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Habitat Characteristics of the Horse Mussel *Modiolus modulaides* (Röding 1798) in Iloilo, Philippines

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Despite the ecological importance of horse mussels, they have not received enough attention because they are considered of less economic value than other fisheries resources and not as charismatic as other marine resources. As a result, research efforts are often limited and information on biology and ecology is scant, affecting resource management. Recognizing this, the present study investigated the habitat characteristics of a local bioengineering species in Iloilo, Philippines – the horse mussel *Modiolus modulaides*. Analyses of water properties, sediments, phytoplankton composition in the water column, and food items pre-ingested by *M. modulaides* during the wet and dry seasons in Dumangas, Iloilo, Philippines were conducted. The water temperature (27.33–27.76 °C), dissolved oxygen (4.22–5.21 mg/L), salinity (30.97–32.63‰), pH (7.55–8.01), total dissolved solids (31736.70–33079.48 mg/L), and conductivity (50121.56–53971.26 µS/cm) favor the growth and maintenance of *M. modulaides*. Sediments exhibited increasing deposition of fine material and high organic matter content as a result of the deposition of feces and pseudofeces. Diatoms comprised the majority of phytoplankton in the water column and among pre-ingested food items of *M. modulaides*. Based on pre-ingested food items, *M. modulaides* appears to practice selective feeding with preferences on *Thalasionema* spp., *Diploneis* spp., *Pleurosigma* spp., *Detonula* spp., and *Rhizosolenia* spp. Copepods and tintinnids may also be important additional food sources. Horse mussel density drastically decreased from 105.33 ± 30.15 individuals/m^2 during the wet season to 24.47 ± 3.78 individuals/m^2 during the dry season due to intense exploitation in the area. Aside from providing baseline data, these results are essential in the development of a management framework and an initial step towards the development of culture technology for *M. modulaides*.

Keywords: mussel aquaculture, plankton analysis, sediment, water quality

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INTRODUCTION

Mussels, which are euryhaline bivalve mollusks of the Family Mytilidae, are the most common biogenic substrate organisms in shallow subtidal areas, rocky intertidal habitats, and estuarine flats (Borthagaray and Carranza 2007; Gosling 2015). They are ecosystem engineers that provide a complex habitat (*i.e.* interstitial space on the surfaces of mussel shells and in the mussel bed matrix) for a variety of marine organisms (Ragnarsson and Raffaelli 1999; Borthagaray and Carranza 2007). Moreover, they are not only responsible for filtering large plankton biomass but also organic matter and pollutants (Pruell *et al*. 1986; Hatcher *et al*. 1994; Hawkins *et al*. 1996; Hargrave *et al*. 2008). Aside from their ecological and environmental importance, mussels provide food and livelihood for many (Napata and Andalecio 2011; Sumagaysay 2014).

The Family Mytilidae is comprised of 32 genera, including the genus *Modiolus* of the horse mussels (Gosling 2015). *Modiolus* bivalves are comprised of species that thrive in the tropical, subtropical, and temperate regions of the world. Tropical *Modiolus* are semi-infaunal species distributed in the Indo-West Pacific region. They thrive on muddy and sandy substrates in the littoral and sub-littoral zones down to a depth of 40 m, buried with half to two-thirds of its body in the sediment and using byssal threads for support and attachment to sediment particles (Ozawa 2001). In the western and central Pacific, four species are of interest to fisheries: *M. aratus*, *M. auriculatus*, *M. modulaides* (formerly *M. metcalfei*), and *M. philippinarum* (Poutiers 1998).

In the Philippines, only *M. modulaides* and *M. philippinarum* are commercially-exploited (Yap 1978; Rochanaburanon 1980; Napata and Andalecio 2011; Uba *et al*. 2020). They are collected for human consumption in many areas and marketed notably in Malaysia and the Philippines (Poutiers 1998). In Panay Island, central Philippines, it is heavily exploited for food and aquaculture feed (Rochanaburanon 1980; Gallardo *et al*. 1995; Napata and Andalecio 2011). Compared to the green mussel *Perna viridis*, *Modiolus* is cheaper (PHP 15.00/kg) but more nutritious (Rochanaburanon 1980; Uba *et al*. 2020).

Studies on reproductive biology and population dynamics (Walter and dela Cruz 1980; Lopez and Gomez 1982; Tumanda *et al*. 1997), aquaculture potential (Yap 1978), and fishery (Napata and Andalecio 2011; Uba *et al*. 2020) of *Modiolus* bivalves have been conducted in the Philippines but there is still scant information about its biology and ecology. Overexploitation coupled with habitat degradation has resulted in dwindling wild populations of horse mussels (Napata and Andalecio 2011). This warrants more studies to fully understand the ecology of the organism to come up with sound management strategies.

Thus, the present study aims to characterize the habitat of *M. modulaides* during the wet and dry seasons in Dumangas, Iloilo, Philippines. To characterize the habitat, the physicochemical properties of the water, sediment grain size composition and organic matter content, and mussel density were determined. Also, food availability and composition were determined through the qualitative and quantitative analysis of phytoplankton taxa composition both in the water and pre-ingested by *M. modulaides*.

