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Species distribution and Abundance of Shipworms in the mangrove ecosystem along Pitogo Zamboanga Del Sur, Philippines

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Abstract

Shipworms are specialized bivalves found in brackish environments where productivity is high such as mangrove forests. They are adapted for burrowing into wood substrates, which they efficiently and rapidly decompose and consume. Nonetheless, the information given to the activity of shipworms in transporting nutrients from mangroves to the adjacent area is limited. Thus, in acquiring such information, we first investigated the distribution and abundance of shipworms in the mangrove area of Balabawan, Balong-Balong, and Liasan by collecting washed-up logs. The study lasted for three months from February to April 2020. A single species, *Teredo navalis*, was found colonizing driftwood. Mean densities (inds. cm^{-3}) of *Teredo navalis* found show highly no significant differences in mangrove habitat between the three sampling sites during February to April, as well as the interaction of months among sites. The results show that the activity of shipworm in burrowing driftwood logs is quite constant during the whole sampling period. Although variation in physico-chemical parameters was observed, only humidity shows a significant relationship between densities. Variations on humidity and rainfall determine shipworms' survival (e.g., increased air humidity and rainfall during the wet season). Nonetheless, driftwood logs disintegration data are necessary for this proposition.

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Introduction

Highly specialized bivalves of the family Teredenidae, Shipworms (locally called "tamilok") are obligate wood-borers that effectively break down and consume wood with the aid of intracellular cellulolytic and nitrogen-fixing symbionts (Distel *et al.,* 2002), except for some species that bore into mudstone, sediments, rock, and sea-grass rhizome. Shipworms exist in extensive wood substrates, which include mangroves driftwood, wooden maritime structures, submerge wood and woods that float (Lozouet and Plaziat, 2008; Distel *et al.*, 2016). It uses wood for food by digesting wood particles with the help of endo-symbiotic bacteria (Distel, 2003; Voight, 2015) and shelter through constructing tunnels with the file-like denticles on their shells. Nonetheless, even though shipworms are known to be wood borers, their capability in using wood as a source of food may differ among species (Turner, 1996). Throughout history, shipworms have caused a vast amount of damage to wooden structures in coastal areas. In fact, Turner (1996) mentioned the teredinids fossil records found that were believed to have arisen in Cretaceous time (65 million years ago). Even as far back as 412 B.C., the human was already using chemicals to fight the devastating activity done by shipworms (Castagna, 1973). Pliny, Ovid, Aristophanes and Homer acknowledge shipworms in their writings. Furthermore, Columbus lost his ships, the 'Capitana' and 'Santiago', during his voyage due to these organisms (Rayner, 1983). Even so, its lineage and status are still unknown in many areas. Shipworms are believed to be 65 species comprising of 14 genera existing across the globe, where genus *Teredo* is the most commonly acknowledged (Distel *et al.,* 2011). Its density may be limited due to the number of individuals fighting for space and food and by the availability of wood volume (Macintosh *et al.,* 2012-2014). Its geographical distribution is also limited with the following factors such as temperature, salinity (Borges *et al.,* 2014a-2014c; Pati *et al.,* 2014) and a suitable mechanism for dispersal due to their effects on the physiological and ecological behaviors of shipworms (Nair & Saraswathy, 1971). *Teredo navalis* is a long, worm-like organism with a reddish pale in color. Its typical mollusk appearance is lost because, unlike most bivalves that depend on its shell for protection. *T. navalis* has a small (up 2 cm long) helmet-like shell consisting of two valves that enclose only a small portion of the animal, which acts as a wood-boring instrument (Distel *et al.,* 2002; NIMPIS, 2002). Practically, *T. navalis* is undetectable from outside of wood, with the mollusk often only being detected when the damage they create is extensive (Lane, 1959). The volume of different species of genus *Teredo* can vary enormously. In the Philippines, shipworm has long been utilized as food by locals in communities near mangrove forests (Elam, 2009), specifically in the locality of Pitogo Zamboanga Del Sur where locals harvested *Teredo navalis* for commercial purposes. Locals in the area sold shipworm "tamilok" in a glass of about 2.5 grams with a price of php 50.00. Thus, there is a valid concern that overharvesting of this species for tourism purposes might disturb mangrove ecosystems in the province, particularly in areas frequented by visitors. Thus, there is a need for greater vigilance and advocacy in preserving mangrove areas and other marine resources. In this study, the researcher seeks increasingly sophisticated ways to understand how abiotic and biotic (e.g., human influence) interaction influences species' abundance of shipworms in the area, why this factor could greatly give impact on the abundance of an organism and what might be the effect of this organism to the mangrove ecosystem, as will be assessed in a three (3) months study that was carried out in 2020.

