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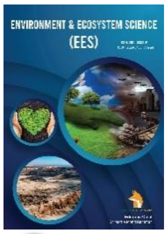

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RESEARCH ARTICLE

EFFECTS OF FOREST FLOOR ENVIRONMENTAL FACTORS ON THE SPATIAL DISTRIBUTION PATTERNS OF *POLYMESODA SPP*. IN THE MANGROVE FOREST OF IRIOMOTE ISLAND, JAPAN

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ABSTRACT

Polymesoda spp., which represent bivalves in the mangrove ecosystem, inhabit the mangrove forests of the Indo-Pacific region. They are edible bivalves consumed by inhabitants located around the mangrove forests in the region. The bivalves also have a cultural significance because their shells are used for religious ceremonies on the Yaeyama Islands in Japan. However, detailed studies of these bivalves is scarce and their biology is not well understood. We conducted this study in the mangrove forest along Urauchi River of Iriomote Island, Japan. The spatial distribution patterns of the bivalves and the forest floor environment were surveyed. We used 75 large (10m^2 quadrat) plots to survey plant species and above-ground root density, and small (1m^2 quadrat) plots to count the number of bivalves and measure median particle diameter, sediment temperature and Oxygen Reduction Potential (ORP) in each large plot. In addition, the relationships between these forest floor environmental factors and the spatial distribution patterns of the bivalves were analyzed. *Polymesoda* spp. was present in 34 plots. *Bruguiera gymnorhiza* was dominant in 79.4% of plots. A correlation between the distribution and median particle diameter and ORP and sediment temperature was not found. In 94% of the plots, the above-ground root density was over 50% of the large plot. The relationships between the spatial distribution patterns of the bivalves and plant species and the above-ground root density were revealed.

KEYWORDS

Mangrove bivalve, Special distribution pattern, Soil environment, Dominated mangrove plant species, Above-ground root

1. INTRODUCTION

Polymesoda genus belongs to the Cyrenidae family and has a wide distribution in the mangrove forests of the Indo-Pacific region (Solander,1786). It is a representative bivalve in the mangrove ecosystem. Especially *Polymesoda erosa* (Solander,1786) and *Polymesoda expansa* (Mousson,1849) are widely found in this region. Aswanii and Wiant, Clemente, Flores, Clemente and Ingole, Dolorosa and Dangan-Galon, and Carter described that these bivalves are consumed by inhabitants located around the mangrove forests of the Indo-Pacific region, the Solomon Islands and the Philippines (Shankar and Weiant, 2014; Clemente, 2007; Flores, 2009; Clemente and Ingole, 2011; Dolorosa and Galon, 2014; Carter, 2014). According to an archaeological survey on the islands of Indonesia, the shells date back to the Holocene (Spriggs et al., 2007). On the islands of Yaeyama in Japan, Miyagi reported that these species are used as food and the shells as tools for drawing water (Miyagi, 1982). W can also confirm that the shells are used as containers for the “liquor of God” on Iriomote Island. These species serve not only as an important food resource but the shells also as culturally significant objects. However, there are few studies of the biology of these species. We have investigated their distribution pattern in a mangrove forest. A group researchers asserted that *Geloina (Polymesoda) erosa* were often found on the forest floor and in the surface layer of the soil (Fukuoka et al., 2010). We considered that the soil condition affected the distribution of these species and consequently decided to investigate the soil condition.

In the field, we realized that these bivalves are not randomly located, but are distributed predominantly in the mangrove forest. Mangrove forests have a band structure of clear zonation by dominant mangrove species from the seaward area to the landward area (Figure 1). The difference of duration of tidal inundation and salinity tolerance determine the dominant species (Watson, 1928; Macnae, 1968). Semeniuk describes that soil composition and changes in topography also affect the structure (Semeniuk, 1980; Semeniuk, 1983). Additionally, certain species of mangrove have above-ground roots. In mangrove forests, there are many variations of the forest floor. In one place, there may be no above-ground roots, but in another location, there may be a high density of above-ground roots on the forest floor. The bivalves live around these mangrove roots (Morton, 1975). We focused on the particular features of zonation by dominant species and above-ground roots. We hypothesized there were relationships between the dominant mangrove species and the above-ground root density, and the distribution of the bivalves. In this study, we carried out an investigation to verify these hypotheses in addition to the investigation of the soil condition.

These bivalves have existed both as a means of food and have also been part of the traditional culture around the mangrove forests for a considerable period of time. These bivalves have existed both as a means of food and have also been part of the traditional culture around the mangrove forests for a considerable period of time. However, there is little known about them and we believe our investigation will contribute to accumulated information for resource management.

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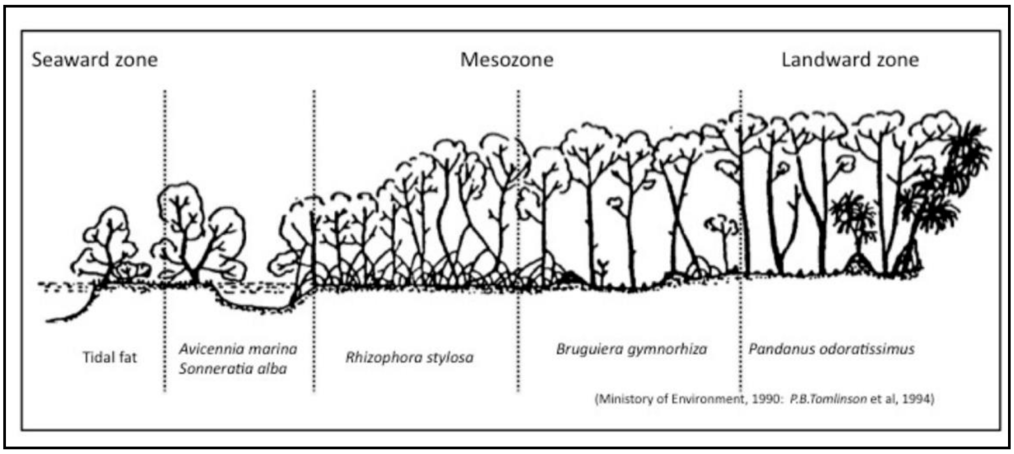