MATERIALS AND METHODS

Study Area

This study was conducted from October 2018 to March 2019 in the coastal area of Dumangas, Iloilo, Philippines, which is located northeast of Iloilo City on the island of Panay, central Philippines (Figure 1). The coastal waters of Dumangas is an important habitat for horse mussels that covers a wide area with high biomass (Napata and Andalecio 2011). We selected an area with large subtidal mussel beds (10°47'15.74"N and 122°44'12.51"E) for this investigation. The horse mussels were found to be thriving in the subtidal area, which is 200 m away from the shoreline at depths of 0.5–1.5 m during low tide. The bottom topography is generally flat with sandy-muddy bottom sediment. The habitat was characterized in terms of the physicochemical parameters of the water, sediment grain size composition and organic matter content, mussel density, phytoplankton composition analysis, and pre-ingested food composition of *M. modulaides* during two seasons (wet season from October to November 2018; dry season from January to March 2019).

Determination of the Physico-chemical Parameters of the Water

Samplings for the determination of physicochemical parameters of the water were done with the aid of three 50-m long transects laid parallel at 25 m apart. The transects were laid starting from the point where mussel populations are present (200 m away from the shoreline) perpendicular to the shoreline. Monthly measurements of water parameters were done at three sampling points (0 m, 25 m, and 50 m marks) along each transect. Water parameters such as temperature, dissolved oxygen, salinity, pH, total dissolved solids, and conductivity were measured using a YSI multiparameter (Professional Plus, USA). Also, monthly total rainfall data during the period

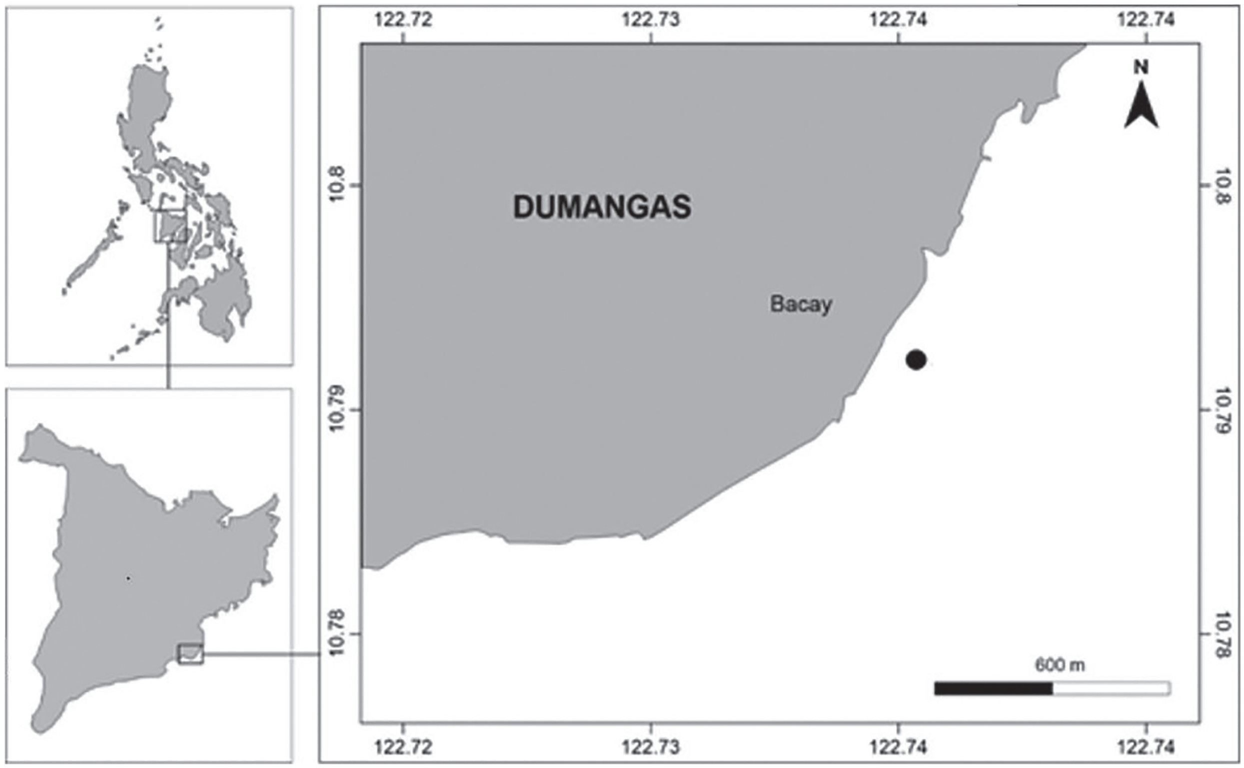

Figure 1. Map of the study site.

of study was provided by the Philippine Atmospheric, Geophysical, and Astronomical Services Administration.

