Massive stranding of Physalia physalis (Hydrozoa: Physaliidae) on the Northwestern coast of Cuba

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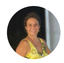

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SCIENTIFIC NOTE

Massive stranding of *Physalia physalis* (Hydrozoa: Physaliidae) on the Northwestern coast of Cuba

Varamiento masivo de *Physalia physalis* (Hydrozoa: Physaliidae) en la costa noroccidental de Cuba

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Abstract

Historically, *Physalis physalis* (Linnæus, 1758) massive stranding events have been either infrequent or poorly documented. However, their occurrence can significantly affect human health and the stability of coastal ecosystems. This study analyzes a massive *P. physalis* stranding that affected Cuba's NW coast in December 2022. During the event, eighty-five people were stung, with 38 having strong allergic reactions. To determine *P. physalis* abundance, we counted all colonies during the massive event along ~ 3 km coast within a 5 m strip. Density, dimorphic form (left/right-handed), and colony size were quantified using a 0,25 m^2 quadrat placed every 50 m, 10 m from the shoreline. Over ten thousand beach cast colonies were recorded, making this the event with the highest mean colony density (29,3 per m^2) ever reported. The massive stranding coincided with the lowest Arctic Oscillation index (-2,59) in the past 11 years during December, which led to northeasterly winds reaching up to 24 km/h, which might have favored the landings. Wind direction and speed, coupled with the dominance of left-handed colonies (71,4%), suggest the North Atlantic Subtropical Gyre as a possible origin source of the bloom. The high prevalence of juvenile *P. physalis* colonies (68%) likely aligns with the autumn breeding season in the northern hemisphere. The potential causes of *P. physalis* blooms are still poorly understood. Systematic monitoring of the distribution and abundance of this species should be a research priority considering the potential risk to human health and the fact that the blooms could become more frequent on the Atlantic coasts due to its eutrophication and climate change.

Keywords: Beach cast, bloom, dimorphism, health risk, juvenile colonies, Portuguese man-of-war, Western Atlantic.

Resumen

Los varamientos masivos de *Physalia physalis* (Linnæus, 1758) han sido poco frecuentes o mal documentados. Sin embargo, pueden tener un impacto significativo en la salud humana y los ecosistemas costeros. En este estudio, analizamos un varamiento masivo en la costa NO de Cuba en diciembre de 2022. Durante el evento, 85 personas sufrieron picaduras y 38 experimentaron reacciones alérgicas graves. Para cuantificar la abundancia, se contó el número de colonias que vararon a lo largo de ~ 3 km de costa. Adicionalmente, se cuantificó la densidad, la forma dimórfica y el tamaño de las colonias utilizando cuadrantes de 0,25 m^2 colocados cada 50 m a 10 m de la orilla. Se registraron más de diez mil colonias, convirtiendo este evento en el de mayor densidad media de colonias (29,3 por m^2) reportada hasta la actualidad. El varamiento masivo coincidió con el Índice de Oscilación del Atlántico más bajo (-2,59) en los últimos 11 años durante diciembre, que provocó vientos del noreste de hasta 24 km/h, lo cual pudo favorecer los varamientos. La dirección y velocidad del viento, junto con la dominancia de colonias con velas orientadas a la izquierda (71,4%), sugieren que el Giro Subtropical del Atlántico Norte podría ser una posible fuente de origen de la floración. La prevalencia de colonias juveniles (68%) coincidió con la temporada de reproducción en el hemisferio norte. Las causas potenciales de las floraciones de *P. physalis* han sido poco estudiadas. El monitoreo sistemático de la distribución y abundancia de esta especie debe ser una prioridad de investigación, dado el riesgo potencial para la salud humana y la posibilidad de que las floraciones se vuelvan más frecuentes en las costas del Atlántico debido a su eutroficación y al cambio climático.

Palabras clave: Varamiento, floración, dimorfismo, riesgo para la salud, colonias juveniles, Fragata portuguesa, Atlántico occidental.

