An Initial Exploration into the Population Dynamics and Reproduction of *Patelloida saccharina* on Rocky Shores in Taklong Island National Marine Reserve (TINMR), Southern Guimaras, Philippines

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ABSTRACT

The population dynamics and reproduction of the limpet *Patelloida saccharina* (Linnaeus, 1758) on rocky shores in Taklong Island, Guimaras were examined in September 2016 (Southwest monsoon; SW) and December 2016 (Northeast monsoon; NE). Transects were laid parallel to the shore at five different tidal heights and 10 quadrats (25cm x 25cm) were placed randomly along each transect. Shell lengths (SL) of limpets encountered in each quadrat, at every tidal height, were measured to the nearest 0.1 mm using a Vernier caliper. Limpets were observed to occupy the low shores, with sizes ranging from 5.5 to 39.3 mm during the SW monsoon and 3.2 to 38.9 mm during the NE monsoon. *P. saccharina* showed a significant seasonal pattern whereby more limpets were observed during the SW monsoon (108 ind) than the NE monsoon (78 ind). A separate group of 30 limpets, during each season, was also collected to investigate the reproductive characteristics, with SLs ranging from 20.7 – 32.8 mm for females and 21.9 - 34 mm for males. Sex ratio between males and females showed no significant differences between sampling periods ($p > 0.05$). Investment in gonads during the SW monsoon was higher than during the NE monsoon, showing seasonal differences in reproductive effort, with females showing higher GSI compared to males. The higher abundance and increased reproductive investment during the SW monsoon may indicate seasonal differences in food availability or a general reduction in external stress. Further research to elucidate the cause of the observed differences is needed.

KEYWORDS

Intertidal, Limpet, Monsoon, Vertical Distribution, Abundance, GSI, Population Structure, Rocky Shore

INTRODUCTION

Rocky shores are seen as a model system for examining broad ecological concepts and are studied in depth world-wide. Rocky shore ecology is well studied in Asia from Japan (e.g. Fuji and Nomura 1990, Niu et. al. 1992, Imazu and Asakura 1994, Akioka et. al. 2006) to China (e.g. Morton 1990, Williams 1994, Williams et. al. 2000, Dong et. al. 2012) and across much of South East Asia (e.g. Huang et. al. 2006, Tsang et. al. 2008, Samakraman et. al. 2010). However, in the Philippines these studies are few (e.g. Campos et. al. 2010, Campos and Burgos 2017). While this is likely, and understandably, due to the prioritization of habitats with large economic value and greater public appeal, it is time that the rocky shores of the Philippines receive similar consideration to that of rocky shores world-wide. This paper represents the first contribution from what will be a continued effort by the authors to establish ecological baselines for rocky shores of the Philippines. In ecological studies, it is necessary to determine the biological characteristics and life history of species to gain an understanding of the community structure and ecosystem dynamics (Underwood 1979, Fletcher 1987). Rocky shores, being generally accessible, are suitable for study and allow the assessment of general processes such as the distribution and abundance of its various inhabitants (Underwood 1979).

Rocky shores are one of the most productive habitats in the world and are home to some of the most biologically diverse communities (Menconi et. al. 1999). In the Philippines, rocky intertidal areas are made of either volcanic (granitic, basaltic) rocks, limestone from uplifted coral reefs or in few cases, concrete from artificial breakwaters and seawalls (Vallejo 2015). Both sessile and mobile organisms are present in the

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rocky heterogeneous environment (Menconi et. al. 1999). Crabs, grazing snails, bivalves, barnacles, worms, macroalgae, zoanthids, ascidians and adult organisms which are sessile at maturity (i.e. brachiopods, bryozoans, tunicates, sponges) are present on rocky shores (Branch 1981, Underwood 1984). In Taklong Island, Guimaras, rocky shores are covered with coralline encrusting microalgae and biofilm which serves as food for some of the marine invertebrates living in the area. Marine snails and other intertidal invertebrates thus graze on the surface of these rocky shores.

Intertidal areas are regularly submerged and exposed by the tides and the proportion of time spent submerged or emersed differs depending on tidal height. Therefore, the intertidal ecosystem can be divided into levels of tidal heights (i.e. subtidal, low-intertidal, mid-intertidal, and high-intertidal). Each tidal height shelters different types of organisms determined by their tolerances to various physical (e.g. light availability, degree of exposure, temperature and salinity) and biological (e.g. predation and competition) factors, which therefore creates distinct zones in the intertidal community of invertebrates (Branch 1976, Underwood 1984). For example, species in the high-intertidal can best tolerate long exposure to sunlight and air without drying out but are some of the worst in avoiding predation or competing for resources. Species on the low-intertidal are some of the best at avoiding predation but are, however, worse at tolerating high temperatures and extended exposure to air.

