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SHORT COMMUNICATION

A protocol for measuring spatial variables in soft-sediment tide pools

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ABSTRACT. We present a protocol for measuring spatial variables in large (>50 m^2) soft-sediment tide pool. Secondarily, we present the fish capture efficiency of a sampling protocol that based on such spatial variables to calculate relative abundances. The area of the pool is estimated by summing areas of basic geometric forms; the depth, by taken representative measurements of the depth variability of each pool's sector, previously determined according to its perimeter; and the volume, by considering the pool as a prism. These procedures were a trade-off between the acquisition of reliable estimates and the minimization of both the cost of operating and the time spent in field. The fish sampling protocol is based on two consecutive stages: 1) two people search for fishes under structures (e.g., rocks and litters) on the pool and capture them with hand seines; 2) these structures are removed and then a beach-seine is hauled over the whole pool. Our method is cheaper than others and fast to operate considering the time in low tides. The method to sample fish is quite efficient resulting in a capture efficiency of 89%.

KEY WORDS. Beach-seine, capture efficiency, crypto-benthic species, tidal flat.

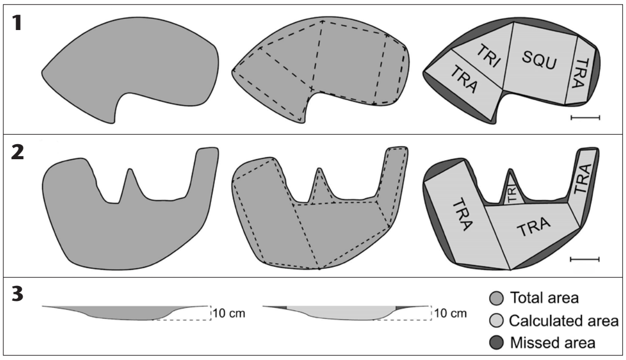
Soft-sediment tide pools, which are formed according to the local hydrography, bottom topography and sediment composition, are very common depressions in tidal flats of coastal ecosystems worldwide and are important habitats for fish, birds, and invertebrates (Meager et al. 2005, Chargulaf et al. 2011). Tide pools also serve as a shelter for many early juveniles and larvae of shallow water fish species (such as Engraulidae, Gerreidae, and Mugilidae) that, eventually, do not follow the tide when it recedes (Russel & Garrett 1983, Chargulaf et al. 2011). Tidal flats, as a typical depositional environment, hold a large amount of debris and litter in the pools (especially when near urban and port areas), serving as habitats for juveniles and adults of many intertidal, crypto-benthic species, such as Gobiidae and Blenniidae (Kwik & Tibbets 1999, Crabtree & Dean 1982, Chargulaf et al. 2011).

Several studies have been carried out aiming to describe the composition and abundance of fish species, and their spatial and temporal variability in soft-sediment (e.g., Crabtree & Dean 1982, Russell & Garrett 1983, Able et al. 2005, Meager et al. 2005, Chargulaf et al. 2011) and hard-bottom (e.g., Cunha et al. 2007, Cunha et al. 2008) tide pools. The area and volume of hard-bottom pools have been obtained through the calculation of basic geometric forms (e.g., squares and cubes – Cunha et al. 2007). Although this procedure is also theoretically applicable for soft-bottom pools larger than 50 m^2, it has not been carefully described and evaluated for such pools yet. Able et al. (2005) estimated accurately the area of large soft-sediment pools through aerial photographs, but it is a costly procedure. A demand for inexpensive methods for sampling fish is growing especially in developing countries, where the resources for surveys, environmental impact assessments, and monitoring are generally limited (Barletta et al. 2010).

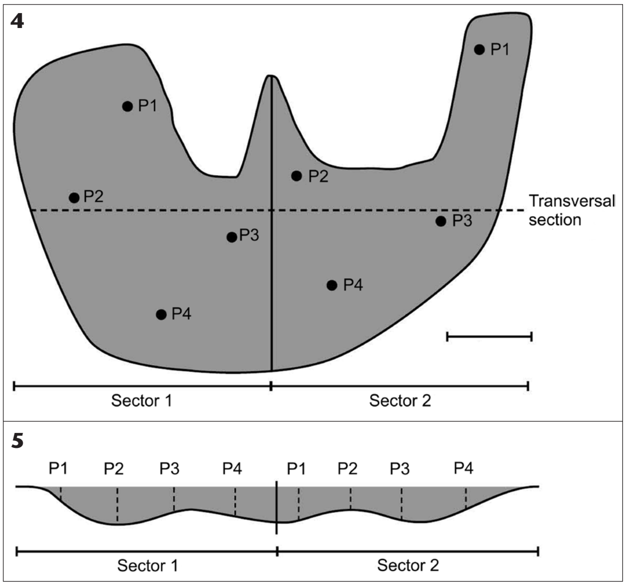
Moreover, the capture efficiency of the gears used for capturing fish in soft-sediment pools has not been, or has been poorly, assessed. For example, Meager et al. (2005) concluded that the use of dip-nets may result in an efficiency of 90%, which was obtained comparing the abundance from dip-nets with that obtained thereafter, by saturating the pool with carbon dioxide. However, this is not a reliable estimate, as it was not drawn through an analytical approach.

