PANAMJAS
Pan-American Journal of Aquatic Sciences

Analysis of tools for trophic status assessment of water in Cienfuegos bay, Cuba

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Abstract. Different indices are used to assess the trophic status of marine coastal waters, often proving different results for the same aquatic system. The aim of this paper is to compare the assessments of trophic status by applying three different indices in the particular case of Cienfuegos bay, Cuba. This semi-enclosed bay with estuarine characteristics poses a challenging case study due to presence of some eutrophication symptoms previously. Results of 1) chlorophyll *a* concentration, 2) nutrients: ammonium, nitrate, nitrite and phosphate and 3) dissolved oxygen saturation, from four sampling campaigns, carried out on this system during the 2009, were considered. Some incongruities among assessments of trophic status were obtained suggesting taking into account a previous comparison among contexts before of applying the used indices. In general, our assessments showed a global non-eutrophic condition for the waters of Cienfuegos bay, in both seasons (dry and rainy), which indicates a positive change of water quality from the trophic status. The spatial analysis showed lack of correspondence between the areas with the maximum concentrations of nutrients and chlorophyll *a* suggesting that the response of this system to the changes in nutrient levels is not immediate.

Key words: eutrophication, trophic indices, nutrients, chlorophyll *a*, Cienfuegos bay

Resumen. Análisis de herramientas para la evaluación del estado trófico de las aguas en la bahía de Cienfuegos, Cuba. Para evaluar el estado trófico de aguas marino-costeras se utilizan diferentes índices, que en algunos casos, generan evaluaciones diferentes para un mismo sistema acuático. El propósito de este trabajo es comparar las evaluaciones del estado trófico de las aguas de la bahía de Cienfuegos utilizando tres índices diferentes. Esta bahía, semicerrada con características estuarinas, demanda esta clase de aproximación debido a la identificación de algunos signos de eutrofización en estudios previos. Se consideraron los resultados de 1) concentración de clorofila *a*, 2) nutrientes: amonio, nitrito, nitrato y fosfato y 3) saturación de oxígeno disuelto, obtenidos durante cuatro campañas de muestreos realizadas en 2009. Se presentan incongruencias entre las diferentes evaluaciones del estado trófico, que sugieren tener en cuenta una comparación previa entre contextos antes de la aplicación de los índices utilizados. En general, las evaluaciones mostraron una condición global no eutrófica de las aguas de la bahía de Cienfuegos para ambas estaciones (seca y lluviosa), contrario a resultados previos, lo cual indica cambios positivos de la calidad del agua en su estado trófico. El análisis espacial mostró escasa correspondencia entre las áreas con concentraciones máximas de nutrientes y clorofila *a*, lo cual sugiere que la respuesta de este sistema a los cambios en los niveles de nutrientes no es inmediata.

Palabras claves: eutrofización, índices tróficos, nutrientes, clorofila *a*, bahía de Cienfuegos

Introduction

One of the most significant processes related to the deterioration of coastal water quality is the eutrophication (US-EPA 2001). This process is a consequence of the influx of high nutrient (nitrogen and phosphorus) concentrations from anthropogenic activities, leading in some cases to high chlorophyll *a* levels, anoxia (0 mg l^{-1} dissolved oxygen) and hypoxia (<2 mg l^{-1} dissolved oxygen) events and consequently, blooms of toxic and noxious algae

(CENR 2000, Kennish 2002, Rabalais 2002, Beman *et al*. 2005, Xiao *et al*., 2007). The urban growth around estuarine regions is cause of these serious environmental problems (Flores Montes *et al.* 2011).

The expression type of eutrophic symptoms in a coastal system depends on some of the system attributes, such as morphology and residence time of the water body (NRC 2000, Boesch 2002). A large number of cause and effect variables are involved in the process of eutrophication, according to the conceptual contemporary model of the coastal eutrophication, phase II (Cloern 2001).

