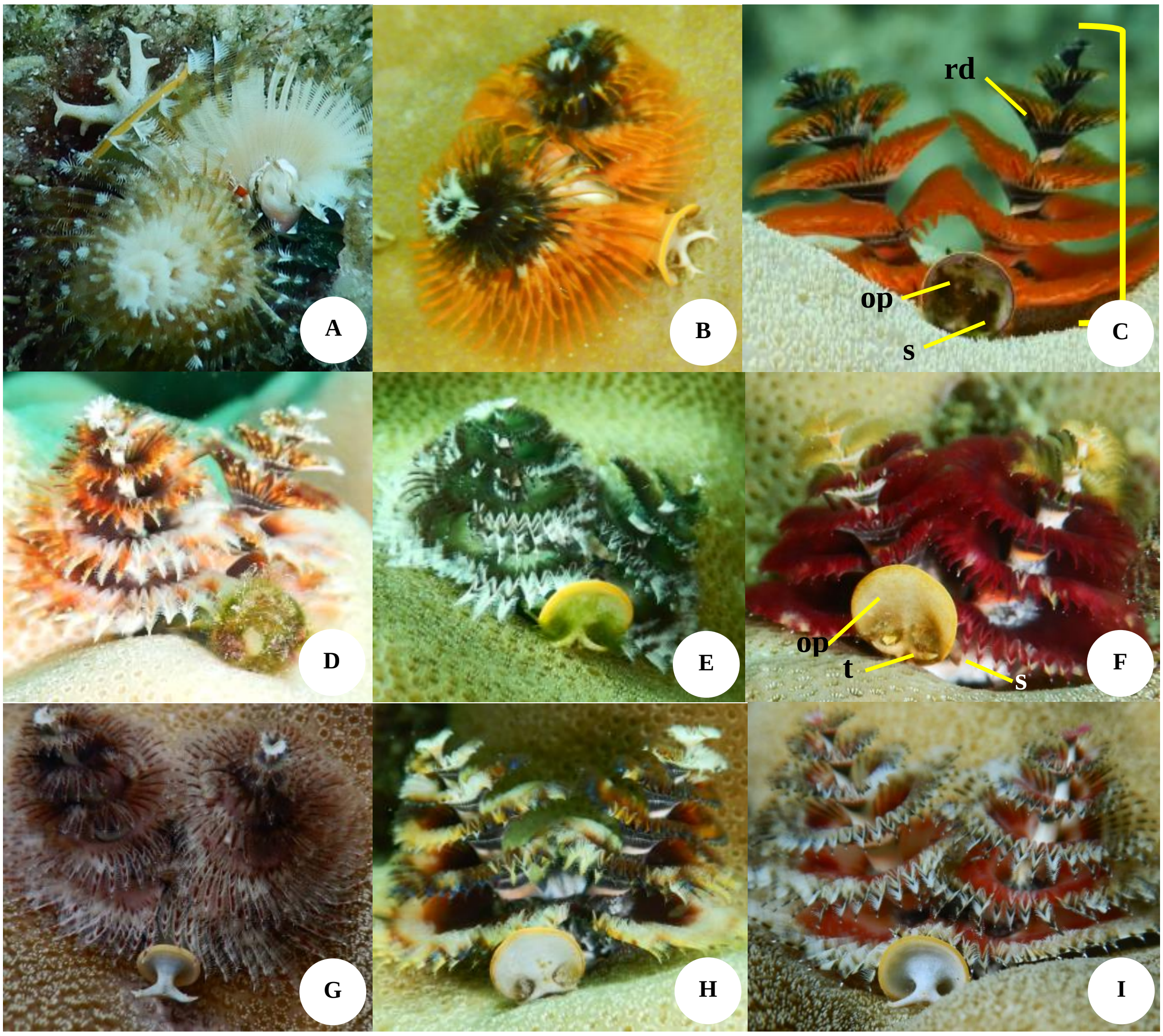

Figure 7. Several species of *Spirobranchus* were found in the Beurawang Waters, Aceh Province, Indonesia. A. The *S. corniculatus* (morphotype *cruciger*); B. The *S. corniculatus* (morphotype *corniculatus*); D. Not detected because the operculum is covered by turf algae; C, E-I. The *S. corniculatus* (morphotype *gaymardi*). Abbreviations: op: operculum; s: spine; t: tine; rd: radiole