Introduction

The understanding of blooms involving gelatinous zooplankton remains limited, mainly because they are not commonly the focus of fisheries and oceanographic research efforts, resulting in a dearth of information about their origins and causes (Licandro *et al*., 2010; Canepa *et al*., 2020). The excessive proliferation of these species can negatively affect marine ecosystems' stability through excessive predation and have adverse consequences for human activities such as tourism and fisheries, as usually these blooms are composed of stinging species (Purcell & Arai, 2001; Canepa *et al*., 2014). Among the gelatinous zooplankton species, *Velella velella* (Linnaeus, 1758), *Porpita porpita* (Linnaeus, 1758), and *Physalia physalis* (Linnaeus, 1758) are frequent contributors to the blooms found stranded on coasts, propelled by wind and currents (Graham *et al*., 2001; Canepa *et al*., 2014).

P. physalis, commonly called Portuguese man-of-war, is a cosmopolitan colony formed by specialized zooids, a pneumatophore, and tentacles that have stinging cells (cnidocysts) with toxins to paralyze prey and that are powerful enough to harm humans gravely (Burnett *et al*., 1994). It is an effective predator, comprising fish larvae up to 90% of their diet (Purcell, 1984). Gut contents analyses of colonies collected in the Gulf of Mexico and the Sargasso Sea showed that one colony consumes an average of 120 fish larvae daily (Purcell, 1984). Thus, when *P. physalis* is in high quantities, excessive predation can affect the marine ecosystem's stability (Mitchell *et al*., 2021). Also, *P. physalis* is among the worst stinging species in the Pacific and Atlantic oceans, affecting tourist and fishery activities (Canepa *et al*., 2020). Its sting can cause cardiac, neurological, gastrointestinal, respiratory, and allergic reactions in humans (Martínez *et al*., 2010; Mitchell *et al*., 2021).

Strandings of *P. physalis* are common on the coasts but usually in low quantities (Torres-Conde *et al*., 2022). For example, between 1914 and 2021, less than 200 beach cast colonies per year were reported for the Mediterranean Sea (Tiralongo *et al*., 2021), while on the northwestern coast of Cuba, annual densities from 2018 to 2021 were estimated at less than 150 colonies/100m (Torres-Conde & Martínez-Daranas, 2020; Torres-Conde *et al*., 2021). Scientific reports of massive strandings of this species are scarce (Table 1), most likely because these events are sporadic and

Table 1. Studies of massive stranding of *Physalia physalis*. NAOi: North Atlantic Oscillation Index; ENSO: El Niño Southern Oscillation.
Tabla 1. Estudios de varamientos masivos de *Physalia physalis*. NAOi: Índice de Oscilación del Atlántico Norte; ENSO: El Niño Oscilación del Sur.

Year	Month	Location	Coast length (km)	Number of colonies	Possible causes	Source
2010	February	Doñana National Park (Spain)	~ 50	~ 10,373	Unusual low NAOi event	Prieto *et al.*, 2015
2010	August	Bay of Biscay (France and Spain)	~ 250	3,500	Prevailing west-southwesterly and northwesterly winds	Fonseca & Pastor, 2020
2014-2016	May-March	Chilean coast (Chile)	~ 3,300	44,683	ENSO event, zonal wind anomalies and cold water upwelling	Canepa *et al.*, 2020
2016	January-March	Chilean coast (Chile)	~ 3,300	~ 9,010	ENSO event	Fierro *et al.*, 2021
2022	December	NW Cuba	~ 3	10,441	Unusual low AOi event, northeasterly winds	This study

primarily triggered by unusual meteorological and oceanographic conditions often associated with mesoscale oceanic disturbance processes (e.g. ENSO) and enhanced by climate change effects.

Gelatinous zooplankton blooms have been associated with environmental factors, such as light, temperature, salinity, and food availability (Purcell *et al.*, 2012), while onshore strandings are known to be influenced by wind and wave direction, as well as the geomorphology of the shoreline (Torres-Conde *et al.*, 2021; Bourg *et al.*, 2022). In the case of *P. physalis* strandings, the speed and direction of the wind have been identified as the primary factors for predicting the source of the bloom, as the pneumatophore acts as a sail that can be oriented left or right (Woodcock, 1944; Totton & Mackie, 1960; Ferrer & Pastor, 2017). The Arctic Oscillation index (AOi), the North Arctic Oscillation index (NAOi), and the El Niño Southern Oscillation (ENSO) have been used as indicators for predicting standings. These indices demonstrate stochastic variations between positive and negative phases and are associated with climate variations in middle and high latitudes (Prieto *et al.*, 2015; Canepa et al., 2020; Torres-Conde, 2022).

