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The Havana littoral, an area of distribution for *Physalia physalis* in the Atlantic Ocean

Eduardo Gabriel Torres-Conde[a,*], Beatriz Martínez-Daranas[a], Laura Prieto[b]

[a] Center for Marine Research, Havana University, 16 Street, No.114, Playa, PC 11300, Havana, Cuba
[b] Department of Ecology and Coastal Management, Institute of Marine Sciences of Andalusia (CSIC), 11519 Puerto Real, Cadiz, Spain

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ABSTRACT

The hydrozoan Portuguese man-of-war (*Physalia physalis*) is distributed throughout the Havana littoral zone, which is one of the circulation points of the currents that form the North Atlantic Subtropical Gyre run. For the first time, a study was conducted monthly from May 2018 through May 2019 to better understand the temporal and spatial variation of *P. physalis* in this region. This study covered five beaches in Havana (Cojímar, Bacuranao, Tarará, Mégano and Santa María). Transects of 50 m were located parallel to the shoreline and the colonies that arrived at the intertidal zone were counted. The colonies of *P. physalis* were mostly observed in May 2018 (80), November 2018 (110), December 2018 (132), January 2019 (152) and March 2019 (126), which coincided with the dry season in Cuba. This season was related to the presence of cold fronts and a negative average magnitude of the Arctic Oscillation Index (-0.05). The beaches with a relatively linear shape had a higher number of arrivals (549 colonies) than the beaches with a horseshoe shape (109 colonies). In addition, the highest number of colonies was associated with wind velocity above 33 km.h^{-1} (especially northerly wind), wave height above 1.5 m, and temperatures below 30 °C.

1. Introduction

Physalia physalis Linnaeus, 1758 (phylum: Cnidaria, class: Hydrozoa, order: Siphonophora, family: Physaliidae), also known as the Portuguese man-of-war or blue bottle, is a colony formed by numerous polyps (Mapstone, 2014). It is a pleustonic and cosmopolitan pelagic species that move with surface currents and winds (Ferrer and Pastor, 2017). These colonies are typical of tropical and subtropical warm waters (Ferrer and Pastor, 2017). According to Ferrer and Pastor (2017), *P. physalis* colonies are commonly found in Florida, USA, the Gulf Stream, the Gulf of Mexico, the Caribbean Sea and the Sargasso Sea, although they are a native species of the Pacific and Indian Oceans (Kirkpatrick and Pugh, 1984), where they can also be found. In the Mediterranean Sea, *P. physalis* is an allochthonous species (Prieto et al., 2015). The appearance of colonies on the coasts is due to temporary meteorological/oceanographic changes, such as the El Niño phenomenon in the Pacific Ocean, which modify the direction and speed of the winds (Prieto et al., 2015). The North Atlantic Oscillation index (NAOi) and the Arctic Oscillation index (AOi) are one of the major modes of variability in the Northern Hemisphere atmosphere and they are especially significant in winter (December to March) according to Prieto et al. (2015) and Cedeño (2015). Both indices perform a strong control on the climate of Atlantic Ocean by regulating the intensity of zonal winds and precipitation patterns (Barnston and Livezey, 1987; Cedeño, 2015). Prieto et al. (2015) used the NAOi as a measure to explain specific oceanographic and climatic conditions that led to the occurrence of the *P. physalis* within the Mediterranean basin in summer 2010. Moreover, the AOi has been used as a measure of frequency and intensity of cold fronts in Western Cuba (Cedeño, 2015), but has not yet been used for *P. physalis* distribution.

As other jellyfishes, the species *P. physalis* plays a crucial ecological role in aquatic ecosystems, since they are important for the recycling of nutrients, such as carbon, nitrogen, and phosphorous, which are subsequently used by phytoplankton (Ponce García and López Vera, 2013). Codon et al. (2012) stated that when a jellyfish bloom occurs, the carbon contained in the ecosystems near the shoreline could be much higher than the carbon flux under normal conditions. Pitt et al. (2014) argued that a mass of stranding and decaying medusa on the beach can increase the input of carbon to beach environments, given that these are poorly productive sites. It is also worth mentioning that many species of jellyfish and hydrozoans serve as food for birds, chum salmon, spiny dogfishes, and sea turtles (Pitt et al., 2014), such as the

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Abbreviations: NAOi, North Atlantic Oscillation index; AOi, Arctic Oscillation index

[*] Corresponding author.

E-mail addresses: etorresconde2@gmail.com (E.G. Torres-Conde), beatriz@cim.uh.cu (B. Martínez-Daranas), laura.prieto@icman.csic.es (L. Prieto).

