University of Algarve

Diet and feeding activity of *Olivella minuta* (Link, 1807) (Mollusca, Gastropoda, Olividae) along the intertidal – subtidal zone of a dissipative sandy beach in the north coast of São Paulo – Brazil

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Declaração de autoria de trabalho

"Declaro ser a autora deste trabalho, que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída."

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Abbreviations

I-HT – Intertidal during high tide

I-LT – Intertidal during low tide

S – Subtidal zone

NI – Numeric importance index

FO - Frequency of occurrence index

SW- Weight of full stomach

WG- weight of sediment

SCW- weight of stomach contents

IR – Stomach repletion index

S – Species Richness – Margalef index

J – Pielou´s Evenness Index

H`- Shannon-Wiener diversity index

D – Simpson's Dominance Index

Resumo

As praias arenosas são dos ambientes mais hostis para as comunidades de organismos bentónicos. Estas áreas estão sujeitas a uma enorme intensidade de factores que as moldam morfologicamente ao longo do tempo e que, consequentemente, afectam a distribuição e o comportamento dos organismos que nelas ocorrem. O dinamismo ambiental, resultado da variação de parâmetros abióticos, tais como regime de ventos, ondas, correntes e marés, com consequentes alterações na morfodinâmica da praia, leva os organismos intertidais a desenvolverem adaptações morfológicas, fisiológicas e comportamentais que os permitem suportar o dinamismo do ambiente costeiro. Dito isto, acredita-se que a estrutura de comunidades e populações em praias arenosas é determinada pela morfodinâmica, na qual os factores físicos são predominantes. De acordo com a Hipótese de Severidade Ambiental (HSA) para praias arenosas, as populações de praias reflectivas deverão exibir menor abundância, crescimento, fecundidade e maior esforço reprodutivo e maior taxa de mortalidade quando comparadas a populações de praias dissipativas, uma vez que o impacto de facotes abióticos em praias dissipativas é considerado reduzido, fornecendo aos organismos estabilidade para o seu estabelecimento nestes ambientes.

O conhecimento sobre como a interacção de factores bióticos e abióticos pode modular a distribuição de uma espécie, são fundamentais para entender a dinâmica e ecologia da população em um ecossistema de praia. Além disso, a análise da dieta, através da análise do conteúdo do estômago, é uma ferramenta importante para a compreensão da ecologia de uma comunidade, pois além de nos fornecer dados de como as espécies se sobrepõem no uso de recursos alimentares, a interacção dos mecanismos biológicos das espécies em uma comunidade também é observada. Deste modo, a análise do conteúdo estomacal, torna-se uma ferramenta importante para validar a importância da posição trófica de um predador particular no fluxo de energia de um ecossistema, bem como determinar a estratégia de alimentação e da composição de alimentação.

Gastrópodes têm uma grande quantidade de hábitos alimentares, podendo ser detritívoros, necrófagos, predatórios, herbívoros, e muitos são omnívoros. Em muitos fundos moles, as suas actividades alimentares são conhecidas por afectar a estrutura da comunidade, especialmente macro e meiofauna. Por outro lado, são esperadas variações dentro das populações desde que os recursos tornam-se fonte de heterogeneidade na distribuição e abundância dos organismos. Assim sendo, neste estudo foram avaliados quais os efeitos dos ciclos de maré bem como diurno/nocturno, na dieta alimentar e actividade locomotória do gastrópode *Olivella minuta*, numa praia arenosa de baixa energia dissipativa, Praia de Barequeçaba, localizada no Litoral Norte do Estado de São Paulo (Brasil), tendo como base, a HSA. As amostragens foram realizadas tanto em condições de submersão, (na zona intertidal durante maré alta e no subtidal durante maré baixa) com o auxilio de um puçá, bem como quando sujeitos à exposição do ar (no intertidal durante maré baixa), através das marcas sinuosas deixadas por este predador no sedimento. Trinta indivíduos com comprimento de concha igual a 7 mm foram amostrados em cada situação e os seus conteúdos estomacais foram analisados tanto por métodos quantitativos (importância numérica (NI) e frequência de ocorrência (FO)), bem como por meio de análises qualitativas, através da determinação dos índices de diversidade de Shannon, equitabilidade de Pielou, dominância de Simpson e Riqueza de espécies.

O índice de repleção estomacal mostrou actividade alimentar desta espécie em todas as situações, com um acentuado pico de actividade quando exposta a períodos de maré baixa. Um total de 49 itens alimentares foi registado no trato digestivo de *O. minuta*, sendo macroalgas (48%), microalgas (15%), artrópodes (12%) e foraminíferos (12%) os recursos mais consumidos por este gastrópode. Itens alimentares com proporções inferiores a 10% também foram identificados nos estômagos deste gastrópode, tal como itens indeterminados (7%), Porífera (3%), vermes (2%) e moluscos e ciliados ambos com 1% de NI. Bactérias foram também identificadas na dieta alimentar de *O. minuta* mas não apresentaram importância significativa na composição alimentar deste gastrópode.

A maré não mostrou ser factor chave na selectividade alimentar de *O. minuta*, dado que a composição alimentar destes organismos não se mostrou significativamente variável entre as três situações estudadas (Intertidal durante maré alta, intertidal durante maré baixa e zona subtidal), onde macroalgas e foraminíferos foram os itens alimentares mais abundantes nos estômagos deste organismo em cada situação particular estudada. Os resultados sugerem que a espécie não possui uma preferência por uma única fonte de alimento, e a variação dos valores de NI e FO ao longo das situações pode ser meramente consequências da dinâmica de cada um dos itens alimentares face ao ciclo das marés. Também a fase de maré não se mostrou relevante na actividade locomotora de *O. minuta.* Por outro lado, o ciclo dia / noite simulado em condições de laboratório mostrou grande significância, onde menores percursos foram observados nos tratamentos sujeitos a períodos de dia. Estudos prévios realizados em gastrópodes sobre o seu comportamento locomotor associado a alimentação, leva-nos a reforçar a hipótese proposta neste estudo, em que o comportamento locomotor de *O. minuta* é influenciado pela disponibilidade de recursos alimentares no ambiente. Os resultados do nosso experimento laboratorial reforçam a ideia de que estes organismos quando emersos e durante períodos de maré baixa apresentam uma maior actividade alimentar, essencial para a manutenção dos seus recursos vitais, tais como crescimento e reprodução. Também o enterramento em profundidade no sedimento durante o dia, como foi observado em laboratório, pode ser um mecanismo de defesa contra a dessecação e predação. Os resultados deste estudo vão de acordo com a hipótese da severidade ambiental para praias protegidas, morfodinâmicamente dissipativas, como foi modelo deste estudo, praia de Barequeçaba. Neste extremo dissipativo, a influência de factores abióticos (neste caso o ciclo de marés), não mostrou ser o factor mais importante nas funções vitais (alimentação e deslocamento) deste gastrópode. O seu comportamento (diurno e enterramento no sedimento) sugere uma possível adaptação destes organismos de forma a evitar a predação bem como uma forma de maximizar a qualidade ou quantidade de alimento disponível no local quando expostos ao ar e á luz em ambientes arenosos.

Palavras-Chave: Praias arenosas; Zonas subtidal e intertidal; estrutura de comunidades e populações; actividade alimentar; Índice de repleção estomacal; *Olivella minuta*

Abstract

The present study aimed to investigate the diet and feeding activity of a sandy-mud snail, *Olivella minuta* along the gradient subtidal-intertidal of a dissipative morphodynamic beach: Barequeçaba (southeast coast of Brazil). Locomotor behavior of the species was also evaluated in laboratory conditions. The sampling was carried out in March, April and May, 2013 in the intertidal zone during low and high tide and in the subtidal zone during low tide, to further comparisons if these organisms change their diet according to the variation of the tide. Thirty specimens from 7 mm of length were caught in each situation and stomach contents were analyzed by means of qualitative (richness, diversity, evenness and Simpson) and quantitative indexes (numeric importance (NI) and frequency of occurrence (FO)). Also, the index of stomach repletion was calculated to complement the analysis of the feeding diet of this gastropod.

A total of 49 items was registered in the digestive tracts of *O. minuta* being the most frequents: macroalgaes (48%), microalgaes (15%), artropodes (12%) and foraminiferans (12%). The remaining items had frequency of occurrence lower than 10%. The results of the diet composition of the individuals did not differ along the tidal range of the beach, suggesting that the species does not possess a preference for a single food resource, and the variation on NI e FO in all studied situations can be merely consequences of the dynamics of each food items during the tidal cycle.

The results of the stomach repletion suggest that this snail feed in all studied situations, but with higher intensity when emerged during low tide and the results of locomotor behavior tested experimentally, reinforce this idea and still suggests that during the day this organisms have a higher feeding activity rather than at night, since a lesser movement was displayed in these conditions.

Keywords: Sandy beaches; Subtidal and intertidal zones; community and population structure; feeding diet; stomach content; *Olivella minuta*

1. Introduction

The open coastlines of the world are dominated by sandy beaches (Bascom, 1980), and are highly valued by society since they are the prime sites for human recreation and support many coastal economies (Klein *et al*, 2004).

Sandy beaches have special ecological features because besides harboring an enormous biodiversity that is generally not recognized (Brown & Silva, 1984; Armonies & Reise, 2000), also provide unique ecological services, supporting coastal fisheries (McLachlan *et al*, 1996), providing habitats for endangered species (feeding and nesting sites) (Rumbold *et al*, 2001), nutrient recycling (McLachlan *et al*, 1985), filtration of large volumes of water (McLachlan & Brown, 2006), exporting productivity to adjacent ecosystems, and due to their great extension, they are also very important to total coastal productivity (Wilson, 1999).

Beaches are resilient, however, these ecosystems are facing anthropogenic pressures that coupled with natural impacts, alter ecological features such as the hydrodynamic conditions or sediment features resulting in loss of diversity at local and large scale (McLachlan, 1996; Schlacher *et al*, 2007).

These unique ecosystems are one of the most dynamic environments on the surface of the planet, where basic parameters such as water, sand and winds coupled to its effects on intensity of environmental factors such as tides, currents and waves, leads to a hydrodynamic and depositional complex processes, shaping the morphology of these environments (Brown & McLachlan, 1994; Bergonci, 2005). Coastal dynamics not only affect the beach morphology but also the geomorphology, being the main force responsible for the constant variation of erosion and deposition processes in the development of sandy beaches (Short & Wright, 1983). Interactions between these natural physical factors allow the beaches to be classified according to the exposure degree, from very exposed to very protected; and according to the degree and intensity of these factors, the beaches can be classified into several morphodynamic types: two extreme states: dissipative and reflective, and four intermediate stages (McLachlan, 1980, Short & Wright, 1983).

Reflective beaches are formed under conditions of intense wave action and small tides; and are characterized by steep slopes, no surf zone, coarser sand and wave energy breaking directly on the steep beach face. Crustaceans are the most common organisms in this type of beach, besides presenting great mobility, support better the impact of the waves. On the other hand, the dissipative state is characterized by fine sand, soft beach slope, wide surf zone and formed under conditions of high wave energy and large tides, grade into tidal flats. Due to the compaction of sediment, this type of beach promotes the formation of burrows and tubes for living organisms, being composed mainly by mollusks and polychaetes. A series of intermediate states are recognized between the above extremes, later subdivided according to different degrees of wave-sediment interaction (Wright & Short, 1984; Short, 1996).

Various indices of beach type have been used by ecologists in order to group beaches with similar morphodynamic features, being the most used the Ω Dean (Wright & Short, 1984) and the RTR (Masselink & Short, 1993) parameters (Figure 1.1).

Dean parameter (Ω), classifies the beaches into reflective or dissipative taking into consideration aspects as height and period of waves and sedimentation velocity. Essentially, measure the ability of the wave energy to erode sand (Wright & Short, 1984) while the *Relative Tide Range* (RTR) parameter, proposed by Masselink & Short (1993) classifies the beach type having as criteria the influence of waves versus tides in morphology of the beach.

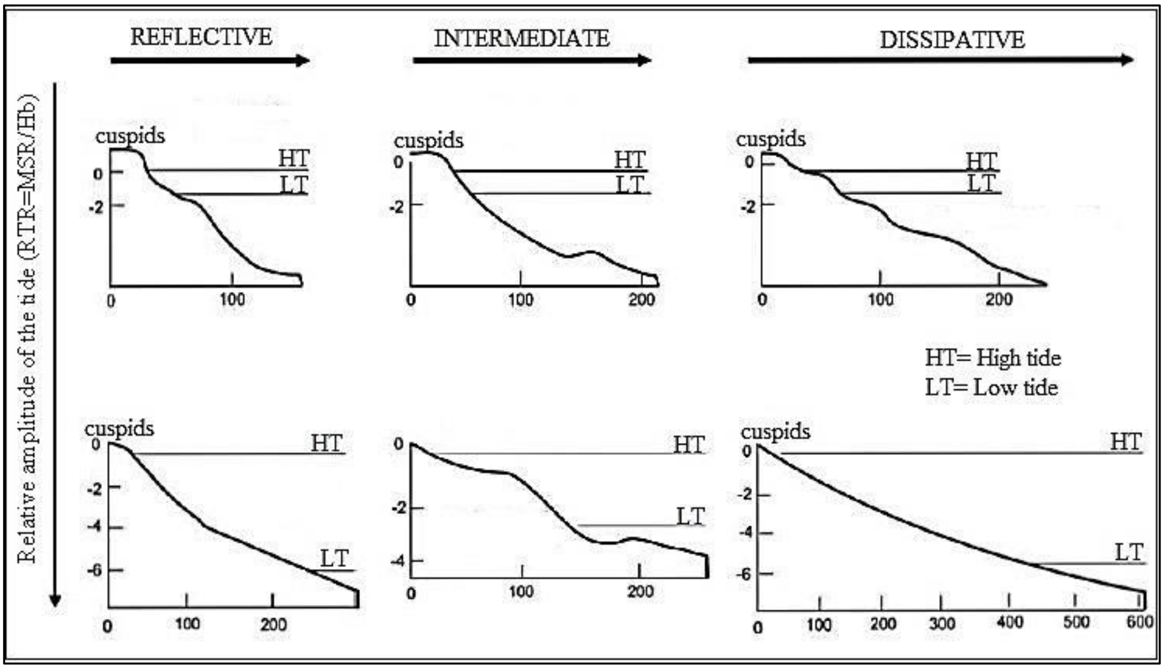

Figure 1.1 - Classification of beach morphodynamic states, defined by the parameters of Dean Ω (Wright & Short, 1984) and RTR (Masselink & Short, 1993) (Adapted from Souza, 2012)

The environmental changes associated with the morphodynamic gradient seem to have relevant consequence on the distribution and zonation pattern on intertidal macrofauna (Mclachlan, 1990, 1996; Mclachlan *et al.*, 1993; Jaramillo *et al.*, 1993; Mclachlan & Jaramillo, 1995). In the intertidal zone, an area subject to a great physical variation (temperature, salinity, humidity, light intensity, and wave impact), depending on the season and the slope of the beach, the organisms may remain exposed to these stresses (Veloso *et al*, 1997). So, macrofauna have to develop specific adaptations to inhabit different types of the beach in response to fluctuations on physical parameters (sediment grain size, wave action, tides, water content, temperature and salinity of the interstitial water) as well as biological factors, such as recruitment, competition, predation, and migration (McLachlan & Jaramillo, 1995; Neves & Bemvenuti, 2009).