In this study, we describe the most significant density stranding event of *P. physalis* documented in the Atlantic and examine the climatic conditions that could have favored their transport to the northwestern coast of La Habana, Cuba, in December 2022. The results should raise awareness within the scientific community to monitor *P. physalis* strandings along the Atlantic coast, considering the risk they represent to human populations, tourism, and fisheries, particularly because increments in jellyfish populations are often associated with warming caused by climate change and eutrophication (Purcell *et al.*, 2007).

Methods

Data on a *P. physalis* stranding event in December 2022 were obtained in La Habana (23^{0}06′ 50” N, 82°26′24” W), northwestern coast of Cuba, by sampling ~ 3 km of the littoral of Paseo Marítimo, from streets 1st on the east to the west. The beach is dominated by rocky supralittoral and sublittoral and an abrasive rocky zone down to the terrace edge, where there is a continuous coral reef that extends to a depth of 20 m (Zlatarski & Martínez-Estalella, 1980; Caballero & de la Guardia, 2003). The dominant winds are from the northern component in the dry season and the east in the rest of the months (Lluis-Riera, 1983; Torres-Conde, 2022). The coastal area is urbanized. Locals and tourists visit the beach and coastal waters to swim, snorkel, and dive.

Samplings were conducted between the 27th and 31st of December 2022, when the massive arrival of *P. physalis* occurred. No colonies were stranded a week before and after this massive arrival. All fresh colonies along the ~3 km coast were counted each day in a ~5 m wide stripe. Additionally, 0,25 m^2 quadrats were placed every 50 m along the beach 10 m from the shoreline to quantify the density, the percentage of each dimorphic form (left-handed or right-handed), and the size of the colonies (accuracy = 1 mm). Colony density was standardized to a square meter. At each monitoring, the counted colonies were removed to further back sections of the beach (~ 5-10 m).

Possible differences in the frequency of *P. physalis* among dimorphic forms and size were tested with a chi-square test. A post hoc analysis for Pearson's chi-squared test was used for paired comparison. A significance level of 0.05 was used for all tests. All analyses and graphics were done in R (R Core Team, 2023) using packages: ggplot2 (Wickham, 2016), ggpubr (Kassambara, 2020), and GAD (Sandrini-Neto & Camargo, 2012).

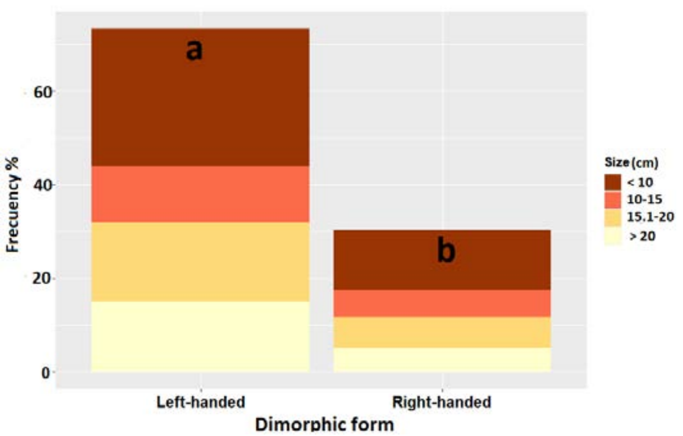

Fig. 1. Percentage of *Physalia physalis* colonies in four size classes (<10, 10-15, 15.1-20, > 20 cm) and dimorphic forms (Left-handed and Right-handed) that stranded on the northwestern coast of La Habana, Cuba, on December 28th and 29th 2022. Different letters indicate significant differences between dimorphic forms using the chi-squared test at the 0.05 significance level.

