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Could Ambient Vibrations Be Related to *Cerithidea decollata* Migration?

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Abstract

Physiological and behavioral systems exist to reduce the stress that the intertidal fauna may face during the unsuitable tidal phase. *Cerithidea decollata* is a common western Indian Ocean mangrove gastropod. It feeds on the ground at low tide, and climbs the trees two-three hours before the water arrival to avoid submersion. Moreover, it regularly settles on the trunk roughly 40 centimeters above the level that the water will reach, in spite of the irregular East African tidal pattern. Migration usually takes place about twice a day unless at Neap Tide, when snails may remain on the dry ground. Biological clock cannot account for water level foreseeing while direct visual cues or chemical information from the water itself or from previous migrations have already been experimentally discarded. Indirect cues could be hypothesize related to the effect of the oceanic wave reaching the coast and the barrier reef (seismic noise), or alternatively related to changes in ground resistivity (self potential) caused by the sea water moving close. To verify these hypotheses a seismic noise and self potential survey was carried out at Mida Creek (Kenya). This paper presents the first results of the seismic noise measurements. A significant correlation between the time evolution (mean value) of the low frequency seismic signal, tides, and snails movements has been identified.

Keywords

Ambient Noise Vibration, Microseismic Monitoring, Tidal Zeitgeber, Ocean Tide, Intertidal Migration

1. Introduction

Intertidal fauna faces several problems caused by the periodic adverse conditions created by the continuous variation of the water-air border. Animals are usually able to exploit only air or water respiratory phase. Presence or absence of water, body temperature, food availability, and capability of avoiding predation are constantly changing according to the tidal excursion. Thus, tide is shaping the whole intertidal animal life [1], often more than the diurnal light-dark variation [2]. Physiological and behavioural systems exist to reduce the stress that the intertidal fauna may face during the unsuitable tidal phase. Behavioural responses mostly consist in hiding in appropriate refuges or else migrating across the intertidal belt to reach the suitable intertidal level [2] [3]. Such responses are usually told to be triggered by an internal biological clock (12.4 h periodicity), able to anticipate the actual respiratory phase change, and not by direct cues such as the water presence/absence or sudden temperature variation [4] [5]. It has been recently questioned whether a regular 12.4 h clock can actually cope with the variable pattern of water level due the several tide irregularities within the synodic month [6]. In East Africa, where a research has been conducted since a few years on an excellent model for such studies [6] [7], the above irregularities are mainly due to: 1) two adjacent tidal oscillations are usually of different intensity ("diurnal disparity"); 2) tidal oscillations are getting wider from Neap Tide (NT) to Spring Tides (ST) and weaker from ST to NT; 3) ST are stronger and NT weaker around the equinoctial periods; 4) 48 min average delay is just an average, the actual delay going from about 20 min (usually around equinoctial ST) up to about 2.5 h (around equinoctial NT); and 5) the relative intensity of full moon and new moon ST switches every 7 months.created in MS Word 2007, provides authors with most of the formatting specifications needed for preparing electronic versions of their papers. While points 3 and 5 mostly involve reproductive activity [8], the other points are known to modulate more or less directly the daily movements of most of intertidal organisms. At the same time, a simple 12.48 h biological clock cannot account for shaping the above movements, and local cues must play some role in real time changing the clock, and thus adjusting the animal behaviour with the irregularity of actual tide variation [6] [9]. *Cerithidea decollata* (Gastropoda, Caenogastropoda, Potamididae) is a common western Indian Ocean mangrove gastropod characterized by a shell approximately 15 - 25 mm long with a truncated apex. In East Africa it is commonly found within the *Avicennia marina* belt [7] [10] [11]. It is confined in the upper part of the mangrove belt, where *A. marina* grows, above the average height levels of High Water [10] [11], and already proved to be an excellent model suitable for intertidal migrations [7] [9]. It is known to feed on the ground and climb the trees settling on the trunk to avoid submersion [7]. Before the water arrival, tenths of snails can be seen climbing, and clustering about 40 cm above the level that water will reach only 2 - 3 hours later [9] [12]. Migration takes place about twice a day with relevant exceptions: around certain STs, snails may remain permanently on the trunk and only few individuals can be seen crawling on the ground, while during certain NTs—when water doesn't reach the observation site—animals can settle on the dry ground for 1 - 3 days [9]. Because of the irregularity of both tidal timing and amplitude, the existence of direct signals triggering the upward migration have been hypothesized. Direct visual cues or chemical information from the water itself or from previous migrations have already been discarded from previous studies [9]. Thus, more hidden signals have been taken into account [6], e.g., the possibility of direct gravitational signals acting at least on plant behaviour [13], the effect of the oceanic wave reaching the coast and the barrier reef (seismic noise trigger) [14], or alternatively the changes in ground resistivity (self potential) caused by the sea water moving close. In the field of environmental sciences, seismic noise is generally considered as promising and reliable to investigate subsurface properties, especially for its ease of acquisition and simplicity in making qualitative interpretations [15] [16] [17]. The persistent vibration of the ground, that cannot be felt by humans, comprises microseisms (≤1 Hz) and microtremors (>1 Hz). It is usually agreed that low frequency waves are caused by natural sources such as oceanic waves (0.05 - 1.2 Hz), meteorological condition (both local and at a wide scale) and wind, while high frequency vibrations are associated with volcanic or man-made activity [18] [19]. To verify these hypotheses an integrated geophysical survey (seismic noise and self potential measurements) was carried out at Mida Creek (Kenya). In this preliminary study, we examined the existence of possible cues caused by variations of microseismic intensity correlated with the tidal gravity variation [20] [21] that can be felt by the *C. decollata.* We characterize the local seismic noise wavefield in terms of its amplitude, with the final goal of verifying whether a correlation exists between the time evolution of this value and the snails movements.