Some authors (López-Cortés *et al*. 2003, Coelho *et al*. 2007, Pettine *et al.* 2007, Ferreira et al. 2007, Boikova *et al.* 2008, Flores Montes *et al.* 2011) have used diverse indices for the classification of trophic status in European and Latin-American coastal zones. Nevertheless, Salas *et al*. (2008) using TRIX index (Vollenweider *et al.* 1998) for assessing thophic status of waters in two estuarine ecosystems of Spain and Portugal, pointed out the inconsistency of the results regarding estuarine waters. In some studies of Latin-American coastal waters with tropical and estuarine characteristics (Aranda 2004, Reyes 2008) other indices have also been used for assessing trophic status, which are based on intervals of the chlorophyll *a* concentrations (Contreras *et al*. 1994) and nutrient levels (Karydis *et al.* 1983). These assessments are used to guide management decisions in order to mitigate the presence of some eutrophication symptoms.

The trophic status indices are not always based on the same indicators and also, they sometimes generate different assessments in a same aquatic system. Some examples were obtained in the assessments of the trophic status in five Cuban bays (Reyes 2008). In addition, from trophic status point of view, the Cienfuegos bay showed some eutrophication symptoms such as high chlorophyll *a* levels and toxic algal bloom events in previous studies (Areces 1986, Moreira *et al*. 2007).

The purpose of this paper is to compare the trophic status assessments of water using three different indices in Cienfuegos bay, in order to evaluate the applicability of such scientific tools for coastal management.

Materials and methods

Study area

Cienfuegos bay is situated in the southern central part of Cuba (22◦1′ N, 80◦20′ W, see Figure 1). It is a semi-enclosed bay connected to the Caribbean Sea by narrow channel 3.6 km long. It spans over an area of 88.46 km^2, with total volume of 0.84 km^3 and an average depth of 9.5 m. This bay is divided into two natural lobes. The northern lobe suffers more anthropogenic impact (from sewage discharges from Cienfuegos city and the industrial area; and the contribution of the Salado and Damují rivers). The southern lobe is subjected to a lesser pollution degree originated mainly from the Caonao and Arimao rivers (Muñoz-Caravaca *et al*. 2012).

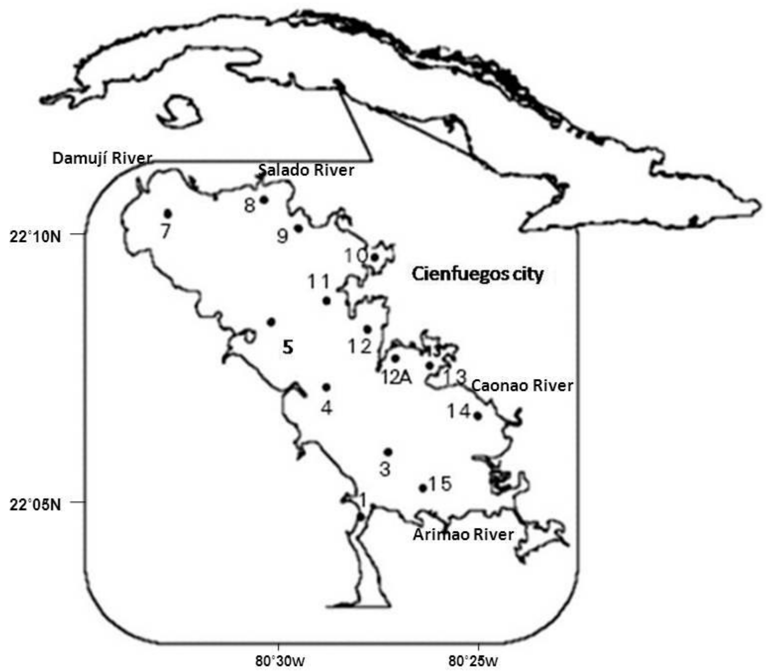

Figure 1. Study area and stations of the hydrological sampling program of Cienfuegos bay.

From a rainfalls time series (1967 –2006) in Cienfuegos province, the annual accumulated rainfalls was 1507.5 mm; whose 81 % corresponds to rainy (May – October) season and 19 % to dry (November – April) season (Barcia *et al.* 2009). Cienfuegos bay has a residence time of 39 days during the rainy season; while it is 50 days for dry season (Muñoz *et al.* 2012) and its circulation pattern depends on combined action of the tides, the wind and freshwater contributions (Muñoz *et al.* 2008). Some authors (Areces 1986, Seisdedo & Muñoz 2005, Moreira, *et al.* 2007) pointed out the importance of a seasonal analysis in several previous studies of this bay.