Fig. 1. Porcentaje de colonias de *Physalia physalis* en cuatro clases de tamaño (<10, 10-15, 15.1-20, > 20 cm) y formas dimórficas (zurdo y diestro) que vararon en la costa noroeste de La Habana, Cuba, el 28 y 29 de diciembre de 2022. Diferentes letras indican diferencias significativas entre las formas dimórficas utilizando la prueba de chi-cuadrado con un nivel de significancia del 0.05.

Wind direction, wave height and direction, and air temperature were obtained for the eight days before the massive beaching of *P. physalis* from the Windguru website (https://www.windguru/cz/). The climatic situation for the month of the arrival was obtained from the monthly summaries of the Cuban Meteorology Institute (https://www.insmet.cu). The daily Arctic Oscillation Index (AOi) and the North Atlantic Oscillation Index (NAOi) for the month of the massive beaching (December 2022) were attained from the database of the United States Climate Prediction Center (www.cpc.ncep.noaa.goc) (CPC, 2023). Data on the number of people affected by *P. physalis* stinging in the study area during the bloom event was provided by the Instituto de Ciencias del Mar-ICIMAR from la Habana, Cuba.

Results and discussion

Between December 27th and 31st, 2022, 85 individuals, including tourists, experienced *Physalia physalis* stings at the study site, with 38 suffering severe allergic reactions. No fatalities were reported. Along the studied shoreline, 10,441 *P. physalis* colonies were recorded (~345 colonies per 100 m) (Fig. 2a-b). The average colony density was 29,3 per m^2 (SE: 30,2). Statistical significant differences in the frequency of *P. physalis* were found between the dimorphic forms (χ-squared= 31,48, df = 1, p = 0,001) and sizes (χ-squared= 18.21, df = 3, p = 0,008). Left-handed colonies were more prevalent (71.4%) than right-handed colonies (28,6%), with 68.8% of the total being in a juvenile state (≤ 10 cm) (Fig. 1, Fig. 2c-d). A week before the standings, the prevailing winds and waves were northeasterly, with a mean wind speed of 12,1 km/h, a mean wave height of ~1 m, mean air temperature of 22,3 °C, and mean water temperature of 27,4 °C (Table 2). The Arctic and

Table 2. Mean (± SE) air temperature (°C), water temperature (°C), wave height (m), wind speed (km/h), and direction of prevailing winds and waves from eight days before *Physalia physalis* massive strandings in the northwestern coast of La Habana, Cuba, in December 2022.

Tabla 2. Temperatura media (± SE) del aire (°C), temperatura del agua (°C), altura de las olas (m), velocidad del viento (km/h), y dirección de los vientos y olas predominantes de ocho días antes de los varamientos masivos de *Physalia physalis* en la costa noroccidental de La Habana, Cuba, en diciembre de 2022.

Day	Temperature of the air (°C)	Temperature of the water (°C)	Wave height (m)	Wave direction	Wind Speed (km/h)	Prevailing wind direction
20	25 ± 0,5	28 ± 0,5	1,0 ± 0,1	NE	6,11	ENE
21	24 ± 0,7	28 ± 0,5	0,4 ± 0,1	NE	6,43	NNE
22	25 ± 1,1	28 ± 0,8	0,2 ± 0	No waves	6,43	SO
23	24 ± 1,2	27 ± 1,0	0,4 ± 0,1	N	6,92	N
24	19 ± 1,6	27 ± 0,6	1,5 ± 0,3	N	24,30	NNE
25	18 ± 0,5	28 ± 0,7	1,2 ± 0,2	NNE	22,20	NNE
26	19 ± 0,5	27 ± 0,9	1,1 ± 0,2	NE	14,32	NE
27	21 ± 0,5	27 ± 0,5	0,8 ± 0,1	NE	12,07	NNE
28	23 ± 0,5	27 ± 0,8	1,0 ± 0,2	ENE	9,65	ENE
29	25 ± 0,5	27 ± 1,1	1,2 ± 0,1	ENE	12,71	ENE

North Atlantic Oscillation indices displayed negative values (AOi: -2,59; NAOi: -0,13) (Table 3). Four days before the strandings (December 24, 2022), a cold front reached the coast of La Habana, bringing northeasterly winds reaching 24 km/h, an average wave height of 1,5 m, and an average air temperature of 19 °C.