Objectives of the study

This study aims to assess the abundance of shipworm *Teredo navalis* in the mangrove area of Pitogo Zamboanga del Sur through the point transect method.

The specific objectives that would facilitate the achievement of this aim are:

1. To identify the species of Teredo navalis present in the area qualitatively;
2. To identify the number of logs colonized by *Teredo navalis*;

3. To determine the relative abundance of *Teredo navalis* between sites and months;

4. To determine the physico-chemical environment of the water such as water temperature, water transparency, total suspended solids, pH, Salinity, and DO of the area; and

5. To correlate the relative abundance of shipworm *Teredo navalis* with physico-chemical parameters.

Significance of the study

Shipworms contribute an ecological function to the mangrove ecosystem through assorting wood into finer organic materials which modify shallow marine and brackish environment (Gollasch and Nehring, 2006), that aid in the recycling of nutrients and lessen the amount of build-up wood debris wherein the borer exerts energy stored in suppress driftwood log. The tunneling activity of *T. navalis* generates habitat for other small organisms such as species of crustaceans that are known to reuse caves carved in the wood by *Teredo* (Iljin, 1992). In general, shipworm detritivorous action is extremely important in the mangroves ecosystem (Borges, 2007), where the production of wood biomass is high (Kohlmeyer *et al.,* 1995). Aside from their ecological role in the mangrove ecosystem, shipworm is of great economic value because of the fact that they are used for food and livelihood purposes by locals in communities near mangrove areas. Knowledge gathered in this study may be used to propose appropriate actions towards the improvement and conservation of biodiversity and sustainable development in the Pitogo mangrove forest.

Materials and methods

Study area

Pitogo is classified as a 5th class municipality located on the southernmost part of the province of Zamboanga Del Sur which lies in the Baganian Peninsula. The municipality of Pitogo has a total land area of 95.94 square kilometers or 37. 04 square miles which constitute 2.13% of Zamboanga Del Sur's total area with 15 barangays. Among this barangays, only three barangays were considered as the sampling site which is Balabawan (7°46'75" North, 123°30'53" East), Liasan (7°48'22" North, 123°29'81" East), and Balong-Balong (7°50'48" North, 123°30'59" East), Pitogo Zamboanga Del Sur (PSA) (Fig. 1).

