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Influence of the drought period 2014-2017 on the water quality and occurrence of harmful algal blooms in Cienfuegos bay (Cuba)

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Abstract. Cienfuegos bay represents one of the most important natural resources in the central-southern region of Cuba. This bay is a semi-closed marine ecosystem with estuarine influence due to the discharge of four important rivers. Weather in the study area; divided in two seasons (dry and rainy), has influence on the water quality of the bay. The aim of this study was to analyze the influence of the drought period 2014-2017 on the water quality of Cienfuegos bay and its relation with the red tides occurred in the same period. The values of a Water Quality Index (WQI) and rainfalls during 2012-2014 were considered for this analysis. The physic-chemical results showed notable changes during the rainy season of 2015, which were related to the increase of salinity, temperature, BOD_5 and nutrient concentrations. In addition, harmful algal blooms were recorded in the bay during the drought period, which were more frequent in the rainy season.

Key words: drought, WQI, bay, harmful algal blooms.

Resumen: Influencia del período de sequía 2014-2017 en la calidad del agua y ocurrencia de florecimientos algales nocivos en la bahía de Cienfuegos. La bahía de Cienfuegos representa uno de los recursos naturales más importantes de la región centro y sur de Cuba. Esta bahía es un ecosistema semicerrado con influencia estuarina debido a la descarga de 4 ríos importantes. El clima en el área de estudio, dividido en dos estaciones (seca y lluviosa) tiene influencia en la calidad del agua de la bahía. El objetivo de este estudio fue analizar la influencia del período de sequía 2014-2017 en la calidad del agua de la bahía de Cienfuegos y su relación con mareas rojas ocurridas en el mismo período. Para este análisis se consideraron los valores de un Índice de Calidad del Agua (ICA) y de precipitaciones durante 2012-2017. Los resultados físico-químicos mostraron cambios notables durante la estación lluviosa de 2015, los cuales se relacionaron al incremento de salinidad, temperatura, DBO_5 y concentraciones de nutrientes. Además, se registraron florecimientos algales nocivos en la bahía durante el período de sequía, los cuales fueron más frecuentes en la estación lluviosa.

Palabras clave: sequía, ICA, bahía, florecimientos algales nocivos.

Introduction

Estuarine habitats contain transitional waters with ecosystems between riverine and coastal marine. These environments are complex coastal areas with strong alterations in the hydrodynamic processes, which have repercussion in the biological and ecological parameters (Flores *et al*. 2011). They provide also significant ecosystem services and societal goods and benefits (Wolanski & Elliott 2015).

Coastal and transitional ecosystems are being adversely affected by global climate, including increasing temperatures and sea levels as well as more severe droughts and storms (Day & Rybczyk

2019). Similar trends have been recorded in the Latin American region in recent years where for example changes in weather patterns have become more frequent, leading to hurricanes and recurring and intense drought periods in some areas (ECHO 2014). In the most recent literature on climate variability in Cuba, droughts have been reported as more frequent, intense and extensive both temporally and spatially (Planos *et al*. 2013).

River flows represent the integrated response of all hydrometeorological processes acting upon a catchment (Hannaford, 2015).The residence times and the susceptibility to eutrophication also will increase in estuarine ecosystems as a result of reduced freshwater inflow. Regarding this, Scavia *et al.* (2002) reported that changes in freshwater inputs alter the estuarine stratification, residence time, eutrophication and primary production.

Some studies in the Carolinas and the United Kingdom have addressed impacts of droughts such as changes in the trophic status of waters in coastal systems (Gilbert *et al.* 2012, Robins *et al.* 2016). However, most of the reports on the trophic status of bays in Cuba and other countries of Latin American (Herrera-Silveira *et al.* 2011, Alves e*t al.* 2013, Alamo *et al.,* 2013, Montalvo *et al.* 2014, Moreira *et al.* 2014) emphasize the application of indices, for example, the index TRIX, proposed by Vollenweider *et al.* (1998) and the ASSETS method (Bricker *et al.* 2003), as well as reports of eutrophication symptoms, such as high chlorophyll *a* levels and toxic algal blooms events.

Cienfuegos bay represents one of the most important natural resources in the central-southern region of Cuba, more specifically, for its contribution in recreational, touristic and industrial development of Cienfuegos province. This aquatic system presents estuarine characteristics for being a semi-closed bay with influence of four rivers. Some intense and extensive drought periods have generated negative impacts on socio-economic activities in this province. In the last years, the water deficit began in mid-2014 and persisted until June 2017 in the Cienfuegos province (Barcia *et al*. 2019).

Several studies have recorded the incidence of anthropogenic activities and storms on physic-chemical and biological parameters in Cienfuegos bay (Moreira *et al*. 2009, Seisdedo *et al*. 2012, Moreira *et al*. 2012). Although some water quality assessments from trophic point of view in this bay have showed non-eutrophic conditions (Seisdedo *et al.,* 2014), it was classified with eutrophication risk (Seisdedo *et al.,* 2016). However, the influence of drought periods on the environmental water quality of this bay has not been previously evaluated. Therefore, the aim of this study was to analyze the influence of the drought period in 2014-2017 on the water quality of Cienfuegos bay, as well as its relation with the red tides occurred in the same period.

Materials and methods

Study area: Cienfuegos bay is located in the central-southern region of Cuba. It is connected to the Caribbean Sea by a narrow channel 3.6 km long. Its area is 88.46 km^{2}and a total volume of 0.84 km^3 with an average depth of 9.5 m (Muñoz *et al.* 2012) (Fig. 1). This bay has several socio-economic uses (fishing, port, industrial, urban, tourism, etc.). It is divided into two natural lobes. The northern lobe has more anthropogenic impact (produced by the discharges of the Cienfuegos city and the industrial area, as well as the contribution of the Salado and Damují rivers).

The southern lobe is subjected to a lower degree of pollution originated mainly from the Caonao and Arimao rivers.

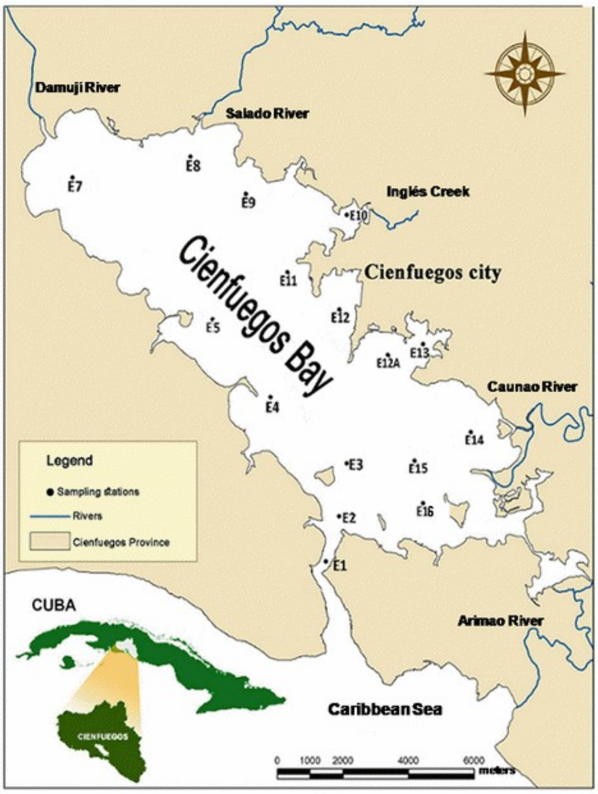

Figure 1. Study area and sampling stations during the monitoring program in Cienfuegos bay.

This bay is influenced by two seasons (Seisdedo & Muñoz 2005) extremely associated to rainfall which is the element of greatest variability in the Cuban climate, the rainy season (May to October) when 75-80% of the annual total rainfall occurs and the dry season (November to April), when the rest percentage precipitates (IANAS 2019). The annual average rainfall is 1256 mm (Barcia *et al*. 2011).

Sampling and data analysis: Considering the objective of this paper, we decided to analyze data from 12 sampling campaigns carried out in Cienfuegos bay during 2012-2017 to evaluate the changes occurred with this drought period. These campaigns included the two seasons (rainy and dry) which have influence on this aquatic system, as well as the 16 stations considered in the hydrological monitoring program of this bay (Fig. 1).

Water sampling and analytical assays were performed by the Center for Environmental Studies in Cienfuegos. Niskin bottles (5 L) were used for sampling and the specifications of APHA (2017) were considered. The sampling was at 0.5-m below water surface and nearest 0.5 meter off the bottom.