Figure 1: The Zonation of a Mangrove F+orest

2. Materials and Methods

2.1 Survey Area

We conducted the investigation in the mangrove forest along the Urauchi River on Iriomote Island (24°17' N and 123°52'E) in daytime during low tide in September and December, 2011. This island belongs to the Okinawa Prefecture, Japan and its mangrove forests are protected by forest law (Figure 2 and 3). The Urauchi River is about 18km long and is the longest river in the prefecture. The investigation site was set in a mangrove forest located at the river mouth. This mangrove forest contains five mangrove species (*Rhizohora stylosa*, *Bruguiera gymnohiza*, *Kandelia obovata*, *Lumnitzera racemosa*, *Pandanus odoratissimus* and *P. erosa* and *P. expansa)*.

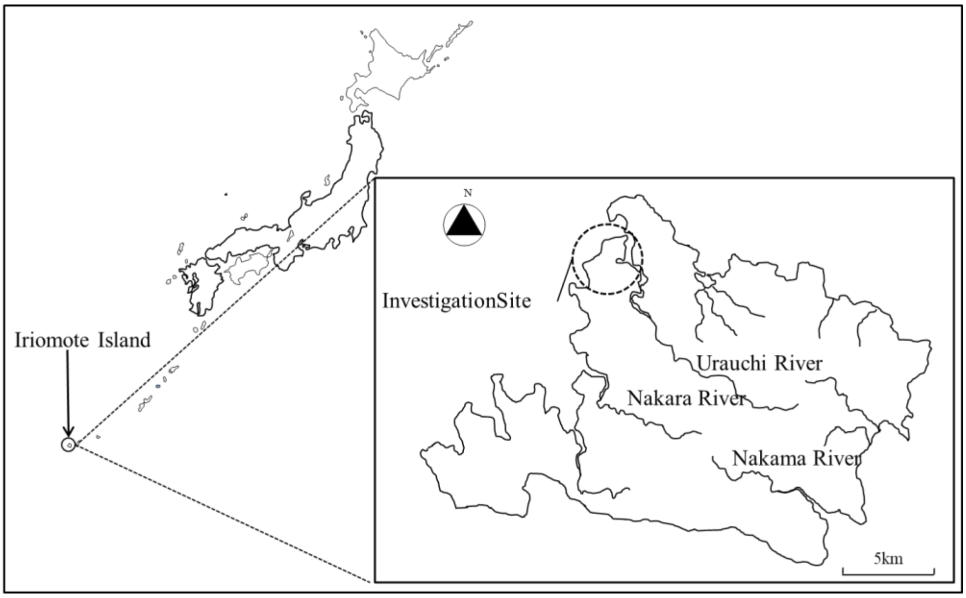

Figure 2: Map of Iriomote Island

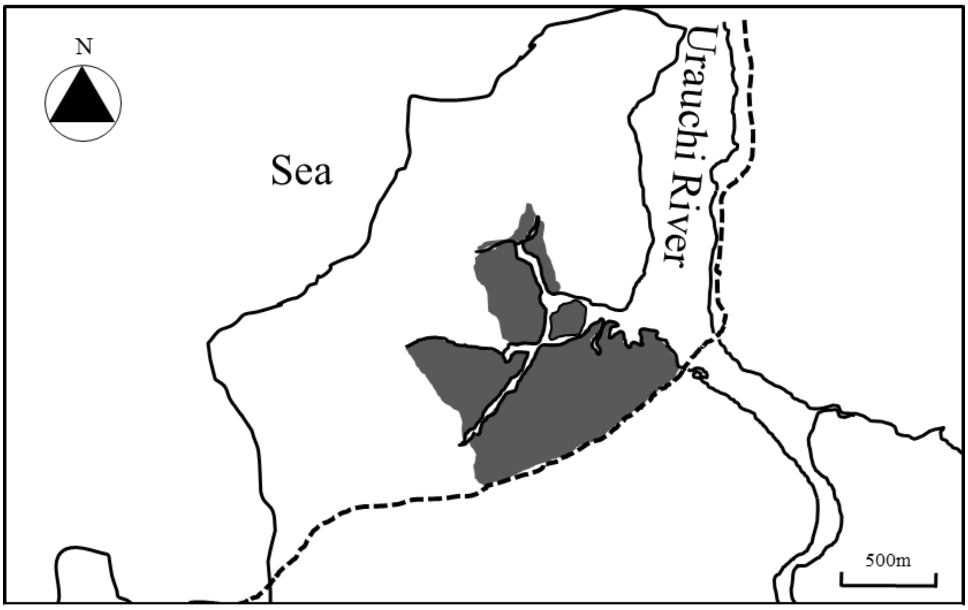

Figure 3: Investigation Site

2.2 Survey Objects

In this study we treat these bivalves as *Polymesoda* spp. without distinction of species. Morton mentioned that it was difficult to morphologically clearly distinguish *P.erosa* from *P.expansa* (Morton, 1984). An accurate method of morphological distinction of these two species in the field has not yet been established.

2.3 Survey Point Settings

We set seventy-five survey points in the forest randomly. At all points, two varieties of quadrat were created: the large ones were ten square meters in area and the small ones were one square meter in area.