The number of *Physalia physalis* colonies that washed ashore during the last week of December of 2022 was two to seven times higher than the annual records (range: 44-145 per 100 m) along the northwestern coast of Cuba in previous surveys (Torres-Conde *et al.*, 2021; Torres-Conde, 2022). The density of strandings was also significantly higher than that reported in other massive swarm events of the Portuguese Man-of-War. For example, 2010 was an anomalous year in *P. physalis* sightings (more than 100,000 colonies) on the coast of the Mediterranean Sea, Iberian Peninsula (both Atlantic and Mediterranean coastlines) (Prieto *et al.*, 2015). However, the number of *P. physalis* stranded colonies along ~50 km of Doñana National Park in Spain was only 10,373, giving a density of around 20 colonies per 100 m. This event was likely influenced by unique climatic conditions during the previous winter, including a negative NAOi

Table 3. Daily North Atlantic Oscillation Index (NAOi) and Arctic Oscillation Index (AOi) in December 2022.

Tabla 3. Índice de Oscilación del Atlántico Norte (NAOi) e Índice de Oscilación del Ártico (AOi) diarios en diciembre de 2022.

Day	NAOi	AOi
1	0,034	-0,95
2	-0,286	-1,69
3	-0,925	-1,61
4	-1,67	-2,42
5	-1,94	-2,08
6	-1,11	-2,58
7	-0,67	-2,87
8	-0,72	-3,52
9	-1,07	-3,69
10	-1,34	-4,1
11	-1,3	-4,1
12	-0,84	-3,65
13	-0,33	-3,15
14	-0,02	-3,19
15	0,2	-2,92
16	0,2	-2,66
17	-0,2	-3,73
18	-0,3	-4,15
19	-0,1	-3,67
20	0,01	-3,32
21	-0,02	-3,33
22	-0,06	-3,39
23	0,13	-3,43
24	0,13	-3,51
25	0,3	-3,03
26	0,8	-1,81
27	1,3	-0,54
28	1,3	-0,22
29	1,4	-0,27
30	1,4	-0,51
31	1,4	-0,28