Water quality analysis: The following parameters or variables were determined: temperature, salinity, pH, dissolved oxygen (DO) nitrites (NO_2), nitrate (NO_3), ammonium (NH_4), orthophosphate (PO_4), all these analyzed both at surface level as in bottom, and Biochemical Oxygen Demand (BOD_5) and thermotolerant coliforms (T. Colif.), were only analyzed at surface level. Salinity and temperature were determined in situ using a YSI-30 model digital probe; the pH analysis was performed by using a HANNA digital pH meter, while the determination of BOD_5 was by incubation method at 20 °C for 5 days. Dissolved oxygen was analyzed by the Winkler method, NO_2, NO_3 and NH_4 were determined according to the methodology of UNESCO (1983), while the PO_4 analysis was performed by using the method presented by UNEP (1991). The thermotolerant coliforms were analyzed by Fermentation in multiple tubes according to APHA (2017)

In order to assess the water quality, we used a Water Quality Index (WQI) implemented in this bay since 2012 considering the water quality criteria established in the Cuban standard for fishing use (NC.25, 1999) except for pH, salinity and temperature because this index only considers causal and response parameters related to eutrophication and the combining method proposed by CCME (2001):

$$WQI = 100 - \left(\frac{\sqrt{F_1^{\,2} + F_2^{\,2} + F_3^{\,2}}}{1.732} \right)$$

where:

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}} \right) \times 100$$

F1- represents the percentage of variables that do not meet their objectives or quality criteria (“failed variables”), relative to the total number of variables measured

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}} \right) \times 100$$

F2- represents the percentage of individual tests that do not meet objectives or quality criteria (“failed tests”)

$$F_3 = \left(\frac{nse}{0.01nse + 0.01} \right)$$

F3- represents the amount by which failed test values do not meet their objectives or quality criteria. F3 is calculated in three steps.

The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions, or *nse*, is calculated as:

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{\#\ of\ tests}$$

The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an “excursion” and is expressed as follows.

$$excursion_i = \left(\frac{FailedTestValue_i}{Objective_j} \right) - 1$$

For the cases in which the test value must not fall below the objective.

$$excursion_i = \left(\frac{Objective_j}{FailedTestValue_i} \right) - 1$$

The 1,732 divisor normalizes the resulting values based on obtaining a range of 0 to 100, which is divided into 5 different categories of water quality: poor (0-44), marginal (45-64), fair (65 -79), good (80-94) and excellent (95-100).

Although the CCME proposal (2001) requires four sampling campaigns as a minimum quantity to determine the WQI, we adapted this tool changing from a temporary approach to a spatial one, considering four sampling stations instead of campaigns (Seisdedo *et al*. 2016).The Mapinfo v 6.5 program was used to represent the spatial distribution of some indicators in Cienfuegos bay.

Statistical analysis: The RKWard 0.7.1, a graphical interface of statistical languaje R (Rödiger *et al*. 2012) was used for data processing. The non-parametric Wilcoxon test and the Spearman's Rho correlation were used because the data do not obey a normal distribution. We employed Wilcoxon test to analyze the significant differences between the WQI results corresponding to two seasons and between indicator results of both depth levels. Spearman's Rho correlation was analyzed to reveal the relationships among the water quality indicators and WQI values. A correlation coefficient near −1 or 1 means a strong negative or positive linear relationship between two variables, while one closes to 0 demonstrates a weak relationship. In this study, the relationships with correlation coefficients greater than 0.5 at the significant level of $p < 0.05$ were chosen for further detailed analysis.

Rainfall data analysis: The rainfall and historical average values per quarter in the Cienfuegos province were considered in order to identify the rainfall deficits.

Red Tides: Water discoloration or red tides (>10^6 cells/L) were recorded during the drought period, principally around the Cienfuegos city. These records did not necessarily coincide with the same stations and dates of the sampling network. Microalgal taxa were identified almost always to species using a number of taxonomic texts (Tomas 1997, Hallegraeff *et al*. 2003, Lassus *et al*. 2016).

Results:

Water Quality: The analysis of the WQI values using the Wilcoxon test showed significant differences between the two seasons analyzed (p <0.05) in the period studied (2012-2017). The best assessments of water quality per year corresponded to the dry seasons, except in 2016. In 2015, the lowest mean value of WQI and the greatest variation between the values of both seasons was obtained, while in 2014 and 2017, this difference was little and both WQI mean values showed good water quality (Fig. 2).

In the analyzed period, strong significant correlations were obtained between WQI and indicators such as DO at the bottom level, BOD_5, and the nutrients: orthophosphate, ammonium in bottom, nitrite and nitrate in both depth levels (Table I).

During the period 2012-2013, mean values of salinity varied between 5,5 and 35 psu, with higher results in the deepest zones in dry seasons, while the lowest value was recorded in the surface level in rainy season-2012. The salinity levels during the rest years ranged between 28 and 36,2 psu. The rainy season with the maximum value and less difference between both depth levels corresponded to 2015 while the lowest value was obtained in the same season of 2016. Temperature mean values ranged between 25,8 and 31,8 °C, with the maximum value during the rainy season-2015 and the minimum in the dry season 2014-15. The pH mean values varied between 7,8 and 8,4 units, obtaining this maximum value in the rainy 2015 season and the surface level while the minimum corresponded to the dry season 2016-17 and the bottom level. The DO mean concentrations were between 3,2 mg/L at the bottom and 7,8 mg/L at the surface level. The maximum and minimum values were obtained in the rainy season-2012. (Fig. 3). The analysis of salinity, pH, DO values corresponding to rainy seasons showed significant differences between the two depth levels (p<0,05) while in the dry seasons were observed only for DO.

The mean values of thermotolerant coliforms were between 2,5 and 359 MPN/100 mL with a reduction in the time. The highest mean value corresponded to rainy season in 2012 and the lowest value was obtained in the dry season 2013-14. The BOD_5 mean concentrations varied between 1,4 and

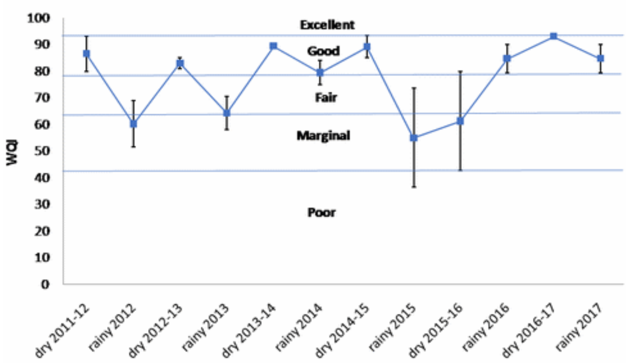

Figure 2. Temporal assessments of WQI (mean ± SD) in the Cienfuegos bay during the period 2012-2017.

Table I. Spearman correlation matrix (n = 48, * p < 0,01 and ** p< 0,05)

	WQI	DOs	DOb	P-PO4s	P-PO4b	N-NH4s	N-NH4b	N-NO2s	N-NO2b	N-NO3s	N-NO3b	BOD5	TColi
WQI	1,000	-,306	,642**	-,724**	-,644**	-,389*	-,655**	-,750**	-,704**	-,631**	-,714**	-,595**	-,481**
DOs		1,000	-,215	,473**	,339*	,291	,477**	,253	,163	,238	,235	,216	,434**
DOb			1,000	-,620**	-,606**	-,175	-,402*	-,629**	-,548**	-,342*	-,459**	-,479**	-,496**
P-PO4s				1,000	,646**	,352*	,526**	,659**	,576**	,376*	,528**	,610**	,506**
P-PO4b					1,000	,518**	,495**	,723**	,618**	,373*	,395*	,492**	,573**
N-NH4s						1,000	,320	,447**	,333*	,061	,059	,146	,334*
N-NH4b							1,000	,308	,256	,333	,355	,297	,280
N-NO2s								1,000	,923**	,447**	,556**	,645**	,437**
N-NO2b									1,000	,379*	,518**	,626**	,426**
N-NO3s										1,000	,796**	,474**	,287
N-NO3b											1,000	,481**	,371*
BOD5												,735**	,683**
TColi												1,000	,553**