Sampling and data analysis

Fourteen samplings stations (Fig. 1) were selected taking into account their locations in defined vulnerable areas characterized by incidence degree of the industrial and urban activity (st.1-2, 9-13) as well as freshwater contributions (st.7-8,14, 15). Four sampling campaigns were carried out during 2009, corresponding to dry (March and November) and rainy (June and September) season. The sampling of water using bottles Niskin of 5 L, was carried out during low tide, in the superficial level (0.5 m) (APHA 1998). The salinity and the water temperature were determined *in situ* using a digital probe model YSI-30. It was required to analyze the hydrological indicators: nitrite (NO_2^-), nitrate (NO_3^-), ammonium (NH_4^+); phosphate (PO_4^{3-}), dissolved oxygen saturation (DOsat.) and chlorophyll *a* concentration.

The analysis of the samples was carried out in the laboratory of the Centro de Estudios Ambientales de Cienfuegos; dissolved oxygen was determined by Winkler method, while the nitrite, nitrate, ammonium and phosphates were determined according to Grasshoff (1999) and UNEP (1991). The dissolved oxygen saturation (%) was obtained using an empirical equation (Weiss, 1970). The concentration of chlorophyll *a* was measured by filtering a volume of water (0.2–2.5 L), until the filter (Whatman GF/F). Pigments were extracted with 90% acetone and were measured by spectrophotometric method (UNEP 1991).

All environmental variables data are reported as the mean, range and standard deviation (±sd). A seasonal analysis was carried out comparing the results of dry and rainy seasons. The variables were compared by non parametric test Wilconxon (data did not obey normality assumptions) at 5% level of significance. Statistical analyses were carried out using SPSS software v15.

Methods of trophic status assessment

The first method used was the classification proposal by Contreras *et al.* (1994) (Table I) based on intervals of the chlorophyll *a* concentrations.

Table I. Classification proposal of trophic status (Contreras *et al.* 1994).

Categories	interval of Chl. *a* concentrations (μgL^{-1})	Trophic Index
Ultraoligotrophic	0.000 – 0.122	0 - 9
α Oligotrophic	0.123 – 0.340	10 - 19
β Oligotrophic	0.350 – 0.940	20 - 29
γ Oligotrophic	0.950 – 2.600	30 - 39
α Mesotrophic	2.700 – 7.200	40 – 49
β Mesotrophic	7.300 – 20.000	50 – 59
α Eutrophic	21.000 – 55.000	60 - 69
β Eutrophic	56.000 – 155.000	70 - 79
γ Eutrophic	156.000 – 425.000	80 - 89
Hipereutrophic	> 426.000	> 90

The second method used was the eutrophication index (EI) according to Karydis *et al.* (1983), which requires the nutrient concentrations: inorganic nitrogen (IN= NH_4^++NO_2^-+ NO_3^-) and inorganic phosphorus (IP= PO_4^{3-}). The EI equation is:

$$EI = \frac{C}{C - \log x_i} + \log A \quad (1)$$

where:

EI: eutrophication index for nutrient of each sampling station, for campaign.

A: number of sampling stations during the study period (14)

C: logarithm of the total nutrient concentration during the study period; it is the sum of the concentrations Xij of the nutrient obtained in each one of the Ai stations during the Mj samplings.

The classification scale is the following one: if EI < 3 indicate oligotrophic status, for 3≤ IE≤ 5 for mesotrophic status and IE>5 for eutrophic status.