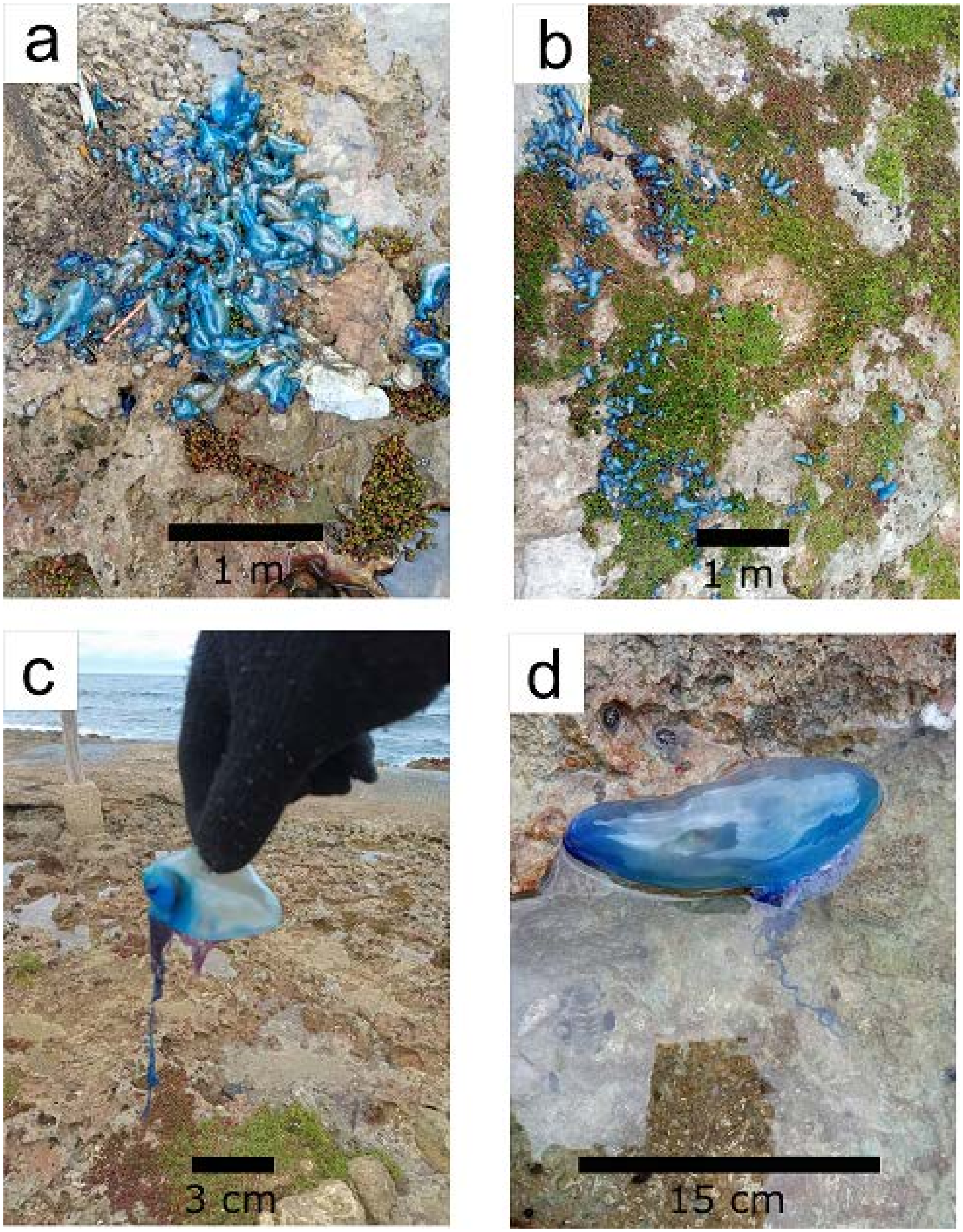

Fig. 2. a and b) Massive stranding of *Physalia physalis* on the northwestern coast of La Habana, Cuba, on December 28th and 29th, 2022; c) Juvenile colony of *P. physalis;* d) Mature colony of *P. physalis.*

Fig. 2. a y b) Varamiento masivo de *Physalia physalis* en la costa noroeste de La Habana, Cuba, el 28 y 29 de diciembre de 2022; c) Colonia juvenil de P. physalis; d) Colonia madura de *P. physalis*.

(-4,64) and anomalous strong westerly winds (Prieto *et al*., 2015). Also, in 2010, over 3,500 colonies arrived on the Basque coast in August (~1,4 colonies per 100 m), possibly due to a combination of west-southwesterly and northwesterly winds between August 2009 and August 2010 (Ferrer & Pastor, 2017). The southeastern Pacific Ocean also witnessed strandings of *P. physalis* from 2014 to 2016 (Canepa et al., 2020). Over this three-year period, 44,683 colonies were documented, with 71% occurring in 2015, and of these, 89% were found along the Chilean coast (between 25 and 36°S). The central and south-central coasts of Chile were the most affected, resulting in nearly 200 people being stung and the closure of over 120 beaches. The substantial landings followed a north-to-south stranding pattern and were associated with a Niño Southern Oscillation (ENSO) event, zonal wind anomalies, and cold-water upwelling (Canepa *et al*., 2020). The maximum monthly density recorded at a particular beach along the southeastern Pacific Ocean during the events was – 3,000 colonies, which is lower than the density recorded in the present study.

The arrival of the Portuguese Man-of-War in large numbers along Cuba's northwestern coast in our study occurred during the most negative mean AOi in the past 11 years (CPC, 2023). Negative AOi values promote the influx of cold fronts with robust northeasterly winds and low air temperatures from high latitudes to mid-latitudes (Thompson & Wallace, 2001; Thompson *et al*., 2003; Cedeño, 2015). Previous studies by Torres-Conde *et al*. (2021) and Torres-Conde (2022) have established an association between *P. physalis* and holopelagic *Sargassum* spp. strandings on the northwestern coast of Cuba with a negative AOi phase, cold fronts, and moderately strong northeasterly winds (> 18 km/h), which align with the conditions observed in the current study.