Sediment Analysis
Sediment samples were collected once every season (wet season in November 2018; dry season in February 2019) using an improvised polyvinyl chloride corer (diameter = 5.08 cm). Sediments were collected along the transect in the 0 m, 25 m, and 50 m marks. Only the first 3 cm of the sediment from the core was collected since the horse mussels bury up to this depth. The sediment samples were stored in labeled plastic bags and then placed in a freezer of approximately 4 °C temperature until processing in the laboratory.

The sediment in the study area was analyzed for grain size composition and organic matter content. The sediment grain size composition was determined based on the method of Eleftheriou and McIntyre (2005). Each 25-g sediment sample was dispersed in 250-mL tap water added with 10 mL of 6.2 g/L sodium hexametaphosphate and soaked overnight. The sediment suspension was washed from the beaker onto a 63-µm sieve and wet-sieved. Sieving and washing of the sediment were continued until no further fine particles were washed out. The sieve and its contents were placed in an oven and dried at 100 °C for 4 h. The sediments retained in the sieve were weighed. The fraction of sand in the sediment was expressed as a percentage of the total sediment weight, while the silt-clay fraction was the difference between the weights of the sediment sample and the sand fraction.

The sediment total organic matter (TOM) content was determined using the loss on ignition (LOI) method (Dean 1974). Sediment samples were placed in small metal bowls and were oven-dried at 100 °C for 24 h. Five grams (5 g) of oven-dried sediment samples were placed in crucibles and then combusted in a muffle furnace for 6 h at 550 °C. The percentage of dry weight LOI was calculated using the following equation:

$$LOI_{550} = [(DW_{100} - DW_{550}) / DW_{100}] * 100 \quad (1)$$

where LOI_{550} represents LOI at 550 °C (expressed as a percentage), DW_{100} represents the dry weight of the sample before combustion, and DW_{550} the dry weight of the sample after heating to 550 °C (expressed both in g). The weight loss should then be proportional to the amount of organic carbon contained in the sediment sample.

Estimation of Horse Mussel Population Density
The population density of horse mussels was estimated once in every season (wet season, in November 2018; dry season in February 2019) using the transect-quadrat

sampling method. In the study site, three 50-m long parallel transects were laid perpendicular to the shore at every 25 m starting where mussel populations begin. A 1-m^2 iron quadrat subdivided into 16 sectors (0.25 m x 0.25 m) by nylon monofilament grids was laid along the transect line at 10-m intervals to determine the density of the horse mussels.

When the mussel cover was 100%, the population density was estimated by counting, at random, a subsample of horse mussels contained in a 0.25 m x 0.25 m area of each quadrat. On the other hand, when the mussel cover was less than 100%, all the horse mussels inside the quadrat were counted. The sum of horse mussels in all quadrats over the number of quadrats was used to estimate the mean horse mussel population density per square meter along the transect line. The estimate of the mean population density in the sampling area for a particular sampling period was derived from the means of the three transect lines.

Phytoplankton Collection and Analysis

Sampling for phytoplankton was conducted once every season (wet season in November 2018; dry season in February 2019) in three sampling points in the horse mussel site. Twenty liters (20 L) of water were collected 0.5 m below the surface using a calibrated 2-L bucket and were filtered through a 28-μm mesh plankton net. Samples were then placed in properly labeled container bottles and preserved in a 10% seawater-buffered formalin solution. In the laboratory, the volume of collected samples were concentrated to 20 mL through sedimentation in a 100-mL graduated cylinder for 48 h.

In the laboratory, a series of 1-mL aliquots were examined using a Sedgewick-Rafter counting chamber under a compound microscope to construct a genera cumulative curve to determine the minimum aliquot sample needed to adequately represent each sample. The total number of cells was calculated following the formula (Stirling 1985):

$$N = (A \times 1000 \times C)\ (V \times F \times L) \qquad (2)$$

where N is the number of phytoplankton cells per liter of the original water, A is the number of phytoplankton counted, C is the volume of the final concentrate of the samples in mL, V is the volume of a field in mm^3, F is the number of fields counted, and L is the Volume of original water in L. Phytoplankton were identified to the lowest possible taxon (genera) and were further grouped into major taxa: diatoms and dinoflagellates. Identification was based on the works of Omura *et al*. (2012) and Yamaji (1984).

Pre-ingested Food Composition

Initially, the food preference of horse mussels was investigated by analyzing the stomach contents. However, food items in the stomach were not recognizable; thus, pre-ingested food was analyzed instead through the examination of the gills. While food items found on the mussel gills may not necessarily be ingested by the organism, it offers valuable insights into the possible food habits and preferences of the organism. Pre-ingested food composition analysis was conducted once every season (wet season in November 2018; dry season in February 2019). For each season, 30 live adult horse mussels were collected and immediately fixed with a 10% seawater-buffered formalin solution to stop digestion and preserve the pre-ingested food items until further processing in the laboratory. In the laboratory, the gills of each horse mussel samples were removed and placed in a vial with 5 mL of 10% seawater-buffered formalin solution. Based on the methods of Yamaji (1984) and Omura *et al*. (2012), the food items were identified to the lowest possible taxa level (genera) and counted using a Sedgewick-Rafter counting chamber under a microscope.