Discussion

Spirobranchus found in the waters of Beurawang tend to be found in poor coral conditions, most of which are found in turf algae in the former *Spirobanchus* tube basins, as well as health problems in the form of pigmentation responses. Hoeksema et al. (2019a) stated that damage to coral caused by *Spirobranchus* may be difficult to heal; this is also clearly seen when the worm tubes cannot be covered by coral tissue or when the empty tubes are occupied by other organisms.

The initial attachment of *Spirobranchus* occurs when the larvae tend to attach to coral that is still healthy. As planktonic larvae, they settle on coral surfaces and start secreting a calcareous tube to be used as a dwelling (Hoeksema et al. 2020). After planktonic larvae settle on a reef, Christmas Tree Worms undergo drastic morphological and physiological changes. As a temporary residence, juveniles will produce mucus tubes to form and develop calcareous tubes. Field results show that young tube worms tend to be found in good coral conditions, and then over time, the calcareous tubes secreted by *Spirobranchus* will be covered by the host coral tissue. The limestone walls formed by coral polyps will thicken after a few years to form a reef with *Spirobranchus* tube, which will also continue to grow.

Petrocelly (2022) stated that after a *Spirobranchus* worm settles on a coral reef, other tubeworm larvae will most likely follow and settle on the same coral (Figure 6.A). Previous research also linked the similarity of the distribution of planktonic larvae with the distribution of adult Spirobranchus on host corals, so they tend to be found on the same reef. However, there are several coral locations with low *Spirobranchus* densities. This reflects the limited number of *Spirobranchus* that can be supported by the host coral before it disrupts the health of the coral, but most corals are unable to control the growth of the *Spirobranchus* that inhabit them.

The *Spirobranchus* tube worm has a high sensitivity to stimulation and movement, so if the diver makes active movements around this tube worm, the *Spirobranchus* will enter the tube (Figure 5.B). This is in accordance with the statement of Pezner et al. (2016) that *Spirobranchus*, which tends to live a sessile lifestyle, will limit itself from predator interference by hiding. When the area around the *Spirobranchus* becomes dark or the water pressure changes, the christmas tree worms use their operculum quickly to retract the spiral crown into their tube and hide until the danger has passed, so this hiding condition can interfere with their feeding and breathing activities if done for a long time. During observations, recording activities were carried out at a close distance of about one meter so that the *Spirobranchus* did not enter the tube.

Empty *Spirobranchus* tubes are occasionally inhabited by other biota. During observations, empty tubes tended to be inhabited by coral hermit crabs (*Paguritta* spp.), while the remaining ones remained vacant (without other organisms). The length of the tube in adult *Spirobranchus* worms can exceed the length of the worm's body, which is thought to be an effort to protect itself from predators. This is in accordance with the statement of Hoeksema et al. (2019b) that sometimes Christmas Tree Worms do not extend along the calcareous tubes formed by them; as a defense mechanism, if damage occurs to their host, the christmas tree worms can withdraw further into their burrows to ensure their survival.

Spirobranchus species have a variety of colors with varying patterns, a mixture of green, purple, white pigments (Perry et al. 2018a; Idris et al. 2022). According to research by Mursawal et al. (2021), in the waters of Lamteung Pulo Aceh, the *Spirobranchus* consisted of red, orange, blackish orange, yellow, maroon, and several other color patterns. This result is similar to the findings in Beurawang Waters, which have color patterns that, if sorted from Figures 6.A-6.H, include marigold, blackish orange, orange, whitish orange, blackish white, yellowish maroon, whitish brown, whitish black and whitish red. The observation results also show that differences in depth do not determine the color pattern of *Spirobranchus* because some of the same colors are also found at different depths.