2.4 Data Collection and Analysis

2.4.1 In the Large Quadrats

In the large quadrats, we estimated the ratio of the first dominant species of mangrove and second dominant species, and the ratio of the density of above-ground roots on the forest floor. Mangrove forests are characterized by clear band zonation by plant succession. Each zone has a dominant species. In this study, we divided the mangrove forest into four zones and assigned numbers 1 to 4 (Figure 4). According to the ratio of dominant species, we arranged the numbers to each quadrat. In the same manner, we assigned numbers 1 to 4 (“1” was 0-25%, “2” was 25-50%, “3” was 50-75%, “4” was over 75%) to the ratio of above-ground root density (Figure 5 and Figure 6).

The mangrove species names replaced by the species inhabiting the investigation site based on Figure 1.

We investigated each quadrat and confirmed the presence or absence of bivalves. Where we were unable to find any, we recorded “absence (Plot No. A1, A2, A3,…)”, and where we found, we recorded “presence (Plot No. P1, P2,P3,…) ”.

2.4.2 In the small quadrats

In the small quadrats, the soil temperature and Oxidation-Reduction Potential (ORP) were measured at three points. Then, the soil temperatures and ORP data were averaged and used for analysis. The surface soil (0-10mm layer) was collected using an acrylic pipe sampler with an internal diameter of 50mm at three points in the quadrat. The soil samples were brought to the laboratory and used for analysis of the particle size distribution of the soil by SIMADZU SLAD-3100. After this analysis, the median particle diameters were calculated. When we removed a 150mm layer of soil from of one square mater and bivalves were discovered within this layer, the shell length, shell width and shell height were measured. If no bivalves were found, we created a second small quadrat and performed the same excavation process and did this until bivalves were found.

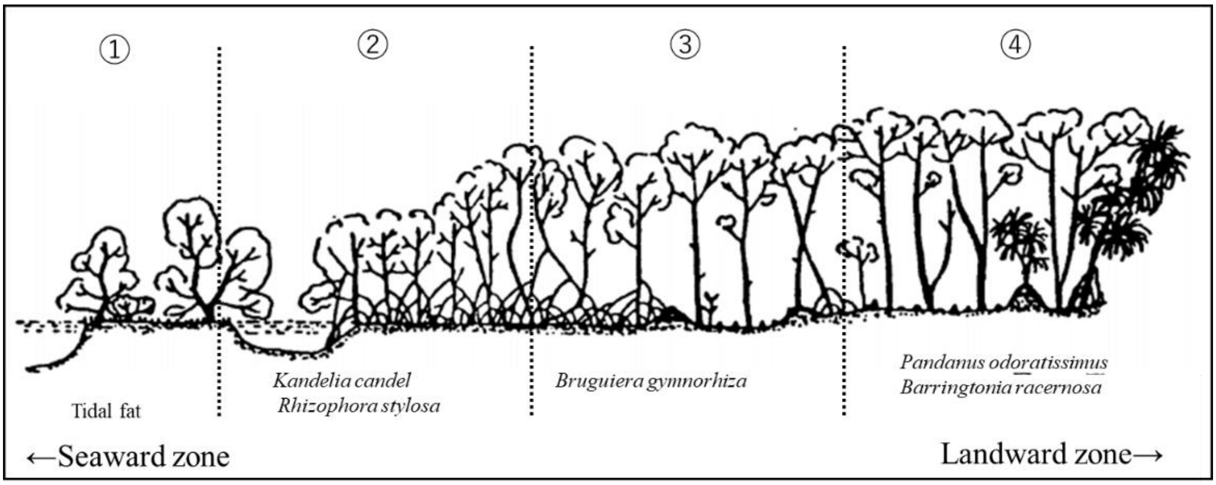

Figure 4: The Rank Numbers Assigned to Each Zone by the Dominant Mangrove Species

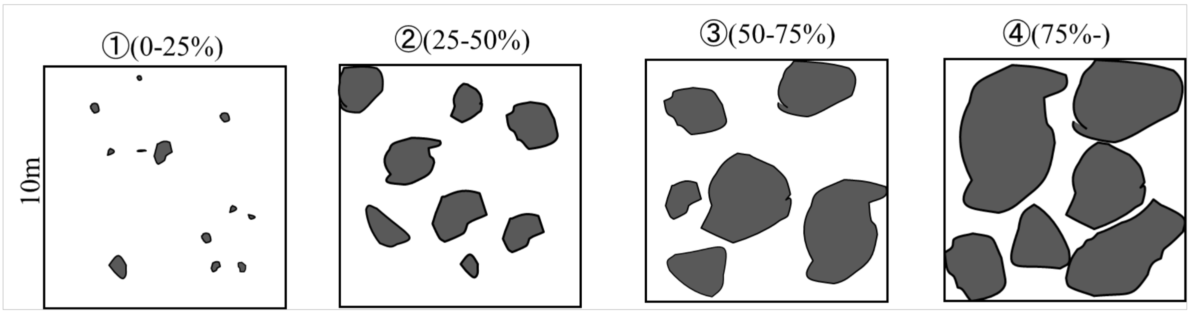

Figure 5: The Ratio of the Above-Ground Root Density on the Forest Floor Gray Parts are Mangrove Above-Ground Roots and White Parts are Vacant