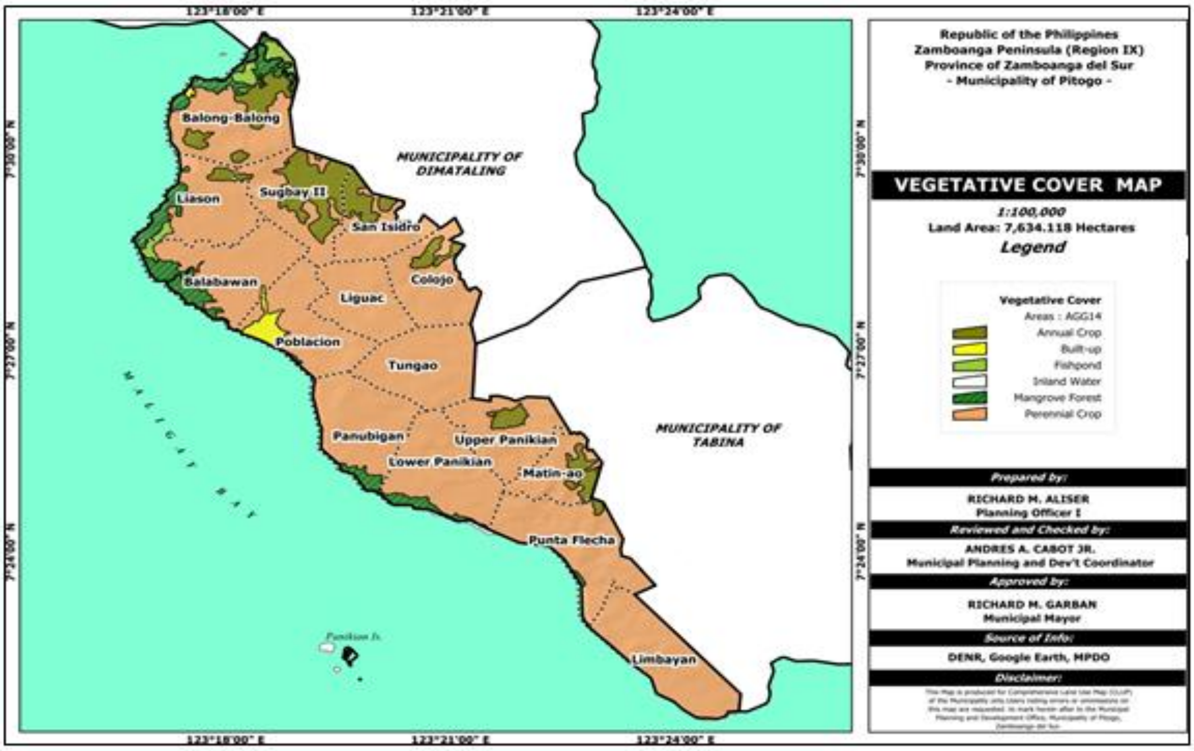

Fig. 1. Map of the sampling stations in Pitogo Zamboanga Del Sur, Philippines.

Sampling station: Using a GEOCAM app., a total of 9 sampling stations were established in the study area (Table 1).

Study period: Shipworm collection was done once a month for a period of three (3) months covering the months of February to April 2020 (Table 2).

Collection and preservation of shipworm samples

A fifty (50) meters transect line laid horizontally during low tide along with areas in mangrove forest. Logs found were collected and numbered to avoid baffling. Signs of shipworm inhabitation would be bore holes and calcareous (white, chalk-like) lining.

Driftwood logs collected were opened using an axe, a hammer and a wood chisel. Shipworms found were then released gently using forceps to avoid damage to the organism.

For microscopy, samples were soaked overnight at 4°C in a 4% paraformaldehyde in phosphate-buffered saline (PBS, 10 mM Na2HPO4, 2.7 mM KCl, 140 mM NaCl, pH 7.4). Afterward, samples were then transferred to 70% ethanol at a temperature of -20°C.

Laboratory analysis

The formula $v=\pi.r^2.h$ was used in calculating the volume of each log collected, where *r* corresponds to radius and *h* corresponds to the length. A total number of individuals found colonizing driftwood logs were counted and the density obtained was expressed as the number of individuals per cm^3. Species found were identified based on its appearance observed in a stereomicroscope, using the guide of Turner (1966, 1971) in identifying and illustrating shipworms.

Physico-chemical parameters

Temperature: Air and water temperature were determined using a mercury thermometer. The half portion of the thermometer was immersed into the water for one minute in order to get the water temperature (Hackettstown, 2014). For the air temperature, the thermometer was exposed to the air for one minute (Fondriest Staff, 2010). Total suspended solids: TSS was measured using the gravitational filtration method. One liter of surface water was collected.

The collected one-liter water sample was then poured into a filter paper previously oven-dried and weighed. After filtration, the filter paper was oven dried for 24 hours at 100°C. After the allotted time, the oven-dried paper was weighed. The total suspended solids were calculated by subtracting the filter paperweight before the samples were poured with the filter paperweight that was oven-dry after the samples were poured.

The difference of the filter paperweight before filtration and after oven drying corresponds to the total suspended solids and will be expressed as g/li (Murphy, 2007). Total dissolved solids: TDS meters were used in determining the" *in situ*" of the combined inorganic and organic substances dissolved in water (Yida, 2020).

pH: The determination of the "*in situ*" hydrogen ion (H^+) concentration of the water was made through the use of the Eutech pH meter (Thermo Scientific).

Salinity: In obtaining the "*in situ*" salinity of the water, and Atago hand refractometer was used (Ishika, 2017).

Dissolved Oxygen: DO meters were used in determining the "*in situ*" dissolved oxygen content of the water (Hakanson, 2005).