The third method used was the TRIX index (Vollenweider *et al.* 1998). This index has been applied in similar systems (Coelho *et al*. 2007, Mangialajo *et al.* 2006, Salas *et al.* 2008, Reyes 2008)

The main equation is:

$$TRIX = \frac{\log(Chla \times D\%O \times IN \times IP) + 1{,}5}{1{,}2} \quad (2)$$

where:

TRIX: trophic status index

Chl*a*: Chlorophyll *a* concentration (μg/L)

D%O: absolute deviation value of the saturation percentage of dissolved oxygen, |100 - DOsat |

IN: inorganic nitrogen concentration (μg/L)

IP: inorganic phosphorus concentration (μg/L)

The classification of trophic status using the TRIX index was according to four water quality categories: High (2-4), Good (4-5), Bad (5-6) and Poor (6-8) (Penna *et al*. 2004).

Results

All environmental variables showed significant differences (p<0.05) between both seasons except dissolved oxygen saturation (Table II).

Table II. Environmental variables (N=28 for each season). IN: sum inorganic Nitrogen chemical species; IP:_inorganic Phosporous, * p<0,05

Environmental variables	Concentration (dry)		Concentration (rainy)	
	Range	Mean (SD)	Range	Mean (SD)
Temp. (°C)	25,3-29,4	26,3 (0,82)	28,8-32,9	30,2 (1,00)*
Salinity	34,1-35,3	34,8 (0,28)	23,3-34,7	30,3 (3,24)*
Chl. *a* (μg/L)	0,73-38,17	4,72 (6,79)	1,68-10,76	5,17 (2,50)*
DO sat (%)	88,3-133,1	100,6 (14,9)	70,9-123,3	105,2 (11,1)
IP (μM)	0,14- 3,9	1,29 (1,27)	0,14- 9,32	0,69 (1,67)*
IN (μM)	0,8-11,5	2,09 (2,6)	0,8-7,26	3,12 (1,9)*

According to the classification based on chlorophyll *a* concentrations suggested by Contreras *et al.* (1994) as trophic indicator, the average results indicated mesotrophic conditions of the waters in Cienfuegos bay, for both seasons (Table III). According "classification ranges" a bigger interval of trophic status classifications was obtained during the dry than rainy season.

Table III. Assessments of waters trophic status in Cienfuegos bay based on proposal of Contreras *et al.* (1994).

seasons	classification ranges	average classification
Rainy (N=28)	γ Oligo-β Mesotrophic	α Mesotrophic
Dry (N=28)	β Oligo-α Eutrophic	α Mesotrophic

From the spatial analysis, the classification of eutrophic waters was obtained in a single station (st.9) during dry season (Fig. 2).

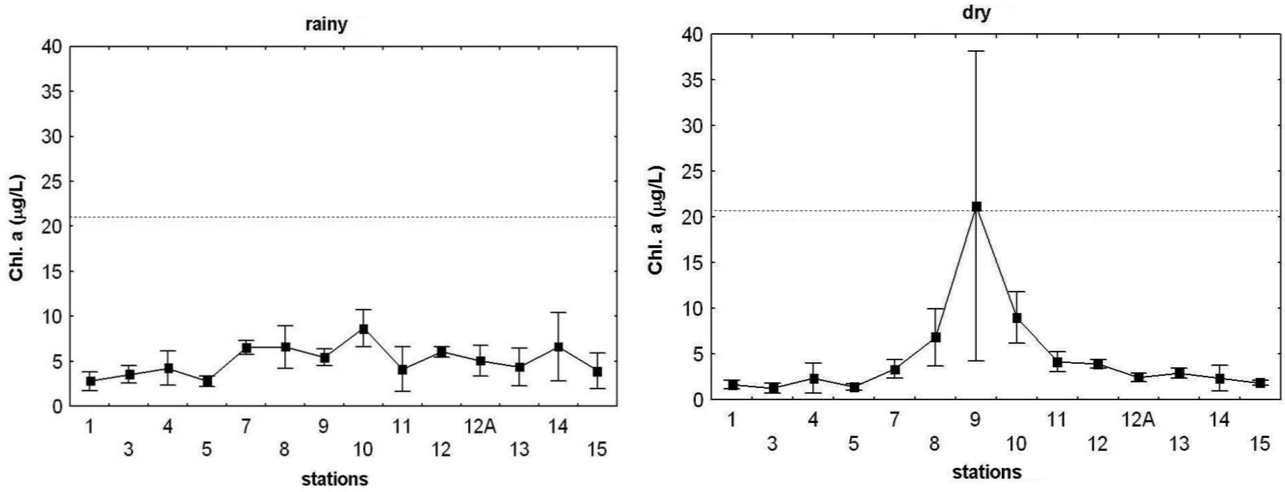

Figure 2. Spatial distribution of the chlorophyll *a* concentrations (x ± sd) in Cienfuegos bay during 2009 (rainy and dry season). (dotted line: limit of α eutrophic status according to Contreras *et al*. 1994)