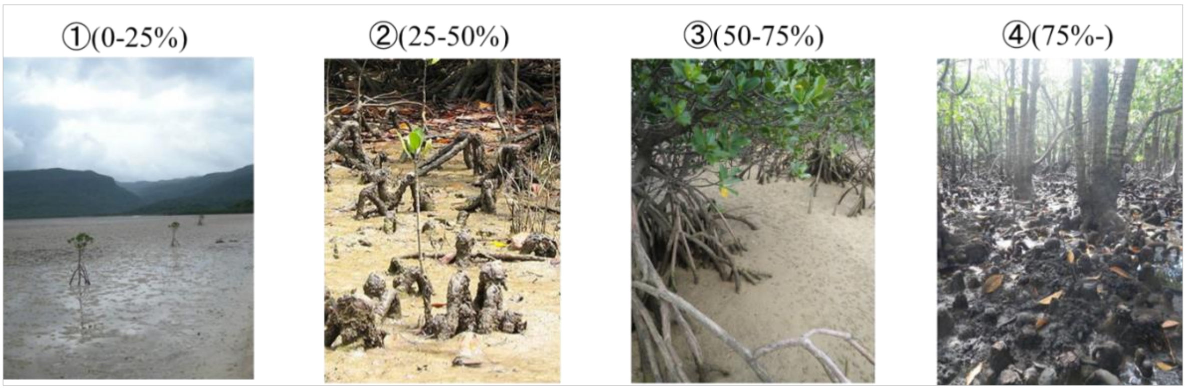

Figure 6: 1-4 Typical Images of Each Ratio

3. Results and Discussion

3.1 Appearance Tendency, Individual Density, and Individual Size

Bivalves were found at 34 locations. The sum of bivalves found was 51.

The highest density of individuals was five individuals per one square meter in P33 and the density of most locations was one or two individuals per one square meter. Figure 7 shows the shell lengths. The shortest shell length was 49.8 mm in P15, and the longest shell length was 116.8 mm in P32.

3.2 Relations with Soil Conditions

Table 1 and 2 show the average of median particle diameter, soil temperature and ORP in each small quadrat. Where bivalves were present, according to the method of characterizing soil by the International Soil Science Society (ISSS), the soil in P5,9,16,28,30 and 31 was characterized as coarse sand, and the others were characterized as fine sand by using the average of the median particle diameter. Where no bivalves were found, the soil in quadrat A1,4,9,10,12,17,18,20,21,22,28,30 and 31 was characterized as coarse sand, and in the others it was characterized as fine sand. Concerning the average of soil temperature, in the quadrats where bivalves were found, the maximum soil temperature was 37.3℃ in P12, and the minimum soil temperature was 21.7℃ in P28. In the quadrats where there were no bivalves, the maximum soil temperature was 33.4℃ in A4, and the minimum soil temperature was 21.2℃ in A29. Concerning the average of ORP, in the quadrats where bivalves were present, the maximum ORP was 145.5 mV in P6, and the minimum ORP was -312.7 mV in P3.

In the quadrats where no bivalves were found, the maximum ORP was 191.3 mV in A7, and the minimum ORP was -501.0 mV in A4. Figure 8, 9 and 10 show comparisons between quadrats with bivalves present or absent of the median particle diameter, soil temperature and ORP. There was no significant difference when all factors were taken into consideration Where bivalves were present, some locations seemed not to have good soil conditions for the bivalves. For example, in one quadrat, soil temperature was 37.3℃, in another quadrat, the ORP value was under -200 mV. This meant that the soil constituted an anaerobic environment. In general, bivalves close their shells and protect their soft tissue against bad conditions, for example, in the case of the salinity level of seawater changing rapidly (Murachi and Furukawa, 1985). If Polymesosa spp. living underground are exposed to bad soil conditions during low tide, they survive by keeping their shells closed. And this species can breathe without water (Morton, 1957). This means that if an individual lives on the surface of the soil, it can survive without being affected by soil conditions.

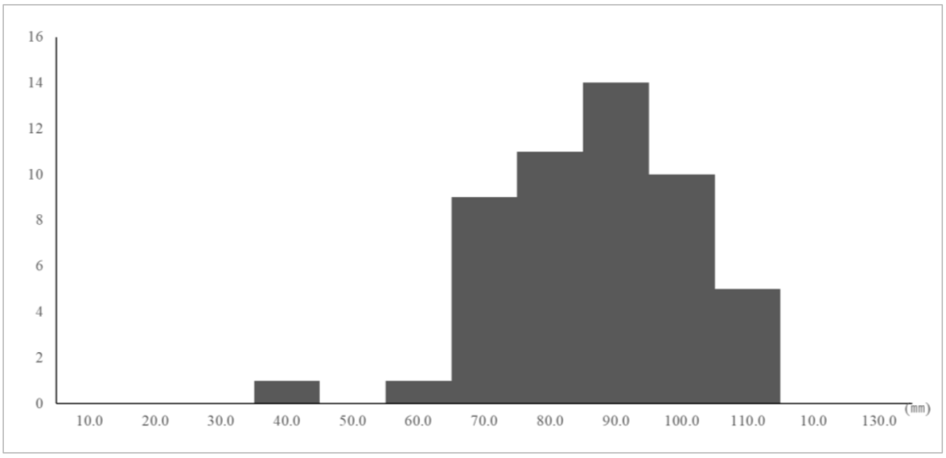

Figure 7: Size Composition of *Polymesoda spp.*

Table 1: The Average of Median Particle Diameter, Sediment Temperature, ORP, First and Second Dominant Species Name, Zone Number and Above-Ground Root Density Rank of Present Quadrats