Statistical analysis

Chi-square (χ^2) was used to test the relationship between the presence and absence of shipworms and the driftwood log size (Zar, 1999). In determining the differences in the mean density of the colonized logs, a two-way analysis of variance (ANOVA) was also used. The relationship between physico-chemical measures and density was analyzed using Spearman Rank correlation. A critical level of significance $\alpha=0.05$ was used in all the analyses (Underwood, 1997).

Results and discussion

Throughout the study, only one species of shipworm, *Teredo navalis* (Linnaeus, 1758), was found colonizing in logs collected in the area. A total of 39 logs was examined, but only 26 (66.67%) contained *Teredo navalis,* with a total of 111 specimens. Images of *Teredo navalis* with its corresponding external parts (Fig. 2). No substantial relationship was observed with regards to the presence or absence of shipworms and sites. Total number of logs found are of the same count in each sites (χ^2 = 2.537, d.f.= 2, p>0.281) at p<0.05 (Table 2). Balabawan consists of 19 total logs, 13 total logs for Balong-Balong, whereas Liasan has a total of 7 logs (Table 3). Between months, no difference resulted in the overall frequency of the month of February to April.

Table 1. Geographical locations of shipworm *Teredo navalis* in Balabawan, Balong-Balong, and Liasan sampling areas.

Sampling stations	Station no.	Coordinates
BALABAWAN		
	1	7°27'53"N, 123°18'42"E
	2	7°28'52"N, 123°17'42"E
	3	7°28'6"N, 123°17'50"E
BALONG-BALONG		
	1	7°30'47"N, 123°17'54"E
	2	7°30'51"N, 123°17'53"E
	3	7°30'51"N, 123°17'55"E
LIASAN		
	1	7°29'2"N, 123°17'26"E
	2	7°28'59"N, 123°17'29"E
	3	7°29'3"N, 123°17'28"E

Turner (1996) mentioned that wood is requisite in order for shipworms to establish populations. Wood such as mangrove wood is more suitable for shipworm species to penetrate (Leonel *et al.*, 2002, 2006). However, moisture content, permeability and microbial coating formation of wood are also considered in colonizing ability of shipworms to wood (Nair and Saraswathy, 1971).

Table 2. The number of colonized and non-colonized mangrove driftwood logs by site and its expected frequencies from Chi-square tests (given in parenthesis).

Sites	Colonized	Non-colonized
Balabawan	15 (12.7)	4 (6.33)
Balong-Balong	7 (8.67)	6 (4.33)
Liasan	4 (4.67)	3 (2.33)

According to Nair and Saraswathy (1971) and Turner (1976), there are species of tree that contain a higher amount of chemical content, especially trees where the bark is present that might cause shipworm larvae to die. Nonetheless, a study conducted by Lopes and Narchi (1997) observed that no shipworms population that settled using artificial collectors made of pine, while using collectors made of native mangrove wood had observed greater settlement of shipworms. Only one species, *T.* navalis was found colonizing in collected mangrove driftwood log.

This result contrasts with the observation that pieces of wood in the mangrove forest are always colonized by shipworms, predominantly *T. navalis*. It may be due that much of this driftwood is exported from the mangrove before shipworms are able to colonize it (Krause and Glaser, 2003).

Table 3. The number of logs found in three sampling sites from February to April 2020. A total of 39 logs were collected.

	Months		
Sites	February	March	April
Balabawan	8	6	5
Balong-Balong	5	3	5
Liasan	3	1	3

Species abundance of Shipworms in Balabawan, Balong-Balong, and Liasan

Teredo navalis density observed in colonized logs collected obtained an overall mean of 0.01132795 cm^{-3}, which varies between 0.0005738066 cm^{-3} and 0.0855848753 cm^{-3}. Mean density with regards to months showed a significant difference (Table 4; February: 0.0855848753±0.000759678 cm^{-3}, March: 0.0005738066±0 cm^{-3}, April: 0.0010717603±0.0022804919 cm^{-3}). Between sites, the density of shipworms also shows no significant differences (Table 4). The mean density in Balabawan (0.0855848753±0.002081056 cm^{-3}) was not significantly different in Balong-Balong (0.004444892±0.0005738066 cm^{-3}) and Liasan (0.0022804919±0 cm^{-3}). Interaction between months and sites was not significant (Table 4, Fig. 3). Density was highest in February but decreased during April. Shipworm densities were lowest in March (Fig. 4).