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leatherback turtle (*Dermochelys coriacea* Vandelli, 1761), which is a compulsory consumer of gelatinous zooplankton (Ponce García and López Vera, 2013). However, overfishing affects the presence of many fishes and sea turtles, which have decreased markedly according to Mazaris et al. (2017), with a possible consequence for the abundance of jellyfishes.

One of the most common problems on the shoreline is the appearance of jellyfishes and other gelatinous organisms, such as *P. physalis*. They can cause a relevant socio-economic impact, mainly in sun and beach tourism (Ferrer et al., 2015). The Portuguese man-of-war may have systematic effects on humans: cardiovascular, respiratory, neurological, gastrointestinal, renal and hematological/immunological (Martínez et al., 2010). Prieto et al. (2015) have reported the death of a person in the Mediterranean Sea, caused by a *P. physalis* sting.

Ferrer and Pastor (2017) describe a northern region of the North Atlantic Subtropical Gyre (NASG) as a possible origin of the Portuguese man-of-war, and the importance of the appearance of atypical weather conditions for unusual arrivals to the Bay of Biscay. Prieto et al. (2015) suggested that the arrival of *P. physalis* at the Eastern Atlantic coast and later on in the Mediterranean Sea, entering through the Strait of Gibraltar, may be due to the action of the currents that make up the NASG, under specific climatic and oceanographic conditions that also modify the wind patterns. In recent years, the arrival of these colonies have been seen more frequently not only on the coasts of the Caribbean Sea but also in the Eastern Atlantic, although the causes remain to be identified. Longer time series and additional monitoring points on both sides of the Atlantic Ocean will be the key to untangling the variability of these colonies and minimizing the social-economic impact by improving forecasting systems.

For a better understanding of the arrival of *P. physalis* at one of the zones where the currents of the NASG run, we analyzed the spatial and temporal variations of *P. physalis* on five beaches in Havana, Cuba, during one year. The principal aim of this study was to analyze the beaching dynamics of these colonies with the associated environmental variables, and to contribute for the first time on a high temporal resolution (monthly) to their monitoring in the Western Atlantic Ocean.

2. Materials and methods

2.1. Study area

Five beaches in Havana, located on the northwestern coast of Cuba (Fig. 1), were selected. They all have physical, geographic, and environmental characteristics suitable for recreational activities for the communities living nearby (Comisión Nacional de Nombres Geográficos, 2000). The chosen beaches were: Cojímar, Bacuranao, Tarará, Mégano, and Santa María del Mar. Cojímar has an extension of 370 m. It is located 7.5 km east of the mouth of Havana Bay, at 23°09′47′′N and 82°17′38′′W. It has a horseshoe shape characterized by its brownish-gray sand (Comisión Nacional de Nombres Geográficos, 2000). It is a highly contaminated area, consequence of the bad management of the region and the drainage of the homonymous river (Ramos et al., 2005). Bacuranao has an extension of 319 m. It is located 12 km east of the mouth of Havana Bay, at 23°10′36′′N and 82°14′30′′W. It has a horseshoe shape characterized by its brownish-gray sand and by the mouth of the Bacuranao River (Comisión Nacional de Nombres Geográficos, 2000). Tarará has a coastal length of 500 m. It is located 16 km to the east of the mouth of Havana Bay, at 23°10′50′′N and 82°12′11′′W. It has a relatively linear shape and is known as a great tourist destination for its fine white sands (Comisión Nacional de Nombres Geográficos, 2000). Mégano has an extension of 500 m and is located 17 km to the east of the mouth of Havana Bay, at 23°10′45′′N and 82°11′53′′W. It has a relatively linear shape contiguous to the Tarará beach, also known as tourist destination and fine white sands (Comisión Nacional de Nombres Geográficos, 2000). Santa María del Mar has an extension of 3 km and is located 18.5 km to the east of the mouth of Havana Bay, at 23°10′41′′N and 82°11′42′′W. It has a relatively linear shape contiguous to the Mégano beach. It is one of the most popular beaches due to its fine white sands. It has well-developed dunes and tourist and recreational facilities (Comisión Nacional de Nombres Geográficos, 2000). From the latter, a section of 500 m was selected for this study.

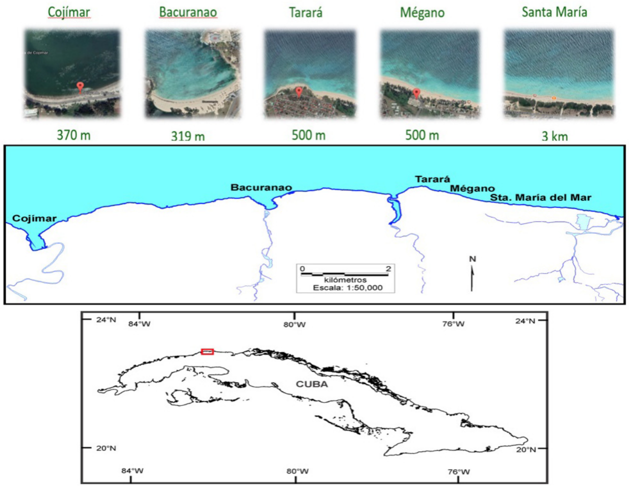

Fig. 1. Study area.
Source: Torres-Conde and Martínez-Daranas (2020).