The frequency of occurrence (F_o) was determined by recording the number of horse mussels containing individuals of each food item, expressed as the percentage of all the horse mussels examined according to the formula of Alves *et al*. (2016):

$$F_o\ (\%) = Ta \times 100\ /\ TA \qquad (3)$$

where Ta is the number of samples where the taxon occurred and TA is the total number of samples. The results were presented as percentages and interpreted using the following criterion: > 70% = very frequent (VF); 40–70% = frequent (F); 10–40% = infrequent (IF); < 10% = sporadically (S); and 0% = absent (A) (Alves *et al*. 2016).

Statistical Analysis

The two-way analysis of variance was used to determine the seasonal variation between and within transects on the environmental parameters and mussel density. Homogeneity of variance was conducted using Levene's test. Also, data with unequal variances (*i.e.* salinity and density) were log-transformed before analysis. Moreover, rainfall data were analyzed for a significant difference between seasons using a t-test. Furthermore, data on the seasonal variation of sediment grain size and TOM content were analyzed using the Mann-Whitney rank-sum test as it did not satisfy the normality and homogeneity of variance criteria for parametric testing. All statistical tests were conducted at a 95% confidence level using SPSS software version 25. Values were expressed as means ± standard error of the means (SEM).

RESULTS AND DISCUSSION

Physico-chemical Parameters

The physicochemical parameters of the seawater in Dumangas, Iloilo, Philippines during the wet and dry seasons are summarized in Table 1. Dissolved oxygen, salinity, and pH were found to be significantly different between seasons but not between transects while temperature, total dissolved solids, and conductivity were not significantly different ($P < 0.05$; two-way ANOVA). The total amount of rainfall was also significantly different between the dry (20.00 ± 9.79 mm) and wet (135.33 ± 38.42 mm) seasons ($P < 0.05$; t-test). During the wet season, higher pH and total rainfall were recorded while lower dissolved oxygen and salinity were recorded during the dry season.

The physicochemical parameters recorded in Dumangas, Iloilo were within normal range with small observed seasonal differences. Therefore, it is deemed appropriate for the development of mollusk communities (Gosling 2015). Based on the criteria of the Philippine Department of Environment and Natural Resources, the area is still suitable for shellfish harvesting for direct human consumption (DAO 2016-08). Also, the lower levels of dissolved oxygen and salinity and high level of pH during the wet season can be attributed to the high amount of rainfall during this period.

Temperature and salinity are the main factors affecting the distribution and survival of adult mussels (Gosling 2015). In the present study, water temperature ranged from 27.33 ± 0.10 °C to 27.76 ± 0.13 °C during the dry season and wet season, respectively. This was the same range reported by Parulekar *et al*. (1978), Lopez and Gomez (1982), and Tumanda *et al*. (1997). Interestingly, the salinity level ranged from 30.97 ± 0.39‰ to 32.63 ± 0.05‰ during the wet and dry season, respectively. This is in contrast with what was reported by Tumanda *et al*. (1997) in *M. metcalfei* beds in Panguil Bay, southern Philippines where a horse mussel population thrived in a brackish water environment (salinity of 11‰) but is similar to the reports of Parulekar *et al*. (1978) in Goa, India, and Lopez and Gomez (1982) in Calatagan, Batangas, northern Philippines. This difference can be attributed to the unique geophysical characteristics of Panguil Bay, wherein the inner portions of the bay are brackish environments due to high freshwater inputs. Interestingly, this reveals that *M. modulaides* can survive in a wide range of salinity levels, which is an ideal characteristic for aquaculture. In the present study, the physicochemical parameters of the water may favor the growth and maintenance of *M. modulaides* populations. However, indications of a deteriorating ecosystem condition in Dumangas, Iloilo inferred from morphological analysis of *M. modulaides* shells were reported by Uba *et al*. (2019). This may have effects on the dynamics of the population of *M. modulaides* in the study area.

Sediment Grain Size Composition and TOM Content

The sediment grain size composition in the study site during the wet and dry seasons is shown in Figure 2. During the wet season, the silt-clay fraction of the sediment was at 39.1% while the sand fraction was at 60.9%. However, during the dry season, the silt-clay fraction of the sediment was at 26.0% while the sand fraction was at 74.0%. The sediment grain size composition was not significantly different between seasons ($P > 0.05$; Mann-Whitney rank sum test).

Figure 3 shows the sediment TOM content in the study site during the wet and dry seasons. During the wet season, the TOM content was at 7.0% while during the dry season it was at 5.5%. The sediment TOM content was not significantly different between seasons ($P > 0.05$; Mann-Whitney rank sum test).

Table 1. Seasonal variations of environmental parameters between and within transects in the horse mussel site in Dumangas, Iloilo, Philippines. Values are mean ± SEM. The means followed by different letters differ significantly at $P < 0.05$; ns – not significant (two-way ANOVA).

