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## Hydrological Characteristics of Cienfuegos' Bay, Cuba, Related to the Presence of the Invasive Green Mussel *Perna viridis*

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**Abstract** The aim of this work was to analyze hydrological condition variations in Cienfuegos' Bay in 2011 and its possible influence in life cycle and distribution of the green mussel *Perna viridis*. The hydrological parameters in the bay are described according to the campaigns performed in February, May and November. Samples from two levels (surface and bottom) were taken, in order to get water temperature, salinity and dissolved oxygen. The results show the climatic seasonality influence (dry and rain) both in spatial as well as in vertical distribution of the observed parameters. The mean concentrations of the analyzed hydrological markers were in agreement with the NC 25: 1999 requirements of good quality water for fishing use. The observed hydrological variability allows the growth and development of the green mussel in Cienfuegos Bay waters.

**Keywords** Hydrological markers; Cienfuegos Bay; *Perna viridis*; Cuba

### Background

Cienfuegos Bay is a semi-closed bay, with estuarine characteristics mostly in rainy season, which has an influence in dynamics and quality of their waters (Tomsack and García, 1975; Seisdedo, 2006). This aquatic system is one of the major industrial seaports in Cuba, and thus there is an extreme vulnerability to anthropogenic effects. Many previous data account for hydrometeorological influence in distribution and behavior of sea species (Blumberg et al., 2000; Laodong et al., 2000). Many ecological damage signs have been described in Cienfuegos Bay so far, such as: benthic community changes, decrease of commercial marine species, loss of microalgae biodiversity and increase in sedimentation rates as well as higher contamination levels (Moreira et al., 2003; Pérez et al., 2004; Alonso et al., 2006).

Non intentional introduction of the green mussel *Perna viridis* in this bay first reported by Fernández-Garcés and Rolán (2005), had generated several research topics. In general this bivalve inhabits in intermareal marine, submareal and estuarine environment with elevated salinity levels where they

frequently form high density colonies (Rajagopal, 2006). This mussel is highly valued from the commercial point of view, mainly for his lofty yield, fast growth and easy culture handling practices. Being a sessile and strainer species, *Perna viridis* maintains a close relationship to the environment, and so, temperature, salinity, dissolved oxygen and other physicochemical markers are the key in its growth, development and distribution.

Cienfuegos Bay is located in the south central region in Cuba, 22°09' N and 80°27' W (Figure 1). It's a typical pocket bay that it communicates with the adjacent sea by a tight three-kilometer channel. Its shape is oval and it is oriented from NW to SE. An irregular littoral morphology of their costs is characteristic. The total area is about 88 km<sup>2</sup>, 19 km of maximum longitude and 7.5 km in the widest part, and a mean deep of 9.5 m (Tomsack and García, 1975). It is naturally divided in two lobules, with well defined hydrographic characteristics delimited by "Las Cuevas" shoal to the north of Carenas Key, which has an enormous influence in water circulation inside the bay.

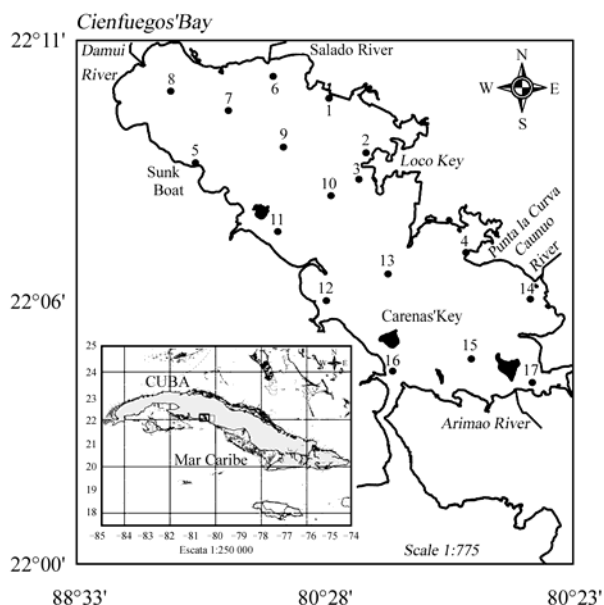


Figure 1 Location of the study area and distribution of the sampling network in Cienfuegos Bay

Water mass in Cienfuegos Bay receive fresh water contribution from Caunao, Arimao, Damuji, and Salado rivers, that modify the saline structure of the bay and input an important amount of organic material and contaminants (Tur and Becerra, 1991; Novoa, 2004).

Cienfuegos Bay is one of the best described aquatic systems in Cuba related to its oceanography. Besides of contributing to this knowledge and taking into consideration the importance of those markers for green mussel development, the aim of this work is to analyze the hydrological condition variation in Cienfuegos Bay waters in 2011 and its possible influence on that species development and distribution (Tomzack and García, 1975; Seisdedo, 2006; Seisdedo and Muñoz, 2005; Muñoz et al., 2010; Muñoz et al., 2011).