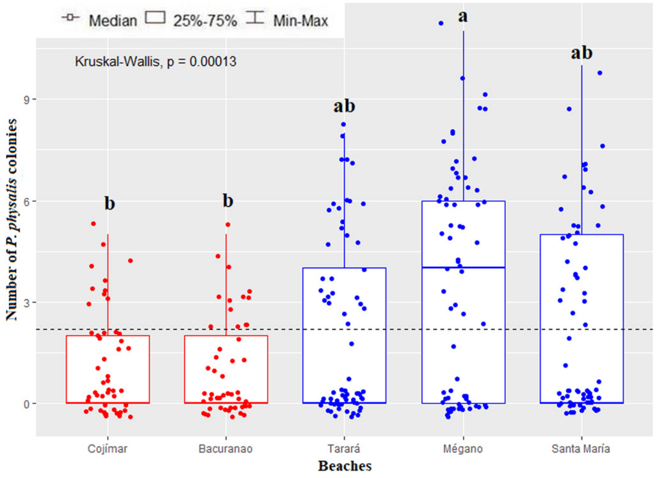

Fig. 2. Spatial variation of the number of *P. physalis* colonies. Different letters represent significant differences. Red color represents beaches with horseshoe geomorphology and blue color represents beaches with lineal geomorphology. The horizontal line represents the median of the whole data set.. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2.2. Data collection

Sampling was carried out monthly, with a station at each of the five beaches, from May 2018 through May 2019. To measure the length of the beach, the method described by Areces

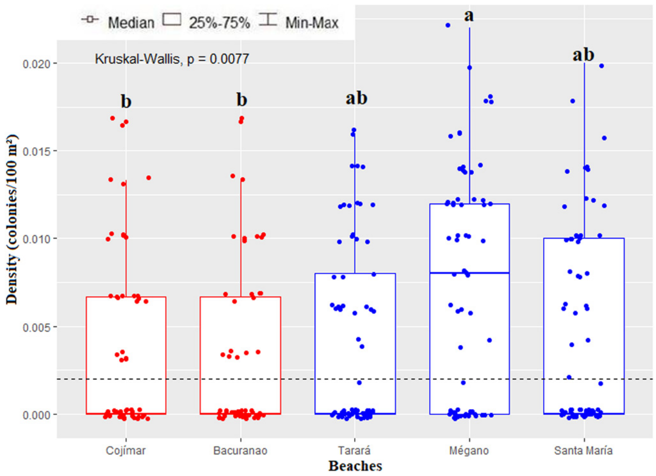

Fig. 3. Spatial variation of the density of *P. physalis* colonies (colonies/100 m^2). Different letters represent significant differences. Red color represents beaches with horseshoe geomorphology and blue color represents beaches with lineal geomorphology. The horizontal line represents the median of the whole data set.. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

et al. (1993) was modified according to the characteristics of the beaches. The measurements were carried out with a measuring tape and with the help of a map, from the coordinates taken with a GPS, using the MapInfo Professional 10.5 program. Equidistant transects of 50 m (separated by 5 m) were located parallel to the shoreline, so that approximately 75% of the length of the beach was covered. Five transects for Bacuranao and Cojímar, and seven for Tarará, Mégano, and Santa María were used corresponding to the length of each beach. The number *P. physalis* colonies was counted every month in each transect, covering the intertidal zone for the five beaches.

For seven days prior to each sampling, wind speed and direction, and wave height and temperature data were obtained from the Windguru website (https://www.windguru.cz/). This information is from the GFS (Global Forecast System) model with a resolution of 27 km, and measured four times per day (00 UTC, 06 UTC, 12 UTC, and 18 UTC). The synoptic states that appear in the Monthly Summaries on the Cuban Institute of Meteorology's website (http://www.insmet.cu/) were also noted. In addition, the Arctic Oscillation (AOi; CPC, 2020a) and North Atlantic Oscillation (NAOi; CPC, 2020b) indices were obtained from the database of the United States Climate Prediction Center (www.cpc.ncep.noaa.gov). The data of *P. physalis* sightings in the Atlantic Ocean were acquired from the Global Biodiversity Information Facility (GBIF.org) (www.gbif.org).