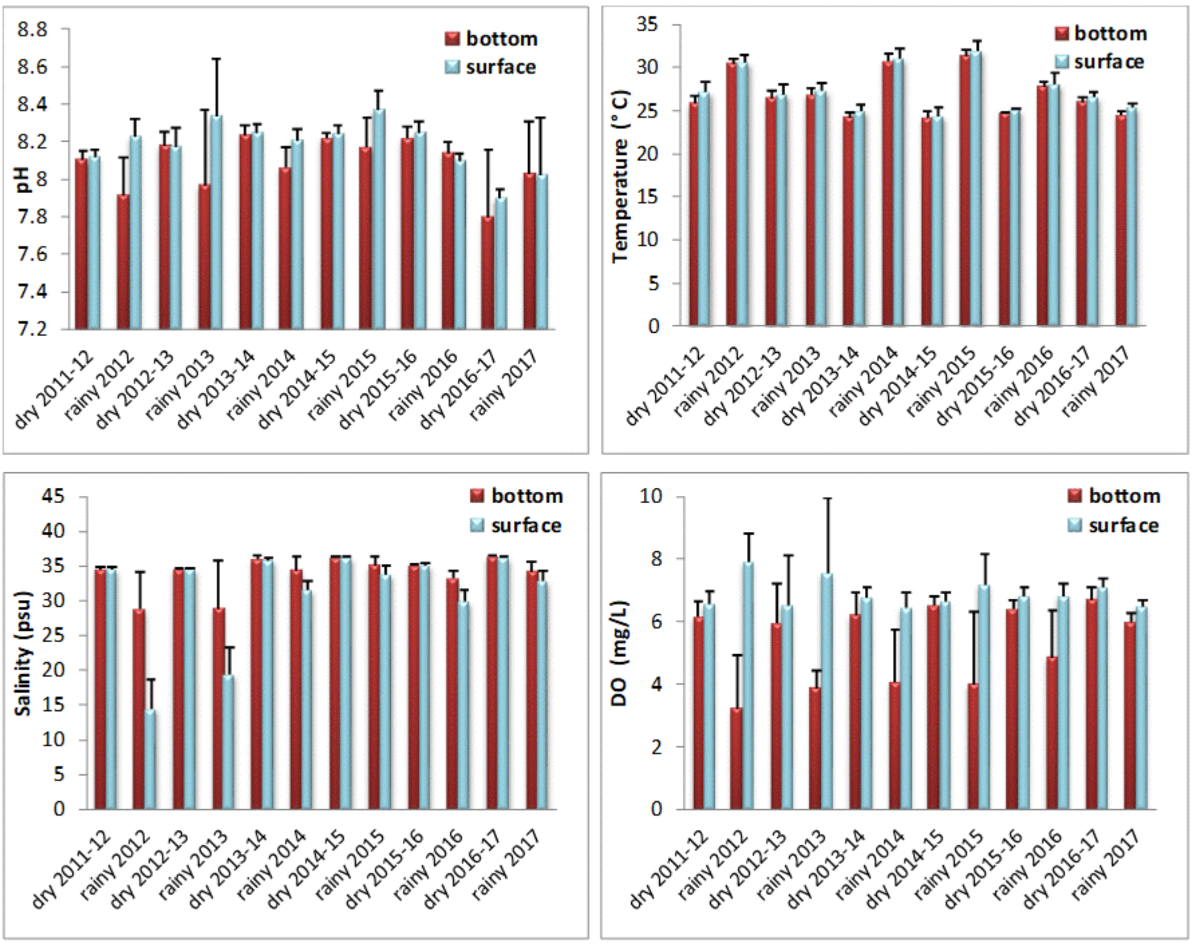

Figure 3. Temporal distribution of pH, temperature, salinity and DO values (mean + SD) in the waters of Cienfuegos bay during 2012-2017.

6,2 mg/L, with a maximum value during the rainy season-2015 and the minimum value during the rainy season 2017 (Fig. 4).

With respect to nutrients, orthophosphate mean concentrations ranged between below 0,14 and 1,3 µmol/L and more than 60% of its results were lower than quantification limit. The highest mean value corresponded to the rainy season-2012 and the lowest value was obtained in the rainy season 2017. Among nitrogen ions, ammonium showed mean concentrations between below 0,6 and 7 µmol/L, with a maximum value during the rainy season-2012 and the minimum value during the dry season 2013-14. The nitrite means ranged between less than 0,02 and 0,64 µmol/L, with a maximum value during the rainy season-2012 and the minimum value during the dry season 2016-17. The nitrate mean values were between 0,1 and 28 µmol/L. It is noted that nitrate mean values showed a notable increase during rainy season-2015 and continued being high

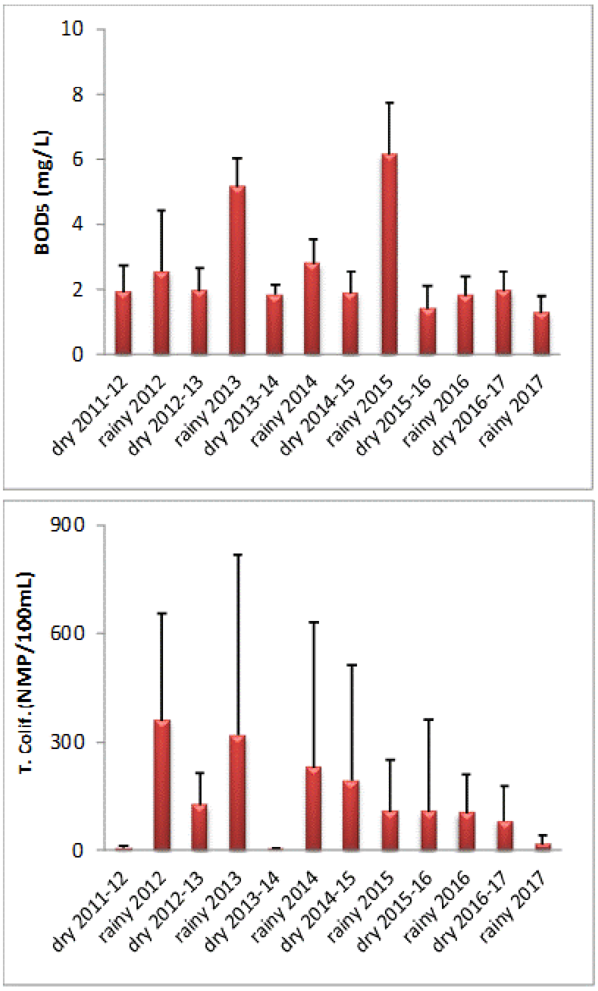

Figure 4. Temporal distribution of BOD5 and thermotolerant coliform values (mean + SD) in the waters of Cienfuegos bay during 2012-2017

during the following dry season 2015-16. The minimum value of these parameters corresponded to dry season 2017. These nutrients showed the highest values at the bottom and the lowest at the surface (Fig. 5).

The obtained results for some indicators (BOD_5; and DO, $N\text{-}NO_3$ and $N\text{-}NH_4$ at bottom) negatively affected the minimum mean value of WQI and its great variability during the rainy season-2015. Consequently, the concentration of these parameters at most of stations from the north lobe of the bay showed bad quality conditions according the Cuban criteria (NC. 25, 1999) (Fig. 6).

The comparative analysis between rainfall and its historical average values per quarter in the Cienfuegos province (Fig.7) showed the three highest rainfall average values in the second quarter of the rainy season in 2017 and in the both quarters of the rainy season in 2012. Besides, since the first quarter of rainy season in 2014 was noticeable the beginning of a period in which rainfall deficits predominated.

Red tides: Red tides in the studied period were mainly due to monospecific blooms of dinoflagellates. Among them, the athecate, chain forming gymnodinioid, *Margalefidinium polykrikoides* (Margalef) Gómez, Richlen *et* Anderson; the thecate *Gonyaulax* cf. *polygramma* Stein, *Blixaea quinquecornis* (Abé) Gottschling, *Protoceratium* cf. *reticulatum* (Claparède *et* Lachmann) Bütschli and *Vulcanodinium rugosum* Nézan *et* Chomérat (Fig. 8). Other dinoflagellates, such as *Dinophysis caudata* Saville-Kent, *Prorocentrum compressum* (Bailey) Abé *ex* Dodge, *Prorocentrum micans* Ehrenberg, *Scrippsiella trochoidea* (Stein) Balech *ex* Loeblich III, *Tripos furca* (Ehrenberg) Gómez and the diatom *Pseudo-nitzschia* sp. were observed occasionally in the composition of blooming phytoplankton.