Transect	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Salinity (‰)	Total dissolved solids (mg/L)	Conductivity (µS/cm)
1	27.45 ± 0.18	4.72 ± 0.37	7.74 ± 0.13	31.93 ± 0.49	32396.72 ± 683.62	52410.94 ± 1379.76
2	27.59 ± 0.17	4.68 ± 0.33	7.79 ± 0.13	31.83 ± 0.49	32411.00 ± 676.44	52330.44 ± 1370.86
3	27.59 ± 0.18	4.76 ± 0.26	7.79 ± 0.13	31.64 ± 0.55	32416.56 ± 680.03	51397.83 ± 1718.54
Season						
Dry	27.33 ± 0.10	5.21 ± 0.18 a	7.55 ± 0.09 a	32.63 ± 0.05 a	31736.70 ± 629.82	53971.26 ± 239.98
Wet	27.76 ± 0.13	4.22 ± 0.19 b	8.01 ± 0.02 b	30.97 ± 0.39 b	33079.48 ± 261.86	50121.56 ± 1369.61
Transect x season interaction	ns	ns	ns	ns	ns	ns

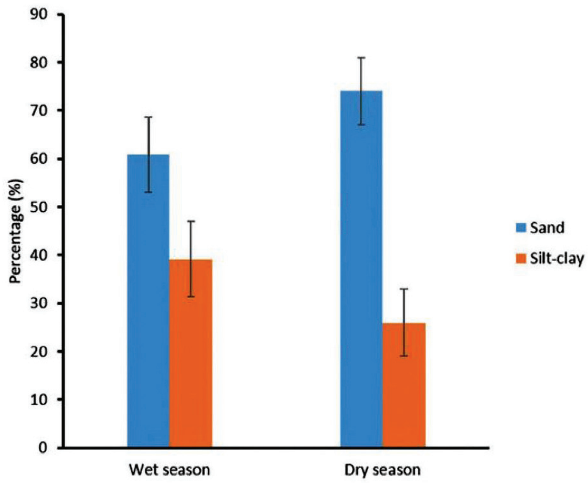

Figure 2. Sediment grain size composition of a *Modiolus* bed during the wet and dry seasons in Dumangas, Iloilo, Philippines.

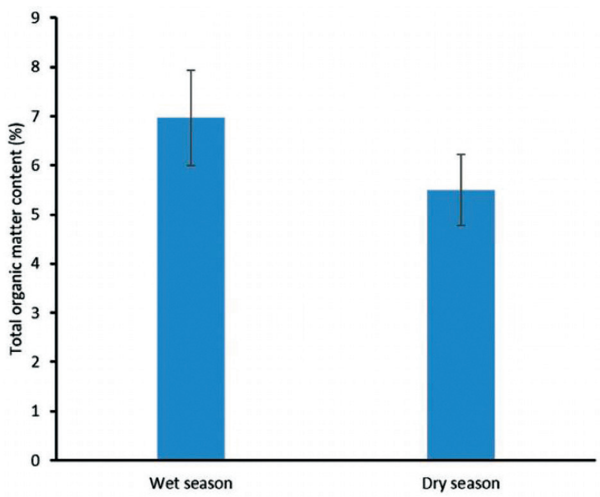

Figure 3. Sediment TOM content in a *Modiolus* bed during the wet and dry seasons in Dumangas, Iloilo, Philippines.

The sediment characteristics exhibited the effects of filter-feeding keystone bivalves on the surrounding substratum, increasing deposition of fine material and an increase in organic matter content due to the accumulation of feces and pseudofeces (Hatcher *et al*. 1994; Albrecht 1998; Ragnarsson and Raffaelli 1999; Meadows *et al*. 2012).

Horse Mussel Population Density

The population density of horse mussels in Dumangas, Iloilo was estimated during the wet and dry seasons (Table 2). There was a significant difference in horse mussel density between seasons but not among transects ($P < 0.05$; two-way ANOVA). During the wet season, the density was at 105.33 ± 30.15 individuals/m^2 while during the dry season, this was drastically reduced to 24.47 ± 3.78 individuals/m^2. The result of the present study is remarkably lower than what was reported by Tumanda *et al*. (1997) in Panguil Bay, southern Philippines where densities of *M. metcalfei* were recorded at an average of 3600 individuals/m^2. The disparity between the two areas may be attributed to the intensive exploitation occurring in Dumangas, Iloilo.

Table 2. Seasonal variation of horse mussel population density between and within transects in Dumangas, Iloilo, Philippines. Values are means ± SEM. Means followed by different letters differ significantly at $P < 0.05$; ns – not significant (two-way ANOVA).