In the Philippines, one of the organisms competing for resources such as food, nutrients and space, are limpets. Limpets are major grazers on rocky shores, feeding on encrusting algae and biofilm which are abundant on specific vertical zones (Ballantine 1961, Branch 1981, Fletcher 1987, Niu et. al. 1992, Emam 1994, Saad 1997, Jenkins and Hartnoll 2001, Nakano and Ozawa 2007, Paulo Cabral 2007). In Taklong Island, Southern Guimaras, the limpet *Patelloida saccharina* (Linnaeus 1758) is one of the most abundant gastropod molluscs on the rocky intertidal shores. This limpet is used for making shell crafts and sometimes as food (Laureta 2008). The abundance of this limpet, however, has never been quantified and there has not been a single study on the biology or ecology of P. saccharina in the Philippines.

In other countries, several studies have been conducted on *Patelloida saccharina* and its congenerics. In Hong Kong, the impacts of pollution on the biology and population structure of the limpets *P. saccharina* and *P. pygmaea* were investigated, whereby the life history of individual limpets and limpet populations where found to be affected by changes in their environment (Liu and Morton 1998). In a separate study, sex showed an influence on the abundance of *P. saccharina*, with females appearing to be more dominant than males (Min and Chin 2012). In a study conducted in New South Wales, Australia, the population density of the acmeid limpet *P. alticostata* inhabiting the rocky intertidal platform was higher compared to the subtidal reef (Fletcher 1987).

Generally, the abundance of limpets may lead to competition wherein smaller limpets have limited food consumption compared to larger limpets (Creese 1980). In a given population, limpets vary in size (i.e. the length, width, and height of shells) and these variations account for the different size classes which make up the population structure. In general terms, population structure describes the trends of a population in a given area, for example, juvenile limpets may appear in higher density in the subtidal or low intertidal areas while adult limpets are more common in the mid or high intertidal areas. Differences in population structure can also be observed seasonally, depending on differences in precipitation, temperature and time of day organisms are exposed.

Patelloida saccharina is relatively common on the rocky substrates of Taklong Island, especially between the low- and mid-shores. Despite the ecological importance of limpets and other rocky shore invertebrates, rocky shore ecosystems in the Philippines are understudied with very few records of research conducted on these ecosystems or their inhabitants. This study, therefore, was designed to determine the ecology of the limpet *P. saccharina* on rocky shores in Taklong Island, Southern Guimaras, to provide baseline information of this limpet's abundance and distribution patterns, population structure and reproduction. Results from this research may serve as a scientific basis for future studies, which can be used to help develop the conservation of ecologically important species on rocky shores. Information from this study will also help understand the dynamics of this relatively understudied ecosystem in the Philippines.

MATERIALS AND METHODS

Study Sites and Sampling Period

To obtain a general information on the

biology and ecology of *Patelloida saccharina*, its abundance and distribution, population structure and reproduction were studied on two semi-exposed rocky shores in Taklong Island National Marine Reserve (TINMR) (Site 1: 1 10°24'12.94"N 122°30'37.04"E, Site 2: 10°24'13.99"N 122°30'21.81"E), Southern Guimaras (Figure 1). Field sampling was conducted twice, during low tides, in September / October 2016 and in December 2016, to represent Southwest and Northwest monsoons, respectively.

Comparison between sites was not of interest in this study and subsequent analyses were conducted to show only temporal differences (SW versus NE) apart from specific tests made to compare results between sexes or to show spatial distributions on a tidal height scale. In addition, the field sampling interval between monsoons was short and it should be noted that SW monsoon sampling, conducted in September, did not account for the peak months from June to August.

Abundance, Distribution and Population Structure

Standard transect method (Krebs, 1989) was used to monitor the abundance and vertical distribution of *Patelloida saccharina*. In each site,