On sandy beaches, zonation pattern is not so clear as in coastal ecosystems like rocky shores and biological zones are dynamic and difficult to define, due to high hydrodynamic of these habitats (Amaral *et al*, 1990). Most of the organisms are small or buried in the unconsolidated substrate (Raffaelli *et al*, 1991).

Dahl (1952), based on biological parameters and Salvat (1964), based on physical parameters, proposed different classifications of distribution and zonation of the benthic macrofauna for these highly hydrodynamics environments (Figure 1.2). According to Dahl (1952), three distinct zones can be defined: 1) sub-terrestrial fringe, occupied by talitrid amphipods, ocypodid crabs and other species of terrestrial origin; 2) midlittoral zone with cirolanid isopods, haustorid amphipods and spionid polychaetes; and 3) sublittoral fringe with donacid bivalves, hippid crabs, mysids, amphipods and polychaetes. On the other hand, Salvat (1964), taking into account the amount of water in the sediment, defined four distinct zones along the beach profile: 1) drying zone, barely reached by waves, being washed on rare occasions; 2) retention zone, which despite being washed by all tides, loses water by capillarity; 3) resurgence zone where water flow is controlled by fluctuation of tides; and 4) saturation zone, where the sediment is always saturated with water.

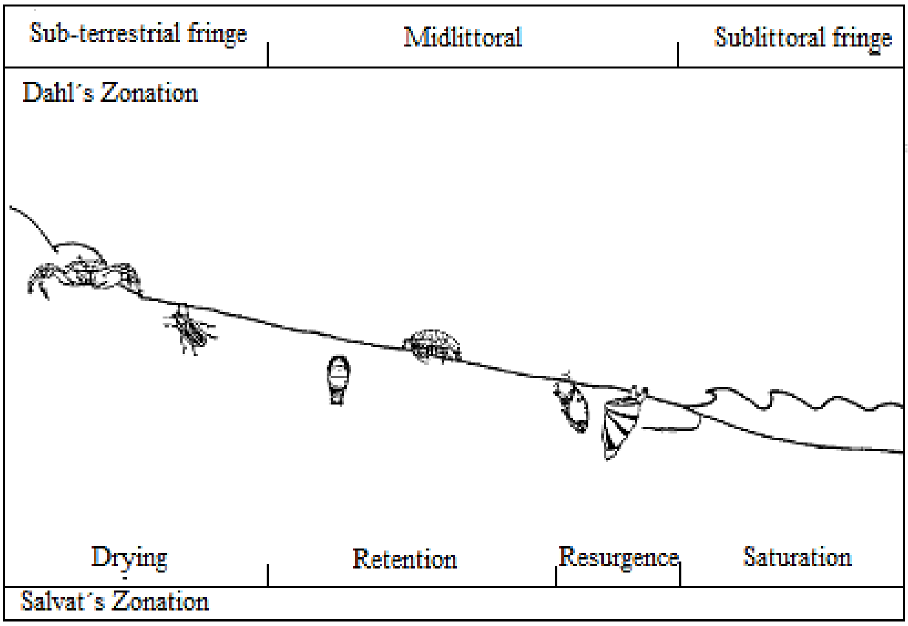

Figure 1.2 -Schemes of biological (Dahl, 1952) and physical (Salvat, 1964) zonation of sandy beaches (Adapted from Veloso et al, 1997).

These zonation schemes, although recognized previously as universal, did not accounted key factors in the distribution of species, such as temporal variability and morphodynamic differences among beaches (Degraer *et al*, 2003). Due to these gaps, later in 1995, Jaramillo *et al*, established a relationship between the physical and biological zones and defined three distinct zones, considering that these areas are adjusted daily to the limit of the beach. These areas are: 1) supralitoral (sub-terrestrial fringe and drying zone) inhabited by talitrid amphipods, oniscid isopods or ocypodid crabs, 2) littoral (midlittoral, retention and resurgence zone) inhabit by cirolanid isopods, haustorid amphipods and spionid polychaetes and 3) subtidal (sub-littoral fringe) where a wide variety of species may be encountered, such as donacid bivalves, mysids, amphipods, hippid crabs and polychaetes.

The action of physical and biological factors at different spatial-temporal scales, will trigger alterations in the morphodynamic of beaches and, consequently, affecting the distribution and behavior of intertidal macrofauna (Veloso *et al*, 1997). In this way, the responses of populations of sandy beaches or even benthic associations fluctuate naturally, according to the disturbances of cyclic periodicity (Schoeman *et al*, 2000), but can also respond to stochastic events (Brauko, 2005). Thus, various types of adaptations of the macrofauna on the intertidal region can be observed, allowing them to integrate the type of environment compatible with their requirements (McLachlan & Jaramillo, 1995).

Such adaptations can be aggregations which result from the passive selection by waves, whereas the scale of patches can vary between 10 m to 100 m from reflective to dissipative beaches of high energy, respectively and are mainly associated with areas of great concentration of food (Mclachlan & Hesp, 1984; Tarr *et al*, 1985). The structure of intertidal organisms in these patches varies according to the susceptibility of each species or population component (recruits and adults) to variations on food availability, temperature, factors influenced by environmental conditions, and local topography (McKillup *et al*, 1993; Cardoso & Veloso, 2003). Example of this can be observed in amphipods, mole crabs and isopods, which indicates different abilities of the components of a population (recruits and adults) to select a favorable microhabitat which reduces intraspecific interactions between them, for space and food (Defeo & Mclachlan, 2005).

Migration and burrowing activity are an escape behavior to the action of predators, excessive turbulence, destructive action of waves or even a way to keep populations in optimal local of availability of food (Trueman, 1971) and the properties of sediment show a significant role in these activities as in the burrowing abilities of errant animals to burrow or construction of tubes by sedentary organisms (Bray & Lawrence, 1993). For example, *Ilyanassa obsoleta* when exposed on wet sediment have the capacity to burrow and remain more active than when is exposed to dry sediment (Coulthard & Hamilton, 2011), thus, the sediment shows great importance in the behavior of these animals, may limiting their survival face harsher conditions of the environment.

Example of migration can be observed in gastropods of the genus *Donax*, resulting of changes in the physical properties of the sediment (sediment water content) (Ansell, 1983). On the other hand, in crustaceans, migration is maintained by endogenous rhythm to produce peaks of activity in order to maintain their position on the beach, the best conditions for production and feeding, as well as a way to avoid predation (McLachlan & Jaramillo, 1995). In talitrid amphipods, small individuals are dependent on passive transport by waves, while larger individuals have the capacity to regulate their position on the beach because these have a highest mobility and are able to burrow fast (Scapini *et al*, 1996).

One strategy to combat thermal stress, another variable parameter in the environment, is to increase the efficiency in extraction of oxygen from water as well as the ventilation rate (Thompson & Pichard, 1969). For example, the neogastropod *Bullia digitalis* when facing conditions of organic pollution becomes an oxiregulator (Wynberg & Brown, 1986) while

Donax sierra, uses anaerobic metabolism when exposed to thermal stress (Trueman e Brown, 1989). Physiological plasticity in the responses of organisms to oscillations in the temperature and salinity occur on a population level. Populations from different latitudes or different areas in the same beach may show varying characteristics (recruitment, fecundity, reproduction time, and growth rate) depending on specific environmental conditions that they are subjected in each habitat (Dugan *et al*, 1994).

Benthic macrofauna are used as environmental bioindicators, providing information about natural and anthropogenic impacts on a habitat, community or ecosystem (Ajmal *et al*, 2004). Since it is associated with unconsolidated substrates, plays an important role in communities, performing a key function in the energy flow, the chains of marine and estuarine food webs at different trophic levels (mineralization, oxygen flow within the sediments, cycling of organic matter and mixing of sediments) (Taheri *et al*, 2012). Example of this can be observed in the burrowing crab *Chasmagnathus granulatus*, considered an ecosystem engineer, because their bioturbator activitiy have direct and indirect effects in the infaunal organisms affecting the interactions with other species (Escapa *et al*, 2004). Also Tubiculous invertebrates are very important in the environment, because they create new habitats and provide feed resources to other species (Barbosa & Chícharo, 2010; Amaral & Nallin, 2011).

As result of these morphological, physiological and behavioral adaptations face to these highly dynamic environments (Brown & McLachlan, 1990; Scapini *et al*, 1997), the community and population structures, composition, abundance and diversity of benthic organisms on these habitats are controlled mainly by the responses of each species to the physical environment (organic matter content, beach slope, salinity, temperature and moisture of the sediment), once the influence of biotic interactions (recruitment, predation, competition and food availability) is considered relatively lower (McLachlan *et al,* 1995, 1996; Defeo & McLachlan, 2005). However, biological factors assume more importance on protected (low energy) beaches with dissipative morphodynamic state (Defeo *et al*, 2003, Defeo & McLachlan, 2005, McLachlan & Dorvlo, 2005), where the reduced influence of abiotic factors generate ideal conditions to the establishment of species, which would not survive in areas with high morphodynamic.

In order to explain the variations in the structure of different communities, hypotheses were established (Defeo & McLachlan, 2005; McLachlan & Dorvlo, 2005) but recently there was an increase in such studies for populations that occur on beaches with different morphodynamic characteristics (Dugan & Hubbard, 1996; Defeo *et al*, 1997; Gómez & Defeo, 1999; Jaramillo *et al*, 2000a,b; Defeo *et al*, 2001; Nel *et al*, 2001; de la Huz *et al*, 2002; Marcomini *et al*, 2002; Cardoso *et al*, 2003; Cardoso & Veloso, 2003; Contreras *et al*, 2003; Defeo & Cardoso, 2004; Brazeiro, 2005; Defeo & Gómez, 2005; McLachlan & Dorvlo, 2005; Celentano & Defeo, 2006; Delgado & Defeo, 2006; Thompson & De Bock, 2009; Celentano *et al*, 2010).

The Swash Exclusion Hypothesis (SHE) proposed by McLachlan *et al*, (1993), states that swash climate is the key factor on the distribution of species along the morphodynamic gradient of sandy beaches. In this way the establishment of the species is much lower on reflective beaches, due to the increasing swash speed and a decrease of swash period and length. In this way, an exclusion of the intertidal species occurs, because they do not tolerate the high hydrodynamic stress. The swash climate has direct consequences on the macrofauna, leading to a reduction of feeding time, risk of organisms being swept or removed from the substrate; elevate exposure to air (desiccation). According to this hypothesis, sandy beach communities increase in abundance, richness, biomass and density, from microtidal reflective beaches to macrotidal dissipative beaches (McLachlan *et al*, 1981, 1993, 1996a; McLachlan, 1990; Jaramillo *et al*. 1995).

Based on theory formulated for communities - SHE (McLachlan *et al*, 1993), Defeo *et al*, 2001 and Defeo & Martínez, 2003, create a Habitat Harshness Hypothesis (HHH) to populations of sandy beaches. These authors related the cause - effect of three factors physically correlated on the morphodynamic of the beaches, they are: swash climate, dynamics of erosion - accretion and sediment size. These authors state that these three factors, will affect the distribution of species along the morphodynamic gradient of the beach. In reflective beaches, dominated by high wave energy, environmental severity will be higher compared to beaches dominated by tides (dissipative).

This hypothesis has a certain importance, because it agrees with the interspecific variability in ecological traits and life history of communities in sandy beaches. It assumes that different limiting factors control species with different characteristics (Brazeiro, 2001). One example is the effect of the dynamics of the swash in organisms with different types of locomotion. In slightly mobile animals like polychaetes and mollusks, the swash effect will have a higher impact when compared to mobile and fast animals, such as crustaceans

(McLachlan *et al*, 1995; Brazeiro, 1999b). According to this hypothesis, reflective beaches populations should exhibit lower abundance, growth, fecundity, and reproductive effort, and higher mortality rates when compared with populations of dissipative beaches. Instead, animals in reflective beaches would require a greater energetic investment in their maintenance than in growth and reproduction (Gomez & Defeo, 1999; Defeo *et al*, 2001). Thus, and due to this dynamic environment in space and time, it is believed that the structure and composition of communities and populations of benthic organisms in reflective morphodynamic beaches are mainly influenced by the physical environment, since the action of biological interactions is considered reduced in this environment. The organisms that support wave impact and the severity of these environments are the most frequent in this type of beaches, for the ability to burying or even a higher mobility, such as crustaceans (Nybakken, 1993). In dissipative beaches, biological interactions assume greater importance, since the higher dissipation of wave energy creates conditions for the establishment of species.

Refuges may be important in maintaining abundance and/or diversity of benthic organisms in areas where physical and biological disturbances have profound effects (Woodin, 1978; Wilson, 1979), since these organisms are food source for birds, insects and arachnids from land, resident invertebrates, notably crabs and fishes from the sea (Nybakken, 1993; Amaral *et al*, 1994; Defeo & McLachlan, 2005). Also, the coexistence of species in a particular habitat is only possible, if strategies to minimize competition between them are developed, such as the use of different sources of energy (e.g., suspension feeders, deposit feeders, scavengers), have different reproductive modes (e.g., pelagic larvae, brooding), and occupy different zones of the intertidal (Brown & McLachlan, 1990; McLachlan & Jaramillo, 1995, Brazeiro & Defeo, 1996; Pianka, 1973).

The knowledge about the trophic position of a particular predator in the energy flow of an ecosystem is important to see how the species overlap in the use of food resources and to understand the biological mechanisms of how species integrate in a community (Amezaga-Herran, 1988; Amundsen *et al*, 1996; Zavala-Camim, 1996). For example, predator gastropods that consume dominant species can raise the local diversity by favoring poor competitors (Kelaher *et al*, 2003). Also, *Nassarius obsoletus* (Say, 1822), a gastropod from the Family Nassaridae, has a great importance in estuaries because their removal from salt marshes results in a significant increase in epibenthic microalgae and microbial communities (Pace *et al*, 1979).

Mollusks are important components of marine benthos with the Class Gastropoda being the most diverse. They are evolutionarily diverse, not only in the substrate, but also in feeding habits (Arruda *et al*, 2003) and show a wide range of anatomical, physiological and ecological possibilities face environmental variations. Also, marine gastropods possess great amplitude of feeding habits such as algae grazing, suspensivory by sessile individuals, detritivory, parasitism and predation (Anderson & Underwood, 1997; Kelaher *et al*, 2003; Taylor *et al*, 1980, Biggatti *et al*, 2010).

According to Rhoads and Young (1970), the distribution of gastropods in sandy beaches, being predators, herbivores, or scavengers, is directly conditioned by the pattern of food availability, which in turn depends on the hydrodynamic and morphodynamic of the beach.