Physico-chemical environment of the different sampling stations of Balabawan, Balong-Balong and Liasan

Variations in the physico-chemical parameters between months of the three sampling sites located in Pitogo Zamboanga Del Sur were shown in Table 5. As shown, mean water temperature ranged from 25.4 ℃ to 30.6 ℃ in Balabawan, 28 ℃ to 34.6 ℃ in Balong-Balong, and in Liasan is at 27 ℃ to 30 ℃. While air temperature in Balabawan measured 25.8℃ to 29.5℃, Balong-Balong measured 28.8℃ to 31.4℃, and Liasan measured 26℃ to 29.6℃.

Table 4. Summary on the effects of months and sites on the mean density of *Teredo navalis* in driftwood log found in three sampling sites (ANOVA).

Effects	*SS*	*df*	*MS*	*F*	*P-values*
Months (M)	0.000548	2	0.000274	1.539902	0.241353
Sites (S)	0.000558	2	0.000279	1.568721	0.235494
Interaction (M:S)	0.000978	4	0.000244	1.374657	0.282013
Error	0.0032	18	0.000178		

In terms of pH readings, it showed a minimum of 7.22 and a maximum of 8.38 in all sampling areas. PH is dictated by the combined effects of respiration, decay, and photosynthesis. Many biological activities can occur only in measurable range; thus it is important to measure pH because any alteration beyond the acceptable range could be lethal to organisms (Tassaduque *et al.,* 2003). Based on salinity values observed, Balabawan ranged from 10 to 35.9 ppt., 25.8 to 37.8 ppt was noted in Balong-Balong, while Liasan measured between 29.6 to 36 ppt.

Table 5. Physico-chemical profile of the three sampling areas during February to April 2020.

Physico-chemical parameters	February			March			April		
	1	2	3	1	2	3	1	2	3
Humidity (%)	±83.8	±79.2	±83.8	±72.6	±81.8	±80.2	±90.3	±88.2	±87.8
Temperatrure (℃)									
water	±25.9	±26.8	±28.5	±29.1	±25.2	±26.5	±29.1	±33.8	±30.5
air	±28.5	±29.2	±30.2	±29.3	±31.1	±29.4	±29.3	±31.3	±29.8
Dissolve Oxygen	±10	±25.8	±29.6	±13.6	±37.8	±34.6	±35.9	±36	±31.2
Salinity	±27.7	±31.1	±26.8	±9.9	±30	±27.8	±22.1	±29.5	±28.6
pH	±6.8	±7.6	±7.5	±7.4	±7.5	±7.6	±7.1	±7.0	±6.7
TDS	±520	±644	±510	±443	±365	±452	±443	±452	±510
TSS	±0.23	±0.10	±0.15	±0.11	±0.29	±0.16	±0.17	±0.13	±0.31

Note: 1-Balabawan; 2- Balong-Balong; 3- Liasan.

These salinity values depend on the degree of water exchange and the mixture of both saline and freshwaters (Uy *et al.,* 2006). Dissolved oxygen was also determined, the maximum dissolved oxygen concentration was found in Liasan. This might be due to the presence of atmospheric oxygen as a result of wave action (acquiring a maximum of 12 ppm) and fish ponds available in the area.

Table 6. Relationship between the density (inbds. per cm^{-3}) of *Teredo navalis* and their physico-chemical profile. Statistical significance levels (%) are given in parenthesis.

Physico-chemical parameters	*P values*	R_s	Remarks
Humidity	0.05 (95%)	- 0.7	*Significant*
Dissolved oxygen	>0.50(below 50%)	- 0.1	*Not significant*
Salinity	>50 (below 50%)	0.2333	*Not significant*
pH	0.20 (80%)	0.65	*Not significant*
TDS	>0.50(below 50%)	0.2667	
TSS	0.50 (50%)	- 0.333	*Not significant*
Temperature: Water	>0.50(below 50%)	- 0.2333	*Not significant*
Air	0	0	*Not significant*

Note: Analysis is based on Spearman rank Correlation; not significant means p-value > 0.05.