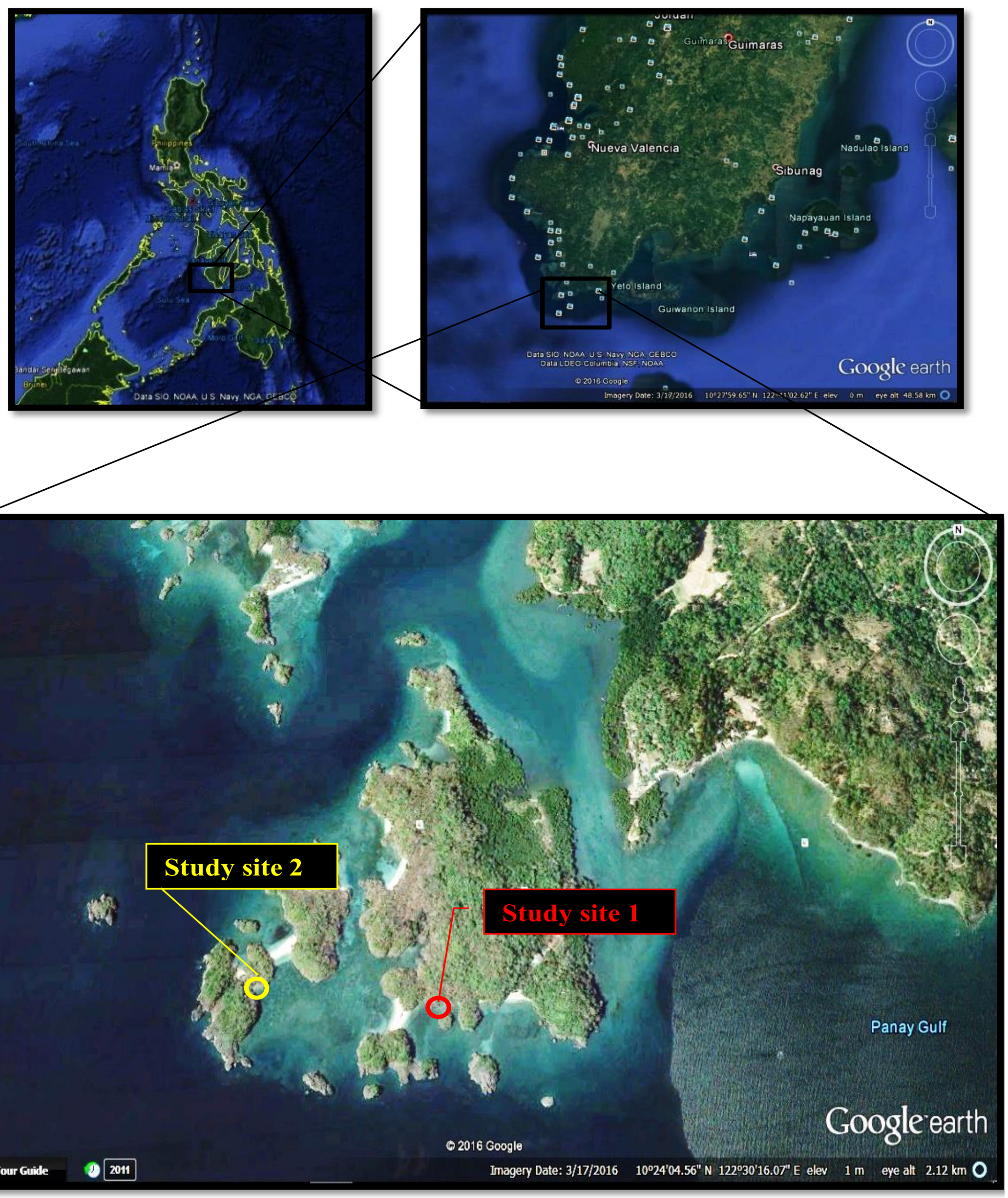

Figure 1. Map Showing the study sites in Taklong Island, Lusaran, Southern Guimaras, Philippines.

five 10m transects were positioned on the low level of the shore at different tidal heights (height intervals of 0.25m) ranging from 0-1.25m above the chart datum (CD) where limpets were observed. On each vertical height, 10 quadrats (25cm x 25 cm = 0.0.625m^2) were placed randomly along each transect line. Limpet densities were calculated for each quadrat and the overall abundance and mean density were determined for each site. Limpet densities were then compared between seasons (temporal) and tidal heights (spatial).

Shell lengths (SL; mm) of limpets encountered in each quadrat, on each tidal height, were measured to the nearest 0.1mm using a caliper to determine the size frequency distribution of the limpet population.

Reproduction

An additional 30 limpets were taken from a separate site for each season for laboratory gonadosomatic index determination (GSI). All individuals sampled were > 20mm SL (i.e. sexually mature) to avoid confounding GSI results from immature individuals (see Villarta 2015). Limpet samples were fixed in a 10% formalin-seawater solution for at least a month to harden the gonads and aid in dissection. During dissection, the gonads were separated from the rest of the body tissue and were macroscopically examined to determine sex. SLs were measured to the nearest 0.1mm using a caliper. Body weights (BW = total weight – shell weight) and gonad weights (GW) were weighed to the nearest 0.01g using a digital electronic balance (Sartorius, Germany). To describe the gonad development, gonadosomatic (GSI in %) was calculated using the following formula (Liu 1994; Belkhodja et. al 2011):

$$GSI(\%) = \frac{\text{gonad weight}}{\text{body weight}} \times 100$$

The limpets were sexed and GSI values were compared and plotted against size for each season. GSIs were compared between seasons (fixed factor, 2 levels), and sexes (fixed factor, 2 levels) using ANOVA. Levene's test was used to check for homogeneity of variances prior to ANOVA.

RESULTS

Abundance, Distribution and Population Structure

Density

The densities of *Patelloida saccharina* (SW: ~6 ind. 0.0625m^{-2}; NE: ~4 ind. 0.0625m^{-2}) showed significant differences between seasons (t-value = <0.011), with more limpets observed during the SW (108 ind) than during the NE (78 ind) monsoon, indicating a seasonal pattern in limpet abundance with respect to monsoons (Figure 2).