The EI for the inorganic nitrogen is shown in Figure 3. The average condition at both seasons was oligotrophic and only the station 3 showed mesotrophic conditions during the dry season.

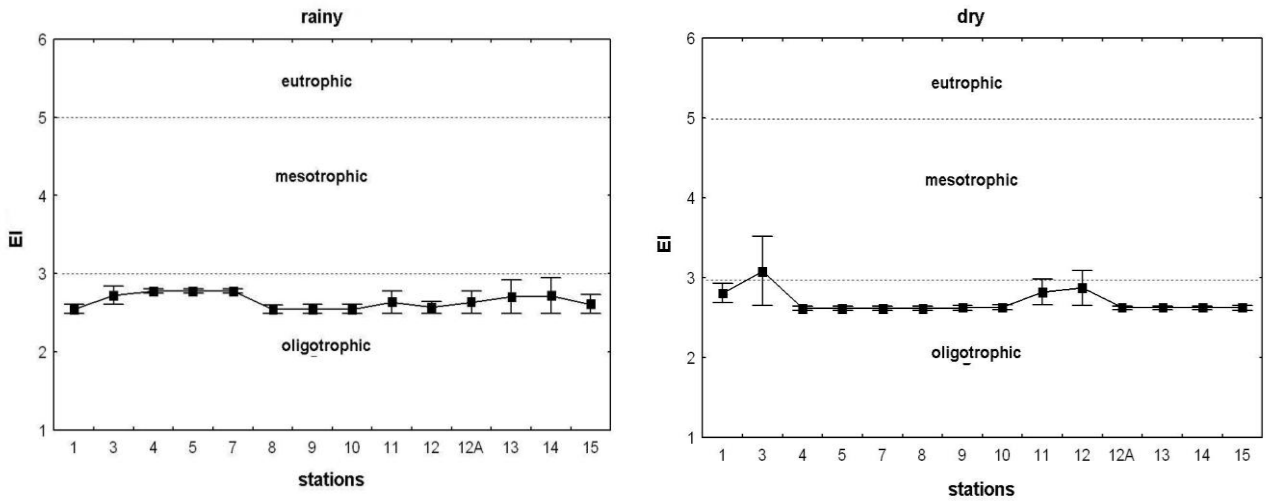

Figure 3. Spatial assessments of the trophic status using the EI (x±sd) based on IN concentration, for rainy and dry season. Classification according to Karydis *et al*. 1983.

The EI for the inorganic phosphorus showed oligotrophic conditions in both seasons and from the spatial point of view, remarkable variation in the values was not obtained, except in the station12, during the dry season (Fig. 4).

According TRIX index the water quality from trophic status was classified between good and high trophic status, in both seasons (Fig. 5).

Discussion

The eutrophic condition according to Chl *a* concentration shown in the station 9 (Fig. 2) could be related to longer residence time (50 days) of water in Cienfuegos Bay during the dry season, which represents a bigger risk of eutrophication (Herrera 2006). According to Cardoso & Carmona (2004), the residence time in dry season in

Cienfuegos Bay, indicates low exporting capacity while the residence time (39 days) in rainy season indicates moderate exporting capacity. Besides, the deterioration condition in this station could be associated with impacts of freshwaters from Salado and Inglés rivers in neighboring areas (st. 8 and 10) which drain more than 50% of nitrogen and phosphorous present in the Cienfuegos Bay (Seisdedo & Arencibia 2010). This effect could be expected considering the change of concentration of chlorophyll *a* as one of the responses to nutrient level changes (Cloern 2001) and also, the circulation pattern of this bay (Muñoz *et al.* 2008). Consequently, management decisions should include some actions in order to reduce the nutrient loading from these rivers into de Cienfuegos Bay.