In marine communities, they are numerically important and the most species are integrated to the family of the order Ceaenogastropoda, especially suborder Neogastropod (Taylor *et al*, 1980). Neogastropods show anatomical differences relative to feeding apparatus, such as modification and elaboration of the anterior digestive system and the radule, elaboration of an extended superficial area through repeated folding in the chemoreceptor osfradium and a well - developed siphon, which differentiates them from other gastropods, and make them more adapted in the exploration of food resources in different habitats (Ponder, 1973).

One of the most common families of neogastropods in sandy beaches is Olividae, which includes the genera *Olivella*, *Oliva* and *Olivancillaria* (Mclachlan & Brown, 2006), inhabiting sandy shores in tropical and subtropical regions of the world (Petuch & Sargent, 1986), measuring from 10 mm to 100 mm in size (Smith, 1998). *Olivella minuta* (Link, 1807) (Figure 1.3), occurs in Texas, western India, eastern Colombia, Venezuela, Suriname and Brazil (Salvador *et al*, 1998). In Brazil, they show a great distribution from the coast of Santa Catarina to Ceara (Rios, 1994) and it is one of the most frequent mollusks on protected beaches on the north portion of the State of São Paulo (Denadai *et al*., 2005). In Barequeçaba Beach corresponds to one of the most abundant species of mollusks (Shimizu, 1991). Despite of its frequency and abundance in protected and exposed sandy beaches (Denadai *et al*, 2005; Rocha- Barreira et al., 2005; Viana *et al*, 2005), estuaries (Rolemberg *et al*, 2008), and tidal plains (Boehs *et al*, 2004), studies of this genus in the sandy beaches of the Brazilian coast, and throughout the world are scarce and limited to systematic (Severeyn *et al*, 2003; Boehs *et al*, 2004), anatomy (Marcus and Marcus, 1959a,b), use of the shell by hermit crabs (Turra &

Leite, 2003; Turra & Denadai, 2004), feeding behavior (Arruda *et al*, 2003) and spatial distribution (Shimizu, 1991; Arruda & Amaral, 2003).

Figure 1.3 - Specie of study – *Olivella minuta* (Link, 1807) (http://www.conchology.be/images/Label/580000web/586555.jpg)

The knowledge about the feeding diet of *O. minuta* is very scarce; Marcus & Marcus (1959) observed individuals of *Donax hanleyanus* (Philippi, 1847) (Bivalvia: Donacidae), as well as foraminiferan, copepods, anfipods, and scaphopods in their stomachs. Another study registered as the most common items on the digestive tract of *O. minuta*, fragments of crustaceans and foraminiferans (Arruda *et al*, 2003). *Olivella minuta* was characterized by the authors as a carnivorous/scavenger. According to these authors, *O. minuta* is not a selective species, a characteristic shared by most neogastropods.

An initial assessment of the pattern of zonation of *Olivella minuta* in Barequeçaba beach along the gradient intertidal - subtidal, indicates a spatial segregation according to the size of individuals, where juveniles were only registered in the subtidal region (Yokoyama & Turra, in prep.a). A cause for this segregation by size is the existence of an advantage to individuals who remain in the intertidal area, as a protection from predators or because of resources of higher energy value. Thus, regarding this last factor, it is expected that there is a difference in the diet of organisms as result of differences in microclimates (Intertidal - Subtidal). This difference cannot be related to feeding preference alone; it can be derived from the adaptations of the snails in relation to local hydrodynamic conditions. The variations in the tidal levels are a key factor in form and intensity of the unequal distribution and in the position of fauna along the beach (Defeo, 1993).

Understand how the diet of the most abundant species are affected when they migrate or move in order to escape of predation pressure and how the tidal submersion affects them, is of extreme importance for the reconstruction of the dynamics of the food chain (Alfaro, 2008). Thus, considering the feeding habits of *O. minuta*, the main aim of the present study was to analyze its feeding diet along the gradient intertidal – subtidal regions in a dissipative sandy beach to investigate the hypothesis: if differences in diet composition and indices of stomach repletion of this species will be found among the areas where their habitat is divided. Moreover, it is also an objective of this study to evaluate the locomotor behavior of individuals of *O. minuta*, testing the following hypothesis: Does the locomotion of *O. minuta* depends on the variation of environmental factors, such as, the condition of tides and period of the day? Also, in the case of locomotion of the *Olivella minuta* be connected directly to their foraging activity, will be expected that smaller movement of the individuals of *O. minuta* are associated with a higher foraging activity due to the greater amount of food found.

2. Goals

The present study had as main goal, a comparative analysis of the diet of *O. minuta* along the gradient subtidal-intertidal of Barequeçaba beach, which was subject to conditions of emersion and submersion along the beach profile, with further comparisons if these organisms change their diet according to the variation of the tide.

In order to complement the analysis of the diet, the locomotor behavior of individuals of *O. minuta* were compared between treatments with different simulated environmental conditions (condition of tide and period of the day). The hypothesis to be tested was based on the fact that if locomotion of the *O. minuta* is connected directly to their foraging activity, smaller movement of the individuals will be expected to be associated with a higher foraging activity due to the greater amount of food encountered in the field.

In sum, in this work, the main objectives are to evaluate:

- Feeding diet of the mud-snail *Olivella minuta* along the gradient intertidal – subtidal of a morphodynamic dissipative beach, in Brazil (through the analysis of stomach contents, with further use of the index of stomach repletion)

- Movement of the mud-snail *Olivella minuta* according to environmental conditions variation, such tidal conditions and period of the day (through observation and measurement of trace left by gastropods on the sediment).

3. Material and Methods

3.1 Study area

The individuals of *Olivella minuta* were collected on the intertidal and subtidal fringe zones of Barequeçaba Beach (23°49’43’’S, 45°26’02’’W), located in the municipality of São Sebastião, northern coast of the State of São Paulo, Brazil (Figure 3.1.1). Barequeçaba is a dissipative and low-energy (sheltered) beach, with a length of 1.1 km (Souza, 2012), a wide surf zone, steep slope (~0.78°), fine and very fine sand with low organic matter content (~0.75%) (Nucci *et al*, 2001; Denadai *et al*, 2005, MacCord & Amaral, 2005), and 2 m of maximum tide range (Furtado & Mahiques, 1990). This beach is located near the São Sebastião channel, close to the Port of São Sebastião and the Oil Terminal of São Sebastião, as well as the outfall of a central sewage, which receives only basic treatment (Denadai, 2001). Thus, given its location, this beach is frequently subject to various forms of man-induced stress such as oil spills, wastewater discharge, structures or activities affecting natural sand transport, and balance (Amaral *et al*, 2003; Schlacher *et al*, 2007; Dugan *et al*, 2008; Defeo *et al*, 2009).

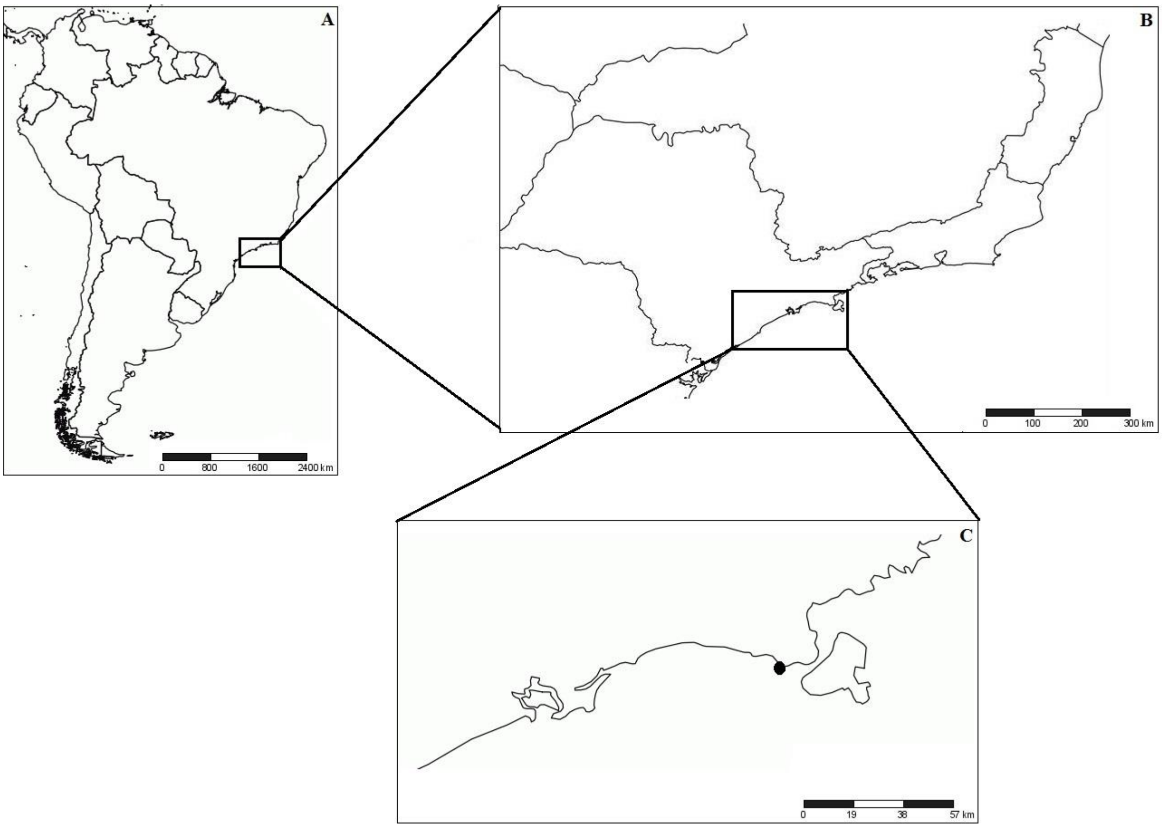

Figure 3.1.1 - Study area showing the position of Brazil (A), the State of São Paulo (B), and Barequeçaba Beach (C), which is indicated by a black dot.

3.2 Sampling and laboratory procedures

3.2.1 Feeding diet

The samplings of *O. minuta* were done in March, April and May 2013 in Barequeçaba Beach with the aim to analyze the feeding diet of this species. Individuals were sampled in three different situations: in intertidal region near the waterline either in periods of high tide as in low tide on the same day and in subtidal region (30 meters from waterline) during low tide. Previous samplings provided data for choosing the best area to achieve the proposed goals, those in which individuals were in high abundance.

In each situation, 30 individuals with shell length of 7.0 mm were handpicked from the sediment.

To obtain biological samples on subtidal and intertidal regions during high tide, small portions of sediment were sieved through a 1.0 mm mesh, and individuals were hand-collected. Characteristic marks left in the sediment by these organisms, allow their collection during low tide. All organisms were immediately fixed on ethanol 70% to avoid further digestion during the transport to the laboratory.

In the laboratory, the individuals had their shell length measured with the aid of a caliper, were extracted from its shell and had their stomach dissected (Figure 3.2.1.1). Each stomach was analyzed for all possible food items, including inorganic matter such as sediment (Yokoyama e Turra, in prep. a) with the aid of a stereomicroscope. The stomach content was photographed and food items were counted and identified to the lowest taxonomic level possible with the help of experts.

The method of dry weight was used to quantify the inorganic material (sediment) on the stomachs. To do so, the sediment was separated from the rest of the stomach content carried to an oven which was subject to a period of 30 minutes at a temperature of 100 °C and then, weighed on an analytical balance with minimum accuracy of 0.0001 g. Besides the weight of the sediment (GW), another parameters were weighted, such as, weight of full stomach (SW) and weight of stomach contents (SCW).

To complement the analysis of the composition of the diet *O. minuta*, we calculated the Stomach Repletion Index (IR), which indicates the feeding activity of the specimens (Hyslop, 1980), and is given by the expression IR = 100 (WE / WT) where: WE: total mass of stomach content (to the nearest 0.0001 g) and WT: total mass of gastropod in grams (to the nearest 0.0001 g) (Brandão *et al*, 2009).

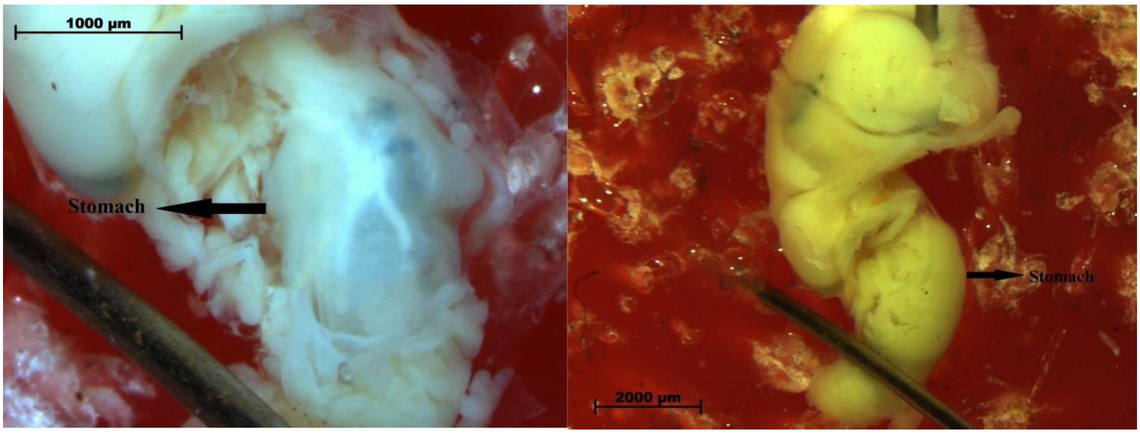

Figure 3.2.1.1 - Dissection process of the stomach of *Olivella minuta* (Source: Leonardo Yokoyama)

3.2.2 Movement

Individuals of *O. minuta* were sampled in April and May 2013 during low tide periods in the intertidal region of Barequeçaba Beach. This experimental test was performed in the laboratory, due to conditions unsuitable for development in the field.

Four treatments were established (Figure 3.2.2.1): NI: Nocturne, Immersion; NE: Nocturne, emersion; DI: diurnal, immersion status; DE: diurnal, emersion status. The methodology for this goal was based in photos taken of the marks left by organisms in the sediment in each treatment, to further comparisons of the distance traveled by the gastropods in the different treatments (Figure 3.2.2.2). Previous observations were done, in order to standardize the waiting time between the movement of organisms and the moment that the photos were taken, in order to reduce deviations in the samples.

A total of 20 individuals (5 per treatment) with shell length > 7.0 mm were collected, were taken to the laboratory and left to acclimate for a period of 24 hours inside an aquarium with water and constant aeration. This step was performed daily until reaching the replicates of each treatment (a total of 120 individuals). The temperature was controlled at 25ºC and the sediment was defaunated in a greenhouse during 24 hours at a temperature of 100 ºC, not allowing the interference - on the analysis of the factors proposed in this study.

Finally, it was started the experiment, and photos were taken at intervals of two hours (waiting time predefined).