		Mussel density (individual/m^2)
Transect	1	56.00 ± 33.06
	2	85.90 ± 52.49
	3	52.80 ± 37.45
Season	Dry	24.47 ± 3.78 a
	Wet	105.33 ± 30.15 b
Transect x season interaction		ns

The dramatic decrease of the horse mussel density within a short period is noticeable. However, this decrease cannot be attributed to the season or variations in the physical and/or chemical environmental parameters. The primary factor causing this decrease was the intensive harvesting of horse mussels in the area as most gatherers heavily relied on this resource for livelihood. In the study site, gatherers collected an average of 30 sacks (50 kg/sack) daily (Uba *et al*. 2020). The high fishing pressure would naturally cause a reduction of the stock after some time. In the study site, the low mussel density often served as a signal for harvesters to transfer to another part of the town to continue harvesting, a practice that may have allowed stocks to briefly recover.

Plankton Composition and Pre-ingested Food Items

A total of 14 and 18 genera of plankton, representative of 12 and 17 families, were identified during the wet and dry season, respectively (Table 3). During the wet season, the dominant phytoplankton species in the water column were *Rhizosolenia* spp. (25.2% of the total density), *Coscinodiscus* spp. (21.2%), and *Pseudonitzschia* spp. (13.3%). In contrast, during the dry season *Thalassionema* spp. (42.9%), and *Coscinodiscus* spp. (18.0%) were the dominant species. Also, the zooplankton *Tintinopsis* spp. had a high concentration in the water column at 12.7% and 15.4% in the wet and dry seasons, respectively. The phytoplankton cell density ranged from 0.13–5.55 x 10^6 cells/L during the wet season and 0.03–16.48 x 10^6 cells/L during the dry season in Dumangas, Iloilo, Philippines.

Table 3. Plankton composition in the horse mussel site in Dumangas, Iloilo, Philippines during the wet and dry seasons.

Genera (Family)	Wet season		Dry season	
	Mean density (x 10^6 cells/L)	Relative density (%)	Mean density (x 10^6 cells/L)	Relative density (%)
Diatoms				
Rhizosolenia (Rhizosoleniaceae)	5.55 ± 0.39	25.2	0.13 ± 0.10	0.3
Coscinodiscus (Coscinodiscaceae)	4.67 ± 0.61	21.2	6.91 ± 0.75	18.0
Pseudonitzschia (Bacillariophyceae)	2.93 ± 0.57	13.3	1.15 ± 0.44	3.0
Thalassiothrix (Thalassionemataceae)	2.51 ± 0.35	11.4	1.39 ± 0.29	3.6
Pleurosigma (Pleurosigmataceae)	0.67 ± 0.12	3.0	1.17 ± 0.27	3.1
Thalassionema (Thalassionemataceae)	0.61 ± 0.03	2.8	16.48 ± 1.52	42.9
Guinardia (Rhizosoleniaceae)	0.45 ± 0.07	2.1	0.00	0.0
Diploneis (Naviculaceae)	0.32 ± 0.05	1.5	0.61 ± 0.23	1.6
Chaetoceros (Chaetocerotaceae)	0.19 ± 0.11	0.8	0.00	0.0
Detonula (Thalassiosiraceae)	0.16 ± 0.00	0.7	0.29 ± 0.10	0.8
Triceratium (Triceratiaceae)	0.13 ± 0.10	0.6	0.51 ± 0.07	1.3
Odontella (Eupodiscaceae)	0.00	0.0	1.36 ± 0.17	3.5
Bacillaria (Bacillariaceae)	0.00	0.0	0.40 ± 0.23	1.0
Skeletonema (Skeletomataceae)	0.00	0.0	0.16 ± 0.05	0.4
Nitzschia (Bacillariaceae)	0.00	0.0	0.13 ± 0.13	0.3
Mastoglia (Mastogloiaceae)	0.00	0.0	0.05 ± 0.05	0.1
Bacteriastrum (Chaetocerotaceae)	0.00	0.0	0.03 ± 0.03	0.1
Dinoflagellates				
Protoperidium (Naviculaceae)	0.19 ± 0.07	0.8	0.59 ± 0.35	1.5
Ceratium (Ceratiaceae)	0.80 ± 0.14	3.6	1.09 ± 0.24	2.9
Zooplankton				
Tintinopsis (Codonellidae)	2.80 ± 0.65	12.7	5.92 ± 0.20	15.4
Number of families	12		17	
Number of genera	14		18	
Mean cell density (x 10^6 cells/L)	1.57 ± 0.48		2.13 ± 0.96	

A total of 16 phytoplankton genera and two zooplankton groups (*i.e.* tintinnids and copepods) were recorded as pre-ingested food items of *M. modulaides* (Table 4), which can be further categorized into four major plankton groups – namely, diatoms, dinoflagellates, tintinnids, and copepod fragments (Figure 4). Of the 16 phytoplankton genera and two zooplankton groups, 13 were recorded during the wet season while 16 were recorded during the dry season. During the wet season, the most frequent pre-ingested food item was *Thalassionema* spp. (F_o = 83.3%) while the least frequent was *Nitzschia* spp. (2.0%). During the dry season, *Coscinodiscus* spp. and *Thalassionema* spp. were observed from all specimens. There was also a high occurrence of *Diploneis* spp. (96.7%) and *Pleurosigma* spp. (86.7%). Interestingly, the dinoflagellate *Protoperidinium* spp. was recorded at 3.3% of the samples. Copepod fragments were recorded at 20.0% and 60.0% while *Tintinopsis* spp. was recorded at 96.7% and 100.0% during the wet and dry seasons, respectively.