2.3. Data analysis

Percentage of colonies and the density by beaches and months were calculated. The temporal (between months) and spatial (between beaches) variation of the number of colonies and densities of *P. physalis* were analyzed. Kolmogorov Smirnov and Lilliefors Tests were subsequently performed. As the data did not fulfill the assumptions for parametric analysis, a non-parametric test of multiple independent groups of Kruskal–Wallis by Rank was implemented. A Pairwise Wilcoxon Rank Sum Test with Holm adjustment was conducted to analyze differences between group levels with correlation of multiple testing.

In order to explore the relationship between *P. physalis* colonies that arrived at the shoreline with meteorological and oceanographic variables (wind speed and direction, wave height and temperature), a Principal Component Analysis (PCA) was used. For this analysis, the values of the number of *P. physalis* colonies of the entire sampled area were averaged monthly, and the maximum monthly values of the meteorological variables were used. In addition, the most prevalent wind direction per month was used. The averages of the number of colonies per month were calculated, and to assess its relation with the number of cold fronts and temperatures, a Spearman‘s rank correlation was implemented. The relation between the number of cold fronts and temperatures was also evaluated. The same analysis was used to assess the relation between the indices (AOi and NAOi) and the number of cold fronts. A map of the sightings of *P. physalis* colonies in the Atlantic Ocean was made. All these analyses were performed using the free software R.

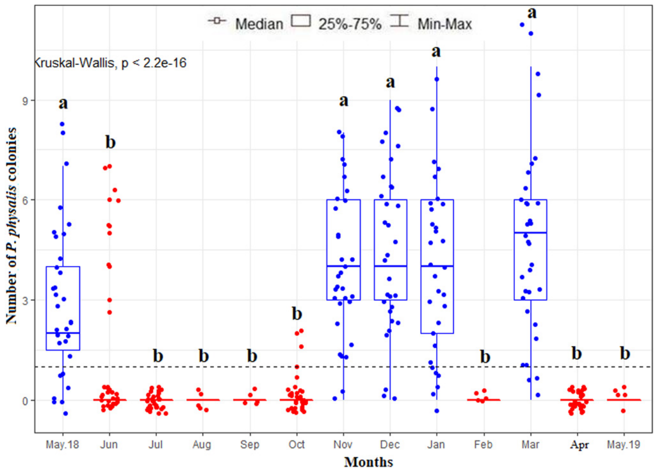

Fig. 4. Temporal variation of the number of *P. physalis* colonies. Different letters and colors represent significant differences. The horizontal line represents the median of the whole data set.

3. Results

3.1. Spatial and temporal variations

Throughout the sampling period, 658 *P. physalis* colonies were found. The number of colonies for each beach was 59 in Cojímar, 50 in Bacuranao, 142 in Tarará, 247 in Mégano, and 160 in Santa María, representing 9%, 8%, 22%, 37%, and 24%, respectively. Significant differences between beaches for both number (N = 299, chi-squared = 23.0 p = 0.000) (Fig. 2) and density (N = 299, chi-squared = 13.87, p = 0.007) (Fig. 3) of *P. physalis* colonies were reported. Mégano, Tarará, and Santa María beaches reported the highest significant differences and Cojímar and Bacuranao the lowest differences. The months with arrivals of *P. physalis* for all beaches were May 2018: 80, June 2018: 26, October 2018: 32, November 2018: 110, December 2018: 132, January 2019: 152, and March 2019: 126, representing 12%, 4%, 5%, 17%, 20%, 23%, and 19%, respectively. No colonies were found in the rest of the months. Significant differences between months for both number (N = 299, chi-squared = 191.42, p = <2.2e−16) (Fig. 4) and density (chi-squared = 194.15, p = <2.2e−16) (Fig. 5) of *P. physalis* colonies were reported. May 2018, November 2018, December 2018, January 2018, and March 2019 had significant differences to other months but not between them.

3.2. Relations between the arrivals and the oceanographic/meteorological variables

The Principal Component Analysis (PCA) obtained for the response variable (average of *P. physalis* colonies) indicates that

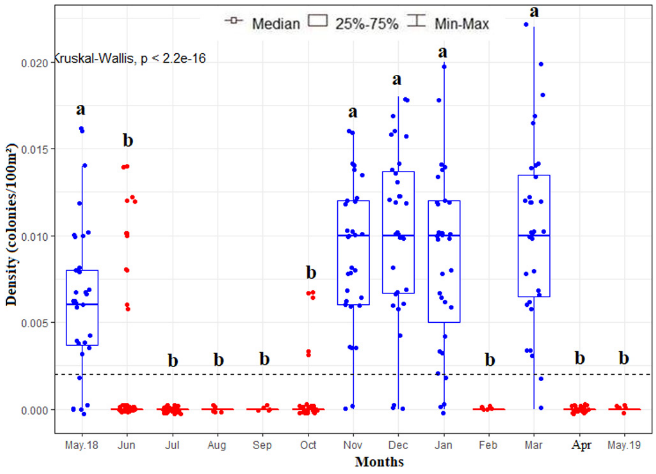

Fig. 5. Temporal variation of the density of *P. physalis* colonies (colonies/100 m^2). Different letters and colors represent significant differences. The horizontal line represents the median of the whole data set.