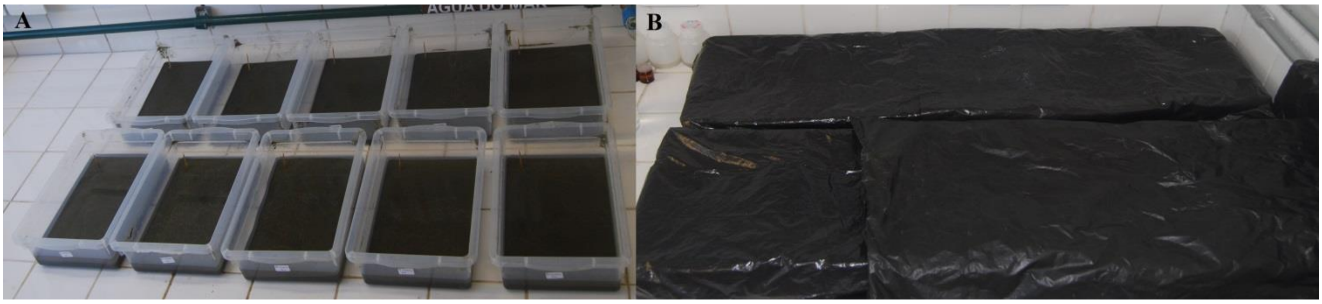

Figure 3.2.2.1 - Movement experiment setup with **A**: Treatments emersion / immersion simulating light conditions; **B:** Treatments emersion / immersion simulating night conditions.

Figure 3.2.2.2 - Marks left by organisms in the sediment in each treatment: A- Diurnal, Immersion; B- Nocturne, Immersion; C- Diurnal, Emersion; D- Nocturne, Emersion.

3.3 Data analysis

3.3.1 Feeding diet

The characterization of the feeding diet of *O. minuta* was based on the methods of Megina *et al*. (2002) and Megina & Cervera (2003) by two main criteria: (I) qualitative and (II) quantitative. The qualitative analysis was based in the count of taxa presented in the diet and in the determination of Shannon diversity (H), evenness of Pielou (J) and indexes of diversity and dominance of Simpson (Krebs, 1989). These indexes were used to produce comparisons in the feeding diets throughout the three situations (I-HT, I-LT and S). The quantitative analysis was based on the numeric proportion of each item in the total number of items identified (NI) given by the equation $NI = (Nti / N)*100$, where Nti is the total number of the feeding item I and N is the total number of all the feeding items. The frequency of each item (FO) was given by the equation $FO = (Nei / Ne)*100$, where Nei is the number of individuals of *O. minuta* in which the item I was registered and Ne is the number of *O. minuta* analyzed.

To analyze the feeding composition per sample in each situation, analyzis were performed using the statistical program PRIMER6 (Plymouth Routines in Multi Ecological Research). First, a worksheet of similarity between paired samples with transformation (logx + 1) was extracted for each situation, through the Bray-Curtis similarity distance. The next step was to test through the analysis of similarity (ANOSIM one-way), the hypothesis that there were no significant differences regarding to the feeding composition of *O. minuta* between the three different tidal conditions (I-HT, I-LT and S). Analyzis of similarity were performed with the general data of each situation to see a pattern of feeding composition of this species. Significance level of $p < 0.05$. The ANOSIM test produces a statistic R, which range from -1 to +1, in which values of R close to +1 indicate groups totally different and values R close to zero indicate similar groups. In other words, R values equal to +1 are obtained when all the samples within the groups (tidal conditions) are more similar than any sample of different groups.

An analysis of non-metric Multi-Dimensional Scaling (n-MDS) for each situation (tide), for each sample within each tidal condition, and the data for the three conditions together were done. This analysis allows the viewing in two-dimensional of the ordination of the samples according to the degree of similarity between them.

To check the contribution of each food item on the differences between two groups a percentage analysis of similarity (SIMPER) was applied. This analysis indicates which items are responsible for the observed clustering pattern and differences between groups of samples are defined a priori. Thus, in order to know if variation of tide has some effect in the feeding diet of the gastropods, both qualitative and quantitative analyses were performed for each tidal condition.

All indexes (IR, S, J, H´and D), as well as, other parameters calculated in the analysis of the feeding diet of *O. minuta* (SW, GW and SCW) were compared between the three situations (I-HT, I-LT and S) through a test of analysis of variance (ANOVA – one way), and in the case of significant differences, a posteriori Tukey's test was applied. The normality and homogeneity of variance were evaluated by chi-square test, and for cases of heterogeneity of variances, Kruskall-Wallis test was applied. All tests had a significance level of 5% ($p < 0.05$).

3.3.2 Movement

The photos were evaluated regarding to the distance traveled by the organism and their direction with the aid of Image J program. To test if significant differences existed between treatments (Immersed – day; Immersed - Night, Emersion-day; Emersion - Night), data was subjected to a bifactorial Analysis of Variance (ANOVA) (2 treatments X 10 samples). Each analysis was followed by a posteriori test of Tukey to identify the treatments that differed significantly from the others. The normality and homogeneity of variance were evaluated by chi-square test, and for cases of heterogeneity of variances, Kruskal-Wallis test was applied individually to each variable of study. In the latter case, to test if significant differences existed between treatments, a Duncan test was applied.

4. Results

4.1 Feeding diet

All individuals of *Olivella minuta* had at least one food item in their stomachs in all three areas. A total of 49 items was registered in the digestive tracts of *O. minuta* (Table 4.1.1). Macroalgae dominated with 48% of the total food items identified followed by Microalgae (15%), Artropods and Foraminifers (both with 12%), undefined items (7%), Porifera (3%), worms (2%) mollusks and ciliates both with 1% of occurrence. Bacteria did not have a significant importance in the feeding composition of *O. minuta* (Figure 4.1.1). Non-plant fibers had a great expression in all situations, however it was not included on the study of the diet of this gastropod, because it is believed that it is probably remains of the digestive tract of the animal as a result of scraping process of the stomach contents.

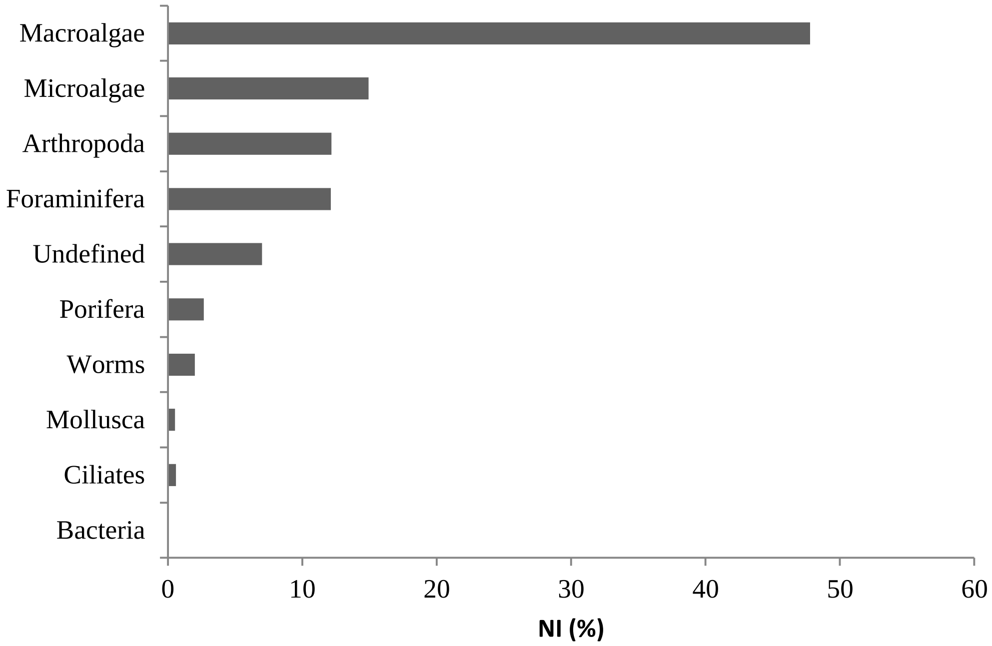

Figure: 4.1.1 - Numeric importance (NI) of the main taxa present on the stomach contents of *Olivella minuta* on Barequeçaba beach.

On I-HT, the most frequent items found on stomachs were the macroalgae *Ulva* (FO=60.00%), macroalgae *Derbesia* and undefined Foraminifera (both with 56.67% of FO), Clorophyta (53.33%), foraminifera Miliolidae and macroalgae *Colpomenia* both with 50 % of occurrence and the microalgae *Prorocentrum* with 46.67%. Other items, such as fragments of crustaceans, vegetable fibers and centric diatoms had FO of about 35%. Pennal diatoms, undefined microalgae, and undefined macroalgae had approximately 16% of FO and the others had less than 10% of occurrence (Table 4.1.1).

On the stomachs of the *O. minuta* from the I-LT, the most frequent items were the macroalgae *Colpomenia* (FO=60.00%), Foraminifera Miliolidae (56.67%), macroalgae *Derbesia* (36.67%), undefined Microalgae (33.33%), and undefined Foraminifera (30.00%). Other items, such as fragments of crustaceans, fixing rizoide and vegetable fibers had FO of about 25%. Undefined macroalgae, Clorophyta, and fragments of Kinorhyncha had approximately 20% of FO. Nematoda had 13.33% of FO and *Ulva*, spicules, and gelatinous organisms had 10% each, the remaining items had less than 10% of occurrence (Table 4.1.1).

Finally, on subtidal zone, fragments of crustaceans were the most frequent food item with 53.34% of FO. Macroalgae *Ulva* was the second food item more frequent with FO of 40%. Macroalgae *Colpomenia* had 36.67%, followed by Centric Diatoms with 33.33% of FO and foraminifera Miliolidae with 30%. Other items, such as undefined macroalgae which had 26.66% of FO, macroalgae *Ulva* and chlorophyta with 23.33%, nematode with 16.67% of FO, Fragments of Tintinnidae, Pennal Diatoms, Vegetable fiber and undefined foraminifera with 13.33% of FO had significant importance in the feeding diet of *O. minuta* in this area. The remaining items had less than 10% of occurrence (Table 4.1.1).

Numeric importance (NI) of the different food items also varied between the three areas sampled (Table 4.1.1).

On I-HT, the macroalgae *Derbesia* with 15.08% of NI, Fragments of Crustaceans (11.45%) and Clorophyta (11.20%) were the food items that had the highest values of NI. Undefined Foraminifera and *Ulva*, each one with NI of 8%, followed by Centric diatoms (7%); Miliolidae, *Prorocentrum* and *Colpomenia* with 6% of NI to all, and Vegetable Fiber with 5% of numeric importance. The remaining food items had values of NI lower than 5%.

On the other hand, the macroalgae *Colpomenia* had the highest NI (30.44%) on I-LT, followed by Foraminifera Miliolidae (12.67%) and *Derbesia* (10.44%). Excluding the item vegetable fiber with 6% of NI and undefined microalgae, Clorophyta and undefined macroalgae with 5% of numeric importance, the remaining items had values of NI lower than 5%.

On Subtidal zone, fragments of crustaceans had the highest value of NI (17%) followed by *Colpomenia* (14%) and *Ulva* (10%). The food item centric diatoms had 8% of numeric importance, Clorophyta and undefined macroalgae showed 6% of NI, while the *Prorocentrum* was the only food item with 5 % of NI. The remaining food items had values on NI lower than 5% (Table 4.1.1).

Table 4.1.1 - List of food items in the stomach contents of *Olivella minuta* of Barequeçaba beach, with relative frequency of numeric Importance (NI), and Frequency of Occurrence of each item (FO).

Taxa	**Food item**	**I-HT**		**I-LT**		**S**	
		NI %	FO %	NI %	FO %	NI %	FO %
Bacteria	*Brucella sp.*	-	-	-	-	0.19	3.33
Ciliates	*Eutintinnus sp.*	-	-	0.22	3.33	-	-
	Fragments of Tintinnidae	-	-	0.22	3.33	1.15	13.33
	Undefined	-	-	0.22	3.33	-	-
Worms	Turbellaria	-	-	0.22	3.33	0.38	3.33
	Nematoda	1.15	3.33	0.89	13.33	1.35	16.67
	Fragments of Nematoda	-	-	-	-	0.19	3.33
	Kinorhyncha	0.57	6.67	-	-	-	-
	Fragments of Kinorchya	-	-	2.44	20	-	-
	Undefined	-	-	-	-	0.38	6.67
Foraminifera	Miliolidae	5.92	50	12.67	56.67	2.88	30
	Rotalida	-	-	0.44	6.67	0.58	10
	Ammonia sp.	0.19	3.33	-	-	-	-
	Eponides sp.	0.19	3.33	0.44	6.67	-	-
	Pararotalia sp.	0.19	3.33	-	-	-	-
	Bulimina marginata	0.19	3.33	-	-	-	-
	Nonion fabum	-	-	0.44	3.33	0.19	3.33
	Undefined	8.4	56.67	3.33	30	0.96	13.33
Microalgae	Pennal Diatoms	2.48	13.33	2.44	6.67	1.73	13.33
	Centric Diatoms	6.68	36.67	0.22	3.33	7.69	33.33
	Pseudoanabaena sp.	-	-	-	-	0.19	3.33

	Prorocentrum sp.	5.53	46.67	0.22	3.33	5.38	30
	Undefined	1.91	16.67	4.89	33.33	4.42	6.67
Macroalgae	Rhodomelaceae	-	-	-	-	0.38	6.67
	Phaeophyta	-	-	1.78	6.67	1.15	3.33
	Chlorophyta	11.26	53.33	4.89	20	5.58	23.33
	Ulva sp.	8.02	60	1.11	10	9.81	40
	Leathesia sp.	-	-	-	-	2.12	3.33
	Chaetomorpha sp.	0.38	3.33	0.67	3.33	0.58	3.33
	Colpomenia sp.	6.49	50	30.44	60	14.04	36.67
	Derbesia sp.	15.08	56.67	10.44	36.67	4.04	23.33
	Ceramium sp.	-	-	-	-	0.19	3.33
	Polysiphonia sp.	0.19	3.33	-	-	0.38	3.33
	Undefined	4.2	16.67	4.89	20	6.16	26.66
Porifera	Spicules	1.34	6.67	4.22	10	2.69	3.33
Mollusca	Pectinidae	0.19	3.33	-	-	-	-
	Mytilus sp.	-	-	0.22	3.33	-	-
	Hiatella sp.	-	-	-	-	0.58	3.33
	Undefined Gastropoda	0.19	3.33	-	-	-	-
	Fragments of mollusca	-	-	0.22	3.33	0.19	3.33
Arthropoda	Pantopoda	-	-	0.22	3.33	-	-
	Harpacticoida	0.19	3.33	0.22	3.33	0.19	3.33
	Ostracode	0.19	3.33	-	-	0.19	3.33
	Fragments of Crustacea	11.45	33.33	2.22	23.33	16.74	53.34
Undefined	Gelatinous fecal pellet	-	-	0.44	6.67	0.58	3.33
	Gelatinous organisms	-	-	0.89	10	0.58	10
	Fixing rizoide	2.67	30	2.22	23.33	4.23	30
	Vegetable fiber	4.77	33.33	5.56	26.67	1.54	13.33
	Animal fiber	-	-	-	-	0.37	3.33

To analyze the variation of feeding composition of *Olivella minuta* between the three situations, we opted to exclude the food items with values of NI lower than 1%, once these items did not show significant for the analysis at issue. So, in the I-HT, 2.67% of items were excluded, 6.44% in the I-LT and 6.33% in the subtidal zone. Thus, from a total of 49 food items identified in the diet composition *O. minuta*, only 20 showed a significant importance for the characterization of the diet of this species, with emphasis to macro and microalgae in all situations, followed by foraminifers as the second food item more consumed by this species on intertidal zone, while on subtidal zone, fragments of crustaceans had a greater relevance (Figure 4.1.2).