The most frequent blooms occurred during July-August months in 2015 around Cienfuegos city, being the dinoflagellates *Margalefidinium polykrikoides* and *Blixaea quinquecornis* the most common causative agents in the red tides (Table II).

Discussion

The behavior of the water quality in Cienfuegos bay is characterized by a marked deterioration during the rainy period according to some indicator levels obtained in previous studies (Seisdedo 2006, Seisdedo & Muñoz 2013). This was also verified with the significant differences between

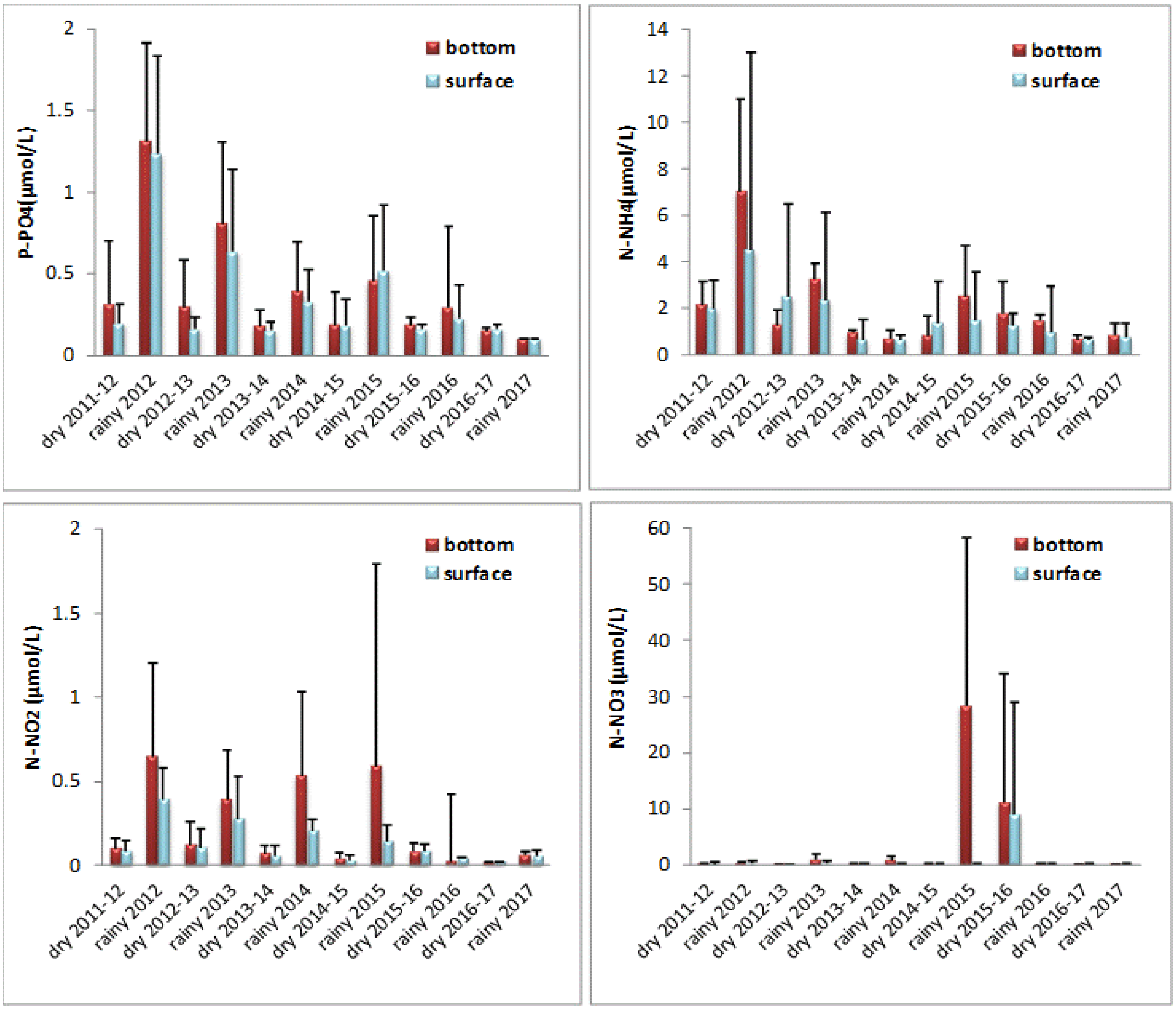

Figure 5. Temporal distribution of mean values of P-PO_4, N-NH_4, N-NO_2 and N-NO_3 in the waters of Cienfuegos bay during 2012-2017.

WQI values corresponding to two analyzed seasons in this study.

The highest rainfall average values justify the obtaining of the lowest salinity values at the surface level during the rainy season in 2012, but not totally the values from the rainy season in 2017 because our sampling campaign was carried out in the first quarter and the drought period finished in second quarter of the same season. The influence of rainfall and freshwaters contributes to the marked vertical haline stratification, characteristic in the rainy seasons (Moreira *et al.* 2014). According to a report by ISMET (2012), the month of August in 2012 had a rainy behavior, with an average value of rainfall in Cuba that represented 127% of the historical average.

The high nutrient levels of ammonium and orthophosphate in the rainy season-2012 could be explained by local freshwater inputs due to increased precipitation (Barcia *et al.*, 2019). These authors, based on the analysis of the Standardized Precipitation Index (SPI), observed a significant decrease in rainfall since May/2014, which was noticeably accentuated in the first quarter of the rainy period/2015, coinciding with high salinity values of our sampling campaign. It is interesting to note that the sampling campaign corresponding to the rainy season-2015 was precisely in the first quarter of rainy season-2015.

The testing of a methodology for managing water quality from trophic point of view during 2014 (Seisdedo *et al*. 2016) could have a positive influence in the water quality of the bay because it allowed implement environmental management actions and to reduce nutrients into the Cienfuegos bay. Besides, some wastewater treatment systems in