## 1 Results

Positive anomalies very well define the rainy period (May-October) (Figure 2). Precipitation maximum was observed in September and October and at the same time, evaporation decreased. Mean monthly evaporation minimum was in November (Figure 2). Maximum of positive evaporation anomaly was shown in spring time, with higher evaporation rate in May, month with the least precipitations of the rainy

period in 2011. Monthly variations of those climatic parameters showed more differences in spring time (March-April-May), with higher positive anomalies of evaporation in relation to precipitation.

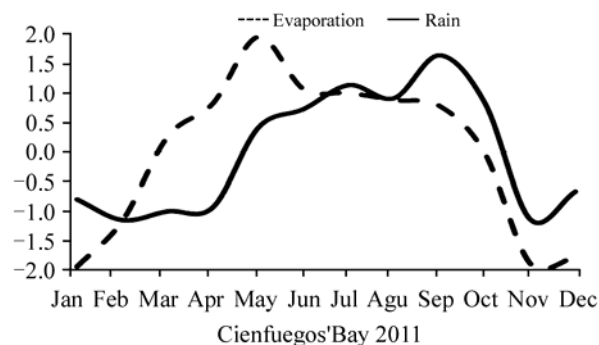


Figure 2 Annual performance of climatic variables for 2011

Water temperature presented the highest values in May (Table 1), a transition month between spring and summer. Temperature minimum was registered in February (dry), a typical winter month. Values of this marker were between 23.30°C (February) and 30.50°C (May), with mean values for sampled months of  $(26.47 \pm 2.29)^\circ\text{C}$ . Although spatial temperature distribution was influenced by daytime cycle, a higher frequency of minimal values near fluvial systems was denoted, due largely to water drains. Vertical distribution was more stratified in November (Table 1), with mean differences between surface and bottom of 0.78°C.

The highest salinity values were presented in February (dry) and May (highest annual evaporation), while the least values were registered in November (Table 1). This parameter oscillated for sampled month between 27.37 psu (November) and 36.98 psu (May), with mean value of  $(35.38 \pm 1.64)$  psu. In spatial distribution, February as well as May showed fewer gradients (Figure 3a) and more stability in the water column (Table 1). Even if November is a typical autumn month from the beginning of the dry period, it showed more estuarine characteristics, with marked gradients that are increased to the south and east. The least amounts are located to NW and near fluvial sources, mainly Damuji River (Figure 3b). In May and November the highest mean salinity in bottom was observed (Table 1), in relation to the surface, which indicates the influence of the rainy period in salinity surface waters.

Table 1 Average value of physic and chemical markers of water in Cienfuegos Bay in 2011

Parameter	Unit	Level	February			May			November		
			Mean	Min.	Max.	Mean	Min	Max	Mean	Min	Max.
Temp.	°C	Surface	24.59	24.02	26.65	29.37	23.53	30.5	27.09	26.08	28.44
		Bottom	24.25	23.30	24.55	28.99	23.3	30.48	27.87	26.89	28.56
Salinity	ups	Surface	35.73	35.51	35.95	36.65	35.81	36.98	32.62	27.37	34.67
		Bottom	35.71	34.97	35.96	36.71	35.57	36.98	34.29	32.20	35.35
DO	mg/L	Surface	5.38	4.45	6.02	4.60	1.56	6.68	5.87	4.66	6.67
		Bottom	5.62	3.20	7.02	4.87	2.54	6.67	4.26	2.05	6.10
DO	%	Surface	79.72	66.8	89.5	73.8	25.1	108.1	88.3	71.0	98.9
		Bottom	82.59	45.1	103.4	77.83	47.2	107.9	65.26	16.8	94.2