The examination of feeding behavior is an initial step in understanding the growth and dynamics of the *M. modulaides* population in the study area. The results suggest that diatoms and other algal cells in the water column were the dominant pre-ingested food items by *M. modulaides*, indicating a strong linkage between mussels and the pelagic food pool in the study area. The importance of diatoms in the diet of mussels had been reported by Parker *et al*. (1998) and Alves *et al*. (2016). It appears that *M. modulaides* rely on phytoplankton as its main diet. This result is similar to numerous studies that reported that phytoplankton serves as a major part of macro-benthos diets in coastal ecosystems (Kaehler *et al*. 2000; Yokoyama *et al*. 2005).

Table 4. Composition and frequency of occurrence of pre-ingested food items by *Modiolus modulaides* during the wet and dry seasons in the horse mussel site in Dumangas, Iloilo, Philippines[a].

Food items	Wet season			Dry season		
	Mean count ± SEM	Frequency of occurrence (%)		Mean count ± SEM	Frequency of occurrence (%)	
Diatoms						
Bacillaria	–	–	A	0.5 ± 0.3	10.0	IF
Bacteriastrum	–	–	A	0.3 ± 0.2	6.7	S
Coscinodiscus	19.8 ± 2.0	30.0	IF	28.0 ± 3.1	100.0	VF
Detonula	2.0 ± 0.6	10.0	IF	3.3 ± 0.8	50.0	F
Diploneis	13.2 ± 2.2	27.0	IF	21.8 ± 3.0	96.7	VF
Guinardia	1.2 ± 0.6	5.0	S	–	–	A
Nitzschia	0.3 ± 0.2	2.0	S	0.8 ± 0.4	16.7	IF
Odontella	0.5 ± 0.3	3.0	S	2.2 ± 0.5	40.0	F
Pleurosigma	4.8 ± 0.9	19.0	IF	11.2 ± 1.5	86.7	VF
Pseudonitzschia	3.2 ± 0.9	12.0	IF	4.2 ± 0.8	53.3	F
Rhizosolenia	6.2 ± 1.0	21.0	IF	5.2 ± 1.3	50.0	F
Skeletonema	1.0 ± 0.4	5.0	S	2.3 ± 0.6	40.0	F
Thalassionema	17.5 ± 4.5	83.3	VF	41.7 ± 8.4	100.0	VF
Thalassiothrix	7.5 ± 2.3	19.0	IF	20.8 ± 9.0	60.0	F
Triceratium	–	–	A	0.7 ± 0.3	13.3	IF
Dinoflagellates						
Proteperidinium	–	–	A	0.9 ± 0.2	3.3	S
Zooplankton						
Tintinopsis	17.7 ± 2.1	96.7	VF	27.8 ± 3.3	100.0	VF
Copepod fragments	9.2 ± 1.8	20.0	IF	8.5 ± 1.6	60.0	F

[a]VF – very frequent; F – frequent; IF – infrequent; S – sporadically; A – absent

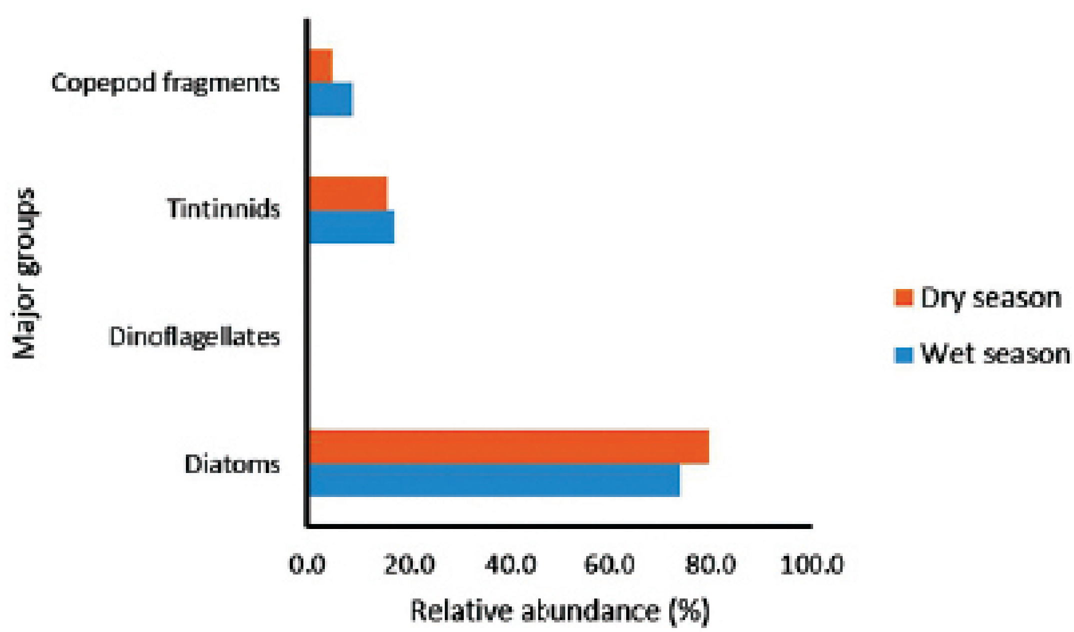

Figure 4. The relative abundance of pre-ingested major plankton groups during the wet and dry seasons in the horse mussel site in Dumangas, Iloilo, Philippines.