Spirobranchus has a much shorter upper radiol lobe than the lower radiole lobe, which forms a pine/Christmas tree shape (Brandão and Brasil 2020). All adult *Spirobranchus* tube worms found have the same number of spiral radiole turns, namely around 5-6 turns (can be seen in Figure 7.C). Even though they have different color patterns, some *Spirobranchus* come from the same operculum shape. As particle-eating organisms, christmas tree worms depend on the availability of food particles scattered around them. They use radioles covered in sticky mucus to filter food particles from seawater. These food particles can be plankton, organic residue, or other small particles carried by ocean currents. In this filtering process, the christmas tree worm indirectly acts as a filtering agent, helping to maintain seawater quality by filtering floating organic particles.

Several species of *Spirobranchus* found in Beurawang Waters originate from species derived from *corniculatus* with different operculum morphotypes, namely *corniculatus*, *gaymardi*, and *cruciger*. Based on the operculum in *Spirobranchus*, it can be seen that the spine (s) type differ between the three morphotypes. The spine in morphotypes *corniculatus* looks like the letter 'U' (Figure 7.B), with tines on the left and right. Tines are small horn-shaped protrusions located on the secondary spinule. Observations indicate that several species possessing these tines tend to embed them into coralite of the coral. *Gaymardi* morphotype have a spine shaped like an inverted 'V' (Figure 7.C, 7.E-7.I), with tines at the bottom of the spine. Meanwhile, the spine in the cruciger morphotype is slightly towering with a visible secondary spine (Figure 7.A). In several cases in the field, the operculum was found to be covered by turf algae (Figure 7.D) so that the shape of the spine of the tube worm could not be seen. In terms of composition, the dominant *Spirobranchus* species found in waters are morphotype *gaymardi* with 222 individuals, followed by *corniculatus* with 129 individuals and *cruciger* with 69 individuals.

Observation results showed that several coral colonies inhabited by *Spirobranchus* left white scars due to erosion by the tube worm operculum. The process of going in and out of the operculum can injure the coral surface and cause pink or white lesions due to tissue loss. This is in accordance with the statement of Hoeksema et al. (2018) and Hoeksema et al. (2019b), that cases of coral damage by tube worms have been recorded in the waters of the Red Sea, which was caused by the process of the worms moving in and out of the tube, so that the operculum erodes the coral surface and causes wounds. The statistical results also show a significance value of 0.00 (p-value < 0.05), so it can be concluded that there is a relationship between the abundance of *Spirobranchus* and coral conditions. The increasing abundance of *Spirobranchus* that inhabit coral ecosystems means it is feared that corals will continue to experience health problems. The strength of the relationship between two variables can be seen based on the contingency coefficient value (Trismon et al. 2016). A relationship can be said to be 'very strong' if the value of the association > 0.80, ‘strong’ if the value is between 0.60-0.79, 'moderate' if the value is between 0.40-0.59, 'weak' if the value is between 0.20-0.39, and ‘very weak’ if the value is < 0.20 (Papageorgiou 2022). Referring to this range, the association between *Spirobranchus* and coral has a 'strong' relationship with a value of 0.611 (Table 4). The strength of the association between these two organisms indicates a mutualistic relationship, where *Spirobranchus* obtains a long-term residence on the coral reef while the coral benefits from improved water circulation facilitated by the fine hairs on *Spirobranchus'* branchial radioles. However, conversely, the coral also suffers negative consequences if a single coral colony measuring one meter is inhabited by 10-20 individual *Spirobranchus*, as seen in Figure 6.B. The presence of a large number of *Spirobranchus* individuals in a coral colony triggers damage such as the proliferation of turf algae, erosion of the coral surface, and the formation of depressions on the reef.