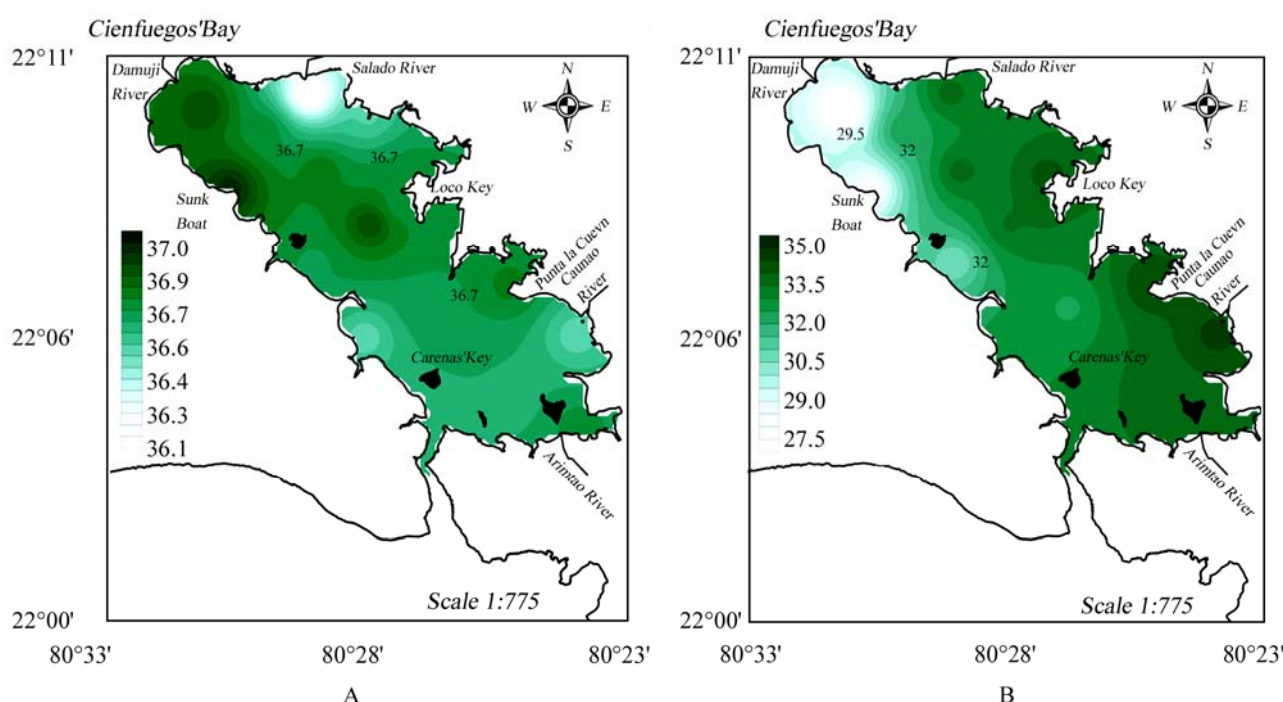


Figure 3 Spatial salinity distribution in the months of May (a) and November (b) in Cienfuegos Bay in 2011

Dissolved Oxygen concentration was higher ( $\geq 5$  mg/L) in February (winter) and November (autumn) and the least mean values occurred in May (Table 1). The biggest differences between surface and bottom were presented in November (Table 1), with mean of 1.61 mg/L, with less bottom levels. Spatial distribution (Figure 4) generally shows minimum in the north lobule and maximum in the south one.

## 2 Discussion

Green mussel *Perna viridis* is found in different

marine environments. Nevertheless, hydrological systems with temperatures between 26°C and 32°C, with salinities of 27 psu to 33 psu, and with dissolved oxygen of 4 mg/L to 7 mg/L, favor its growth rate and surviving (Chatterji et al., 1984; Rajagopal et al., 2006). In situ registered values in the sampled months accomplished those ranges with mean values of 26.5 °C, 35.38 psu and 5.1 mg/L respectively.

Values and marker variations are similar to those obtained by other authors in this bay, and are related