Plot No.	Average of Median particle diameter(μm)	Average of sediemnt temparature(°C)	Average of Oxidation-Reduction Potential (mV)	First Dominant Species	Second Dominant Species	Zone number	Root Density Rank
P1	161.52	31.2	-68.3	*R. stylosa*	*B. gymnorhiza*	2	2
P2	151.35	27.2	-205.7	*B. gymnorhiza*	*B. gymnorhiza*	3	4
P3	128.90	28.2	-312.7	*B. gymnorhiza*	*B. gymnorhiza*	3	3
P4	196.31	27.3	-73.3	*B. gymnorhiza*	*B. gymnorhiza*	3	4
P5	202.40	31.5	25.0	*B. gymnorhiza*	*B. gymnorhiza*	3	4
P6	141.63	27.7	145.5	*B. gymnorhiza*	*P. odoratissimus*	3	2
P7	187.03	30.1	79.3	*B. gymnorhiza*	*B. gymnorhiza*	3	3
P8	141.99	28.4	-306.3	*B. gymnorhiza*	*B. gymnorhiza*	3	3
P9	201.29	30.6	-180.3	*B. gymnorhiza*	*B. gymnorhiza*	3	4
P10	127.73	28.8	100.0	*B. gymnorhiza*	*P. odoratissimus*	4	4
P11	125.73	31.1	-271.3	*B. gymnorhiza*	*B. gymnorhiza*	3	3
P12	189.50	37.3	-64.7	*B. gymnorhiza*	*B. gymnorhiza*	3	3
P13	159.40	33.7	-118.7	*B. gymnorhiza*	*P. odoratissimus*	4	3
P14	151.42	29.1	90.2	*B. gymnorhiza*	*B. gymnorhiza*	3	4
P15	72.97	29.1	51.0	*B. gymnorhiza*	*B. gymnorhiza*	3	3
P16	209.37	30.1	119.7	*B. gymnorhiza*	*R. stylosa*	3	4
P17	190.01	24.6	108.0	*B. gymnorhiza*	*R. stylosa*	3	3
P18	195.49	26.8	74.7	*R. stylosa*	*B. gymnorhiza*	2	3
P19	70.03	26.5	65.3	*R. stylosa*	*B. gymnorhiza*	2	3
P20	80.49	26.3	77.7	*R. stylosa*	*B. gymnorhiza*	2	3
P21	184.08	26.1	105.1	*R. stylosa*	*B. gymnorhiza*	2	4
P22	197.33	24.5	110.9	*B. gymnorhiza*	*R. stylosa*	3	4
P23	82.01	23.0	115.0	*B. gymnorhiza*	*B. gymnorhiza*	3	4
P24	199.91	23.2	100.7	*B. gymnorhiza*	*B. gymnorhiza*	3	3
P25	199.95	24.5	117.3	*B. gymnorhiza*	*R. stylosa*	3	4
P26	188.89	24.6	27.3	*B. gymnorhiza*	*B. gymnorhiza*	3	4
P27	177.80	24.7	99.0	*B. gymnorhiza*	*B. gymnorhiza*	3	4
P28	200.09	21.7	68.3	*B. gymnorhiza*	*P. odoratissimus*	3	3
P29	154.68	22.8	58.7	*B. gymnorhiza*	*B. gymnorhiza*	3	3
P30	206.87	24.8	71.7	*B. gymnorhiza*	*B. gymnorhiza*	3	3
P31	212.15	24.5	119.0	*B. gymnorhiza*	*B. gymnorhiza*	3	4
P32	124.29	24.6	119.7	*B. gymnorhiza*	*B. gymnorhiza*	3	4
P33	35.06	23.4	131.0	*B. gymnorhiza*	*B. gymnorhiza*	3	3
P34	121.19	24.6	6.0	*B. gymnorhiza*	*R. stylosa*	3	4

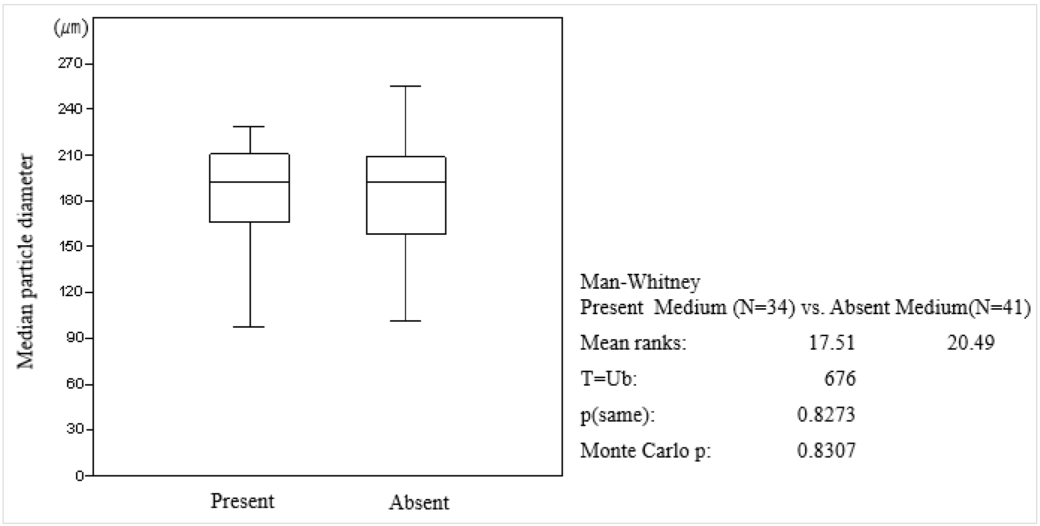

Figure 8: Comparison of the Average of Median Particle Diameter Between Present and Absent Quadrats