According to Duxbury (1996), cultured fishes use up the oxygen faster than the slow circulation of water can replace it; thus competition exists with regards to the oxygen of the water to the other organisms residing in the area.

The water solution available in all sampling areas was relatively in a good water quality environment favorable for organism productivity ranging from 365 to 520 mg/l. Somehow the levels of dissolved solids found in the area were closed to the freshwater value (less than 1,000 mg/L) (Hogan *et al.,* 1973) because accordingly, Balabawan, Balong-Balong, and Liasan have this spring flowing towards the areas. Contained dissolved minerals in water differ in different areas.

Areas with 200 mg/L are considered good and 100 mg/L are considered excellent. Thus, alteration in the amount of dissolved solids in water could promote mortality rate to organisms because TDS below this level corresponds to lower pH, which tends to be acidic. Further, higher than 400 mg/L of contained dissolved solid can make the water un-drinkable (Lawrence, 2020). Suspended solids observed in the area shown in moderately low level. This suggests that there was a low quantity of suspended materials or particles from erosion-prone areas, effluents of domestic sewage, and scouring of substratum during periods of tidal current velocities (Uy *et al*., 2006).

The amount of water vapour present in the air in all the sampling areas was recorded in percent during three months of sampling. Balabawan shows an average humidity ranging from 72.6 to 81.8%, while Balong-Balong had 58.2 to 81.7% and Liasan had 70 to 82.4%, which indicates the likelihood for precipitation, dew, or fog present during the study.

It reveals that there is a significant relationship between the density (inds. cm^3) and humidity (*p*-0.05). This entails that these physico-chemical parameters are associated with the density observed in the organism. Thus, the null hypothesis of no significant relationship between humidity and density was rejected (Table 6).

According to Lane (1959) and Iljin (1992), *T. navalis* survival depends on the humidity conditions of an area. *T. navalis* inside wood of more than 25-27 days that is not absorbed in water could still survive.