Spirobranchus is a unique group of marine annelids and is recorded in all marine habitats in the world, from the intertidal zone, coral reefs in neritic waters to the depths of ravines and cliffs (Nishi et al. 2022). The present research indicate that *Spirobranchus* is more commonly found at a depth of 3 m compared to 7 m, which is assumed to be related to the availability of coral substrate at the depth of 3 m having higher coverage compared to the depth of 7 m. This is consistent with the findings of Aldyza et al. (2022b) and Aldyza (2023), which stated that coral coverage in the waters of Beurawang at a depth of 7 m is very low (5.67%), with the rest being dominated by sand, and patches of dead coral covered by turf algae. The high percentage of sand substrate in the waters of Beurawang suggests that *Spirobranchus* cannot live on soft or sandy substrate, unlike other types of marine worms such as feather duster worms (Sabellidae) which can live in sandy substrat and ocean sediments (Bok et al. 2016).

Most of *Spirobranchus* live in association with hermatypic corals and rarely on artificial substrates. *Spirobranchus* was found to be associated with the massive coral genus *Porites* rather than the coral *Acroprora*. This condition can occur because the availability of coral colonies in Beurawang Waters mostly comes from the genus *Porites*, so *Spirobranchus* larvae choose a place according to the substrate available in that area. This is in accordance with the statement by Hoeksema et al. (2017) and Eagleson et al. (2023) that the distribution of Christmas Tree Worms includes waters in the Indian Ocean, Pacific Ocean, and Atlantic Ocean; they can be found in the waters of various countries such as Indonesia, the Philippines, and Australia. Although Christmas Tree Worms can be found in various regions, they exhibit a preference for certain types of coral, primarily being associated with corals from the families Acroporidae, Poritidae, and several other families (Hoeksema and ten Hove 2017; Perry et al. 2018b; van der Schoot and Hoeksema 2024). These corals provide ideal environmental conditions, such as a proper physical structure and adequate nutrient supply, that support the growth and survival of the Christmas Tree Worms.

Apart from *Porites*, several genera of coral found in the waters of Beurawang include *Favia*, *Favites*, *Montipora*, and *Heliopora,* whereas *Spirobranchus* was not found associated with these corals. Additionally, the Acropora group was not observed in the transect surveys. This case is similar to research by Masucci et al. (2019), who stated that the average coral cover in the Ryukyu Islands, southern Japan, was only around 7.2%, then branching corals from the genus *Acropora* were almost not found at all in observation transects. This condition is believed to be due to the bleaching phenomenon leaving behind massive corals such as *Porites* rather than branching corals such as *Acropora*. According to Idris et al. (2020), *Acropora* is one of the coral groups most vulnerable to disturbance or pressure, both natural and anthropogenic. This indicates that Porites is a genus with better resistance than genera with branching forms (Guest et al. 2016; Aldyza et al. 2022a,b). Even though *Porites* coral's resistance to temperature stress is said to be good, the increasingly abundant presence of *Spirobranchus* in a reef colony can have a negative impact on coral health and cause the coral to become more fragile and lead to excessive turf algae invasion around the reef. If the quality of the reef decreases, it is feared that the ecological condition of the sea will also be disturbed. This is in accordance with the statement of Afkar et al. (2023) that it is necessary to maintain the quality of the coral ecosystem because this ecosystem plays an important role as a protector against coastal erosion, as a habitat for marine biota to find food, a place to breed, a place to spawn, and as an excellent recycler of nutrients. Based on the conditions described, it is necessary to form new corals by carrying out a coral transplantation program as an effort to replace damaged coral fragments in the waters of Beurawang.