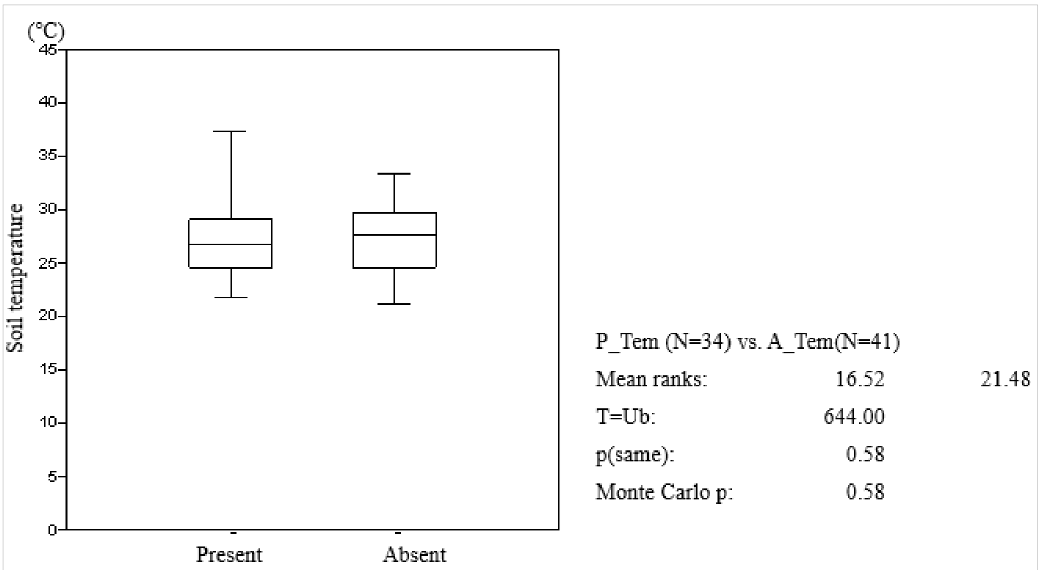

Figure 9: Comparison of the Average Soil Temperature Between Present and Absent Quadrats

In the quadrats where no bivalves were found, the maximum ORP was 191.3 mV in A7, and the minimum ORP was -501.0 mV in A4. Figure 8, 9 and 10 show comparisons between quadrats with bivalves present or absent of the median particle diameter, soil temperature and ORP. There was no significant difference when all factors were taken into consideration Where bivalves were present, some locations seemed not to have good soil conditions for the bivalves. For example, in one quadrat, soil temperature was 37.3°C, in another quadrat, the ORP value was under -200 mV. This meant that the soil constituted an anaerobic environment. In general, bivalves close their shells and protect their soft tissue against bad conditions, for example, in the case of the salinity level of seawater changing rapidly (Murachi and Furukawa, 1985). If Polymesosa spp. living underground are exposed to bad soil conditions during low tide, they survive by keeping their shells closed. And this species can breathe without water (Morton, 1957). This means that if an individual lives on the surface of the soil, it can survive without being affected by soil conditions.

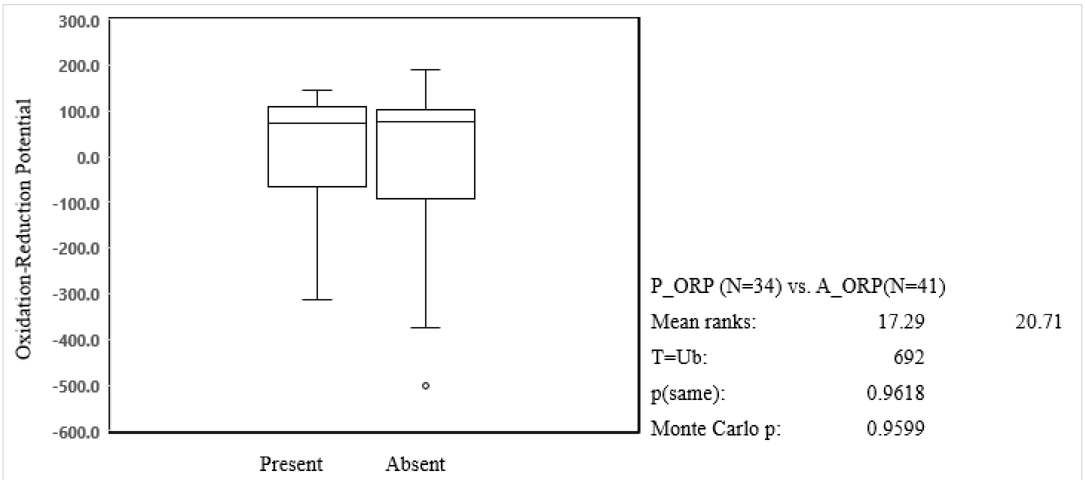

Figure 10: Comparison of the Average of ORP Between Present and Absent Quadrats

3.3 Relations with Dominant Mangrove Species and Root Density

Table 1 and 2 show the first and second dominant species and the zone number of quadrants where bivalves were absent or present. In the quadrats where bivalves were present, *B. gymnorhiza* was dominant in 27 quadrats and the zone number was "3", about 79.4% of all present quadrats. The zone number "3" included an overwhelmingly numbers of quadrats where bivalves were present out of all the zones (Table 1 and Figure 11). In contrast, in the quadrats where bivalves were absent, seventeen quadrats were assigned zone number "1", about 41.5% of all absent quadrats (Table 2 and Figure 12). Although there were a few with higher ratios than the other zones, there was no clear difference among all zones.

Tables 1 and 2, and Figure 13 and 14 show the rank number and the comparison among four ranks of above-ground root density of the quadrats where bivalves were either present or absent. In 94% of quadrats where bivalves were present, the number of the rank of above-ground root density was "3" or "4" where the density was over 50% of a large quadrat.