2. The Study Area

The Malindi-Watamu reef complex is part of the Kenyan coastal fringing reef (**Figure 1**). The test site (dashed circle in **Figure 1**) is located in the south coast region of Kenya, 100 Km NE of the city of Mombasa, near Watamu, at the inlet of Mida Creek (03˚19'37.62"S and 39˚57'44.63"E) which is a highly ramified, mangrove-lined inlet (**Figure 1**). A large part of this creek run dry at low tide so that the watershed area of Mida Creek is very restricted and estimated at approximately 36 km^2. Oceanic current patterns in the area are dominated by the East African Coastal Current, which flows in a northerly direction. Inshore currents are largely determined by wind directions and tides; the offshore currents are directed southward by prevailing northerly winds and tidal currents [22]. The complete sequence of the Kenya coast consists of a Precambrian Basement [23] [24] [25] superimposed by the Karoo Group (Permo-Trias) which includes fluvial, lacustrine and deltaic facies settled during the first of the four principle subsidence and deposition episodes related to the initial stages of continental break-up. Jurassic shales, limestones and sandstones overlie the Karoo Group [24]. Freretown Limestone (Albian-Cenomanian) and Magarini sands almost completely cover the Jurassic rocks except for few outcropping areas where the shales are exposed. During Early to Late Miocene the gradual subsidence led to the deposition of the Lamu Reefs Formation, which is made of a reef enveloped in shale, and includes skeletal material and abundant foraminifera.