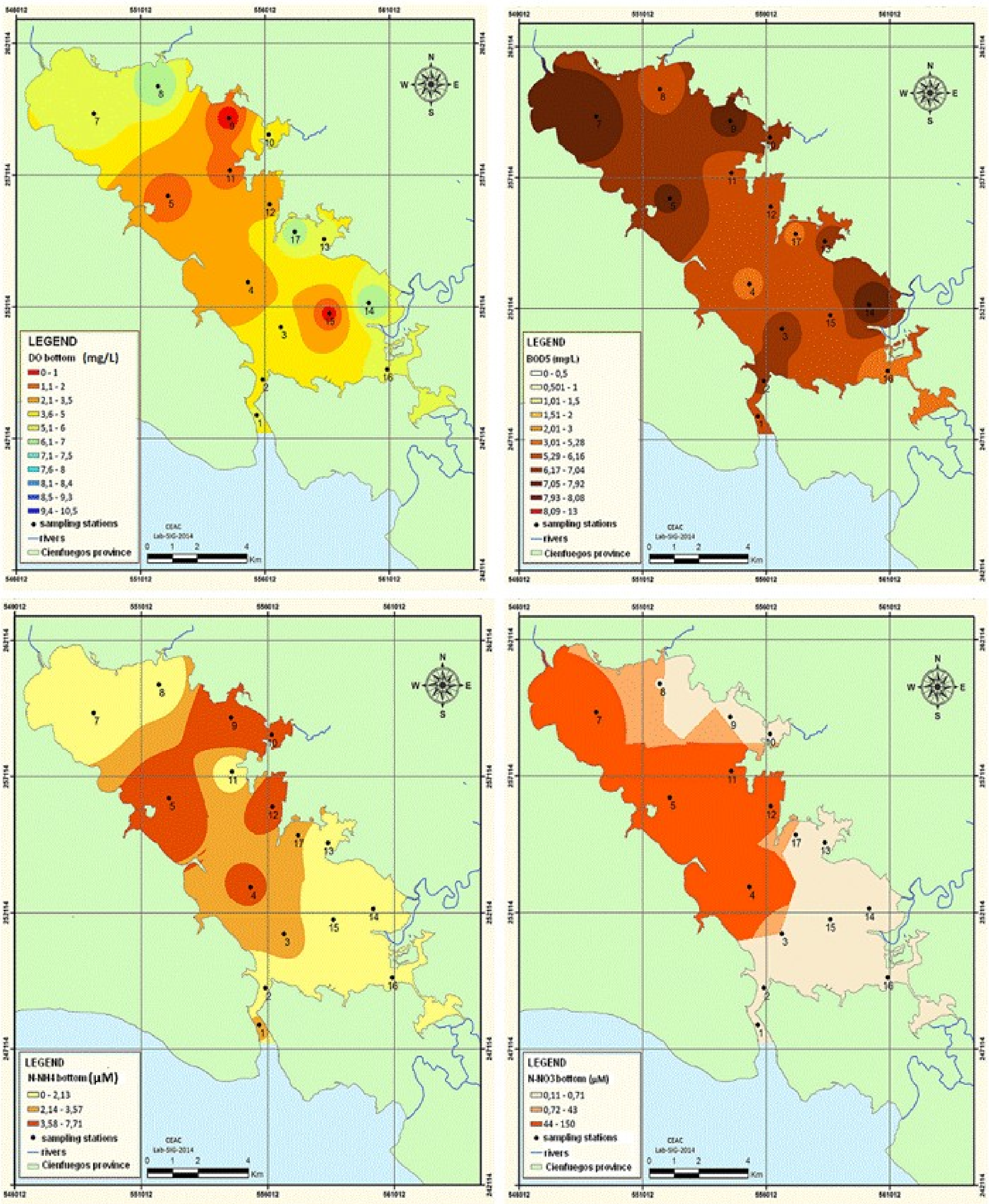

Figure 6. Spatial distribution of DO, BOD_5, $N\text{-}NO_3$ and $N\text{-}NH_4$ values in the waters of Cienfuegos bay during rainy season 2015.

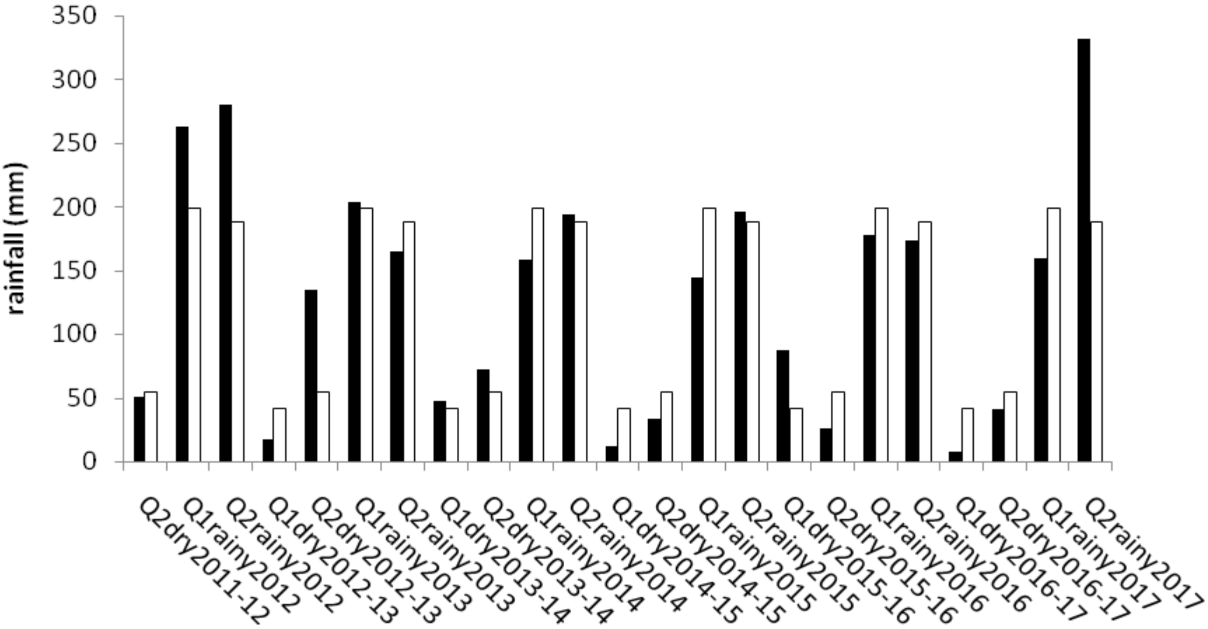

Figure 7. Temporal distribution of rainfall per quarter (Q1: first quarter, Q2: second quarter, black bars: average values, white bars: historical average values) in Cienfuegos province during 2012-2017.

Table II. Documented dinoflagellate blooms around the Cienfuegos city in the period 2014-2017.

Causative species	Date of occurrence	Place of occurrence (areal extension)	Noxious effects
Margalefidinium polykrikoides	21 January 2014	Guanaroca Lagoon (~0.8 Km^2)	Fish, oysters and blue crabs' death
	16 June 2016	Near touristic port area ("Muelle Real") (~0.2 Km^2)	No effects observed
	29 June 2016	Jagua Hotel-"La Punta" Beach (~0.2 Km^2)	No effects observed
Vulcanodinium rugosum	July-August 2015	"Círculo Juvenil" Beach-"La Punta" Beach (~0.5 Km^2)	Skin lesions in swimmers
Gonyaulax cf. *polygramma*	7 November 2016	Near touristic port area ("Muelle Real") (~0.3 Km^2)	No effects observed
Blixaea quinquecornis	17 June 2016	"Laguna del Cura" Beach (~0.2 Km^2)	No effects observed
	19 June 2016	Near touristic port area ("Muelle Real") (~0.4 Km^2)	No effects observed
	21 June 2017	Near touristic port area ("Muelle Real") (~0.3 Km^2)	No effects observed
Protoceratium cf. *reticulatum*	18 July 2017	"Círculo Juvenil" Beach (~0.1 Km^2)	No effects observed

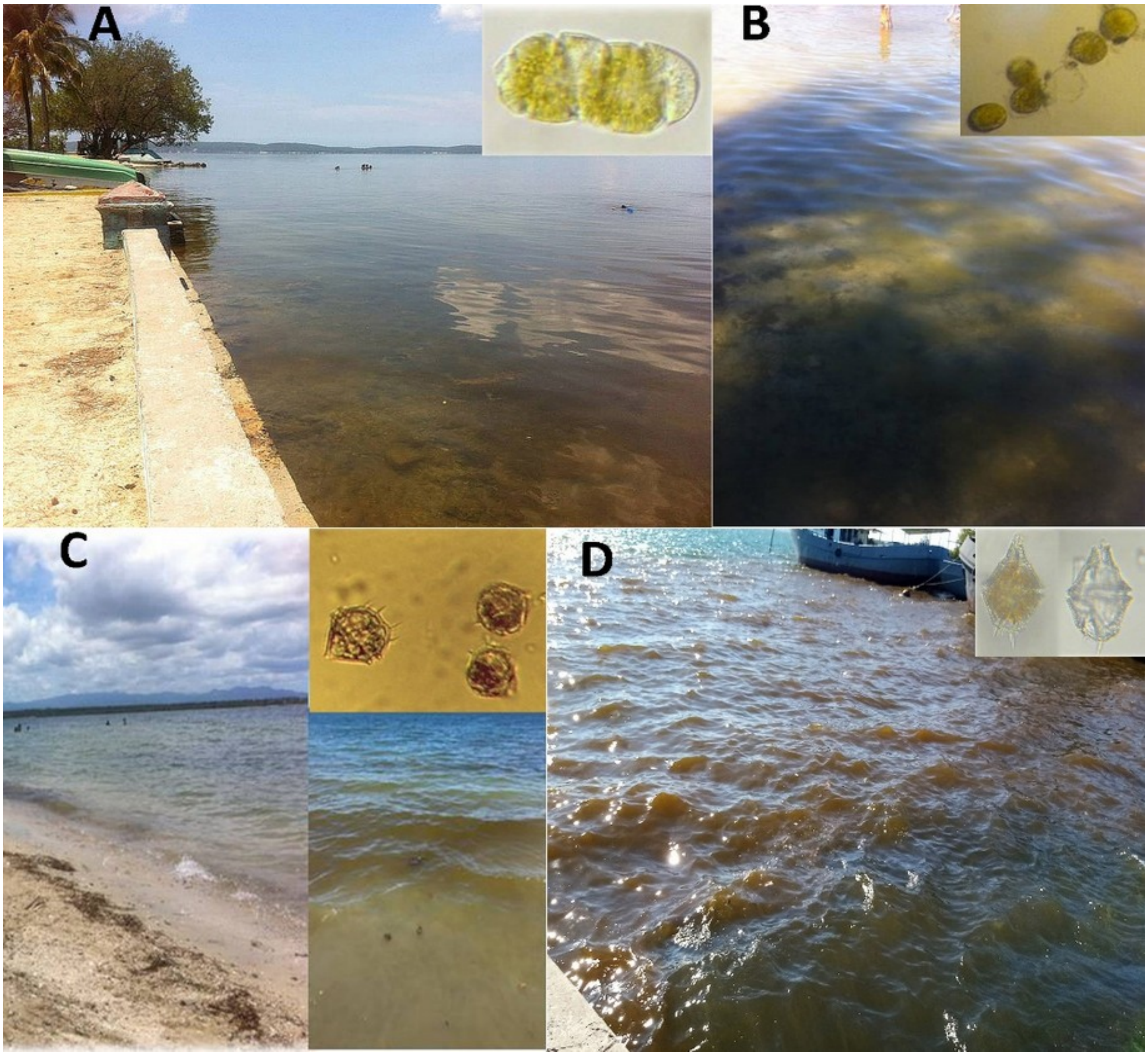

Figure 8. Red tides of dinoflagellates recorded around the coast of Cienfuegos city during the drought period 2014-2017. A. *Margalefidinium polykrikoides*. B. *Protoceratium* cf. *reticulatum*. C. *Blixaea quinquecornis*. D. *Gonyaulax* cf. *polygramma*.