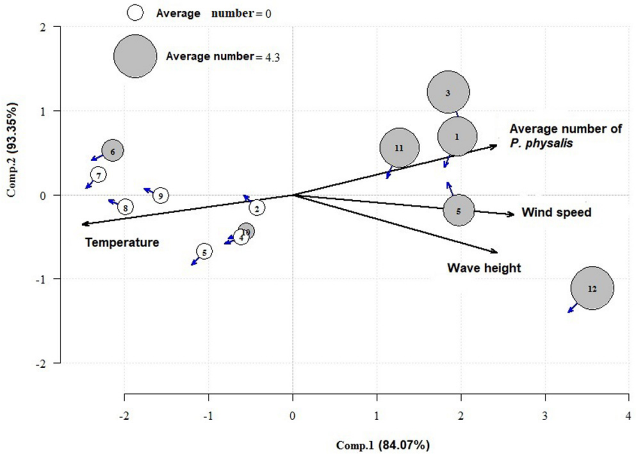

Fig. 6. Principal Component Analysis (PCA) results, showing the relation of meteorological and oceanographic variables on the average number of *P. physalis* studied in Havana. The white circle indicates the months where there were no *P. physalis* arrivals and the gray circle indicates the months where there were arrivals. The circle size indicates the arrival amount. The numbers indicate the months (1-January, 2-February, 3-March, 4-April, 5-May, 6-June, 7-July, 8-August, 9-September, 10-October, 11-November, and 12-December). The black arrows indicate the influence of variables on the PCA axis. The blue arrows indicate the wind direction. The percentage (Comp.1 84.07% and Comp.2 93.35%) indicates how much of the variability is explained by the PCA.. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

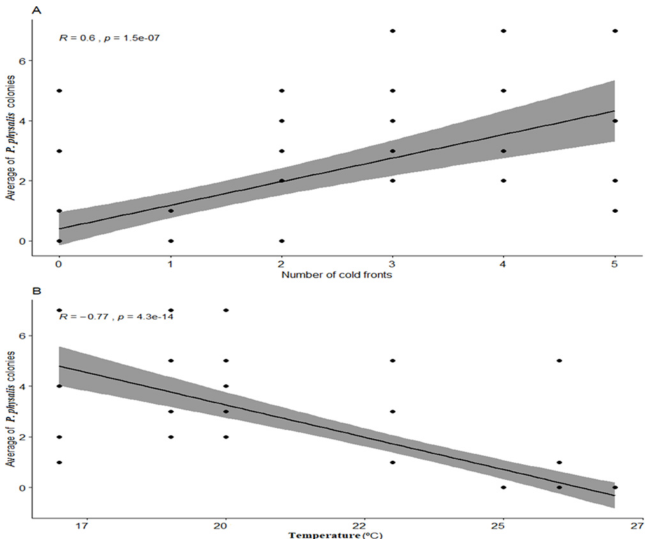

Fig. 7. Relation of the averages of *P. physalis* colonies with the number of cold fronts (A) and temperatures (°C) (B). R: Spearman Correlation Coefficient, p: probability.

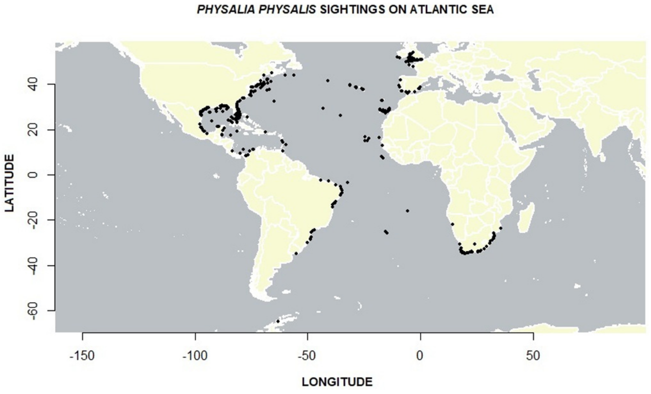

Fig. 8. Updated map with the distribution of *P. physalis* sighting around the Atlantic Sea (www.gbif.org), including the data of this study.