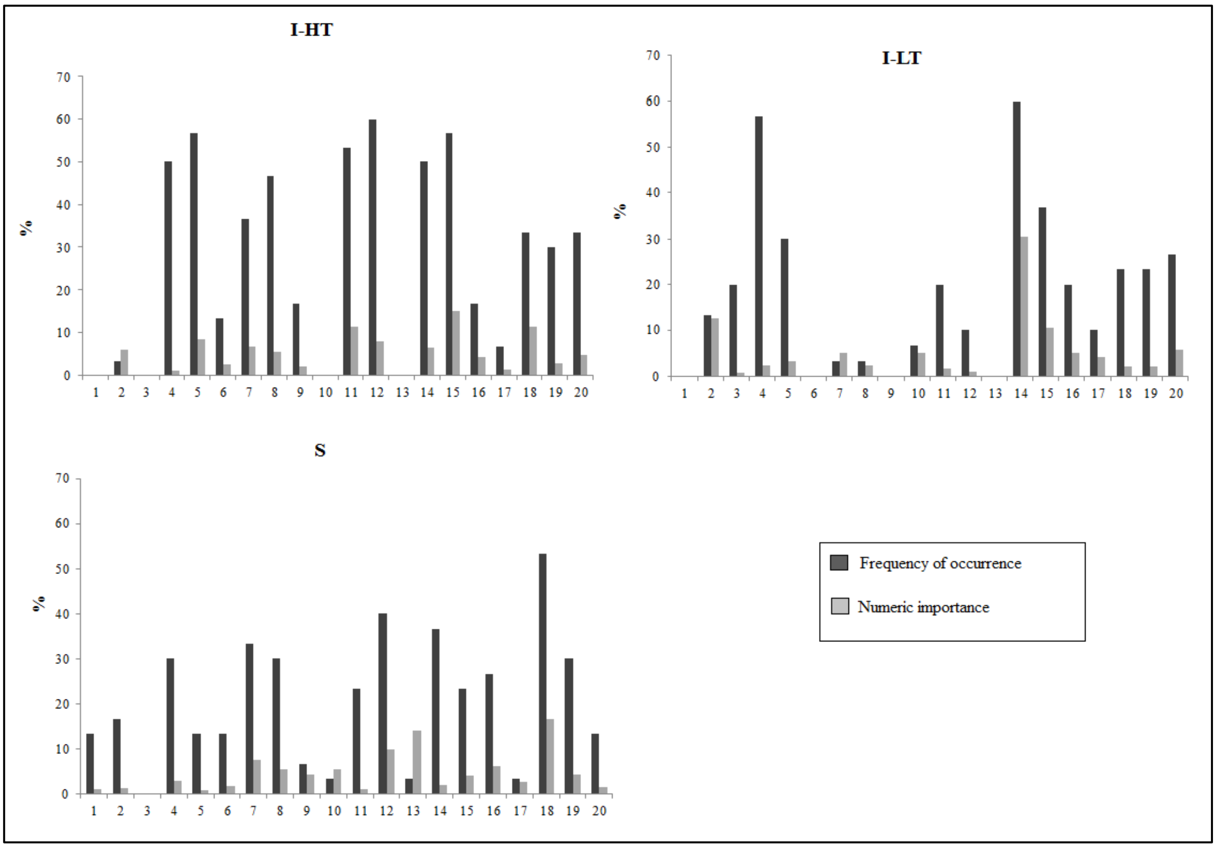

Figure 4.1.2 - Food items with more frequency observed in the stomachs of *O. minuta* and taken into account for the analysis of the diet of this species in I-HT (Intertidal high tide); I-LT (Intertidal low-tide) and S (Subtidal). (1- Fragments of Tintinnidae; 2- Nematode; 3- Fragments of Kynorchya; 4- Miliolidae; 5- Undefined foraminifera; 6- Pennal diatoms; 7- Centric diatoms; 8- *Prorocentrum sp*; 9- Undefined microalgae; 10- Phaeophyta; 11- Clorophyta; 12- *Ulva sp*; 13- *Leathesia sp*; 14- *Colpomenia sp*; 15- *Derbesia sp*; 16- Undefined macroalgae; 17- Spicules; 18- Fragments of crustaceans; 19- Fixing rizoide; 20- Vegetable fiber).

Sediment was also registered in the digestive tract of all individuals of *O. minuta*. In I-HT of Barequeçaba Beach, the average weight of the sediment found in the stomachs of *O. minuta* was 9.67E-05 ± 1.09E-04 g. On the other hand, in I-LT, individuals showed the highest amounts of sediment in their stomachs, with an average of 2.29E-04 ± 1.56E-04 g. Finally, in Subtidal zone, the weight of sediment had an average of 6.00E-05 ± 3.25E-05 g (Table 4.1.2). Regarding to the weight of the stomach content, on I-LT the individuals also showed the highest values, with an average of 6.21E-04 ± 3.56E-04 g, followed by I-HT with 3.29E-04 ± 2.05E-04 g and finally the Subtidal zone with an average of 2.22E-04 ± 1.26E-04 g (Table 4.1.2). Major standard deviations occurred in the areas with higher amounts of sediment in the stomach of individuals of *O. minuta* while, the variability in Subtidal zone with smaller quantities of sediment was lower (Table 4.1.2). I-LT situation was the one which contributed for the significant differences in all parameters analyzed above between the three areas (Figure 4.1.3).

Table 4.1.2 - Mean and standard deviation of the weights (g) of full stomach (SW), sediment (GW), and stomach contents (SCW) for each one of the situations of Barequeçaba Beach: (I-LT) Intertidal low tide, (I-HT) Intertidal high tide and (S) Subtidal zone.

Parameters	I - LT	I - HT	S
SW	7.89E-04 ± 3.34E-04	4.44E-04 ± 2.08E-04	3.88E-04 ± 1.37E-04
GW	2.29E-04 ± 1.56E-04	9.67E-05 ± 1.09E-04	6.00E-05 ± 3.25E-05
SCW	6.21E-04 ± 3.56E-04	3.29E-04 ± 2.05E-04	2.22E-04 ± 1.26E-04

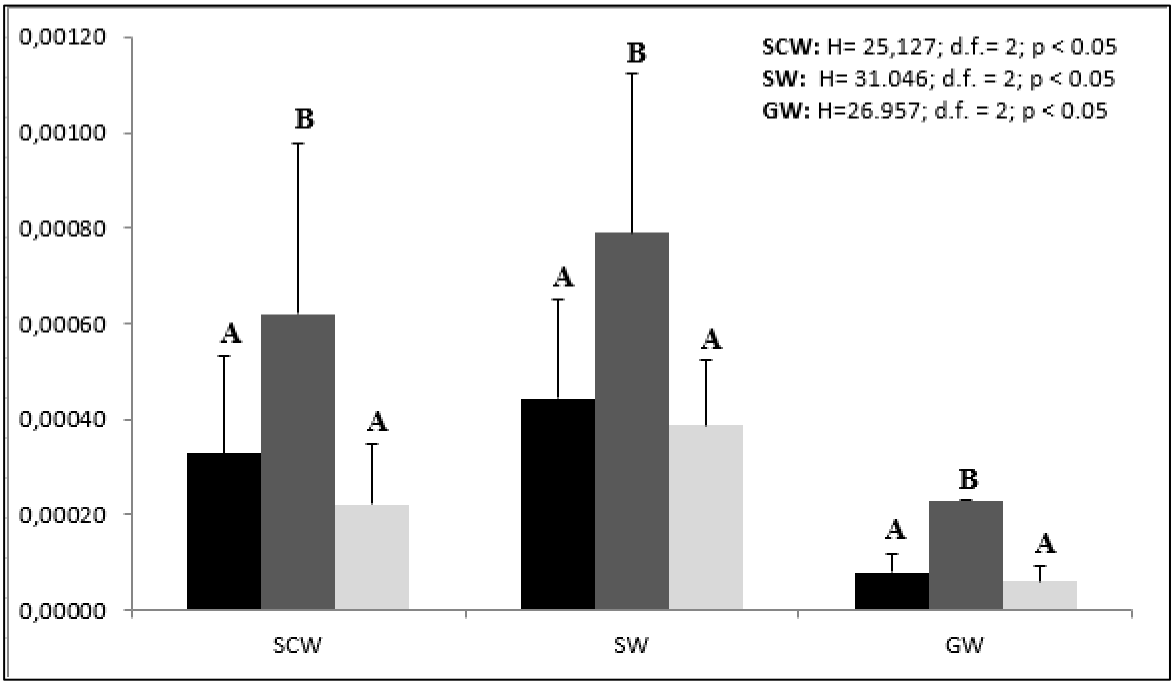

Figure 4.1.3 - Mean weight of stomach contents (SCW) for each one of the situations of Barequeçaba beach, full stomach (SW) and sediment (GW): I-HT (black histograms), I-LT (dark gray), S (light gray). Kruskal-Wallis test were applied to each parameter (SCW, SW, and GW) and the results are indicated in the plot. Different letters above histograms indicate significant differences.

The gastropods from the three situations presented similar feeding composition (Figure 4.1.4.A), where the macroalgae *Derbesia* and *Colpomenia*, and the foraminifera Miliolidae were the most common food items; the difference between the situations was the high abundance of *Colpomenia* in I-LT in comparison to the other sampling areas as well as the high abundance of *Derbesia* during I-HT. The group I-HT with the highest similarity between the food items (31.48%) regarding to other groups was composed mainly by *Derbesia*, Clorophyta and undefined Foraminifera. By following the group I-LT with average of similarity between the food items of 25.98%, *Colpomenia*, Miliolidae, and *Derbesia* were the main items presented on the stomachs of individuals of *O. minuta* in this area. Finally, the subtidal zone, showed the lowest similarity (18.73%) regarding to feeding composition when compared with other sampling areas, where was represented mainly by *Colpomenia*, fragments of crustaceans and *Ulva* (Figure 4.1.4.A.B.).

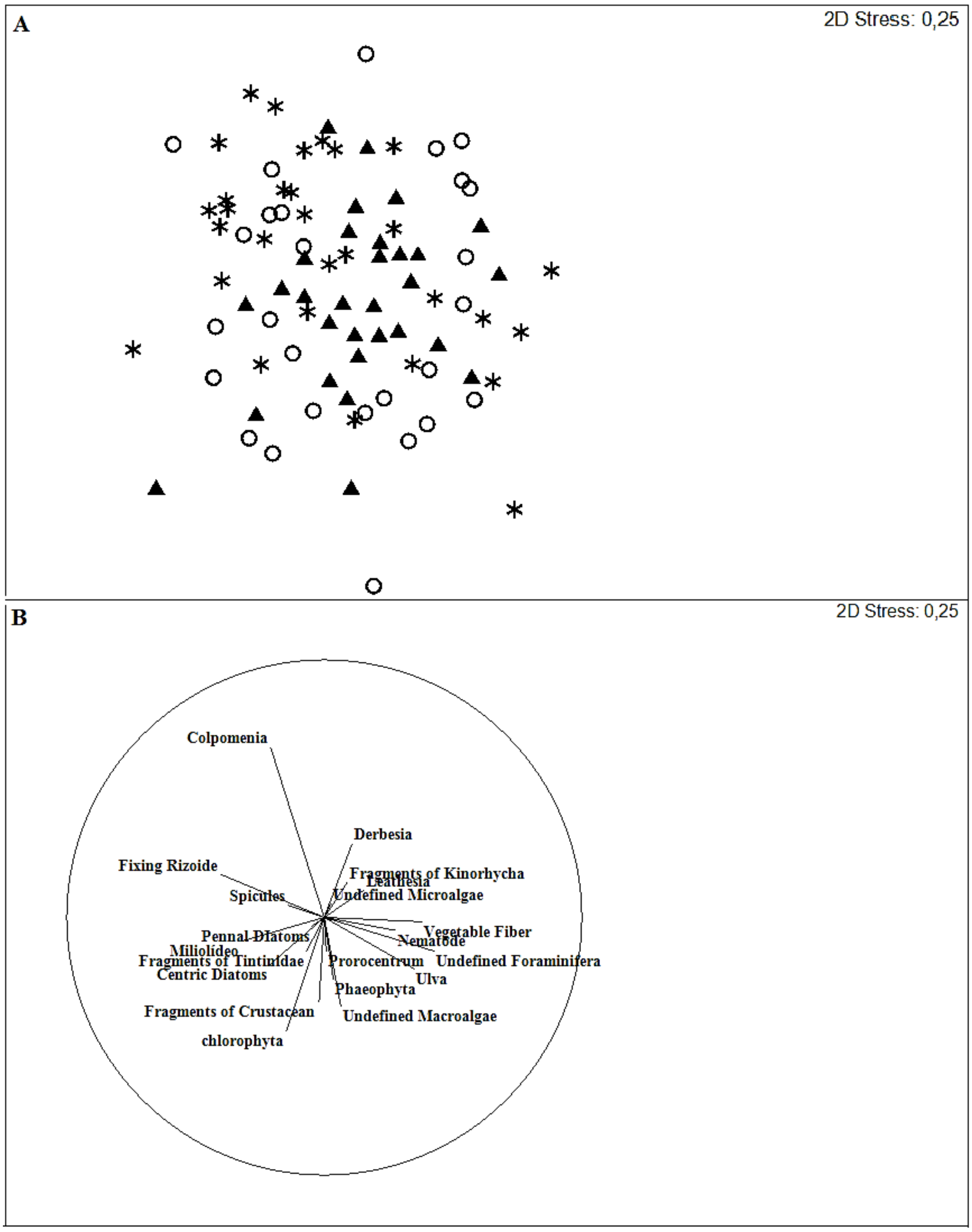

Figure 4.1.4 - Analysis of Non-Metric Multidimensional Scaling (n-MDS) (A) - Ordination of studied situations regarding to feed composition of *Olivella minuta* (abundance of food items in each area). The symbols (▲), (*) and (○) represent the groups I-HT (intertidal High tide), I-LT (intertidal low tide) and S (Subtidal zone) respectively, all formed from the similarity matrix of Bray Curtis with a similarity level of 50%. Each symbol in any situation analyzed in A represent one individual. (B) Correlation of Pearson between the food items of each area, where macroalgae *Colpomenia* was the main food item that contributed for a better correlation (similarity) between the feed compositions of *O. minuta* between all situations.