the Cienfuegos city were improved from dry season 2013-14, contributing to the reduction of thermotolerant coliform levels and organic matter. However, the need of more investments was also recognized by Seisdedo *et al.* (2016) in order to achieve significant changes in indicators such as deforestation and sewage related pollution, which affect negatively the water quality of the bay, mainly in the northern lobe. According to Seisdedo (2015), more than 70% of the total nitrogen and organic matter loads in this bay come from domestic and industrial drainage systems of the Cienfuegos city and rivers of the northern lobe. These factors and the continuous rainfall deficits in the period corresponding to rainy 2014-rainy 2015 seasons could influence accumulation processes leading to the deterioration of environmental conditions in the bay.

One of the factors that influences on the water quality in marine ecosystems is the capacity for self-purification that depends on water renewal. The average residence time of Cienfuegos bay varies depending on the river contributions, increasing as the river contribution decreases, for equal wind conditions (Muñoz *et al*. 2012). Therefore, with the reduction of freshwater flows noted from the high salinity values for both depth levels, the capacity for self-purification was reduced and nutrient concentrations such as nitrate and organic matter were increased, reflected in the temporal and spatial analysis during the rainy season in 2015. According to Souza *et al*. (2003), the combination of large volumes of water with high residence time stimulates primary production due to the accumulation of nutrients. In Kaštela Bay, Northern Adriatic (Mediterranean Sea), Ninčević Gladan *et al.* (2010) reported an increase of phytoplankton abundance, in particular of dinoflagellates, coinciding with years of severe droughts.

The continuous improvement of water quality in the period: dry season 2015-16 - dry season 2016-17, was not the characteristic for this bay. This could be due to the rains that occurred in the November 2015-January 2016 quarter, influenced by the El Niño- Southern Oscillation (ENSO) event and that resulted in higher values than normal ones for most of the country (Barcia *et al*. 2019). In addition, it allowed the reduction of the high values of salinity, nutrients and organic matter.

The increase of temperature during rainy seasons is in correspondence to warmer months. These high temperatures together to the marked vertical haline stratification in the same seasons (Moreira *et al.* 2014) and the occurrence of biotic processes, could be related with the obtaining of significant differences ($p<0,05$) between the two depth levels for some parameters (salinity, pH, DO and nitrate). The solubility of dissolved oxygen depends on both salinity and temperature (Millero 2006), and the decomposition of allochthonous and autochthonous organic matter leads to a decrease in dissolved oxygen concentration (Boesch *et al*. 2001). On the other hand, most phytoplankton species are able to use nitrate as the nitrogen source (Raven & Giordano, 2016) and with increasing nitrogen assimilation into amino acid and proteins, the demand to acquire CO_2 increases, which leads pH change.

The significant correlation between WQI and DO at the bottom level could be also linked to the decomposition process of organic matter by the aquatic organisms which may therefore be responsible for lowering dissolved oxygen, mainly in bottom waters. The obtaining of DO mean values in bottom below the established limit for good water quality (5 mg/L) during the rainy seasons reflects deterioration signs with influence on WQI values. Hypoxic concentrations (DO < 2 mg/L) in bottom are considered as an indicator of eutrophication process (Cloern 2001).

According to Barcia *et al*. (2019), this meteorological drought period caused damage to fish and other aquatic organisms due to the decrease in water flows, which are important for water renewal. Droughts can lead to increased salinity and nutrient concentrations in estuarine systems, which are favorable for the occurrence of harmful algal blooms; more specifically lead to dinoflagellate blooms (Withers 2002, Kopuz *et al*. 2014). Similarly, there was an increase in the dinoflagellate blooms of both toxic and non-toxic species, principally around the coast of Cienfuegos city. Among the toxic blooms, *Margalefidinium polykrikoides* was associated with mortality of blue crabs, fish and shellfish; and *Vulcanodinium rugosum* bloom was associated with dermatitis of swimmers in summer of 2015 (Moreira *et al*. 2016). *M. polykrikoides* have been implicated in mortality of fishes and invertebrates from tropical and subtropical areas worldwide (Kim 1998, Richlen *et al*. 2010). *V. rugosum* is known to produce pinnatoxins, fast acting toxins with high affinities for human neuronal nicotinic acetylcholine receptors (Aráoz *et al*. 2015). *Protoceratium* cf. *reticulatum* is another toxic species that was observed forming small shallow blooms in one beach in Cienfuegos bay without effects on human and ecosystem. *P. reticulatum* is known to produce yessotoxins, lipophilic toxins without effects reported in humans but animal bioassays have showed toxicity (Satake *et al*. 1997).

Among the non-toxic species, monospecific blooms of the dinoflagellates *Gonyaulax* cf. *polygramma* and *Blixaea quinquecornis* were recorded. These dinoflagellates have been previously reported in Cienfuegos bay; and specifically *B. quinquecornis* is known to produce frequent blooms in eutrophic areas of this embayment (Moreira *et al*. 2009, 2010, 2014). Although toxicity of these species has not been reported, their blooms can cause anoxia and have been related to fish kills and economical losses in other parts of the world (Koizumi *et al*. 1996, Al-Yamani *et al*. 2012).

Other species found at low concentrations in these red tides are known to be toxic or harmful, composed mostly by dinoflagellates (*Dinophysis caudata*, *Prorocentrum compressum*, *Prorocentrum micans*, *Scrippsiella trochoidea*, *Tripos furca*) and the diatom *Pseudo-nitzschia* sp.; which have been also previously reported in red tides from Cienfuegos bay (Moreira *et al*. 2014). *D. caudata* produce okadaic acid, dinophysistoxin and pectenotoxin (PTX-2) all of which have potential for diarrhetic shellfish poisoning (DSP) in humans (Reguera *et al*. 2012). *P. compressum*, *P. micans*, *S. trochoidea* and *T. furca* are non-toxic dinoflagellates, however most of them are reported to form extensive blooms associated with mass mortalities of shellfish, fish and another marine biota (Horstman 1981, Hallegraeff 1993, Glibert *et al*. 2002, Anderson *et al*. 2013). Some *Pseudo-nitzschia* species produce domoic acid, a potent neurotoxin (Bates *et al*. 1989). In this bay, *Pseudo-nitzschia pungens* (Grunow *ex* Cleve) Hasle is very frequent and abundant; and blooms of *Pseudo-nitzschia multistriata* (Takano) Takano have also been reported (Moreira 2013, Moreira *et al*. unpublished data)

In overall, harmful dinoflagellate blooms in Cienfuegos bay were linked to extreme weather conditions (high temperature, salinity, solar irradiation, residence time, nutrient increase and high water stability) during the drought period 2014-2017. According to Rojas-Higuera & Ortiz (2007), the abundance/predominance of diatoms and dinoflagellates depend on factors such as temperature, salinity and nutrient availability. Besides, it is considered that tropical ecosystems and in areas with restricted circulation as Cienfuegos bay, can react with more obvious responses to the increase of the eutrophication problems (Aranda 2004, Moreno 2007, Glibert *et al*. 2017).