the speed and direction of winds, wave height, and temperature played an important role. Values of wind speed above 33 km h^{-1}, wave height above 1.5 m, wind directions mainly from the northern component, and temperatures below 30 °C with minimum values of 17 °C coincided with the months of higher numbers of arrival of colonies (May 2018, November 2018, December 2018, January 2019, and March 2019). This PCA explains 93.35% of the variability according to the selected variables (Fig. 6). There were 18 cold fronts in the study period. The appearance of these cold fronts coincided with the months between October 2018 and April 2019 (Table 1). The averages of *P. physalis* colonies are positively significant correlated with the number of cold fronts ($S = 18435$, $p = 1.5-07e$, $R = 0.6$) and negatively with temperatures ($S = 81149$, $p = 4.3e-14$, $R = -0.77$) (Fig. 7). Furthermore, a strong negative correlation between the number of cold fronts and temperatures was found ($S = 81635$, $p = 2.2e-16$, $R = -0.88$). Otherwise, the AOi and NAOi showed a mainly positive behavior compared to other years. The average of AOi and NAOi in the dry season was negative (−0.05) and positive (0.15), respectively. The AOi displayed a moderate negative correlation ($S = 73519$, $p = 8.503e-08$, $R = -0.60$) with respect to the number of cold fronts. Moreover, the NAOi showed a moderate positive correlation ($S = 25069$, $p = 0.000$, $R = 0.45$) with respect to the number of cold fronts. Finally, this study adds the studied region (Havana) to the distribution of *P. physalis* sightings in the Atlantic Ocean (Fig. 8). The wide distribution of *P. physalis* sightings can be observed throughout the Atlantic Ocean.

4. Discussion

Despite a certain geographic proximity among the studied beaches, the distribution of *P. physalis* on the coasts was not completely homogeneous. It was determined that Santa María, Tarará, and Mégano beaches have higher values and percentages of *P. physalis* colonies compared to Cojímar and Bacuranao. This coincided with the highest significant differences reported in Tarará, Mégano, and Santa María. The means of the number of *P. physalis* colonies on linear beaches (Tarará = 2.11, Mégano =

Table 1
The synoptic situation, number of cold fronts, number of *P. physalis* colonies, direction of prevailing winds and Arctic Oscillation (AOi) and North Atlantic Oscillation (NAOi) indices per month presented during the sampling period (May 2018–May 2019).

Months	Cold fronts	Synoptic situation	Number of *P. physalis* colonies	Direction of prevailing winds	AOi	NAOi
May/18	0	Tropical cyclone Alberto	80	SSE	0.11	0.21
June	0	No	26	ENE	0.37	0.10
July	0	No	0	EN	0.61	0.13
August	0	No	0	ESE	0.83	0.19
September	0	No	0	ESE	0.58	0.16
October	1	Michel hurricane, Cold fronts	32	ENE	0.41	0.93
November	2	Cold fronts	110	ENN	−0.11	−0.11
December	4	Cold fronts	132	EN	0.10	0.61
January	5	Cold fronts	152	ENN	−0.71	0.59
February	1	Cold fronts	0	ES	0.11	0.29
March	3	Cold fronts	126	NNO	0.21	0.12
April	2	Cold fronts	0	ENE	−0.25	0.46
May/19	0	No	0	EN	−0.12	−0.26

Fig. 9. *P. physalis* and the pelagic algae *S. fluitans* and *S. natans* arrivals on Mégano beach, Havana (March 24th 2019).

3.63 and Santa María = 2.38) were higher than those on the horseshoe beaches (Bacuranao = 1.00, Cojímar = 1.22). Likewise, the means of the densities of *P. physalis* colonies on linear beaches (Tarará = 0.005, Mégano = 0.007 and Santa María = 0.005) were higher than those on horseshoe beaches (Bacuranao = 0.003 and Cojímar = 0.003). This result may be explained by the fact that while Santa María, Mégano, and Tarará have a relatively linear shape, Cojímar and Bacuranao are horseshoe shaped. Apparently, the horseshoe shape of Cojímar and Bacuranao beaches may be limiting the arrival of *P. physalis* colonies at the shoreline. In contrast, the other three beaches (Mégano, Tarará, and Santa María) are more exposed to the wind. This may be supporting the arrivals, which agrees with Torres-Conde and Martínez-Daranas (2020) for another pelagic species (*Sargassum fluitans* (Børgesen) Børgesen and *Sargassum natans* (Linnaeus) Gaillon). These authors found the most biomass of pelagic *Sargassum* on beaches with a relatively linear shape.