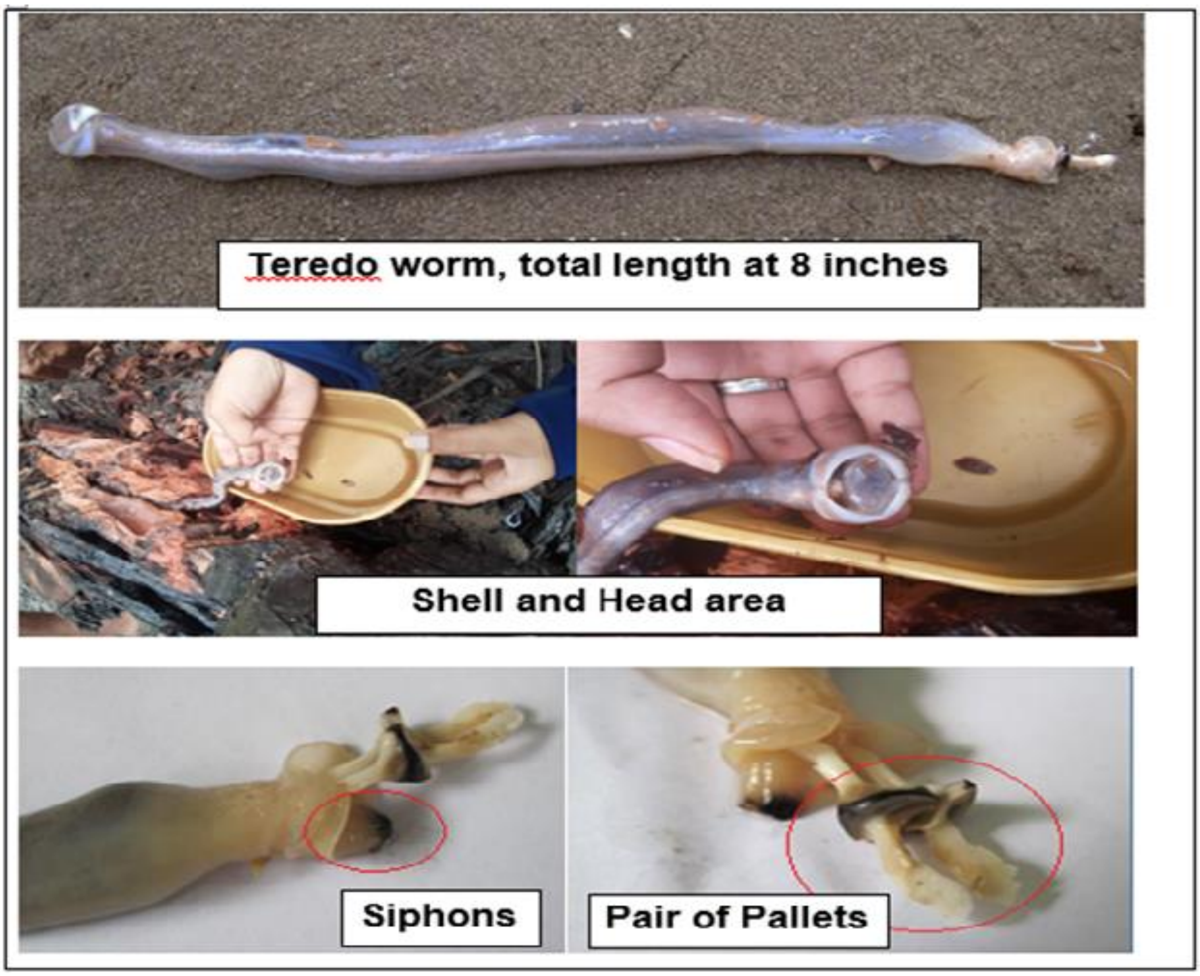

Fig. 2. Images of shipworm *Teredo navalis* showing its parts observed in the sampling sites.

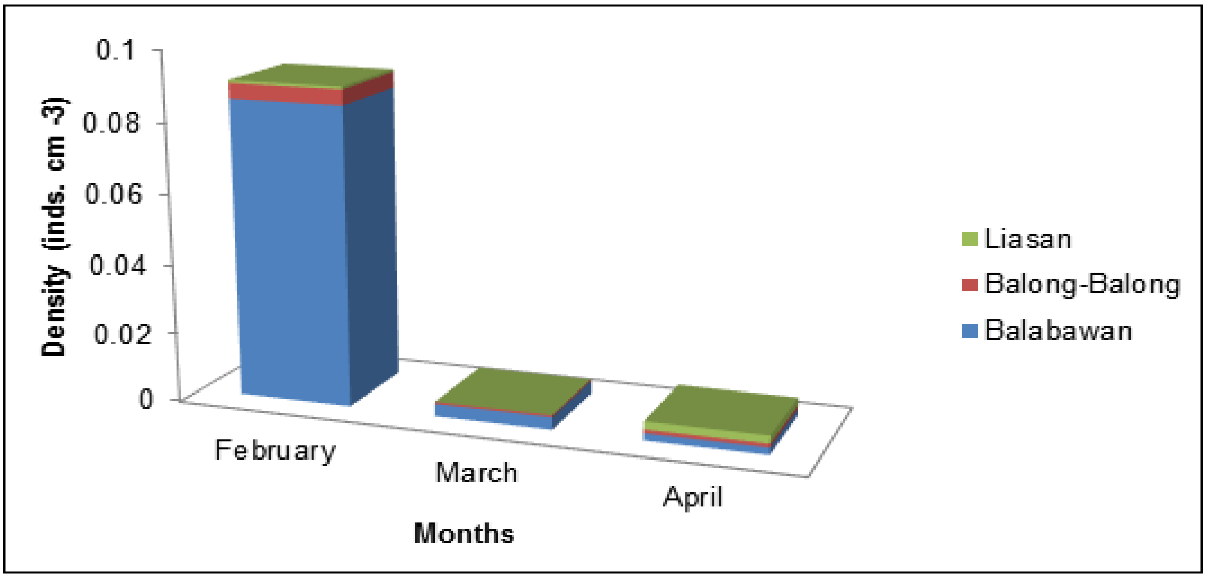

Fig. 3. Density (inds. per cm^{-3}) variation of *Teredo navalis* in three sampling areas during the February to April 2020 sampling period.