Vertical Distribution

Patelloida saccharina were observed only in the low levels of the shore, no individuals were found from 1.25m above C.D. and up. Many of the limpets were recorded between 0.25m and 0.50m

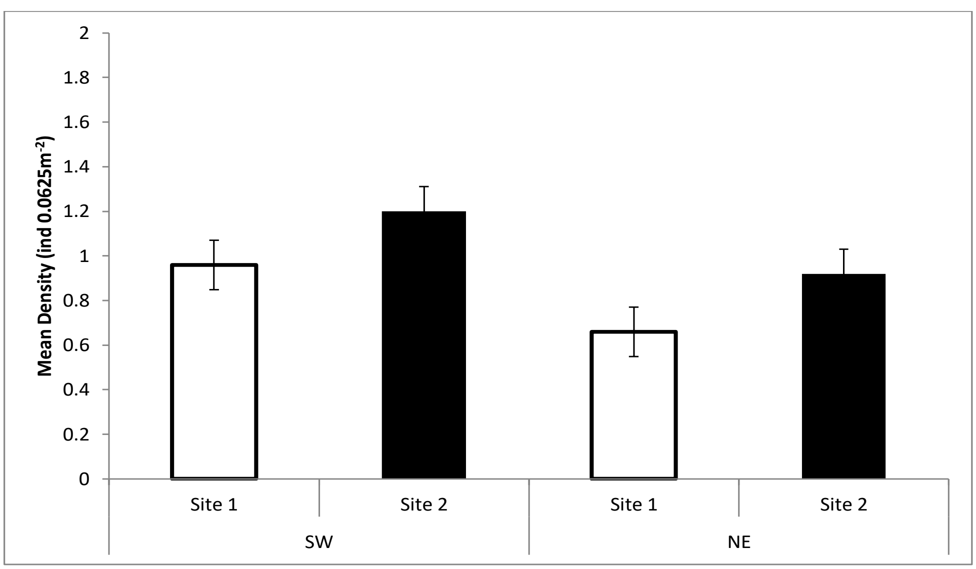

Figure 2. Mean density of *Patelloida saccharina* (No. ind 0.0625m^{-2}) during the SW and NE monsoons, in Taklong Island, Southern Guimaras,

above C.D. (Figure 3) where exposure to sunlight, and consequently high temperature, is minimal.

Size Frequency Distribution and Population Structure

A total of 32 (site 1) and 47 (site 2) individuals were measured during the SW monsoon (size range = 5.5 to 39.3mm) whereas 35 (site 1) and 39 (site 2) limpets were measured during the NE monsoon (size range = 3.2 to 38.9mm). In general, relatively larger limpets were encountered during the SW monsoon (Figure 4) whereas many small individuals were measured during the NE monsoon (Figure 5).

Reproduction

Sex Ratio

A total of 60 individuals (≥ 20mm SL) of *Patelloida saccharina* were examined for gonad development; 30 limpets for each season, size

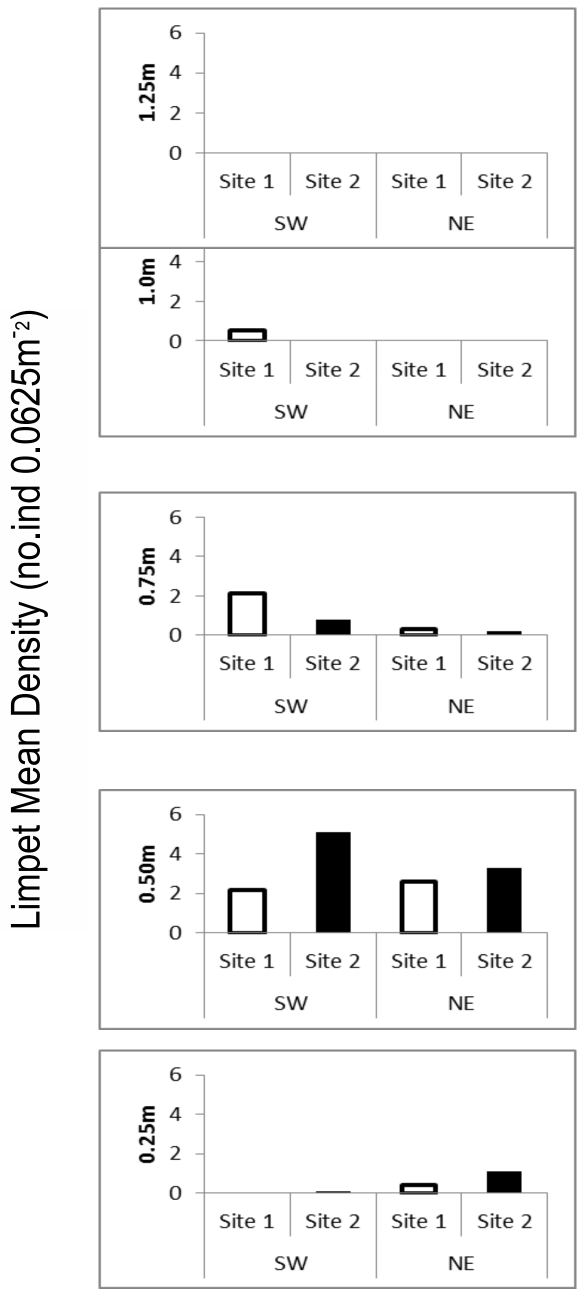

Figure 3. Mean density distribution of *Patelloida saccharina* at different vertical heights during the SW and NE monsoons in Taklong Island, Southern Guimaras.

range = 20.7mm – 32.8mm. The color of the gonads differed between males and females with male gonads being gray to light brown whereas females were pale orange to orange.