The similarity analysis ANOSIM did not show significant differences between the three formed groups (Table 4.1.3). The comparisons between the groups did not show significant values regarding to feed composition, however the highest values of R (0.2) between the two groups I-HT *vs* I-LT means that the similarity between the feeding compositions within each one of this groups was statistically similar to the similarity between the two groups. Then, with a statistical R of 0.138, the groups I-LT and S, were the seconds to show a higher similarity in their feed composition, while the groups I-HT and S when grouped showed the lowest similarity in relation to the remaining (R= 0.08).

Table 4.1.3 - ANOSIM. Result of paired test between similar groups with regard to feeding composition (Global statistic R= 0.138; p = 0.1%).

Groups	R Statistic	Level of significance
I - HT *vs* I - LT	0.196	0.1^{ns}
I - HT *vs* S	0.076	1.7^{ns}
I - LT *vs* S	0.137	0.2^{ns}

ns – Not significant

The Macroalgae *Colpomenia* was the most abundant item in conditions of low tide (Group I – LT) and was the main food item responsible for the dissimilarity between this group and the remaining groups (Table 4.1.4). In the same zone of the beach but in conditions of high tide (Group I-HT), the food item that had the most contribution for the dissimilarity between this group and the remaining ones was the *Derbesia.* In the subtidal (Group S), the high abundance of fragments of crustacean and *Ulva* contributed for the dissimilarity between this group and the others. The high dissimilarity between the groups I – LT *vs* S was due to the high abundance of Miliolidae in the group I – LT when compared to the group formed in the subtidal sampled zone of the beach (Table 4.1.4).

Table 4.1.4 - SIMPER analysis with the contribution of the food items to the dissimilarity between groups, obtained from the cluster analyses- MDS.

Dissimilarity between groups (%)	I - HT *vs* I - LT	I - HT *vs* S	I - LT *vs* S
Nematode	-	-	2.73
Fragments of Kinorhyncha	-	-	2.4
Miliolidae	8.56	6.22	8.88
Undefined Foraminifera	7.52	7.39	4.01
Pennal diatoms	2.55	-	-
Centric diatoms	4.46	6.37	4.24
Prorocentrum	4.92	5.92	3.38
Undefined microalgae	4.72	3.11	5.45
Chlorophyta	8.81	9.26	5.91
Ulva	6.92	8.54	6.92
Colpomenia	12.49	9.3	14.5
Derbesia	10.3	9.8	8.26
Undefined macroalgae	5.13	5.65	5.88
Fragments of crustacean	6.06	9.28	8.02
Vegetable fiber	5.87	4.88	4.74
Fixing rizoide	4	5	5.13
Total	92.31	90.72	90.45

4.1.1 Diversity indexes

Variations in each sampled area in Barequeçaba beach were observed for all feeding composition descriptors (richness, diversity, evenness, and Simpson) (Table 4.1.1.1). The mean richness, diversity, evenness and Simpson of the I-HT were always higher than the other two situations. I-LT and subtidal conditions did not show large variations between them in almost all descriptors. While the I-LT had values of diversity, evenness and Simpson slightly higher than subtidal, this latter prevailed with regard to richness. In sum, intertidal conditions predominated over the subtidal, in all feeding composition descriptors (Table 4.1.1.1).

Table 4.1.1.1 - Mean and standard deviation of the community descriptors: richness (s), evenness (J), diversity (H ') and Simpson (D) in the three sampled areas of Barequeçaba Beach.

	Richness (S)	**Evenness (J)**	**Diversity (H')**	**Simpson (D)**
I - HT	1.85 ± 0.52	0.87 ± 0.12	1.49 ± 0.38	0.79 ± 0.15
I -LT	1.49 ± 0.60	0.85 ± 0.12	1.30 ± 0.40	0.72 ± 0.18
S	1.60 ± 0.47	0.78 ± 0.16	1.26 ± 0.37	0.69 ± 0.19

The I-HT situation was the one which contributed for the significant differences in richness between the three areas (Figure 4.1.1.1, A). On the others descriptors, there was no significant differences between the three sampled areas (Figure 4.1.1.1, B, C, and D).

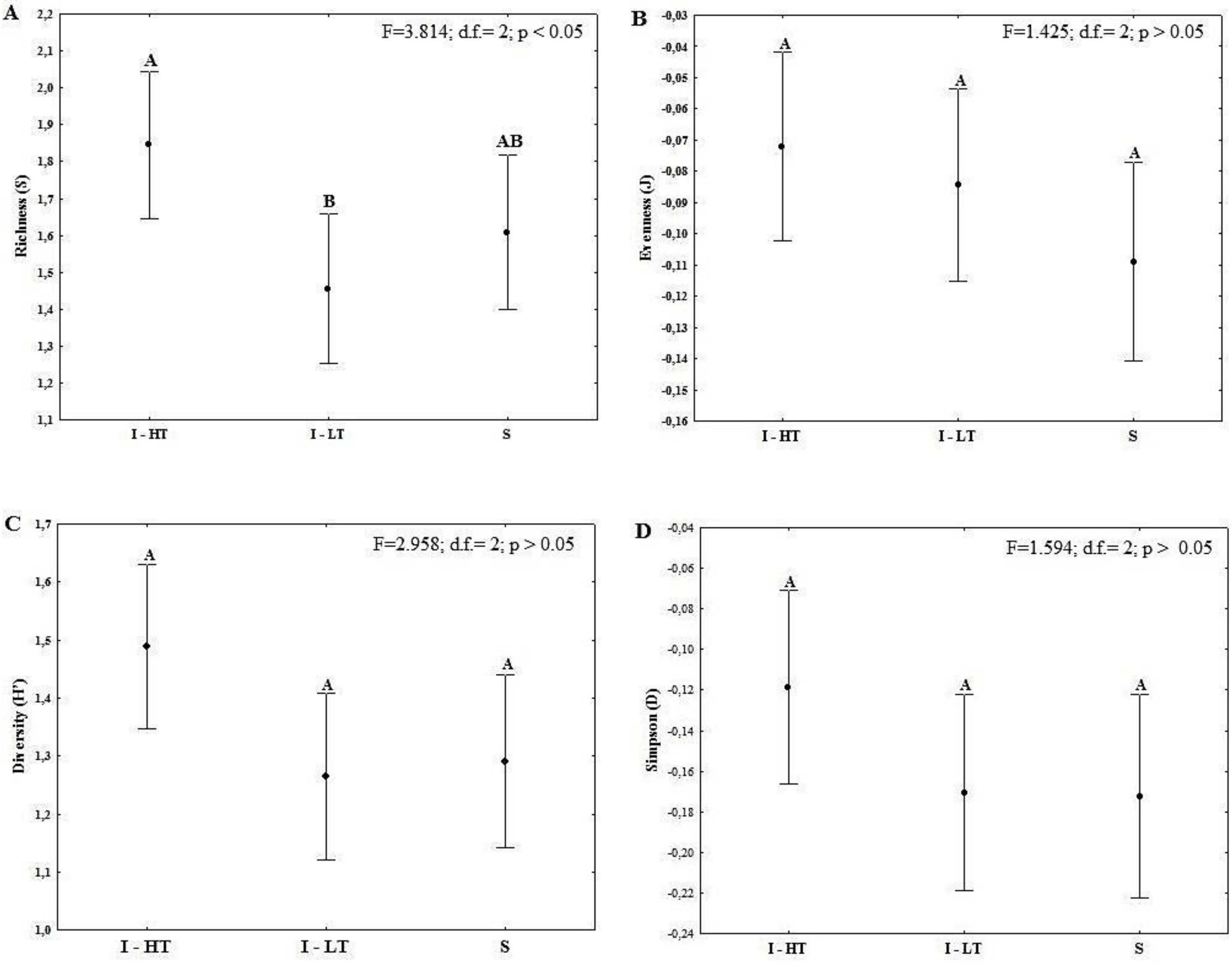

Figure 4.1.1.1 - Mean of (**A**) Richness (S); (**B**) Evenness (J); (**C**) Diversity (H´) and (**D**) Simpson (D) between the three studied situations. Results of one – way ANOVA applied to each descriptor (S, J, H´, and D) are indicated in the plot. Different letters indicate significant differences.

4.1.2 Stomach repletion index

The I-LT situation presented the highest values of mean of stomach repletion index of *O. minuta* (0.009 ± 0.003 g), followed by I-HT with a mean value of 0.005 ± 0.003 g and finally the subtidal situation with mean value of 0.004 ± 0.002 g.

The stomach repletion differed significantly between the **three** situations (ANOVA; F = 8.85, df = 2; $p < 0.05$). Highest feeding activity of the individuals of *O. minuta* were observed during conditions of emersion compared to conditions of immersion (Figure 4.1.2.1).

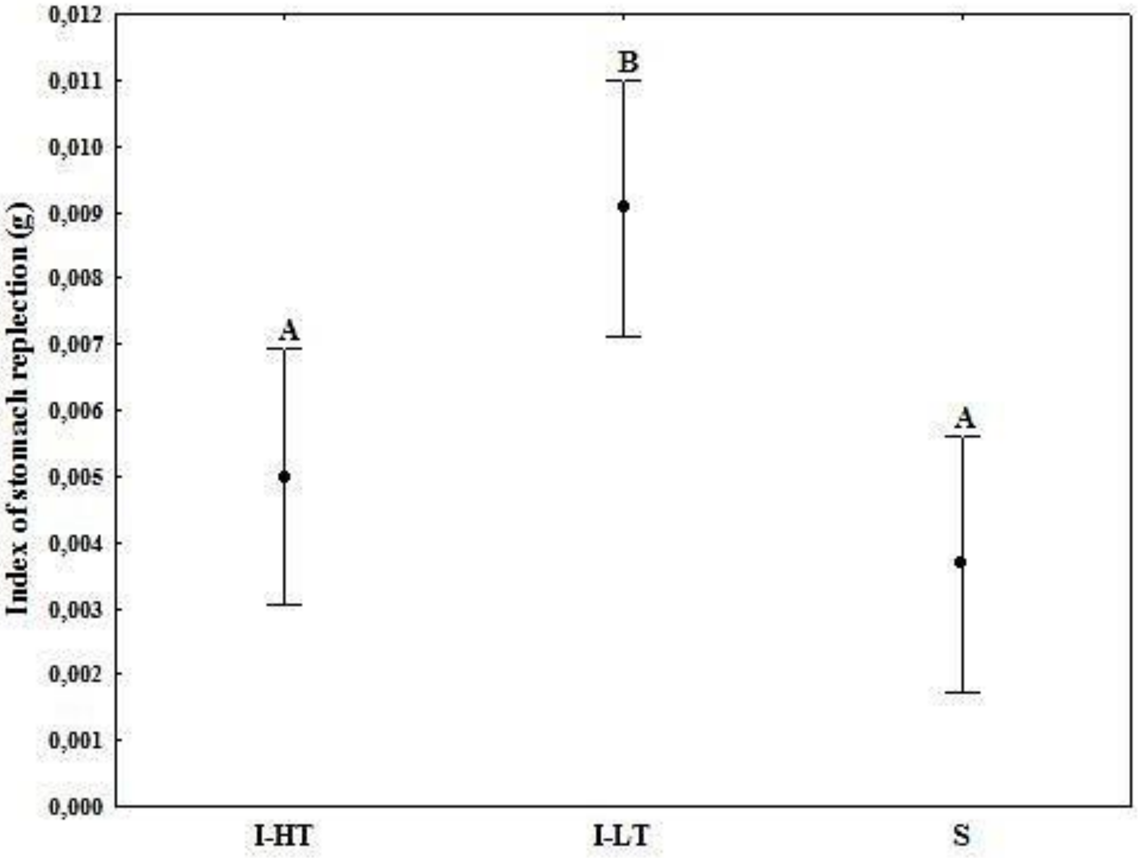

Figure 4.1.2.1 - Mean of stomach repletion index of *O. minuta* between the three studied situations. Different letters indicate significant differences.

4.2 Movement

Olivella minuta showed an non-uniformity regarding the distance travelled on the laboratory experiments. The mean distance travelled under simulated conditions of immersion and nighttime was the highest compared to remaining treatments (1.84 ± 0.63 mm), followed by the treatment of emersion and nighttime (1.39 ± 0.20 mm), the treatment with simulated conditions of emersion and daytime (1.41 ± 0.27 mm) and the treatment that was subject to conditions of immersion and daytime (1.08 ± 0.29 mm).

The statistical test Kruskal-Wallis (Qui-Square) showed one statistical evidence that the movement of *O. minuta* is affected by the phase day, however the condition of the tide did not appear as a significant variable in the displacement of this gastropod (Table 4.2.1).

Table 4.2.1 - Results of the nonparametric test of Kruskal-Wallis applied to analyze the displacement of *Olivella minuta* in different conditions of tide and phases of day

	Chi-Square	**d.f.**	**P**
Condition of tide	1.62	1	> 0.05
Phase Day	8.81	1	<0.05

Under conditions of emersion in both phases day: night and daytime, the displacement of individuals of *O. minuta* did not differ significantly between them, however during periods of submersion during night and light conditions, the difference on the distance travelled by them was significant (Figure 4.2.1).

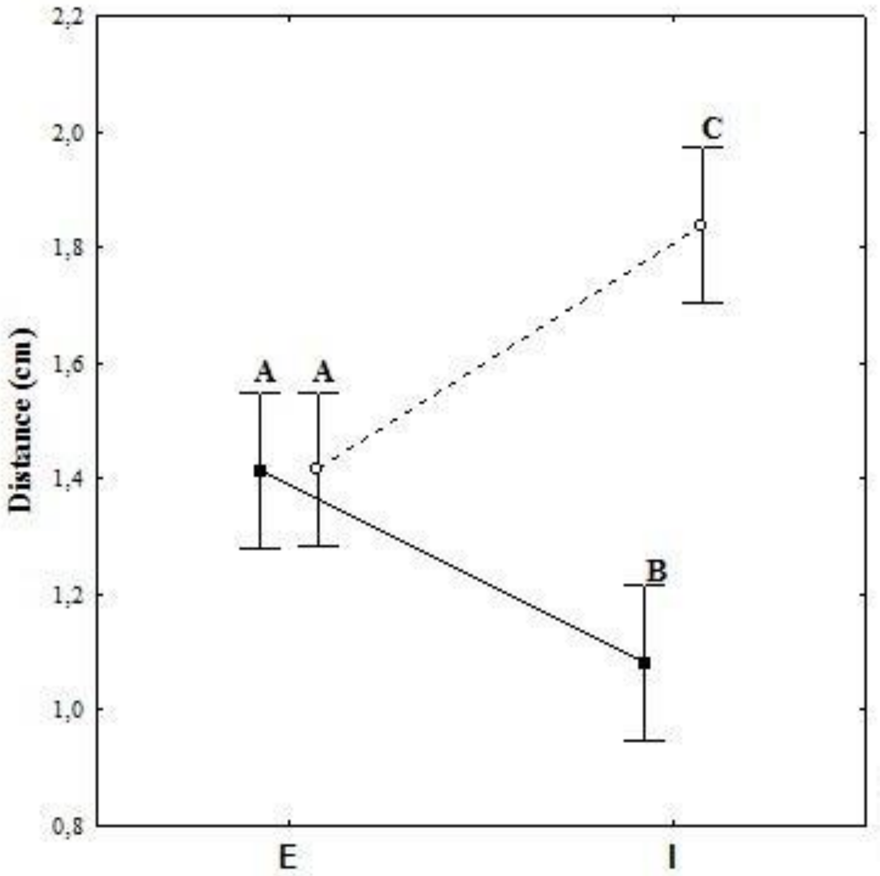

Figure 4.2.1 - Mean of movement of *O. minuta* between the four treatments simulated (E,■; E○; I,■ and I○). The symbols ■ and ○ means daytime and nighttime, respectively; while the letters E and I represent Emerged and Immersion conditions, respectively. Different letters indicate significant differences.