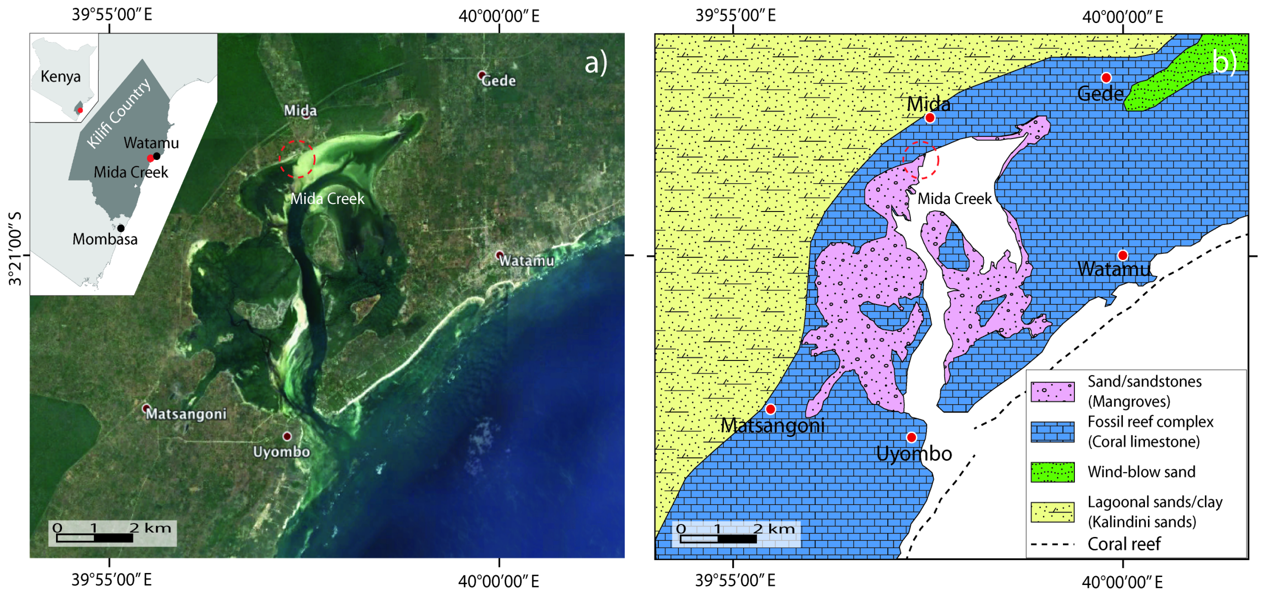

Figure 1. The study area (red dashed circle): (a) satellite view of Mida Creek and (b) geological map of the surrounding area (modified after [24] [25]).

The limestone build-up is substantially uninterrupted. The Pleistocenic complex is generally discordant over the ancient deposits and is settled in between the ancient deposits and the sea. The coastal plain consists of unconsolidated Kilindini sands (Lagoonal sand/clay in Figure 1(b)) and coral limestone (Fossil reef complex in Figure 1(b)), eroded from the Magarini sands in Pleistocene. The coastal deposit of the area shows the existence of two Pleistocene marine transgression: the older one, not faulted, resulted in the deposition of an impressive coralline formation (Fossil reef complex in Figure 1(b)); the newer one has left smaller remnants, as erosional benches, coral deposits, beaches and consolidated or loose dunes. At the test site the main formation is Kilindini sands (Lagoonal sand/clay in Figure 1(b)) with some outcropping deposits of the Fossil reef complex, wind-blow sand, and sand/sandstone where mangroves grow.

3. Materials and Methods

Starting from the pioneering studies of [26] ambient vibrations have been widely used in order to: 1) characterize dynamic behaviour both of soil [16] [17] [18] [19] and structure [27] [28] [29]; 2) to derive quantitative information on site amplification [30] [31] [32] [33]. Moreover, it is widely accepted that coastline wave-induced shaking can be recorded even at considerable distance by means of broadband seismometers. Such seismic waves, as a function of their low frequency (LF), affect a thick portion of the ground, and last for many km inland before fading. Many papers point out the link between microseisms amplitude recorded by near-coastal inland broadband seismometer and ocean wave height [34] [35] [36] showing that most of the microseisms energy recorded inland is generated near the cost by wave events. On the other hand, during the transgression phase, the water infiltrates deep into submerged rocks, especially in region like the study area where coastline formations mainly consist of loose sands and fractured/weathered rock. This event could induce the opening of new or pre-existing fractures, cracks and flaws that can be recognized as seismic transients characterized by high frequency (HF) content, and short duration (0.5 - 2 s). Since both LF and HF contents subject to significant variations through time as a function of the surrounding conditions, we deployed a microseismic network able to retrieve information in a frequency band between 0.1 - 60 Hz. The data acquisition run for 11 days, from 29th June, 2013 to 9th July, 2013. Our microseismic network included three

Tromino® by Micromed (the all-in-one compact 3-directional 24-bit digital tromometer equipped with 4.5 Hz geophones [17]) spread over the study area spaced up to 200 m. The instruments were properly housed to avoid wind noise and human/animal disturbances, and were placed orienting the NS component perpendicular to the coastline. In this preliminary analysis the dataset acquired by the one installed on the edge of the lagoon for the whole monitoring period is used. It acquired in continuous mode except for some brief interruptions caused by the supply batteries change. The sampling rate was fixed at 128 Hz. Time synchronization was achieved using the GPS time base. At this first stage of analysis we processed only the Z component. The seismic noise data analysis was performed by means of Matlab®: the effective amplitude was calculated as the median of the absolute value evaluated over sliding windows of 600 s (76.800 sample points at 128 Hz), with a 50% overlap so that two successive windows are separated by 5 min. Data on *C. decollata* movements were obtained as described in [6] by means of control poles. Unfortunately, these data are available only from the late of 2nd July. The tide height in the Mida Creek was derived shifting of about 1 hour and 7 minutes the Mombasa tide tables available on-line. These data were validated by means of direct observations.