There were some genera such as *Tintinopsis* spp., *Thalassionema* spp., *Coscinodiscus* spp., and *Rhizosolenia* spp. that were found to be abundant in both the water column and in the gills. In contrast, *Diploneis* spp., *Diploneis* spp., *Pleurosigma* spp., *Detonula* spp., and *Rhizosolenia* spp. had low concentrations in the water column but were frequently observed as pre-ingested food items. The high abundance of some phytoplankton genera as pre-ingested food items despite low concentrations in the water column may be an indication of selective ingestion by *M. modulaides*. Selective ingestion is common among filter feeders and is linked to nutrition, wherein highly nutritious species are preferentially pre-ingested (Beukema and Cadee 1991; Hawkins *et al*. 1996; Iglesias *et al*. 1996; Navarro and Widdows 1997; Wong and Cheung 1999; Alves *et al*. 2016; Tan and Ransangan 2016). While phytoplankton are the primary food sources for sedentary bivalves, several studies had pointed out the importance of an additional food source, mainly zooplankton, in bivalve diet (Davenport *et al*. 2000; Lehane and Davenport 2002, 2006; Prato *et al*. 2010; Ezgeta-Balic *et al*. 2012; Tan and Ransangan 2016). In the present study, copepod fragments (*i.e.* swimming legs) and tintinnids constituted up to 20% of the pre-ingested food items of *M. modulaides* during both seasons. The ingestion of zooplankton has been reported in other bivalve species such as in *Mytilus galloprovincialis*, *Ostrea edulis*, *M. barbatus*, and *Arca noae* (Ezgeta-Balic *et al*. 2012); *M. edulis* (Lehane and Davenport 2002, 2006); *Cerastoderma edule* and *Aequipecten opecularis* (Lehane and Davenport 2002); and *P. viridis* (Tan and Ransangan 2016).

In the context of fisheries management, the results of the present study indicate that tidal flats are important habitats for such fisheries and should be protected and considered in zoning and planning, especially when there are reclamation activities. Also, water quality is an important abiotic factor affecting the growth, survival, and maintenance of horse mussel populations and should be considered especially in waste and pollution management in coastal areas. Moreover, establishing effective management plans for the sustainable exploitation of *M. modulaides* would entail the involvement of horse mussel gatherers as they are critical stakeholders for this resource. As declines in wild stocks of *M. modulaides* are reported (Napata and Andalecio 2011), the experience of the South American artisanal mussel fisheries may serve as a guide for local management wherein degrees of co-management together with explicit allocation of territorial user rights for fishing were given to artisanal mussel fishers. These tools are seen as promising for linking economic development and poverty alleviation and can enhance the sustainability of mussel extraction (Defeo and Castilla 2005; Carranza *et al*. 2009).

While horse mussels could not be cultured because they do not attach to mariculture substrates, the prospect of sea ranching and seeding of hatchery-produced juveniles in traditional fishing grounds may be a viable option to replenish stocks, sustain the fishery, and reduce harvest pressure on wild populations (Brumbaugh *et al*. 2006). The present study presents an initial step towards the development of optimum culture conditions and possible diet to aid the rearing of *M. modulaides* for possible spawning and hatchery. The knowledge of the optimum physicochemical parameters for the culture of bivalves is vital to ensure successful production (Gosling 2015). The results of the present study could serve as baseline information for future investigations on the tolerances of *M. modulaides* to different physicochemical factors under controlled environmental conditions. Also, the results on the phytoplankton composition and pre-ingestion may help establish the best algal diets for the production of *M. modulaides* under controlled conditions.

CONCLUSION

The scant information on the biology and ecology of *M. modulaides* hinders the effective management of this resource. The present study determined the characteristics of suitable habitat for *M. modulaides*. The physicochemical parameters were within the range for growth, survival, and maintenance of *M. modulaides* population in Dumangas, Iloilo. Also, the sediment analysis showed the increasing deposition of fine material and high organic matter content as a result of the deposition of feces and pseudofeces. The decline in horse mussel density was attributed to the sustained exploitation of *M. modulaides* in the area. Furthermore, *M. modulaides* appear to rely on diatoms as their primary source of food while zooplankton may be an important additional food source. As an initial step, these findings should be considered in the development of a management framework for this resource. Moreover, the development of culture technology for *M. modulaides* can be explored for purposes of transplantation and/or sea ranching.

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