Conclusion

In summary, the drought period 2014-2017 had influence on the water quality of Cienfuegos bay; however, the most significant signs of deterioration associated with this meteorological event were found between the periods: rainy season-2015 and dry season 2015-16. In addition, this drought period was linked with an increase in the frequency and diversity of both toxic and non-toxic harmful algal blooms (especially dinoflagellates) in some areas of Cienfuegos bay, mainly in its northern lobe.

The results of this study can contribute to the understanding of the drought effects in this bay and should be considered for designing management plans because these meteorological events are predicted to increase over the subsequent years. Consequently, prolonged monitoring programs are required in order to understand the long-term effects of climatic changes in estuarine systems like this bay.

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References

Al-Yamani, F., Saburova, M. & Polikarpov, I. 2012. A preliminary assessment of harmful algal blooms in Kuwait's marine environment. **Aquatic Ecosystem Health & Management**, 15 (sup1): 64-72.

Álamo, B., Loza, S., Sánchez, M., Montalvo, J F., García, I., Reyes, T. & Carmenate, M. 2013. Assessment of the trophic state of six inner bays in Sabana-Camagüey Archipelago, Cuba, using chlorophyll-a as biomarker. **Serie Oceanológica**, No. 13: 9-21

Alves, G., Flores, M., Gaspar, F., Gomes, J. & Feitosa, F. 2013. Eutrophication and water quality in a tropical Brazilian estuary. **Journal of Coastal Research**, Special Issue: 7-12

Anderson, D.M., Keafer, B.A., McGillicuddy, D.J., Solow, A.R. & Kleindinst, J.L. 2013. Improving the accuracy and utility of harmful algal bloom forecasting systems. In: Lewis, J.M., F. Marret, and L. Bradley (Eds). **Biological and Geological Perspectives of Dinoflagellates**. The Micropalaeontological Society, Special Publications. Geological Society, London, pp. 141-147.

APHA – American Public Health Association. 2017. **Standard Methods for the examination of Water and Wastewate**r, 23th Edition.

Aranda, N. 2004. Eutrofización y calidad del agua de una zona costera tropical. **Tesis en opción al grado de Dr. en Ciencias del Mar**, Universidad de Barcelona, 246 p.

Aráoz, R., Hess, P., Pelissier, F., Benoit, E., Servent, D., Zakarian, A. & Molgó, J. 2015. Cyclic imine toxins: From shellfish poisoning to neuroscience: The case of acyl derivatives. **Biochemical Pharmacology**, 97: 622.

Barcia, S., Orbe, G., López, R., Regueira, V., Millán, J., Ceballo, R., Sánchez, R. & Angulo, R. 2011. **Variabilidad y tendencias del clima en la provincia Cienfuegos**. Centro Meteorológico Provincial de Cienfuegos, Cienfuegos, Cuba, 47 p.

Barcia, S., Fontes, M., Ramírez, M. & Viera, E. Y. 2019. La sequía meteorológica 2014-1017, características e impactos en la provincia Cienfuegos. **Revista Cubana de Meteorología,** 25, No. sp.: 319-333.

Bates, S.S., Bird, C.J., Freitas, A.D., Foxall, R., Gilgan, M., Hanic, L.A. & Quilliam, M.A. 1989. Pennate diatom *Nitzschia pungens* as the primary source of domoic acid, a toxin in shellfish from eastern Prince Edward Island, Canada. **Canadian Journal of Fisheries and Aquatic Sciences**, 46(7): 1203-1215.

Boesch, D. F., Burreson, E., Dennison, E., Houde, W., Kemp, E., Kennedy, M., Newell, V., Paynter, R., Orth, K. & Ulanowicz, R. 2001. Factors in the decline of coastal ecosystems. **Science**, 293: 1589-1590.

CCME. 2001. Recommandations canadiennes pour la qualité des eaux: Indice de qualité des eaux du CCME 1.0: Manuel de l’utilisateur, dans Recommandations canadiennes pour la qualité de l’environnement, 1999, Winnipeg.

Cloern, J. E. 2001. Our evolving conceptual model of the coastal eutrophication problem. **Marine Ecology Progress Series**, 210: 223-253.

Day, J.W. & Rybczyk, J.M. 2019. Global change impacts on the future of coastal systems: Perverse interactions among climate change, ecosystem degradation, energy scarcity, and population. In: **Coasts and Estuaries.** Elsevier Inc.

ECHO. 2014. **Lecciones aprendidas y buenas prácticas para la reducción de riesgos frente a la sequía en américa central y del sur. Programa de resiliencia frente la sequía en comunidades de América Central y del Sur**. Dirección de Ayuda Humanitaria y Protección Civil de la Comisión Europea, 20 p.

Flores, M.J., Paulo, J.G., Nascimento, G.A., Gaspar, F.L., Feitosa, F.A., Santos, A.C., Batista, T.N.F., Travassos, R.K., Pitanga, M.E. 2011. The trophic status of an urban estuarine complex in Northeast Brazil. **Journal of Coastal Research**, SI 64: 408-411.

Glibert, P.M., Burford, M.A. 2017. Globally changing nutrient loads and harmful algal blooms: recent advances, new paradigms, and continuing challenges. **Oceanography**, 30(1):58–69.

Glibert, P.M., Landsberg, J.H., Evans, J.J., Al-Sarawi, M.A., Faraj, M., Al-Jarallah, A., Haywood, A., Ibrahem, S., Klesius, P., Powell, C. & Shoemaker, C. 2002. A fish kill of massive proportion in Kuwait Bay, Arabian Gulf, 2001: the roles of bacterial disease, harmful algae and eutrophication. **Harmful Algae**, 1: 215-231.

Hallegraeff, G.M. 1993. A review of harmful algal blooms and their apparent global increase. **Phycologia**, 32: 79-99.

Hallegraeff, G.M., Anderson, D.M. & Cembella, A.D. 2003. **Manual on harmful marine microalgae**. Monographs on Oceanographic Methodology, 11. UNESCO Publishing: Paris, 793 p.

Herrera-Silveira, J.A., Morales-Ojeda, S. M. & Cortes-Balan, T. O. 2011. Eutrofización en los ecosistemas costeros del Golfo de México: V.1. SEMARNAT-NOAA-GEF-UNIDO.

Horstman, D.A. 1981. Reported red-water outbreaks and their effects on fauna of the west and south coasts of South Africa, 1959–1980. **Fisheries Bulletin South Africa**, 15: 71-88.

IANAS. 2019. Calidad del agua en las Américas. Riesgos y oportunidades. Red Interamericana de Academia de Ciencias. México.

INSMET. 2012. Resumen sinóptico mensual (agosto 2012). Instituto de Meteorología de la República de Cuba.

Kim, H.G. 1998. *Cochlodinium polykrikoides* blooms in Korean coastal waters and their mitigation. In: Reguera, B., J. Blanco, Ma L. Fernandez, and T. Wyatt (Eds). **Harmful Algae**. Xunta de Galicia and Intergovernmental Oceanographic Commission of UNESCO, Spain, pp. 227-228.

Koizumi, Y., Kohno, J., Matsuyama, N., Uchida, T. & Honjo, T. 1996. Environmental features and the mass mortality of fish and shellfish during the *Gonyaulax polygramma* red tide occurred in and round Uwajima Bay, Japan, in 1994. **Nippon Suissan Gakkaishi**, 62: 217-224.

Kopuz, U., Feyzioglu, A.M. & Valente, A. 2014. An unusual red-tide event of Noctiluca scintillans (Macartney) in the Southeastern Black Sea. **Turkish Journal of Fisheries and Aquatic Sciences**, 14 (1): 261-269.

Lassus P., Chomérat N., Hess P. & Nézan, E. 2016. **Toxic and harmful microalgae of the World Ocean. Micro-algues toxiques et nuisibles de l'Océan Mondial**. IOC Manuals and guides, 68 (Bilingual English/French). Denmark: International Society for the Study of Harmful Algae/ Intergovernmental Oceanographic Commission of UNESCO, 523p.

Millero, F. J. 2006. **Chemical Oceanography**, third Ed. CRC Press, Boca Raton.

Montalvo, J.F., García, I.A., Almeida, M., Betanzos, A. & García, N. 2014. Modelación de la eutroficación e índice de calidad del agua en algunas bahías del archipiélago Sabana Camagüey. **Tecnología Química**, sep-dic. XXXIV (3), 184-196.

Moreira González, A.R. 2010. Dinoflagellate blooms in eutrophic zones of Bahía de Cienfuegos, Cuba. **Harmful Algae News**, 41: 11-12.