The dimorphic form of *P. physalis* is used to predict the source of stranded colonies (Ferrer & González, 2020). Ferrer and Pastor (2017) propose the North Atlantic Subtropical Gyre (NASG), encompassing the Sargasso Sea, as the primary source of *P. physalis* strandings along Atlantic Ocean coasts. Our results support this hypothesis as a higher percentage of left-handed colonies were stranded in La Habana in December 2022, influenced by predominantly northeast winds and waves. The high prevalence of juvenile colonies likely corresponds to the breeding season of *P. physalis*, which typically occurs in autumn in the northern hemisphere (between September and December; Ferrer & González, 2020). The small left-handed colonies were likely carried from the NASG towards the north coast of Cuba by a combination of wind and current conditions generated by an unusually negative AOi.

Global climate change has caused abrupt and abnormal behaviors in the NAOi, AOi, and ENSO patterns, which in turn influence meteorological conditions with changes in temperature, wind, and currents, which alter the distribution of marine species in the Atlantic Ocean (Fromentin & Planque, 1996; Thompson & Wallace, 2001; Prieto *et al*., 2015; Marx *et al*., 2021). One notable case is the extensive strandings of the holopelagic *Sargassum* spp. in the Caribbean, with high ecological, economic, and human-health-related repercussions (van Tussenbroek *et al*., 2017; Rodríguez-Martínez *et al*., 2023). Similarly, to the holopelagic *Sargassum*, climate change and eutrophication may play a role in *P. physalis* blooms (Hanisak & Samuel, 1987; Purcell *et al*., 2012; Brooks *et al*., 2018; Bourg *et al*., 2022). However, further research is needed to assess the environmental conditions that favor the reproduction of *P. physalis* and the occurrence of blooms. Not enough historical data is available to determine if *P. physalis* is increasing its distribution and abundance and if blooms are becoming more frequent.

The high density of *P. physalis* that was stranded on the northwestern coast of Cuba in 2022 and the risk it implies for human health should serve as a warning to the scientific community about the importance of implementing systematic monitoring efforts along the Atlantic coasts to gain a comprehensive understanding of the distribution and influx patterns of *P. physalis*. Climate change and eutrophication could turn isolated blooms of *P. physalis* into recurring events and affect a higher number of countries and territories. For example, in February 2023, strandings of *P. physalis* with a density of 20 colonies per 100 m occurred in a 70 km coastal stripe in the north of the Yucatan Peninsula, Mexico, where historically only isolated colonies were observed sporadically (Aldana-Arana, pers. comm.). Monitoring initiatives will provide invaluable insights, enhance prediction capabilities, and effectively manage future massive strandings in coastal regions (Canepa et al., 2020). Monitoring initiatives should also include the Sargasso Sea to comprehend the specific conditions that may be responsible for the occurrence of *P. physalis* blooms in the Atlantic. Also, to better understand the relationship between *P. physalis* landings and environmental factors, it is necessary to monitor massive stranding on larger temporal and spatial scales.

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Conflict of interest

All authors of this research paper have directly participated in the planning, execution & analysis of this study. All authors of this paper have read and approved the final version submitted. The content of this manuscript will not be copyrighted, submitted, or published elsewhere, while acceptance by the journal is under consideration. There are no directly related manuscripts published or unpublished by any authors of this paper. My Institute's representative is fully aware of this submission.

Ethical behaviour

The author has followed all applicable international, national, and institutional recommendations related to the use and handling of animals for research.

Permits for sampling and other permits

No permits were required for the conduct of this research.

Author contribution

EGTC, RERM, conceived and designed the research; EGTC, performed the experiments; EGTC, RERM, wrote and edited the manuscript."All authors contributed critically to drafts and gave final approval for publication. On behalf of all authors, the corresponding author states that there is no conflict of interest.

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