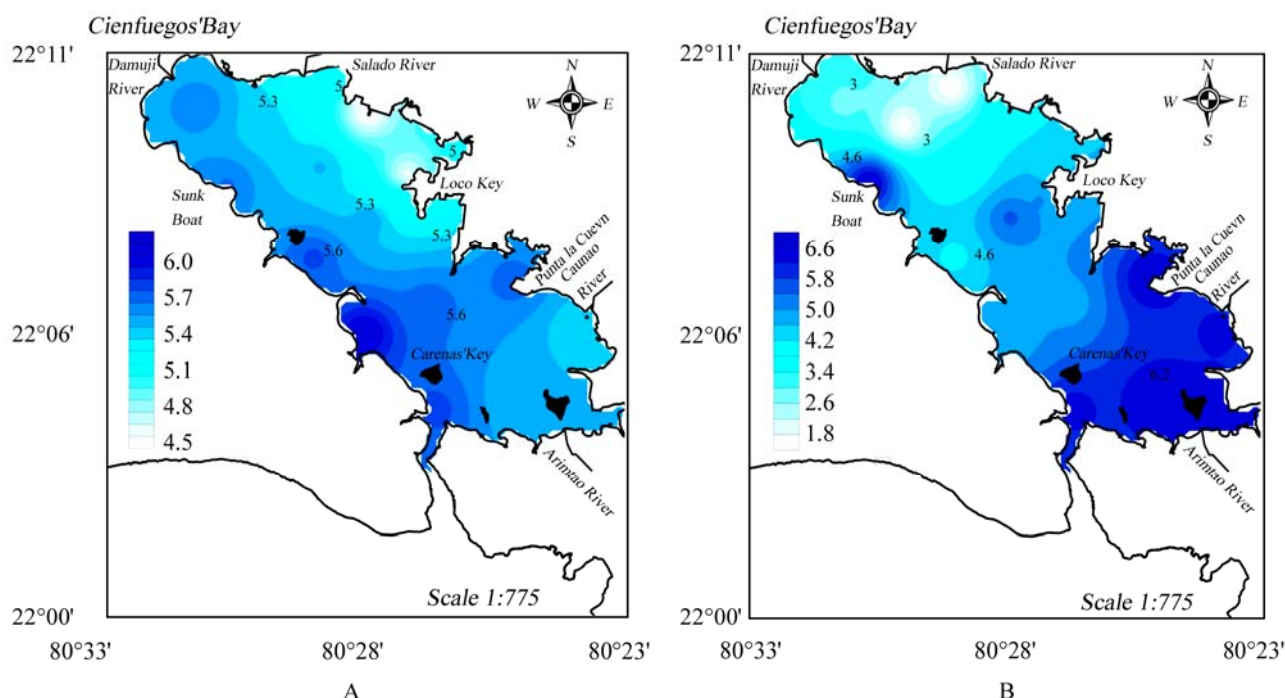


Figure 4 Spatial distribution of dissolved oxygen in the months of February (a) and May (b) in Cienfuegos Bay in 2011

to the climatic panorama and seasonality. February (winter) presented typical characteristics of a dry month, while May (spring) showed the effect of evaporation maximum, with relatively high temperatures ( $\geq 30^{\circ}\text{C}$ ). November manifested hydrological characteristics of a wet month, in spite of presenting the least raining accumulation that year; it was marked by the inertia of the previous months hydrometeorological characteristics, when the maximum mean rain accumulations occurred (254 mm), impinging on the remaining drains. The shift of the maximum of rain to September and October generated instability in hydrology in November, giving characteristics that belong to a wet season to that dry month.

In general, oxygen was under the saturation level, making the bay behave as a system where consumption processes predominate over the production ones, mainly in the North lobule as a consequence of river mouths and residual waters. Mean concentrations of the analyzed hydrological markers were in agreement with the NC 25: 1999 requirements for good quality water for fishing use. Analyzing spatial distribution of

studied variables, it was clear that better conditions and higher hydrological stability were located in the south lobule. However, there is more presence of the green mussel in the north lobule (Fernández-Garcés and Rolán, 2005), more anthropized. This fact may also be related to a greater quantity of hard substrates (docks, pilings, etc.) as well as to more availability of food. In this region there is more eutrophication by nutrients and phytoplankton (Areces, 1986; Moreira et al., 2007; Seisdedo and Moreira, 2007). In the same way, the least mean salinity values by month (32.89 psu) were also registered in the north lobule.

Taking into consideration the hydrodynamic system and the renovation time in Cienfuegos Bay waters (Muñoz et al., 2010), the observed distribution of the green mussel is in accordance with the sense and intensity of the currents. According to those hydrological conditions larvae have fewer probabilities of arriving and fixing in the south lobule. On the other hand, veliger larvae could be transported out of the bay and could colonize near areas. However, the adjacent topography to the bay (Tomsack and García, 1975) decreases the fixation and growth success.

The regions in which this mussel has been reported (e.g. Chatterji et al., 1984; Rajagopal et al., 2006; Baker et al., 2007), manifest similar hydrological panorama to Cienfuegos Bay. In general, studied markers offer satisfactory ranges for development and distribution of the green mussel inside this aquatic system.

### 3 Data and Methods

A seventeen spot network was relied on to take samples at two levels: surface (0.50 m) and bottom, in Cienfuegos Bay (Figure 1). Water Temperature (°C), salinity (psu) and dissolved oxygen (mg/L), were measured with a HANNA HI 9828 multiparameter probe (precision:±0.01) at each point. In the year, three campaigns were made. Two of them (February/2011 and November/2011) are corresponding to dry season, and the other, to wet season (May/2011). Mean monthly precipitation and evaporation data were taken from Cienfuegos Meteorological Station. Maximum and minimum values as well as standard deviations of hydrological parameters were determined. Monthly rain and evaporation mean values were transformed in anomalies for a better graphic interpretation. Cuban Standard Regulation NC 25: 1999 criteria for each marker were taken in consideration to evaluate the results.

### Authors' Contributions

YG and AB designed the station network, collected the data and analyzed it. YG drafted the manuscript. AL helped in data collection and revised critically the manuscript. AA conceived of the study, and participated in its general design and data collection. AA Also helped to draft the manuscript. All authors have read and approved the final manuscript.

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