The aim of this article is to present a protocol for measuring spatial variables in large (>50 m^2) soft-sediment tide pool. We also present the fish capture efficiency of a new sampling protocol that was based on such spatial variables to calculate relative abundances.

This protocol was applied in four surveys (March, June, August, and October 2014) in Araçá Bay (23°48.874'S, 45°24.322'W), located in the São Sebastião Channel, Northern coast of São Paulo state, South-Eastern Brazilian coast (map of the study area in Contente et al. 2015). This subtropical bay is a typical, large, mud-sandy tidal flat area, adjacent to the international Port of São Sebastião (for details of the Araçá ecosystem, see Amaral et al. 2010



Figures 1-3. In a top-down view, sequence to measure area of two (1-2) hypothetical, large (> 50 m^2) pools in soft sediment. (3) Cross-section representation of missed areas derived from our method. (TRA) Trapeze, (TRI) triangle, (SQU) square. Scale bars: 1 m.



Figures 4-5. Representation of the tide pool division in two sectors [in a top-down (4) and cross-section (5) view] to measure the depth (P1, P2, etc.) whose locations were chosen to best represent the pool's variability of depth. Scale bar: 1 m.

and Contente et al. 2015). During low tide, many different-size soft-sediment tide pools are typical in the system. The protocol for taking measures of area, depth, and volume was applied in 18 large-sized (>50 m^2) tide pools across the surveys, and the capture efficiency was assessed once in one pool.

Protocol for area, depth, and volume measurements

Area. Depending on the shape of each pool, its total area was divided into sub-areas of well-known geometric forms (i.e., trapeze, square, rectangle, and triangle), whose the area were calculated using a meter tape (precision 1.0 mm). The total area of the pool was obtained by summing these individual geometric areas. An example of the procedure is shown in Figs. 1-2.

Depth and volume. Firstly, the perimeter of the pool was taken using the meter tape (precision 1.0 mm). Then, the pool was stratified in sectors in accordance with its perimeter: pools < 100 m were divided into two sectors, and those > 100 m, into three sectors. Four depth measures were taken from each sector, being their location chosen to best represent the variability of depth (Figs. 4-5). The depth was taken using a meter tape (precision 1.0 mm) attached to a 1.2-m-broom handle. The pool volumes were calculated as a prism, such that: volume (m^3) = the mean value of depth (m) × pool area (m^2).

A mean of 30 ± 15 (standard deviation) minutes was spent on each pool to take all measures.

Fish sampling protocol and its capture efficiency

In a two-sectors pool (perimeter = 60 m, area size = 113.3 m^2, volume = 4.9 m^3; Fig. 6), the fish sampling was carried out at two successive stages, being each stage repeated three times (passes) in each sector: stage 1 – during 15 minutes, two people searched for fishes under rocks and litters (such as, wooden board, PVC pipes, plastic bags, PET bottles, tyres and pieces of mattress), being the fishes caught by hand-nets (19 x 14 cm, 1.0 mm mesh); stage 2 – after rocks and litters were removed from the pool, a mosquito screen-made beach-seine (2.5 m length, 3.0 mm mesh) was hauled over the whole pool for capturing the remaining fishes. The passes were spaced five minutes from each other. A total of 40 minutes was spent on the pool to sample the fishes.

Capture efficiency. The capture efficiency of the protocol was assessed using the Zippin's removal method for closed populations (Zippin 1956) adapted by Mojica et al. (2014). This method, which estimates the number of individuals of all species taken together, is expressed mathematically as follows:

$$N = \frac{C_T}{(1-q^s)}$$

where N = the estimated total number of individuals from all species, C_T = the total number of individuals from all species captured over s passes and q is the complement of probability of capture (p) that is obtained by solving the equation:

$$\frac{s \times q^s}{(l-q^s)} - \frac{q}{p} + \sum_{i=l}^{s}(i-l) \times \frac{C_i}{C_T} = 0$$

where i is the pass number (1-3), C_i is the number of individuals captured taken all species together in the i^{th} pass, and p is the probability of capture that, from a binomial distribution, it satisfies $p + q = 1$. The success of the sampling was inferred through the capture efficiency CE:

$$CE = \left(\frac{C_T}{N}\right) \times 100$$

Capture efficiency was estimated for the second and third pass. There is no analytical solution for the first pass, as $q = 0$.