Most of the *P. physalis* arrivals occurred during the dry season, which includes the months between November and April (Cedeño, 2015). At this time, cold fronts, surges, and strong winds from the north were frequent (www.insmet.com). The highest significant differences found in the number and density of *P. physalis* colonies between months belonged to this period. The arrival season marked its beginning with a preview of the dry season, which began in October with the formation of Hurricane Michel, and the entry of the first cold front. February, despite being in the dry period, did not display arrivals. This could be due to the fact that only one cold front occurred in this month, accompanied by meteorological conditions with lower maximum values of wind speed (28 km h^{-1}) and wave height (1.3 m) than those reported in the months with the highest number of arrivals (wind speed above 35 km h^{-1} and wave height above 1.5 m). May 2018, which does not belong to the dry season in Cuba, presented arrivals with high and significant scores. This month apparently behaved like an atypical month, due to the appearance of tropical cyclone Alberto (www.insmet.com). This unusual synoptic situation moved from Western Cuba to the Gulf of Mexico, where Ferrer and Pastor (2017) locate one of the agglomeration zones of *P. physalis* colonies in the Atlantic Ocean. The tropical cyclone may have moved part of these colonies towards the northwestern coast of Cuba, through strong winds of up to 42 km h^{-1}, and waves of up to 2.2 m (www.insmet.com).

According to the Principal Component Analysis, the wind (speed and direction) was the variable that most strongly influenced the arrivals of *P. physalis* colonies; whereas, the temperature behaved inversely proportional (values below 30 °C with a minimum of 17 °C) to the months with the highest number of colonies reported. In the months of May 2018, November 2018, December 2018, January 2019, and March 2019, winds exceeded 35 km h^{-1}, fundamentally from the northern component, and wave height was above 1.5 m. These findings are in accordance with Ferrer and Pastor (2017) and Prieto et al. (2015), who state that the wind is the main mechanism controlling the course of *P. physalis*. The months November 2018, December 2018, January 2019, and March 2019 coincided with the presence of two or more cold fronts from the north. According to Cedeño (2015) this synoptic situation may have brought with it strong winds from the north and low temperatures. The strong correlation between the number of cold fronts and low temperatures in this study coincides with that proposed by Cedeño (2015). In this regard, the positive correlation of the averages of *P. physalis* colonies with the number of cold fronts and the negative correlation with the low temperatures, presents further evidence of this hypothesis.

Both the AOi and the NAOi had a relative positive behavior from 2018 through 2019 compared to other years according to (www.cpc.ncep.noaa.gov). These indices give a measure of the influence of climate change in the Atlantic Ocean. The average of AOi and NAOi in the dry season was negative (−0.05) and positive (0.15), respectively. The negative average of AOi could indicate that the differences between atmospheric pressure between the Arctic and the tropical mid-latitudes were not so high in this period. In this study, the correlation between AOi and the number of cold fronts was negative. The AOi- increases the frequency of cold fronts and winds at lower latitudes (Wallace, 2000). Ferrer and Pastor (2017) suggest the NASG region, which surrounds the Sargasso Sea, as a possible origin of these organisms. These facts support the idea that the action of cold fronts are considerable factors to be taken into account in the arrivals at the Western Caribbean. This, in turn, could have favored the influx of colonies from the Sargasso Sea or the Gulf of Mexico to the Havana littoral zone. For example, January 2019 was the month with the highest number of arrivals (152), number of cold fronts (5) and the most negative AOi (−071). Nevertheless, this did not happen with NAOi, which had a positive value for this month. On the other hand, November 2018, which presented high scores of colonies, had a negative AOi and NAOi. This also occurred in May 2019, which did not show arrivals. The differences could be due to the fact that in November 2018, the winds exceeded 35 km h^{-1}, while in May 2019 the winds did not exceed 25 km h^{-1}. The intensity of the local winds may have played an important role even when the AOi and NAOi had a positive or negative behavior. Otherwise, the NAOi had a positive correlation with respect to the number of cold fronts and had more positive magnitudes than the AOi during the study period. This – although not new – has been the prevailing trend in NAOi+ in recent years. The dominance of these positive values has been related to changes in the weather (Hurrel, 1995), and the distribution of marine species (Fromentin and Planque, 1996). In addition, when the NAOi and AOi are positive, the winds from the northern hemisphere are weak, but trade winds and the Azores Anticyclone are stronger (White and Downton, 1991; Cedeño, 2015). According to Mendez-Tejeda and Rosado-Jiménez (2019), these last factors are essential to explain the movement of other pelagic species (*S. fluitans* and *S. natans*) from the Sargasso Sea to the Eastern Caribbean and the South Atlantic region when the NAOi is positive. There might be a seasonal pattern of *P. physalis* distribution in the Atlantic Ocean, which can be closely related to AOi and NAOi variations. It is likely that during the summer (coinciding with the wet season in Cuba), with NAOi+ and AOi+, the trade winds and Anticyclone of Azores boost drifting colonies to the Eastern Caribbean and South Atlantic region. Conversely, in winter (dry season) with NAOi- and AOi-, the cold wind waves from the northern hemisphere boost colonies from the Sargasso Sea and/or the Gulf of Mexico to the Western Caribbean.