The results of in-situ measurements of the physical condition of the waters show that the Beurawang Waters are in unfavorable conditions for the growth and development of coral ecosystems. This is characterized by water temperatures ranging between 32.3-33.3°C. Zamani et al. (2016) stated that surface water temperature plays an important role in coral growth. In the inner coral tissue are Zooxanthellae, which help provide nutrients for the coral to speed up the process of forming limestone and coral color. Coral can grow well at water temperatures between 25-

30°C. When the marine environment changes or conditions do not match the normal range (sea water temperature exceeds 30ºC), the symbiont algae Zooxanthellae can produce substances that are toxic to coral tissue so that the coral becomes stressed and will expel the algae out of the coral tissue. This results in a loss of coral pigment volume (Bussapakorn et al. 2019). So, it is feared that high temperatures in Beurawang Waters could trigger coral bleaching again, although several coral genera can tolerate temperatures of 40°C in the short term (NOAA 2023).

Supriharyono (2007) stated that tropical sea salinity has an average value of 35 ppt and a range of between 34 and 36 ppt for fertile animal growth. The optimal salinity range that is good for coral growth is 25-30 ppt. If we refer to this range, it can be concluded that the salinity in Beurawang Waters is unfavorable, ranging between 33.3-39.3ppt. This range is beyond the optimal limit for coral growth. Several factors, including rainfall, the entry of fresh water into the sea, and the sun's intensity, can cause changes in salinity levels. If salinity changes drastically, coral ecosystems can experience bleaching (Dedi et al. 2017). However, some corals can survive at a salinity of 40 ppt (Guan et al. 2015; NOAA 2023). Even though the temperature and salinity conditions are unfavorable, the pH of Beurawang Waters is still within the tolerance range, namely 7.8. This value is in accordance with the quality standards for pH values according to Minister of Environment Decree No. 51 of 2004, which states that the optimal pH range is in the range of 7-8.5 (Ministry of Environment 2004). Badriana et al. (2021) stated that corals generally grow in an environment with a pH of 8.0-8.5. If the pH is below 7.6, coral reefs can experience damage due to a lack of calcium carbonate.

The current speed observed shows a range of 0.16-0.23 m/s. This value is not much different from the research results by Aldyza et al. (2022a), which states that the average current speed in Beurawang is 0.20 m/s. Referring to the ideal current speed range for coral growth by Paulangan et al. (2019) and Mardani et al. (2021), namely between 0.05 to 0.28 m/s, it can be concluded that the current speed conditions in the waters of Beurawang are in good condition for coral growth. Current flow is important in supporting the growth of coral ecosystems because currents can carry food and oxygen and can function in cleaning suspended particles that cover the coral surface. Aprilian et al. (2021) stated that sediment accumulation can disrupt the growth and development of coral ecosystems. Besides water currents, brightness is also important for coral growth because deep conditions with high light penetration can help Zooxanthellae found in coral tissue carry out photosynthesis. The brightness of Beurawang Waters ranges from 3 to 6.5 m, so it still supports the coral calcification process.

Overall, based on the results of observations, it can be concluded that the condition of the Beurawang Waters is not entirely good for the growth and development of coral ecosystems because high water temperature and salinity can cause corals to experience stress, thereby releasing Zooxanthellae, which are in coral body tissue (polyps), and giving pale/white color effect. This is in accordance with conditions in the field where it can be seen that some corals are experiencing partial bleaching (focal bleaching). However, the physical conditions of these waters do not appear to affect the growth of *Spirobranchus*, marked by the appearance of several young tube worms in several coral colonies and the large number of adult tube worms that 'bloom' on the reef surface. Uniquely, *Spirobranchus* worms are not found in coral colonies that have been exposed to thorough bleaching, it is suspected that *Spirobranchus* selects substrates that are in good condition as hosts for a long period of time in the future. Based on the field observations conducted, *Spirobranchus* spp. can be utilized as a bioindicator to predict the health condition of coral reef ecosystems in the future by assessing the early damages caused by each *Spirobranchus*. Thus, preventive measures can be taken by reducing the proliferation of these marine worms and constructing artificial reefs to replace damaged coral substrates in the waters of Beurawang.

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