Table 2: The Average of Median Particle Diameter, Sediment Temperature, ORP, First and Second Dominant Species Name, Zone Number and Above-Ground Root Density Rank of Absent Quadrats

Plot No.	Median particle diameter(㎛)	Average of sediemnt temparature(°C)	Average of Oxidation-Reduction Potential (㎷)	First Dominant Species	Second Dominant Species	Zone number	Root Density Rank
A1	202.80	31.5	5.3	*R. stylosa*	*R. stylosa*	1	2
A2	177.57	32.4	-109.7	*B. gymnorhiza*	*B. gymnorhiza*	3	3
A3	122.45	27.6	100.3	*B. gymnorhiza*	*B. gymnorhiza*	3	2
A4	215.79	33.4	-501.0	*R. stylosa*	*R. stylosa*	1	1
A5	153.74	30.1	-188.7	*R. stylosa*	*R. stylosa*	1	3
A6	116.56	28.1	-225.0	*B. gymnorhiza*	*B. gymnorhiza*	3	4
A7	191.92	30.2	191.3	*R. stylosa*	*R. stylosa*	1	4
A8	199.67	29.7	-198.7	*P. odoratissimus*	*B. gymnorhiza*	4	3
A9	202.37	29.2	-376.0	*P. odoratissimus*	*B. gymnorhiza*	3	2
A10	203.31	27.7	-137.0	*B. gymnorhiza*	*B. gymnorhiza*	3	3
A11	169.16	27.2	97.7	*B. gymnorhiza*	*P. odoratissimus*	4	3
A12	203.62	27.9	177.0	*P. odoratissimus*	*B. gymnorhiza*	4	1
A13	125.59	29.2	85.3	*K. candel*	*R. stylosa*	1	4
A14	92.56	29.7	77.0	*R. stylosa*	*R. stylosa*	1	3
A15	174.29	29.6	110.3	*K. candel*	*R. stylosa*	1	3
A16	150.73	30.2	-113.3	*K. candel*	*R. stylosa*	1	4
A17	202.00	26.1	97.7	*P. odoratissimus*	*B. gymnorhiza*	4	2
A18	217.18	29.0	-147.3	*P. odoratissimus*	*B. gymnorhiza*	4	1
A19	61.42	27.6	62.7	*B. gymnorhiza*	*B. gymnorhiza*	3	4
A20	226.74	29.3	-197.3	*R. stylosa*	*B. gymnorhiza*	1	2
A21	248.98	28.4	-70.0	*R. stylosa*	*R. stylosa*	1	1
A22	211.46	29.6	168.7	*P. odoratissimus*	*B. gymnorhiza*	4	3
A23	165.63	32.0	47.0	*P. odoratissimus*	*B. gymnorhiza*	4	3
A24	120.73	30.1	125.7	*R. stylosa*	*B. gymnorhiza*	2	3
A25	176.80	23.5	-76.3	*R. stylosa*	*R. stylosa*	1	4
A26	94.77	23.2	61.3	*R. stylosa*	*R. stylosa*	1	4
A27	179.27	23.2	37.3	*R. stylosa*	*R. stylosa*	1	2
A28	203.09	22.6	92.0	*P. odoratissimus*	*B. gymnorhiza*	4	2
A29	141.27	21.2	51.3	*P. odoratissimus*	*B. gymnorhiza*	4	2
A30	203.39	24.2	112.7	*R. stylosa*	*R. stylosa*	1	2
A31	210.74	25.3	100.0	*R. stylosa*	*R. stylosa*	1	2
A32	189.81	24.4	88.0	*R. stylosa*	*R. stylosa*	1	2
A33	196.36	24.6	83.7	*R. stylosa*	*R. stylosa*	1	2
A34	108.86	24.3	104.7	*B. gymnorhiza*	*R. stylosa*	3	2
A35	128.61	24.6	101.3	*B. gymnorhiza*	*R. stylosa*	3	2
A36	45.98	24.8	113.0	*R. stylosa*	*B. gymnorhiza*	2	4
A37	136.88	25.4	77.0	*B. gymnorhiza*	*R. stylosa*	3	3
A38	188.97	25.7	80.3	*R. stylosa*	*B. gymnorhiza*	2	4
A39	94.50	25.9	105.3	*R. stylosa*	*B. gymnorhiza*	2	4
A40	36.06	26.6	71.7	*R. stylosa*	*B. gymnorhiza*	2	4
A41	193.99	26.0	92.0	*R. stylosa*	*B. gymnorhiza*	2	4

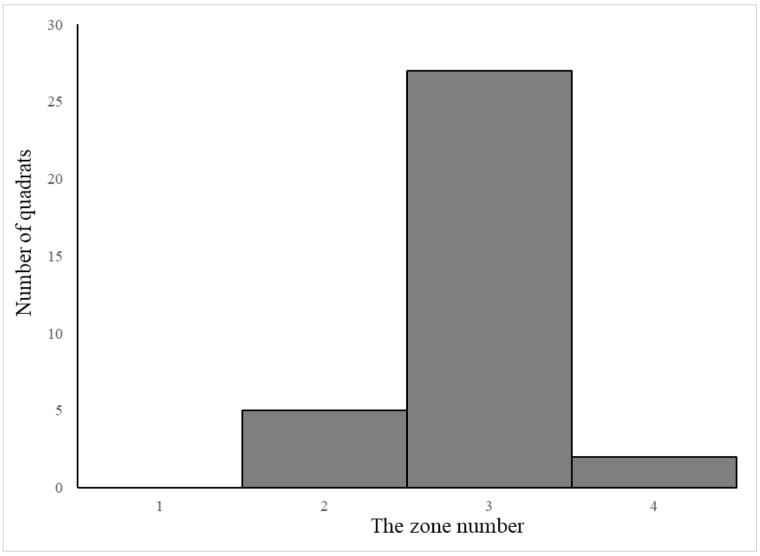

Figure 11: Comparison of The Numbers of Present Quadrat Among Four Zones Assigned by Dominant Mangrove Species