4. Results and Discussion

This case study is based on the premise that, in literature, many papers refer about vibrations carried in the substrate as an old and ubiquitous communication channel for animals [37]. Assuming that the marine transgressions and regressions, due to the tide events, generate pressure fluctuations on the ground that are locally transformed into microseismic waves at the seafloor that propagate inland [14], the main goal of this preliminary work is to evaluate a possible correlation between the seismic signals and the snails' movements, in terms of decision to climb up or not. To do so we performed: 1) the analysis of the trend of the LF (0.1 - 2 Hz) and HF (2 - 60 Hz) seismic noise amplitudes, and 2) the comparison of the seismic signals with the height of tide, the number of animals that climbed to the safety level, and the height that they reached during each tide cycle (**Figure 2**).

The amplitude of both the HF and LF noise seems to have a sinusoidal shape with a period of 24 h, so that the ridges fit whit the spring tides. Nevertheless, starting from 05th July, the LF noise shows a trend similar to that of the tide, and

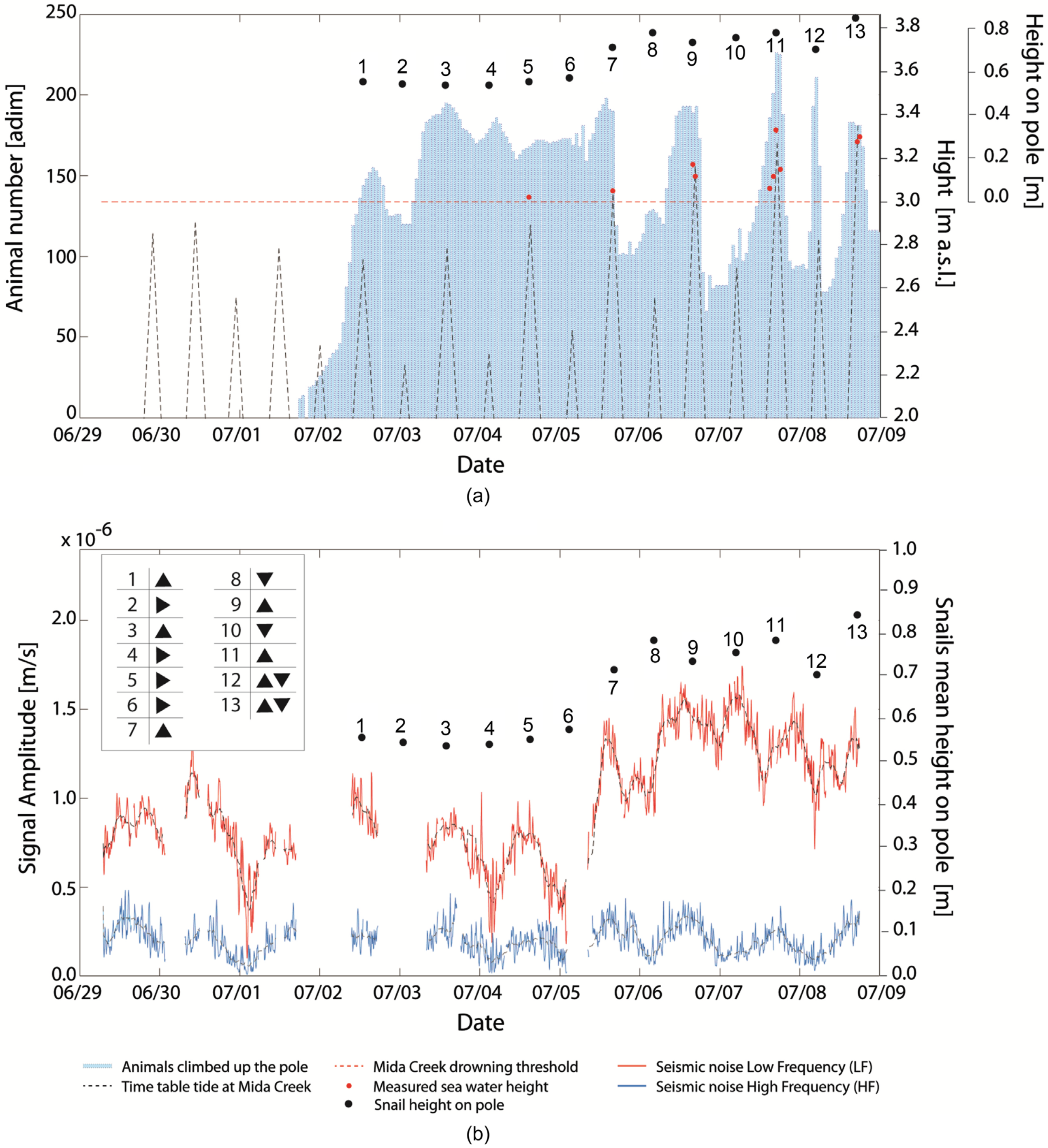

Figure 2. (a) Light blue histogram is the number of snails that climbed up the control poles; black dots are the mean height of the clustered snails on poles at the high tide; dashed black line is the theoretical tide at Mida Creek, while red points are the tide height measured on control poles; dashed red line is the drowning threshold at Mida. Numbered black triangles in the table in the upper left corner show the snails movements: up, down, stable and up/down movement. (b) Red and blue lines are the LF and HF seismic amplitudes, respectively; dashed black lines are the smoothed seismic amplitude; black dots are the mean height of the clustered snails on poles at the high tide.

the peaks occur slightly before the occurrence of the tide peaks both for spring and neap ones. During the first part of the monitoring period the animals have never got off the ground and maintain the height (about 3.5 m a.s.l.) reached during the first movement (1 in **Figure 2**) along the pole. A substantial change in the snails' behaviour occurred in conjunction with the arrival of the tidal waters at the monitoring site. Immediately after movement n.6, the snails moved to the height of 3.7 m a.s.l. (movement n.7-the first high tide event of this cycle that overcomes the Mida Creek drowning threshold) on the pole. After that, the animals began to alternately climb and descend from the pole in sync with the tide trend; majority (80% - 100%) moves up and reaches average higher levels (3.7 - 3.85 m a.s.l.) only during high-tide events. In correspondence with the change in the snails' movements, it is interesting to note that also a shift in the recorded amplitudes at low frequencies (**Figure 2(b)**) occurred. Moreover, the higher levels, characterized by the upward migration of the majority of animals (cases 7, 9, 11, 12 and 13), were reached immediately after a significant increase of low frequency amplitude (with the exception of the movement n.11). In particular, the height and percentage of animals that move up during