Further, shipworm density was directly proportional with humidity and precipitation; thus, an increase in humidity and precipitation led to an increase in shipworms density as well as a higher rate of survival in logs out of the water. However, physico-chemical such as dissolved oxygen, salinity, pH, TSS, and temperatures show no significant relationship, which entails that factors mentioned are not associated to the density of an organism (Table 6). Thus, the null hypothesis of no significant relationship between dissolved oxygen, salinity, pH, TSS, and temperatures and density was not rejected.

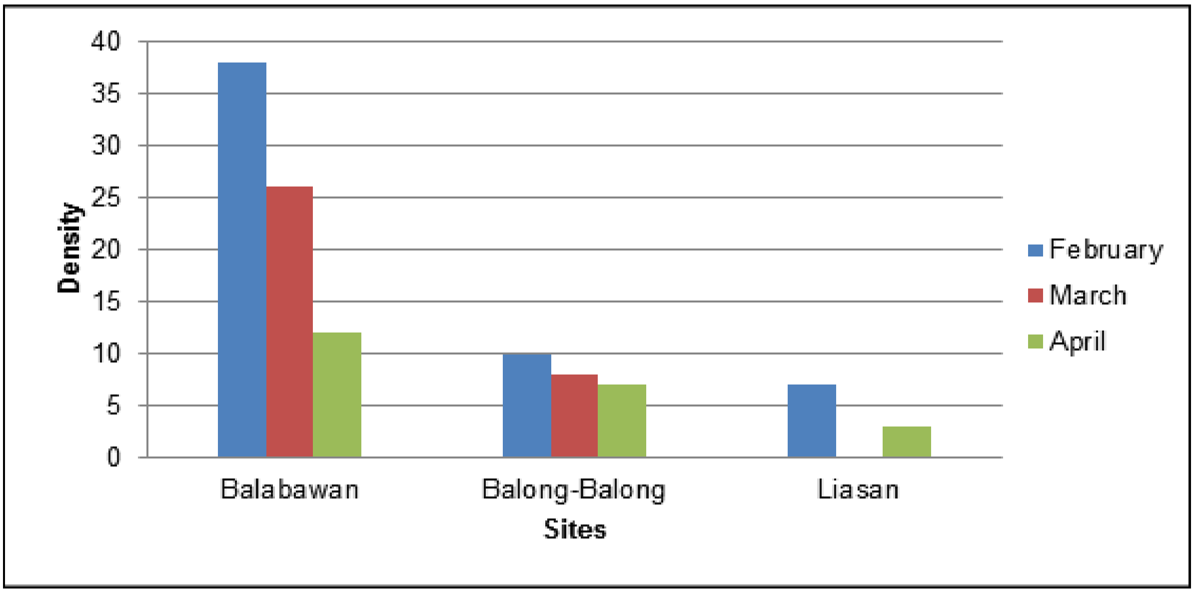

Fig. 4. Average abundance of *Teredo navalis* at all sampling sites in Pitogo Zamboanga Del Sur.

In contrast, although preferring rather brackish habitats, shipworm *T. navalis* in temperatures from 1-30°C and salinity from 7 to 40 ppt where 10-35 ppt is considered optimal can still survive. Hence, Roch (1932) and Nehring (2006) regarded *T. navalis* as a eurythermic and euryhaline type of organism. However, there are limits (upper and lower) of the proposed salinity that might substantially affect the organism's life cycle, therefore, restraining its distribution. With regards to its settlement, the change in the planktonic food supply, temperature, and or salinity may contribute to the delay or stop the development process of the free-swimming larvae and may therefore be unable to enter the submerged wood (Turner and Johnson, 1971; Nair and Saraswathy, 1971; Mann and Gallager, 1984a).

Conclusions and recommendations

In conclusion, the study shows that Pitogo Zamboanga Del Sur was abundant in terms of settlement of shipworms (*Teredo navalis).* It preferred environmental parameters at low levels. *Teredo navalis* in the Municipality of Pitogo has probably been documented for the very first time. Results can be used as baseline data for the abundance of shipworms that could lead to insights into the current impacts in the area.

The following are further recommended by the researcher:

1. Investigate the spatial distribution of shipworm communities employed in the area. A random sampling at the maximum number of logs is more comprehensive.
2. Examine the seasonal species abundance and distribution of shipworm communities through a random sampling method.
3. Determine the seasonal variation of the shipworm in monsoonal sampling and transitional sampling.

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