5. Discussion

5.1 Feeding diet of the mud-snail *Olivella minuta*

All individuals of *Olivella minuta* analyzed on Barequeçaba Beach had at least one food item in their stomachs. Arruda *et al* (2003), observed the presence of food on 86% of the stomachs of this same whelk, on two beaches along the São Sebastião Channel. Our results are higher, when compared with other sandy beaches species. Himmelman & Hamel (1993), observed the use of prey resources by the carnivore whelk *Buccinum undatum,* on the Mingan Islands (eastern Canada) from four different habitats (bedrock, gravel, sand, and mud bottoms) and registered higher proportions of food in the stomachs from the sandy habitat (28%). Despite the fact that sampling was always performed on low tide periods, information about the feeding behavior of *O. minuta* on these conditions is almost null.

The snails *Batillaria attramentaria* and *Cerithidea californica* on three salt marsh localities in central California (USA), cease feeding when exposed during low tide (Whitlatch & Obrebski, 1980). However, *Terebralia palustris* (Fratini *et al*, 2004) and *Hydrobia ulvae* (Vieira *et al*, 2010), have active feed when exposed to low tide conditions.

Arruda, *et al*, 2003 performed an experimental study about the feeding behavior of 50 individuals of *O. minuta* in terms of food choice under submerged conditions. Our results show that *O. minuta* feeds under low and high tide periods; however the feeding behavior of this snail under both conditions was not analyzed in the field.

Although the pattern described in the literature is controversial relatively to feeding behavior of gastropods under different tide periods, our results suggest that *O. minuta* besides feeding under submerged conditions, like was previously noticed by Arruda *et al* (2003), also feeds when exposed to low tide periods.

In the present study, macro and microalgae, fragments of crustaceans and foraminiferans were the most frequent food items ingested by *O. minuta*.

Although diet composition was similar to previous studies (Marcus & Marcus, 1959; Arruda *et al*, 2003), where bivalves, foraminiferans, copepods, anfipods, scaphopods diatoms, nematodes, large proportions of sediment, and fragments of crustaceans, were found on the stomachs of this snail, in the present study was observed the presence of new items which were not perceived before such as poriferans, ciliates and bacteria. This difference may be a result of the higher number of individuals analyzed compared to previous works of this species.

The taxonomic identification was not always possible because certain items (fragments of crustaceans, fragments of mollusks, fragments of nematode, and fragments of Tintinidae) were crushed. For this reason, the taxonomic identification was made at the highest level of specificity possible and analyzis of diversity, richness and evenness took into account this aspect.

There is no possible way to determine if the ingestion of this different state of food items is result of an active or accidental ingestion by the species. Also, the differential digestion of food items (stomach acidity and enzymatic activity) causes partial destruction of the stomach contents, especially food items that do not have hard structures **(**Iken *et al*, 1999). Even though there was a great quantity of fragmented items, entire foraminiferans and Eutintinnus were also observed.

However, few differences on the diet composition of *O. minuta* along the three situations (Intertidal high tide, intertidal low tide and subtidal zone) were observed. Ingestion of a great diversity of food (i.e., worms, foraminiferans, micro and macroalgaes, porifera, mollusks, arthropods) took place on all situations, while ciliates were found only on I-LT and Subtidal zone. Bacteria were also present only on the subtidal zone.

It was clear that the composition of the diet of *O. minuta* was very similar in all studied situations (preferentially macroalgae and foraminiferans regardless of feeding habit of this snail, with the organisms using almost the same group of feeding resources). The differences observed between the three studied situations was the result of the certain different food items, such as bacterias, ciliates and worms which did not appear in all situations and when present in one situation showed low frequencies of occurrence (FO < 5%).

An interesting observation was that on all situations, the most frequent item found was macroalgae. This did not imply an active food selection by this species, given that the species showed a preference for both animal and vegetable food. It seems to be taken in by accident along the wide variety of materials from the environment. It was easily noted from visual observations that macroalgae were very abundant in the sampling period. This dependence of animal and vegetable resources may be crucial for the growth and survival of the organisms, as was noted by Curtis & Hurd (1980) on the mud snail *Ilyanassa obsoleta*.

Microalgaes, mainly diatoms were the second main source of energy for these whelks in all three situations. This food resource are one of the most important energy source for a greater number of gastropods and many invertebrates (Sullivan & Currin, 2000), like *Turbo smaragdus* (Alfaro *et al*, 2007), *Littorina. scutulata* (Voltolina & Sacchi,1990), *Batillaria attramentaria* and *Cerithidea californica* (Whitlatch & Obrebski, 1980), *Hydrobia Ulvae* (Vieira *et al*, 2010) *Tagelus plebeius*, and *Macoma constricta* (Arruda *et al*, 2003).

Richness was higher on the stomachs from the I-HT of Barequeçaba beach, when compared to the other two situations, which can be a reflection of turbulence, induced by the presence of water in the environment (being the subtidal zone the second area with the most richness). The turbulence leads to a re-suspension of sediment and hence tends to maintain high nutrient concentrations in the local, as well as homogeneity of chemical and physical parameters (Smetacek, 1985; 1988).

Other hypothesis can be related to the rhythmic movements and migration patterns of food items, common responses of benthic organisms related to tidal cycle (Chelazzi *et al*, 1988). Once intertidal organisms are subject to a predictable cycle of inundation and exposure as well as to a wide range of changes in temperature, salinity, hydrostatic pressure, food, and predation pressure; migrations are typical responses to tidal cycle, and appears to be associated with maximizing food resources, and other benefits, such as a predator and desiccation avoidances, and reproduction improvement (Reise, 1985; Brown & McLachlan, 1990). This behavior can be observed in caenogastropode *Aragonia propatula,* where adaptive behavior of these organisms to sandy wave-dominated environment, swash surfing behavior, allows them to migrate with the tidal range, allowing them to feed in aggregations on intertidal zone, maximizing food resources under these conditions (Cyrus, *et al*, 2012).

Since Barequeçaba beach is characterized as a dissipative morphodynamic condition (Denadai *et al*, 2005), where disturbance by wave action is almost absent and the action of physical factors are reduced, infaunal organisms are capable to build semi- permanent burrows and moves up and down in the burrows as the tide rise and falls. These movements have been shown in benthic foraminiferans (Alve & Bernhard, 1995) as well as harpacticoid copepods (Reise, 1985).

The bioturbator activity performed by some organisms, such as *Donax* sp and *Tellina* sp, leads to changes on the properties of the sediment and consequently affect the infaunal behavior and therefore their risk of mortality (Brown and McLachlan, 1990). Also, benthic microalgae, one of the most common food resource in the present study, as well as other gastropods like *Hydrobia ulvae* (Vieira *et al*, 2010), are known to perform vertical migrations in response to changes in the environment, which makes the microalgae so abundant in the surface of sediment during low tide (Consalvey *et al*, 2004; Serôdio *et al*, 2006).

All hypothesis, turbulence, migration, and bioturbator activity can be used to justify the higher richness in conditions of submersion regarding to emersion conditions in our results.

In the present study, the values of the remaining community descriptors (evenness, diversity and Simpson) did not show significant differences reinforcing the idea that these gastropods have a similar use of the food resource. Besides the particular differences in the FO and NI between situations, where ciliates were found only on I-LT and Subtidal zone, while bacteria was also present only on the subtidal zone, the general pattern of food use was the same in all situations.

The results of the stomach repletion index suggest that *O. minuta* feeds along all tide conditions, but with more intensity when emerged. These results are not consistent with the values of richness and diversity which were higher in condition of immersion. One explanation for this result may be one potential advantage that individuals of *O. minuta* possess when emerged, taking benefit of the abundance of microorganisms left by the high tide, since this snail does not seem to select or depend from a single source of energy, depending more upon frequency of encounter of prey on the local than active food selection. *Littoraria scabra*, a snail of tropical mangrove trees has a similar feeding behavior, in which they feed more on the outgoing tide compared to incoming tide to take advantage of the abundance of food resources left by the high tide (Alfaro *et al*, 2007). Thus, the ability of *O. minuta* to maintain relatively full stomachs despite a less richness on I-LT, may reflect greater plasticity in their foraging behavior.

Sand particles were present in all stomachs of *O. minuta* analyzed, with high proportion during low tide of intertidal situation compared to submerge. It seems to be a common feature of the species, as was previously observed by Marcus & Marcus (1959) and Arruda *et al* (2003). In other species of gastropods, like *Ilyanassa obsoleta* (Curtis & Hurd, 1980) and *Haminoea orbyginiana* (Malaquias *et al*, 2004) sediment was an important energy source to fulfill the nutritional and vital requirements of these organisms. Being the most abundant material in the environment, it contains sources of nutrition both animal (macrofauna and meiofauna) and vegetable (microflora) (Curtis & Hurd, 1980). Arruda *et al* (2003) noted that the ingestion of large quantities of sediment was a result of the searching behavior of *O. minuta* while moving on the substratum. Malaquias *et al*, (2004) pointed two hypotheses for the use of sand: one was related to the use of sand as an active source of energy by ingestion of bacteria. Another hypothesis is that the sediment grains may help in the process of trituration of plant tissues and diatoms, favoring rapid digestion. Both hypotheses may be applied to our results, since the sediment was frequent in all stomachs of *O. minuta*. Ingestion of sand particles was higher in I-LT when compared to immersion conditions and may be a nutritional advantage that individuals take by the sand as well as the use of sediment to help on crushing the different food types ingested, as was hypothesized by Malaquias *et al* (2004), since these organisms showed a greater foraging activity on intertidal during low tide (IR). The idea that *O. minuta* feeds by non – selective ingestion is reinforced by the great amount of sand found in the gut of individuals sampled at low tide, as was claimed by Malaquias *et al*, (2004) on the mud snail *Haminoea orbygniana* from Ria Formosa, southern Portugal.

Thus, despite the lowest abundance of food on I-LT, *O. minuta* would be taking greater advantage of the food availability in the environment to fulfill its energy requirements to maintain its reproductive and growth active, suggesting that the species is an opportunistic predator.

5.2 Displacement of the mud-snail *Olivella minuta*

The results of the laboratory experiment correlating the influence of tide and day/night cycles on the locomotion of *O. minuta* showed differences in the significance of the impact of these two variables in the behavior of the snails. When individuals were submerged and subject to different day/night cycles, the differences in their movement was evident; a great displacement was observed when they were subjected to dark conditions. In contrast, when emerged, the locomotion displayed by these organisms did not differ significantly face both light and night conditions. The tide did not show to be a key factor ($p > 0.05$) in the movement of these organisms, whereas the day / night cycle was rather relevant.

Since the feeding in marine gastropods is linked to locomotion (Underwood, 1979; Lopez – Figueroa & Niell, 1987) and given the hypothesis proposed in the present study, that a smaller movement of the individuals of *O. minuta* is associated with a higher foraging activity due to the greater amount of food encountered, the results obtained in this study suggest that food selection of *O. minuta* in the natural environment did not changed at tidal cycle (which was proved by the similar use of prey resources along all tides in this study), but a greater foraging activity of this gastropod should occur in the daytime (less movements observed). Variations of the tidal level in sandy beaches that leads to a predictable cycle of inundation and exposure of the intertidal zone, are known by affecting the food availability and locomotor activity which usually is connected with feeding in intertidal gastropods (Underwood, 1979), also expose the inhabitants to a complex mixture of environmental factors such as temperature, sand desiccation (Bally, 1983; McLachlan, 1983; Jaramillo, l987), and biotic factors such as reproductive behavior, and biotic interactions like competition and predation (McLachlan, 1983; McGwynne & McLachlan, 1985; de Alava & Defeo, 1991). However, this variable does not seem to affect the feeding habit of *O. minuta* because besides the strong environmental gradient, the most intertidal organisms develop behavior adaptations (e.g. migrations or burrowing) to regulate several aspects of their ecology and physiology (Defeo, 1993; Palmer, 1995).

Studies of intertidal gastropods on rocky, mangrove and sandy habitats have been shown that those living in mid and upper intertidal levels, time their active phase to coincide with flooding periods, whereas those that live in lower intertidal zone are more active during emerged periods (Vieira *et al*, 2010), being these patterns a way to avoid desiccation, predators and maximizing feeding which are critical factors in intertidal areas (Reise 1985; Brown and McLachlan 1990). The gastropod *Terebralia palustris* (Fratini *et al*, 2004) showed a similar pattern to *O. minuta,* feeding in all light and tide conditions with the consumption of a great quantity of food during the day independent of the tidal cycle. Also, these authors showed that feeding activity of *T. palustris* occurs mainly during low tide (in particular diurnal) even if, during this phase, the amount of food ingested by each individual is the smallest. One distinct pattern was observed by *Patella vulgata* (Davies *et al*, 2006), that opportunistically switch their feeding activity to remain active when emerged and during night. Also, the feeding activity at night of the gastropods *Haliotis discus* and *H. tuberculata*, have been shown to be a strategy to enhance digestive efficiency as well as one way to avoid predation (Tahil & Juinio-Menez, 1999). The mud snail *Hydrobia ulvae* (Vieira et al, 2010) is also more active at night as well as on high water, however when biomass of microalgae, their main source of energy, increases during daylight hours at low tide, these snails display a peak of activity, suggesting that these snails display a tidally-timed endogenous rhythm that coincide with the favorable periods for the species take advantage of nutritional sources appropriate to their growth and survival (Vieira *et al*, 2010).

On a sandy beach in Otsuchi Bay (Japan), the burrowing ability of mysid species at appropriate times of tide and day/night cycles was shown to be an adaptation to avoid predators, as well as a way to ensure feeding and reproduction. These species have the capacity to burrow into the sediment during daylight, escaping the action of visual predators and their activity during the night is known to ensure feeding and reproduction (Takahashi & Kawaguchi, 1997).