In the SW monsoon, 16 males and 14 females were recorded with a male to female ratio of 1.3:1 (X^2 = 0.465, p = 0.515), whereas six males and 24 females were observed in the NE monsoon with

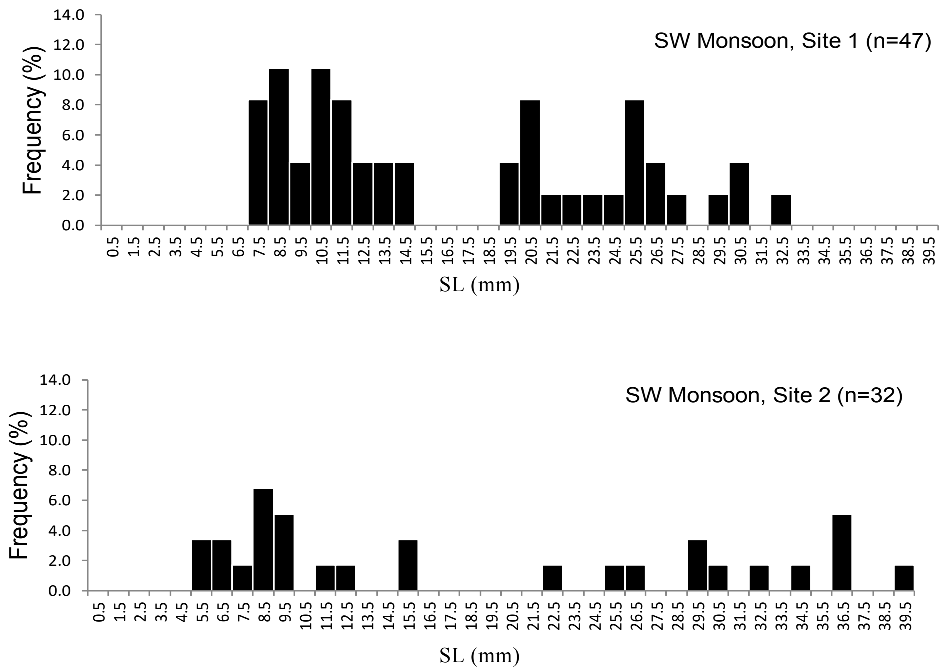

Figure 4. Size frequency distributions of *Patelloida saccharina* in sites 1 and 2 during the SW monsoon in Taklong Island, Southern Guimaras.

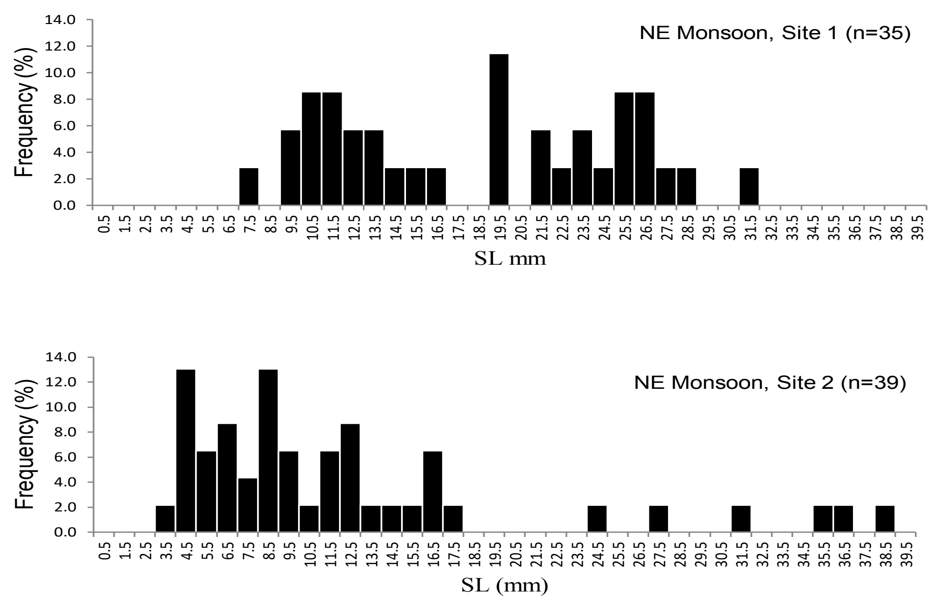

Figure 5. Size frequency distribution of *Patelloida saccharina* in sites 1 and 2 during the NE monsoon in Taklong Island, Southern Guimaras.

a male to female ratio of 0.25:1 (X^2 = 0.001, p= 0.395).