Five species were captured in the tide pool: larvae of *Atherinella brasiliensis* (Quoy & Gaimard, 1825) (Atherinopsidae),

Figure 6. The tide pool in the Araçá Bay where the proposed sampling fish protocol and its capture efficiency were carried out. Photography: Marina R. Brenha-Nunes.

which had a density of 22.3 individuals per m^2 and accounted for 45.5% of the total capture, *Ctenogobius boleosoma* (Jordan & Gilbert, 1882) (Gobiidae, 21.3 ind/m^2, 43.5%), *Bathygobius soporator* (Valenciennes, 1837) (Gobiidae, 4.8 ind/m^2, 8.5%), larvae of *Eucinostomus* sp. (Gerreidae, 0.035 ind/m^2, 2.0%), and juveniles of *Eucinostomus argenteus* Baird & Girard, 1855(Gerreidae, 0.009 ind/m^2, 0.4%). The total capture at each sector decreased with the passes (Table 1). From pass 2 to pass 3, the estimated number of individuals decreased, while the CE increased.

Table 1. Total number of captured individuals, cumulative capture, estimated total number of individuals (N) and capture efficiency (CE) for each sector of the pool by each pass.

Passes	Sector 1	Sector 2	Total capture	Cumulative capture	N	CE (%)
I	44	82	126	126	–	–
II	47	26	73	199	299	66.55
III	7	18	25	224	252	88.89

Clear and detailed descriptions of how to measure area, depth, and volume of tide pools are essential for calculating the relative abundance of fish populations, thus allowing fauna comparisons among different locations (Russel & Garrett 1983, Chargulaf et al. 2011). Moreover, information about field protocols should be enough detailed in order to enable reproduction of the study and sampling process. Here, we presented, in detail, how to take spatial variables in large (> 0 m^2) soft-sediment tide pools. This protocol may be useful in other systems, as it was designed and applied in a typical tidal flat of coastal ecosystem.

The proposed procedures of measuring area, depth, and volume of pools represented a trade-off between the acquisition of reliable estimates and the minimization of both the cost of operating and the time spent in field. In fact, it is a method cheaper than others (e.g., aerial photograph, Able et al. 2005), representing an alternative of sampling for the generally limited-financial resources surveys and monitoring areas in tropics (Barletta et al. 2010). The method is also fast to operate, representing an advantage for sampling tide pools, whose operating time is limited to low tides. In comparison with other intertidal habitats, the very low declivity of flats accelerates the filling of pools during the rise of tide, becoming this time even shorter.

Our method of estimate of areas contained areas out from the geometric forms (i.e., missed areas, Fig. 3), and thus, not considered in the area calculation. The missed areas were apparently very small in relation to the total area calculated, such as illustrated in the Fig. 3. To improve our method, this error should be known and quantified in future studies using more accurate procedures, such as taking photographs of the pool from an aerial perspective and calculating its areas through image software, such as ImageJ (Rasband 2014). For example, the images could be taken from drones or from near-pool areas. In this last case, the challenge is to find the 45º angle in the photography background perspective, so as to obtain a top-down perspective.

The Araçá Bay, as a typical urbanized and near-port tidal flat, has heavy deposition and accumulation of litter and other marine debris. Since 52% of the fishes captured with the proposed protocol were cryptic-benthic species, the searching for them under structures and removals of such structures before seining may have the catchability to increase substantially. This garbage accumulation and a functionally similar fish fauna with dominance of cryptic species are also found worldwide in nearly any near-port tidal flat under high anthropic pressure (Meager et al. 2005, Chargulaf et al. 2011). Therefore, our protocol could be useful in similar systems.

The proposed fish sampling protocol yielded higher capture efficiency when compared with other studies that assessed analytically the fish capture efficiency of different type of nets (e.g., Bryant 2000 reached 93% of efficiency, using minnow traps and Mojica et al. 2014 reached 92%, using seine nets, cast nets, and dip nets). Although we reached a CE of 89% with the protocol, we did three passes and such studies, four ones. This is significant, because had we did more passes (e.g., four passes), we would probably reach a CE even better, between 90 and 100%.

Our conclusion is limited as the protocol was tested in only one pool. Therefore, a potential consistency of this high capture efficiency in other temporal, environmental, and spatial settings should be investigated in future studies.

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