event n.12 supports the existence of a correlation between the two parameters, since the increase of low frequency amplitude is followed by the climb of the animals up to a significant height on the pole (3.7 m a.s.l.), although the drowning threshold is not reached during this event. Since strength and direction of winds can affect the microseisms in the 0.05-1 Hz frequency band [38], it has to be taken in account for LF analysis because it could be the reason of LF variations superimposed to tide variations. No noteworthy transient due to the subsurface microfracturing that could be detected as a signal by the snails is recorded.

5. Conclusions

This preliminary work focuses on the research of some clues able to influence the *Cerithidea decollata* decision to climb up or not to escape from the incoming water and at which height to settle. It points out an interesting similarity between low frequency amplitude trend and the animals' movements that definitely deserve additional in-depth analysis. The relatively good correlation between snails' migratory periodicity and microseismic vibratory pattern doesn't necessarily imply a cause-effect relationship. Nevertheless, it is the first time that a consistent physical cue other than the obvious, but discarded ones (visual and chemical), has been identified that could potentially be detected by the snails as well as by other intertidal organisms, such as fiddler crabs (Genus *Uca*), one of the traditional model for the study of tidal biological rhythms. On the other hand, the pilot study highlight the necessity of an acquisition data targeted to an interval time that includes a greater number of tidal events, at least an entire cycle of low and high level both for spring and neap tide. Detailed study should be carried out at low frequency (around 0.3 Hz) assuming that the snails perceive fluctuations induced directly by the oceanic wave. For that purpose, additional data should be collected using respectively broad-band instruments suitable for very low frequency studies (the devices used in this case study shows unsatisfactory quality of resolution for very low frequencies, in terms of quantitative data), and a higher sampling frequency in order to extend the resolution capability at higher frequencies since microcracks usually show great energy content at higher frequency (>100 Hz). In terms of seismic signal analysis, it would be interesting to acquire also the vibrations induced by the trees as a response to different ground vibration caused by different tidal waves, especially because there are two type of trees in the study area, and each type, as a result of their structure, reacts in a different way to seismic stress, generating different vibration in the nearby ground. Achievement of the goals will require extensive comparison and cross-analyses with other parameters (e.g., self potential) recorded by instruments operative at the monitored site during the seismic acquisition, and now available. In addition, a more detailed dataset on the timing of the snails' movement (at least one measure/5 min) is definitely recommended to explore the nature and the accuracy of the observed correlation.

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