Gonadosomatic index

The gonadosomatic index was used to investigate the reproductive effort of *Patelloida saccharina*. The GSI of male and female limpets from the SW monsoon (September) was significantly higher than those from NE monsoon (December) (p < 0.05; Figure 6). The highest recorded GSI was during the SW monsoon was 9.78% and 16.45% for males and females, respectively (Figure 7). In the NE monsoon, the highest GSI (Figure 8) was 3.99% for males and 5.91% for females. In each season, mean GSI was similar between sexes (SW male = 6.38% and female = 8.71%; NW male = 2.05% and female = 2.88%). The GSI of limpets showed significant interaction between season and sex for both sexes (p < 0.05).

DISCUSSION

Abundance, Distribution and Population Structure

The density of *Patelloida saccharina* was higher during the SW monsoon, indicating a seasonal pattern in limpet abundance. This is similar to observations in the east coast of Thailand showing a decline of limpet abundance during the NE monsoon, which was attributed to a shortage in algal food availability (Samakraman et. al. 2010). In contrast, the limpet *Notoacmea petterdi* in Australia decreased in number during the SW monsoon, but this was also attributed to a decrease in microalgal food (Creese 1980). Food availability, which can be a factor affecting

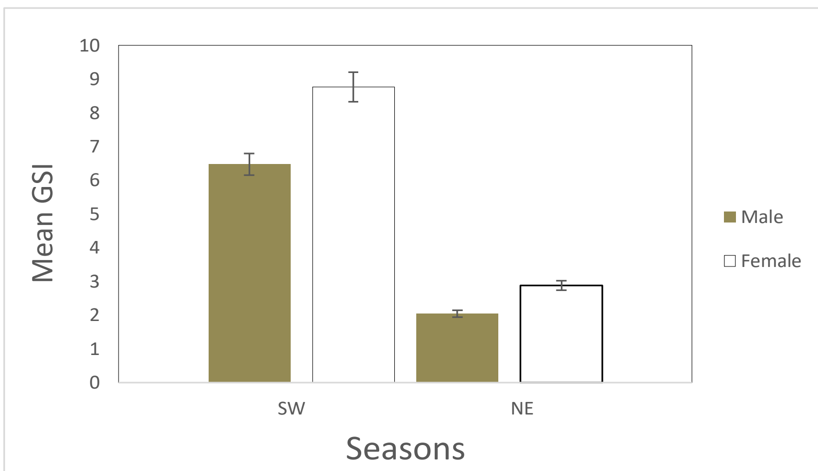

Figure 6. Mean GSI (%) of *Patelloida saccharina* for both sexes plotted against seasons.

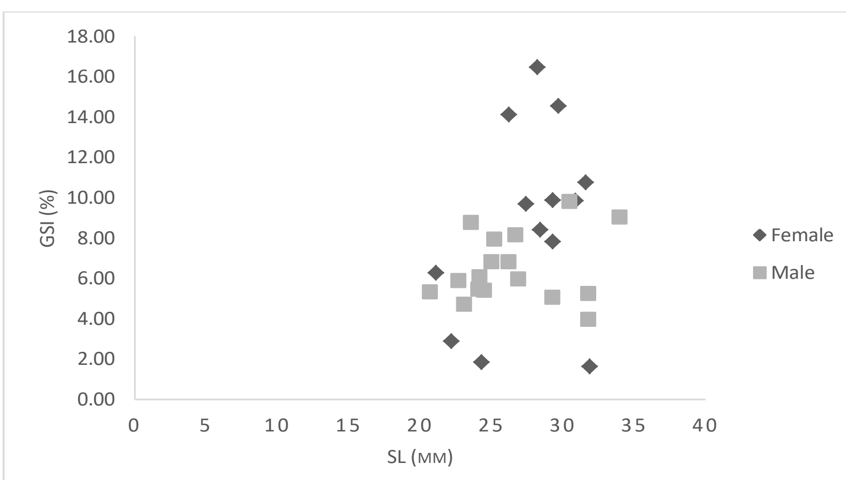

Figure 7. GSI variation in male and female *Patelloida saccharina* in relation to SL during the SW monsoon.

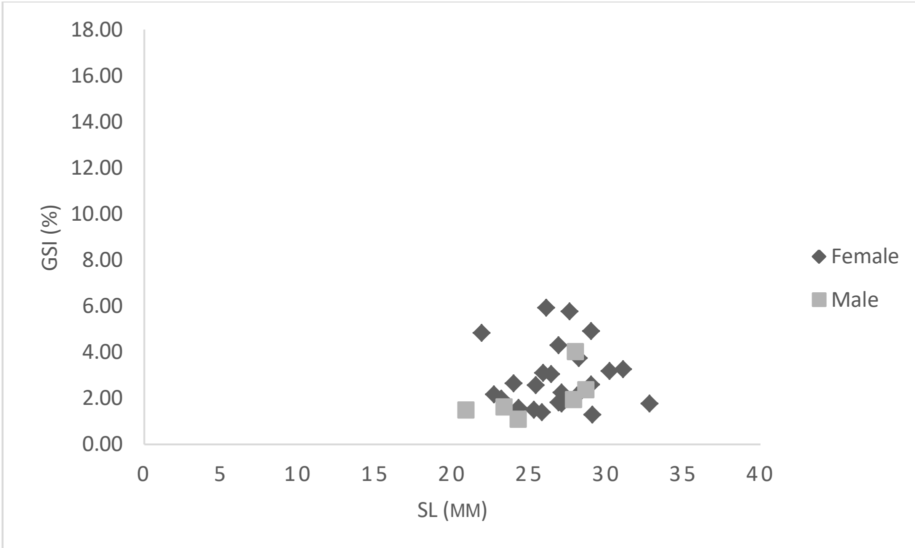

Figure 8. GSI variation in male and female *Patelloida saccharina* in relation to SL during the NE monsoon.