The sand burrowing behavior of *O. minuta* was always observed in our treatments and was previously noticed by Arruda *et al* (2003). This behavior may be a possible adaptation that these organisms exhibit to avoid predation pressure by other invertebrates such as gastropods and starfishes (Araújo & Rocha-Barreira, 2012) or even dissecation when exposed to daylight periods. However, it is uncertain how predation pressure on *O. minuta* is distributed along the tidal cycle.

Predation by *Agaronia* species on *Olivella* species, such as *Olivella semistriata*, can be easily observed on Panamic beaches, being the swash surfing locomotion, an adaptive behavior exhibit by both species to this environment (Cyrus *et al*, 2012). *Aragonia propatula* (Caenogastropoda: Olividae), a swash-surfing predator on sandy beaches of the panamic faunal province, hunts when exposed to low tide during daylight, using the subtidal zone to rest, and have their peak of feeding activity on predictably aggregations in the upper intertidal, maybe due the fact that this predator lives in a mostly tactile world (Gray, 1839; Olsson, 1956) suggesting by these authors, an development of behavioral features that proved adaptive in the intertidal environment (Gray, 1839; Olsson, 1956). Opposite behavior is observed by *Oliva* species that does not show circatidal migrations by swash surfing, but show peaks of activity on nocturne periods and foraging under water (Kantor & Tursch, 2001). As stated by Marcus & Marcus (1959) *O. minuta* resembles *Oliva* species in their anatomical characteristics, and given the fact that various marine gastropods detect the presence of potential predators by the use of chemical signals (Jacobsen & Stabell, 2004; Aschaffenburg, 2008), burrowing depth seems to be a possible manner of *O. minuta* to avoid being preyed when exposed to intertidal environment, where potential predators are a threat.

Coulthard & Hamilton (2011) studying the influence of the interstitial water on the movement of *Ilyanassa obsoleta*, showed that this parameter, quite variable in the intertidal zone, have one important role in their feeding behavior like in *Hydrobia ulvae* (Vieira et al., 2010). These two gastropods when emerged and exposed on dry sediment are inactive, because they do not have the capacity to burrow, staying restrict to substrate surface (Vieira *et*, 2010; Coulthard & Hamilton, 2011). Interstitial water also appears to be an parameter of important role in the burrowing ability of *O. minuta* (sensu McLachlan & Brown, 2006) as well as in other species of the genus *Olivella* such as *Olivella formicacorsii* (Brazeiro & Defeo, 1996) and *Olivella semistriata* (Aerts *et al*, 2004). These species usually occur in the lower intertidal zone, in sandy beaches where sediment is constantly submerged by the tidal range, allowing easily burrowing activity, suggesting by these authors as an adaptive behavior of these *Olivella* species as well as *O. minuta* (Shimizu, 1991 & Rocha-Barreira *et al*, 2005) to intertidal zone.

Since Barequeçaba is a beach with outcropping of groundwater (personal observation) leading to a decrease in the slope of the beach, at least in the lower intertidal zone, where *O. minuta* occur, and therefore, a decreasing of thermal stress, enabling the individuals to forage when emerged during low tide, proved by the high feeding activity (highest stomach repletion index) during this phase. Also, the fine to very fine sand (Nucci *et al*, 2001, Denadai *et al*, 2005) characteristic of this beach, may maintain moisture, decreasing the evaporation process during the low tide (Escapa *et al*, 2004) and thus, allowing individuals of *O. minuta* to forage under this conditions.

However, despite of laboratory experiments were done under similar conditions (temperature, light) and a great number of replicates were done, field observations were not fully reflected in laboratory experiments. Individuals sharing the same set of conditions (temperature, light/dark conditions, with/without water) differed in their behavior, and a given behavioral pattern was not always shared by all individuals from a single treatment. The fact that we do not know the state of satiation of individuals prior to the experiment, may be related to this different patterns observed in each treatment, since the behavior of starved predators often differs from that of satiated ones (Perry, 1980). Also, the accuracy as well as interactions between spatial and temporal patterns in the behavior of organisms is not properly ensured in laboratory conditions, because the behavior of organisms in field cannot be the same and environmental variations such as predation, desiccation, and availability of food are all absent (Connell, 1974; Chapman, 2000).

6. Conclusions

The great diversity of food items eaten by *O. minuta* suggests that the species is an opportunistic predator, since it does not select a single source of energy. The dietary differences in all studied situations, (bacterias, ciliates and worms) appears to be related to a shift in abundance and food composition imposed for the different tidal conditions, rather than active food selection by this snail. Macroalgaes, microalgaes, arthropods, foraminiferans, poriferans, worms, mollusks, ciliates, and bacterias were part of the diverse diet composition of this species. Our results agree with the previous knowledge about the feeding diet of *O. minuta*, and bring new information on the quality of food items, e.g., Bacterias, ciliates, poriferans and molluscks, were never registered before. Their consumption by *O. minuta*, along with other food items previously described, prove that this species does not possess a preference for a single food resource. However, we do not possess enough information to conclude that the individuals change their diet within a specific or a group of food items. The observed variation can be merely consequences of the dynamics of each food items during the tidal cycle.

The results of the movement experiment seem to suggest that the feeding of *O. minuta* in the natural environment should not change with tidal cycle, because no significant influence on the movement was registered and the diet composition of the individuals did not differ along the tidal phase on Barequeçaba Beach. Moreover, feeding should take place mostly during the day rather than at night, since a lesser movement was displayed in these conditions. Although this species feed in all tide conditions (stomach repletion index indicates activity in all the tides), its peak of activity coincides with the daytime period and when emerged at low tide, which suggest a greater feeding activity in these conditions. Despite the lower richness and diversity of this area, this snail seems to maximize prey capture, as observed by high values of IR-stomach repletion in low tide conditions compared to immersion conditions in this present study. Possibly *O. minuta* find greater stability for their foraging activity in emmersion conditions, when there is a lower impact from possible predators and an increase in prey biomass, possibly resulting from the receding tide in the intertidal zone.

A formal test of this hypothesis would require an investigation of the behavior and feeding of *O. minuta* in situ, in different phases of the natural environmental cycles, aiming to better understand the impact of environmental and biological factors over them.

7. References

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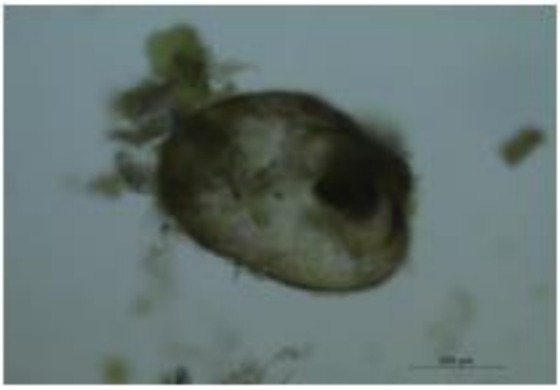
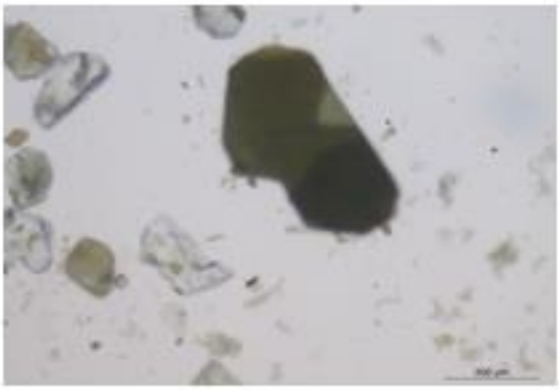
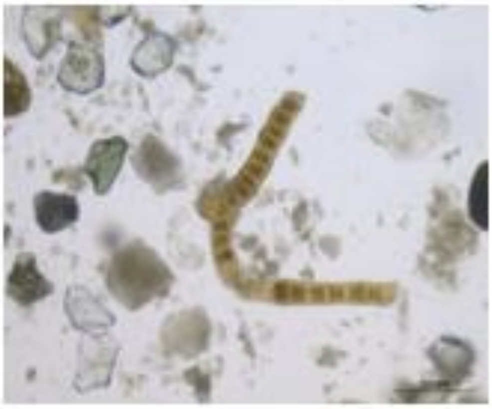
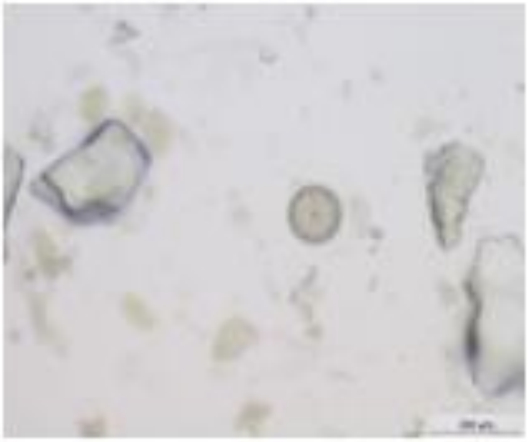
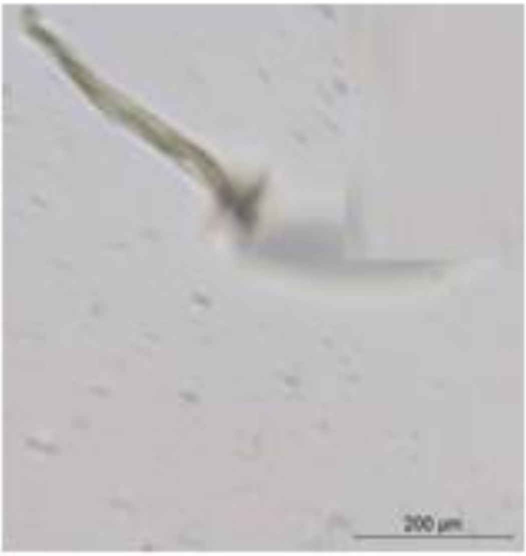
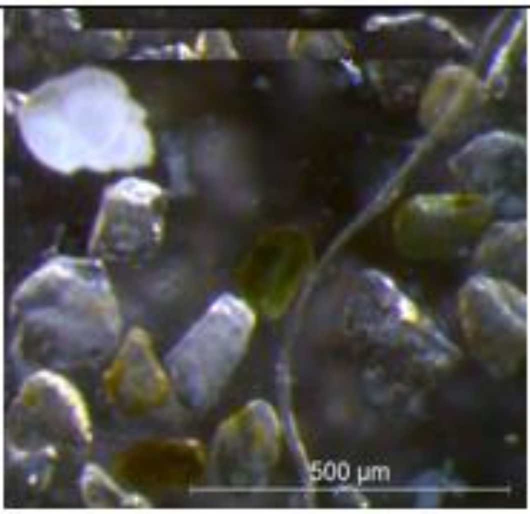
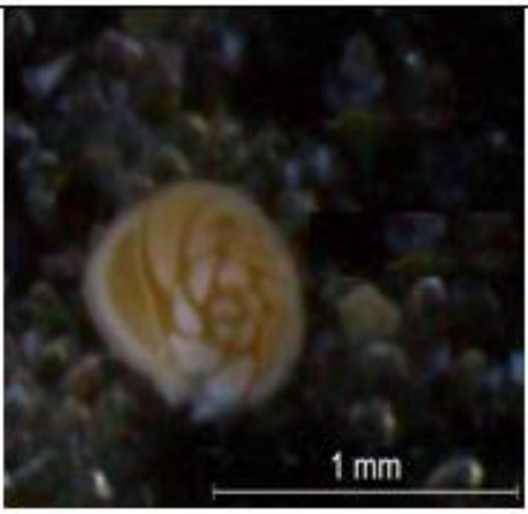
8. Appendix

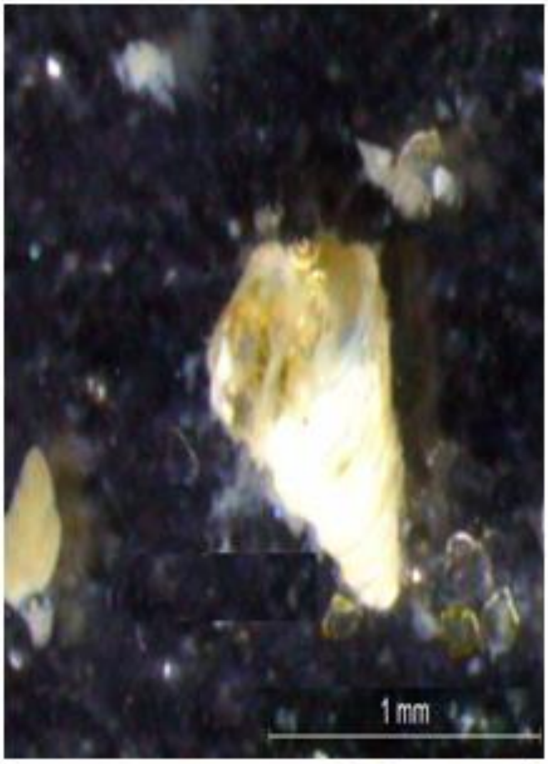
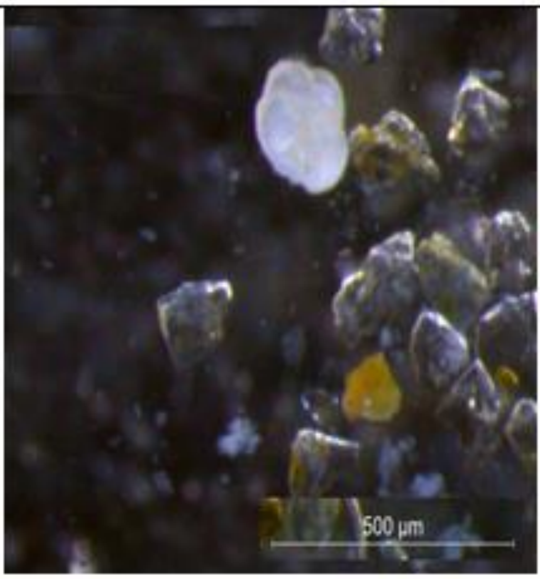
Food items	Maximum level taxonomic achieved
	Arthropoda, fragments of Crustacea
	Mollusca, *Mytilus* sp.
	Macroalgae, Chlorophyta

	Macroalgae, *Derbesia* sp.
	Undefined organisms, fixing rizoide
	Macroalgae, *Ulva* sp.
	Macroalgae, Rhodomelaceae

	Worms, Fragments of Kinorhyncha
	Macroalgae *Polysiphonia* sp.
	Macroalgae *Chaetomorpha* sp.
	Worms, Nematoda

	Microalgae, centric diatom
	Artrophoda, Ostracode.
	Ciliates

	Foraminifera. *Bulimina marginata*
	Foraminifera. *Nonion fabum*
	Foraminifera. *Eponides* sp.

	Mollusca, Gastropoda
	Foraminifera, *Pararotalia* sp.