Moreira González, A. 2013. Florecimiento de la diatomea potencialmente tóxica *Pseudo-nitzschia* cf. *multistriata* en aguas cubanas. **Revista de Investigaciones Marinas**, 33: 27-30.

Moreira, A.R, Comas, A., Valle, A. & Seisdedo, M. 2016. Bloom of *Vulcanodinium rugosum* linked to skin lesions in Cienfuegos Bay, Cuba. **Harmful Algae News** (55).

Moreira, A., Fernández, R., Comas, A., Alonso, C. & Abbate, M. 2009. Microalgas formadoras de mareas rojas en la bahía de Cienfuegos, Cuba. **ALGAS, Boletín de la Sociedad Española de Ficología**, 41: 3-6.

Moreira, A., Seisdedo, M., Muñoz, A., Comas, A. & Alonso, C. 2014. Spatial and temporal distribution of phytoplankton as indicator of eutrophication status in the Cienfuegos Bay, Cuba. **Journal of Integrated Coastal Zone Management,** 14(4): 597-609**.**

Moreira, A.R., Barcia, S., Cabrales, Y., Suárez, A.M. & Fujii, M.T. 2009.El impacto del huracán Dennis sobre el macrofitobentos de la bahía de Cienfuegos, Cuba. **Revista de Investigaciones Marinas,** 30(3): 175-185.

Moreira, A.R., Comas, A., Seisdedo, M. & Barcia, S. 2012. El efecto de la temporada ciclónica 2005 sobre el fitoplancton de la bahía de Cienfuegos, Cuba-diciembre. **Revista Cubana de Investigaciones Pesqueras.** Enero-diciembre, 29 (1):30-37.

Moreno, I. (Ed.). 2007. **Manejo integral costero. Por una costa más ecológica, productiva y sostenible**. (1ra ed., Vol. 3): Universitat de les Illes Balears.

Muñoz, A., Douillet, P., Díaz-García, O., Fichez, R., Herrera, R.H., Alcántara-Carrió, J. & García-Rodríguez, A. 2012. Flushing time in the Cienfuegos Bay. **Nat. Resour. Model.** *25*(3): 434–455.

NC.25. 1999. Evaluación de los objetos hídricos de uso pesquero. Sistema de Normas para la Protección del Medio Ambiente. Hidrosfera. Ciudad de la Habana, Oficina Nacional de Normalización.

Ninčević Gladan, Ž., Marasović, I., Grbec, B., Skejić, S., Bužančić, M., Kušpilić, G., Matijević, S., Matić, F. 2010. Inter-decadal variability in phytoplankton community in the middle Adriatic (Kaštela Bay) in relation to the North Atlantic Oscillation. **Estuar. Coast.,** 33: 376–383.

Planos, E., Rivero, R. & Guevara, V. 2013. **Impacto del Cambio Climático y Medidas de Adaptación en Cuba**. Instituto de Meteorología, Agencia de Medio Ambiente, CITMA: AMA, 430.

Raven, J. A. & Giordano, M. 2016. Combined nitrogen. In Borowitzka M, Beardall J., Raven J. (Eds). The physiology of microalgae, vol. 6, pp. 143-154.

Reguera, B., Velo-Suárez, L., Raine, R. & Park, M.G. 2012. Harmful *Dinophysis* species: A review. **Harmful Algae**, 14: 87-106.

Rojas Higuera, P.J. & Ortiz, J. 2007. Comportamiento del fitoplancton durante el evento ENOS en el Océano Pacífico Colombiano. **Ingeniería de Recursos Naturales y del Ambiente**, No. 6, 5-15. Universidad del Valle. Cali, Colombia.

Richlen, M.L., Morton, S.L., Jamali, E.A., Rajan, A. & Anderson, D.M. 2010. The catastrophic 2008–2009 red tide in the Arabian Gulf region, with observations on the identification and phylogeny of the fish-killing dinoflagellate *Cochlodinium polykrikoides*. **Harmful Algae**, 9: 163-172.

Seisdedo, M., Herrera, R., Arencibia, G. & Sorinas, L. 2016. Tools for managing water quality from trophic state in the estuarine system Cienfuegos bay (Cuba). **Pan-American Journal of Aquatic Sciences,** 11 (4): 264-275.

Seisdedo, M. 2015. Cargas contaminantes dispuestas a la bahía de Cienfuegos desde las cuencas tributarias. Informe técnico. Centro de Estudios Ambientales de Cienfuegos.

Seisdedo, M., Moreira, A.R., Comas, A.A. & Arencibia, G. 2014. Analysis of tools for trophic status assessment of water in Cienfuegos bay, Cuba. **Pan-American Journal of Aquatic Sciences,** 9(2): 103-111.

Seisdedo, M. & Muñoz, A. 2013. Análisis de un Índice de Calidad del Agua para sistemas estuarinos. **Transporte, Desarrollo y Medio Ambiente,** 33(68): 18-23.

Seisdedo, S., Moreira, A. R. & Arencibia, G. 2012.Características físico-químicas de las aguas y del fitoplancton en zonas de baño de la Bahía de Cienfuegos, Cuba (2008-2009). **Revista Cubana de Investigaciones Pesqueras**, enero-diciembre, 29 (1):38-43.

Seisdedo, M. 2006. Variaciones espaciales y temporales en indicadores de la calidad ambiental de las aguas de la Bahía de Cienfuegos, Cuba. **Revista de Investigaciones Marinas,** 27 (2):159-164.

Seisdedo, M. & Muñoz, A. 2005. Efecto de las precipitaciones en la calidad ambiental de las aguas de la Bahía de Cienfuegos. **Revista Cubana de Meteorología,** 12 (2): 64-67.

Satake, M., Mackenzie, L. & Yasumoto, T. 1997. Identification of *Protoceratium reticulatum* as the biogenetic origin of yessotoxin. **Natural Toxins**, No. 5: 164–7.

Tomas, C.R. 1997. **Identifying Marine Phytoplankton**. Academic Press, San Diego, CA, U.S.A. 858p.

UNEP. 1991. **Standard chemical methods for marine environmental monitoring**. Manual and Guides. IOC (Intergovernmental Oceanographic Committee), No. 12.

UNESCO. 1983. **Chemical Methods for use in Marine Environmental Monitoring**. Manual and Guides. IOC. No. 12.

Withers, K. 2002. **Red and brown tides**. In: Tunnell, J.W.J., Judd, F.W. (Eds.), The Laguna Madre of Texas and Tamaulipas. Texas A & M University Press, College Station, TX, pp. 255–258.

Wolanski, E. & Elliott, M. 2015. **Estuarine. Ecohydrology an Introduction**. Elsevier, Amsterdam, p. 322.

Scavia, D., Field, J.C., Boech, D.F., Buddenmeier, R.W., Burret, V., Cayan, D.R., Fogarty, M., Harwell, M.A., Howarth, R.W., Mason, C., Reed, D.J., Royer, T.C., Salleger, A.H. & Titus, J. G. 2002. Climate change impacts on U.S. Coastal and Marine Ecosystems. **Estuaries**, 25 (2): 149-164.

Hannaford, J. 2015. Climate-driven changes in UK river flows. A review of the evidence. **Prog. Phys. Geogr.**, 39: 29-48.

Gilbert, S., Lackstrom, K. & Tufford, D. 2012. **The Impact of Drought on Coastal Ecosystems in the Carolinas.** Research Report: CISA-2012-01. Columbia, SC: Carolinas Integrated Sciences and Assessments.

Robins, P.E., Skov, M.W., Lewis, M.J., Giménez,' L., Davies,' A.G.,Malham, S.K., Neill,' S.P., Mc-Donald,' J. E.,Whitton, T.A., Jackson, S. E., Jago, C.F. 2016**.** Impact of climate change on UK estuaries: A review of past trends and potential projections. **Estuarine, Coastal and Shelf Science**, 169:119-135.

Rödiger, S., Friedrichsmeier, T., Kapat, P. & Michalke, M. 2012. RKWard: A Comprehensive Graphical User Interface and Integrated Development, Environment for Statistical Analysis with R. **Journal of Statistical Software**, 49 (9): 1-34

Souza, M.F.L., Kjerfve, B., Knoppers, B., Landim de Souza, W.F., & Damasceno, R.N. 2003.Nutrient budgets and trophic state in a hypersaline coastal lagoon: Lagoa de Araruama, Brazil. **Estuarine Coastal and Shelf Science,** 57: 843-858.

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