population density, may have changed during the study period but was not measured. The survival of limpets has been shown to correlate with food availability (Branch 1975) wherein high densities of algae can lead to high densities of grazers such as limpets, resulting in a direct proportionality (Lindberg et. al. 1998).

The occurrence of *Patelloida saccharina* exclusively on the low shore means this habitat is more suitable, likely due to lower exposure to sunlight. The presence of limpets on the high shore can be reduced due to exposure to sunlight and wave action (Lewis 1954). Species living in the upper intertidal are subjected to both wetting and drying during each tidal cycle (Branch 1981). The ability to resist desiccation is of primary importance as the loss of body water can be the direct cause of death for these intertidal limpets. When limpets are immersed in sea water, they adjust to its temperature, but when exposed to sunlight and increased air temperatures, body temperatures can exceed the atmospheric temperatures which can cause low growth and death (Blackmore 1969, Branch 1981, Cleland and McMahon 1986).

Most large *Patelloida saccharina* (over 15mm) possess a home scar to which they return after feeding (Figure 9). Studies of *Patella vulgata*, *P. granularis*, and *Lottia gigantea* have been conducted to determine the period of limpets' growth during which they start to establish home scars. According to Gray and Hodgson (1997), some individuals (e.g. *P. granularis*) do not possess fixed scars but tend to return to the same general place after feeding (Branch, 1975). These home scars help the limpets to minimize water loss in times of high temperatures that can lead to desiccation. Water loss can also be reduced depending on the structure of the limpet's shell, including the perimeter of the base, the surface area of exposure and the mass of the soft body (Paulo Cabral 2007). There is a general tendency for limpet species to migrate up the shore over time, so that older and larger individuals are found in the upper regions. Such a zonation according to size is logical in terms of physical stresses, as smaller individuals lose water faster (Blackmore 1969) and are therefore less tolerant to the desiccation stress of the high shores. In addition, juvenile limpets tend to have greater densities at lower tidal levels (Sutherland 1970). Lower mortality rates and a longer period of settlement for larvae are both results of lower desiccation stress at the low shores. High densities of juveniles at the lower levels of the shore have also been observed in *Acmea scabra* (Sutherland 1970), *Patella granularis*, *P. granatina* and *P. concolor* (Branch 1975).

Season is a factor that can also affect the population dynamics of limpets. A study by Niu et. al. (1992) in Hokkaido, Japan showed a typical seasonal growth pattern, wherein all individuals of *Collisella heroldi* grew rapidly from April to October and a high density of juveniles and adults were observed during the SW monsoon. Other organisms such as billfishes in Japan (Kume and Joseph 1969) and the green tiger prawn in Philippines (Villarta et. al. 2006) showed similar seasonal patterns with higher densities observed

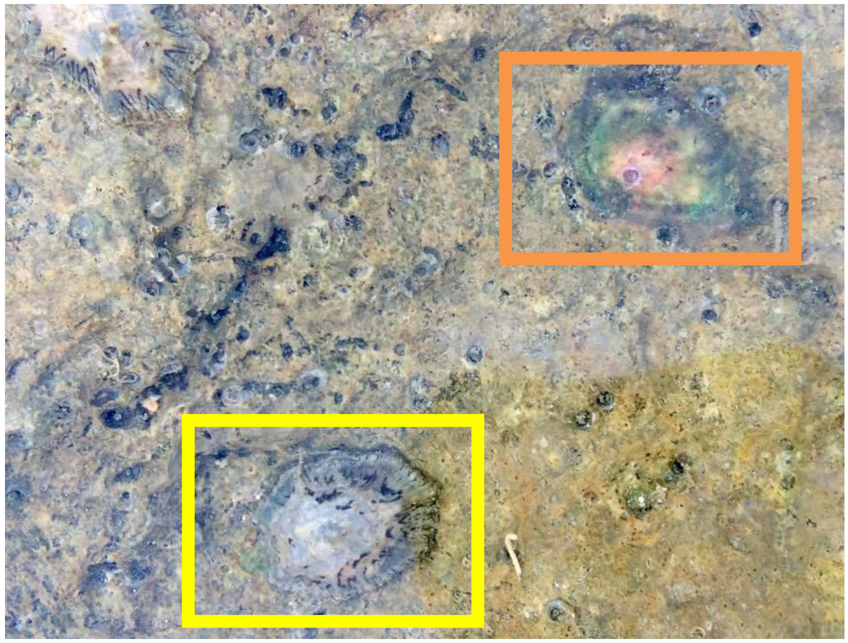

Figure 9. *Patelloida saccharina* (bottom left) returning to its home scar (upper right), photographed on a rocky substrate during a receding tide in Taklong Island, Southern Guimaras.

in warmer months followed by a decrease moving toward colder months. However, a study by Creese (1980) in Australia did not support the claim that limpets prefer warmer months. It was observed that population densities rose between June and September (winter) and stayed constant for the remainder of the study. During these same months, an influx of juveniles accounted for significant increases in population densities. The same was observed in *Cellana toreuma* in Hong Kong where limpet densities are high during winter but are extremely low during summer (Villarta 2015).