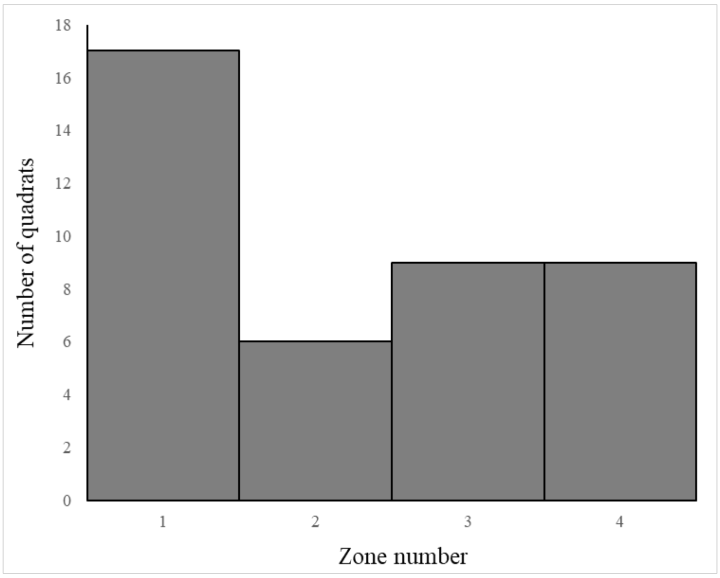

Figure 12: Comparison of the Numbers of Absent Quadrat Among Four Zones Assigned by Dominant Mangrove Species

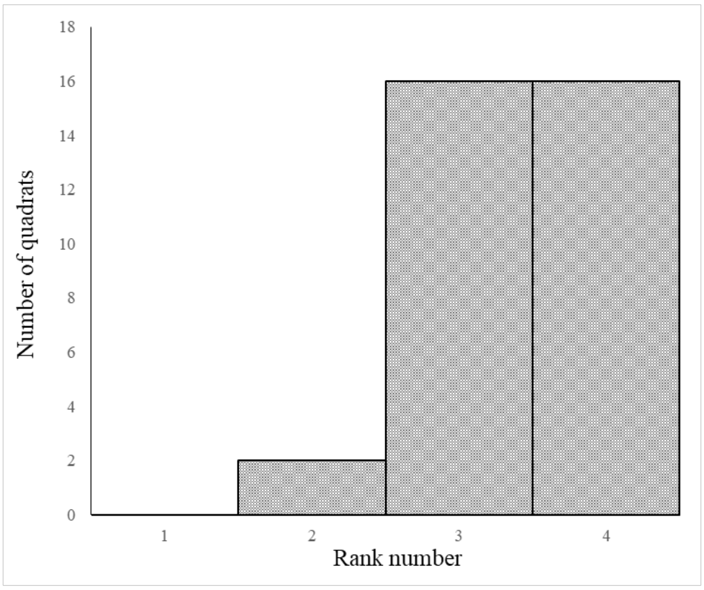

Figure 13: Comparison of The Numbers of Present Quadrat Among Four Ranks Assigned by the Ratio of Above-Ground Root Density

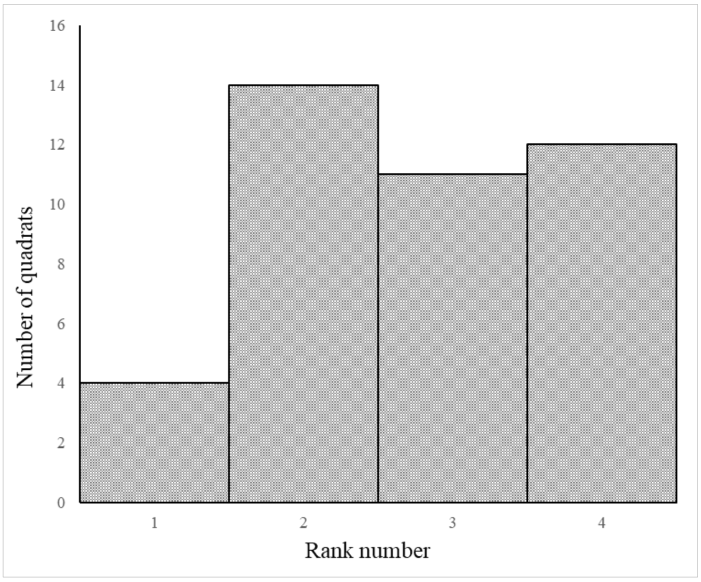

Figure 14: Comparison the Numbers of Absent Quadrat Among Four Ranks Assigned by the Ratio of Above-Ground Root Density

The number of quadrats where bivalves were present where *B. gymnorhiza* dominated was clearly highest. It seems that such areas are suitable for these bivalves. A group researchers verified this through field experiments in November 2012 to September 2013 (Washitani et al., 2017). The survival rate was higher in the area where *B. gymnorhiza* dominates than the seaward and terrestrial areas. Kakino mentioned that the numbers of the bivalve Ruditapes Philippinarum decreased after the piles for Nori (laver) cultivation in the sea were removed because the sediment flowed excessively (Kakino, 2006). Apparently the above-ground roots of mangroves had a function of preventing *Polymesoda* spp. from being flushed out of their preferred habitat. On Iriomote Island, the amount of precipitation increases during the rainy season (May and June) and the typhoon season (August and September) (Japan Meteorigical Agency). When the amount of precipitation is high, the flux of the river also becomes high. This causes surface soil to flush out. If the bivalves are surrounded by many above-ground mangrove roots, they are prevented from being flushed out with the soil.

4. Conclusion

In this investigation, no relevance was seen between the soil temperature, the median particle diameter and ORP, and the distribution pattern of bivalves. Soil conditions do not seem to influence this species' distribution. On the other hand, it was assumed that there was a relationship between the plant species and the above-ground root density, and the distribution of *Polymesoda* spp. These bivalves tended to frequently appear in the areas dominated by *B. gymnorhiza* which have a high density of above-ground roots. These results would contribute not only to data on *Polymesoda spp.* but also to resource management of these bivalves. *P.erosa* individuals of over 40mm were regarded as mature. These individuals can have eggs but no individuals with eggs were found. All of the bivalves collected in this investigation were adults. To verify the distribution patterns of juveniles is next on our research agenda.

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