For the Eastern Atlantic Ocean and Mediterranean Sea, Prieto et al. (2015) reported arrivals between the years 2005 and 2012, reaching up to 100,000 colonies in 2010, although in the other years less than 60 colonies arrived. The authors reported the typical arrival during the winter season, with strong winds, NAOi-, and wind directions mainly from the west. Despite the fact that no previous studies have been published on *P. physalis* arrivals at the Cuban coasts, it should be noted that the colonies that arrived during the sampling period were only on a small portion of the Cuban territory. Nonetheless, we found higher scores than the 60 colonies that have normally been entering the Eastern Atlantic and Mediterranean Sea according to Prieto et al. (2015). This could suggest that Cuba is one of the zones where *P. physalis* colonies arrive in considerable quantities. The map of sightings shows the wide distribution range of *P. physalis*. This is in agreement with Ferrer and Pastor (2017). *P. physalis* can be found from the south to the north and from the east to the west of the Atlantic Ocean. However, there are very few scientific papers published on the subject. It is necessary to increase the spatio-temporal studies in different zones of the Atlantic Ocean due to the impact that these colonies have for the shoreline.

The results of this study for *P. physalis* coincide with the appearance of the other pelagic species *S. fluitans* and *S. natans* in the same months and meteorological conditions (Torres-Conde and Martínez-Daranas, 2020) (Fig. 9). These authors reported the highest pelagic *Sargassum* biomass at the dry season in north-western Cuba. It was also related to the presence of cold fronts, low temperatures, AOi-, and strong winds fundamentally from the north. These macroalgae species have the Sargasso Sea as an origin zone (Wang et al., 2019), coinciding with *P. physalis* (Ferrer and Pastor, 2017). However, since 2011 these algae have been observed creating a belt from Western Africa towards the Gulf of Mexico with a biomass of more than 20 million tons along 8850 km (Wang et al., 2019). These authors argued that the increasing of nutrients in the water could be causing the explosion in biomass, and the consequent massive influx that accumulates on the shores causes a great social, ecological and economic impact. Moreira et al. (2006) describe the presence of synoptic situations in the Atlantic Ocean as a parameter to be taken into account for *Sargassum* brown tide arrivals. In May 2018, which is the beginning of the wet season, the passage of the tropical cyclone Alberto brought not only *P. physalis* colonies but also a great amount of pelagic *Sargassum* to the shoreline. Brooks et al. (2018) describe advection as the main factor controlling the movement of these pelagic algae, similarly as the stranding events of as well as we found *P. physalis* described in this study. Iosilevskii and Weihs (2009) state that *P. physalis* colonies sail with their pneumatophore aligned in the direction where the winds are strongest, which supports our study.

In addition, the decrease of *P. physalis* predators (fishes and sea turtles) due to overfishing may be generating the increase in numbers and frequencies of arrivals of this colonial organism at different locations around the Atlantic. We recommend constant monitoring, given that a large part of the food for these colonial polyps is zooplankton (ex. fish larvae) (Pitt et al., 2014). This could result in unusual *P. physalis* proliferation generating a destabilization in the open ocean ecosystems where they are usually found, and an effect on the food web. Furthermore, the social alarm among shoreline communities is very high, since a systematic effect on humans has been reported, causing a socioeconomic impact on tourism.

Conclusions

Havana littoral is apparently one of the zones of great arrival for *P. physalis* in the Atlantic Ocean, compared with other areas in the Eastern Atlantic. The distribution of *P. physalis* in this area is likely to depend mainly on the presence, intensity and number of cold fronts, the AOi-, or the appearance of some atypical synoptic situation such as a hurricane or a tropical storm in the Atlantic Ocean. These meteorological and oceanographic phenomena could cause that pelagic organisms found on the sea surface to be dragged towards the coastal zone and may appear in large quantities. The presence of pelagic *Sargassum* in almost the same months and conditions could open a new vision to describe the behavior of these pelagic species and their movement on Atlantic Sea.

CRediT authorship contribution statement

Eduardo Gabriel Torres-Conde: Project administration, Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Beatriz Martínez-Daranas:** Methodology, Data curation, Investigation, Writing - review & editing. **Laura Prieto:** Investigation, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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