Results from the size frequency distribution between monsoons suggest that season does not affect the population structure of *Patelloida saccharina* (Fig 3 and 4). This is, however, inconclusive since the sampling interval between both monsoons was short. SW monsoon sampling, conducted in September, did not account for the peak months from June to August. Additionally, the homogeneity between seasons in regard to size frequency distributions and minimum and maximum SLs may be misleading and a more thorough long-term investigation is recommended to provide more information on the patterns of growth, mortality, and longevity of *P. saccharina*.

Reproduction

In the SW monsoon, the sex ratio was nearly even, whereas during the NE monsoon the sex ratio was heavily biased toward females. This may indicate a difference in mortality between the sexes, with more males dying between the two sample periods although this needs further investigation. In other limpets, a slightly female-biased sex ratio has been observed in *Patelloida pygmaea* (1:1.09; Liu 1994) and *Cellana grata* (1:1.13; Liu 1994). Dominance of females over males has been observed in molluscs that are dioecious and is common in older populations (Fretter and Graham, 1964). Other species of limpets showed a more male-biased sex ratio, such as *Patella caerulea* (2.5:1; Belkhodja et. al. 2011), *Patella rustica* (2.58:1; Zegaoula et. al. 2016), *Helcion pruinosus* (1.56:1; Henninger and Hodgson 2001), and in *Patella vulgata* (1.3:1) and *P. ulyssiponensis* (2.4:1; McCarthy et. al., 2008).

The color of the gonads differed between males and females, which is common among limpets. In this study male gonads were gray to light brown whereas females were pale orange to orange. However, other gonad colors are apparent in species of limpet such as *Patella vulgata* which have pinkish white or cream male gonad and green or brown female gonad (Orton et. al. 1956) and the limpet *Cellana radiata* which has yellow or orange male gonad and dark brown female gonad (Rao 1973).

In this study, the gonadosomatic index was used to investigate reproductive effort (Parry 1982), and results showed the GSI of limpets interacted with season and sex, with females having higher

GSIs than males in both seasons, and both male and female GSIs being higher during the SW monsoon. Females allocating more the energy into reproductive activity overall than males is a trend that has also been observed by Parry (1982) in the limpets, *Cellana tramoserica*, *Notoacmaea petterdi*, *Patella peroni*, and *Patelloida alticostata*. In contrast, male investment in gonads is higher in *Helcion pruinosus* from South Africa (Henninger and Hodgson 2001) and *Cellana ornata* from southern New Zealand (Dunmore and Schiel 2010).

The high GSI values observed during the SW monsoon suggests that most *Patelloida saccharina* individuals' gonads may be at the late developing or mature stage, although further investigations are required to confirm this. The observed reduction in the GSI in the NE monsoon, may indicate that the limpets had already released their gametes. In general, reproduction of marine invertebrates is triggered by environmental factors (Zegaoula et. al. 2016). Differences in spawning activity of limpets are thought to be caused by several factors such as food availability (Fletcher 1984), salinity (Rao 1973), and temperature (McCarthy et. al. 2008; Belkhodja et. al. 2011; Rao 1973). Limpets adapted to cold waters spawn when the temperature is low (Cape d'Aguilar, Liu 1994; Algeria, Zegaoula et. al. 2016) and those adapted to hot water spawn when temperature is high (South Africa, Henninger and Hodgson 2001).

Using temperature and rainfall as bases, the Philippine climate can be divided into two major seasons: (1) the rainy season, from June to November; and (2) the dry season, from December to May, influenced by the SW monsoon and NE monsoon, respectively. *Patelloida saccharina* displayed mature gonads during the SW monsoon, suggesting reproductive activity. Rain could also be brought by SW monsoon and it could be that the nutrient inputs from the land affect reproductive activity as more nutrients become available. In addition, wind may also influence the spawning activity of limpets (Belkhodja et. al. 2011). The SW monsoon brings strong winds, causing rough seas, which may also trigger the release of gametes in *P. saccharina* as has been observed in *Cellana radiata* in India (Rao 1973).

CONCLUSION

Patelloida saccharina's distribution and gonadal condition in the Philippines show similar tendencies to those found in other regions of the world. Further study is needed to verify the seasonal trends that the data presented here show. Long-term study of the rocky shore ecology in the Philippines will fill, what is now, a relative dead zone in intertidal research. As a country with an extensive shoreline, intertidal areas are important parts of Philippines' natural resources and studies in this region will contribute further when assessing large scale gradients or trends throughout Asia or the world.

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