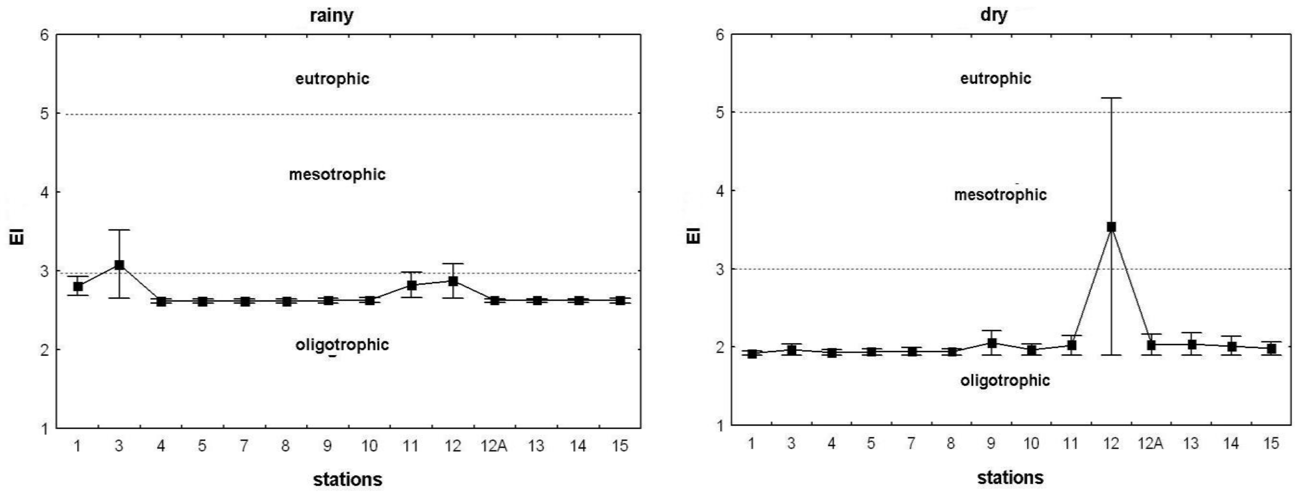

Figure 4. Spatial assessments of the trophic status using the EI (x±sd), based on IP concentration, for rainy and dry season. Classification according to Karydis *et al.* 1983.

The lack of spatial correspondence between the maximum EI values from nutrients and highest chlorophyll *a* levels (Figs. 4, 5 and 3), could suggest that the system response to changes of nutrient levels is not immediate. This is related to one of the advances of the conceptual contemporary model of coastal eutrophication phase II, (Cloern 2001) which includes nitrogen and phosphorus as causal variables of eutrophication and measures of algal biomass (e.g. chlorophyll *a*) as response variable. According to US-EPA (2001) these variables could not correlate well.

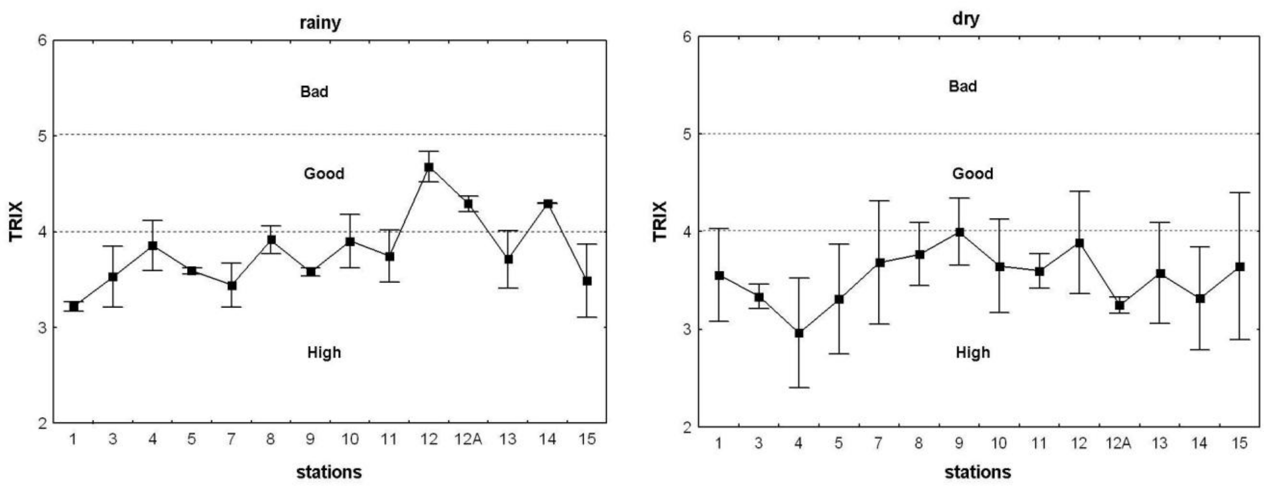

Figure 5. Spatial assessments of the trophic status using the TRIX index (x±sd), for rainy and dry season. Classification according to Penna *et al.* 2004

The global classification obtained for this bay based on chlorophyll *a* concentrations showed worse water quality from trophic status comparing to assessment in Mariel bay and better water quality comparing to that of Havana bay, both Cuban semi-enclosed bays assessed by Reyes (2008). However, the classification using the TRIX index showed better water quality for Cienfuegos bay compared with the assessment obtained for Mariel bay.

The above-mentioned results show incongruities after application of these scientific tools in different contexts, probably due to variations among the attributes of the coastal systems which generate non accurate assessments. Coelho *et al.* (2007) pointed out the geographical dependence of the TRIX index verified also by Salas *et al.* (2008) applying this index in two European estuarine systems. Consequently their results, obtained from Mediterranean Sea, could not be extrapolated to another geographical area without modifications considering the different environmental conditions.

On the other hand, the three indices used did not show eutrophic conditions as the average assessments from trophic status in Cienfuegos bay, neither remarkable difference between the two analyzed periods were detected. However, all environmental variables showed significant differences ($p<0,05$) except for dissolved oxygen saturation. This last variable depends on both salinity and temperature (Millero 2006), and the suspended organic matter could affect the dissolved oxygen concentration in estuaries (Braga *et al.* 2000). The aquatic organisms consume oxygen to decompose organic matter and may therefore be responsible for lowering dissolved oxygen saturation, mainly in bottom waters. In this sense, some authors (Cloern 2001, US-EPA 2000) consider hypoxic concentrations (< 2 mg/L) of dissolved oxygen in bottom as an indicator of eutrophication process. In the present study Od was analyzed only in surface water, then the inverse correspondence between temperature and salinity for each season (the warmest months are involved in the rainy season when this bay receives bigger freshwater volume and showed the lower salinity values) could influence on our result of dissolves oxygen saturation.

In general way, the average assessments from these three indices suggest the improve the water trophic status of this bay because previous results (Areces 1986) showed eutrophic conditions, when some industries located in the North East part (NE) of this bay, fundamentally the Factory of Fertilizers (st.8), incorporated the highest nutrient loads and the average concentration of chlorophyll *a* was 30,3 µg/L.

Conclusions

This study showed the lack of spatial correspondence between the maximum values of indices from causal (IN, IP) and response (Chl *a*) variables, which suggests that the response of this system to nutrient level changes is not immediate.

The incongruities found after comparative analysis among trophic status assessments of similar systems suggest previous analysis of differences among contexts before of applying the indices.

The average assessments from the three used indices showed non eutrophic conditions of the waters in Cienfuegos bay for both seasons, contrary to previous results, suggesting positive changes of the water quality from the trophic point of view.

Acknowledgments

We are very grateful to Miguel Mies for his valuable comments. The authors are also indebted to the staff of the Laboratorio de Ensayos Ambientales of Centro de Estudios Ambientales de Cienfuegos for their important contribution in the sampling and analytical assays.

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Received January 2014
Accepted May 2014
Published online August 2014