Regional Studies in Marine Science 41 (2021) 101557

Contents lists available at ScienceDirect

Regional Studies in Marine Science

journal homepage: www.elsevier.com/locate/rsma

New insights into the abundance and seasonal distribution of the Portuguese man-of-war *Physalia physalis* (Cnidaria: Siphonophorae) in the southeastern Pacific

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ARTICLE INFO

Article history:
Received 10 June 2020
Received in revised form 4 September 2020
Accepted 21 November 2020
Available online 23 November 2020

Keywords:
Jellyfish
Cnidarians
Zooplankton
Siphonophores
ENSO
Chile

ABSTRACT

During summer 2017 an anomalous and unprecedented developing of warm water off the coast of Chile was presented, namely Coastal El Niño event. Coincidentally, a high amount of strandings of Portuguese Man-of-War (*Physalia physalis*) were present at that time. In this work we determine the latitudinal and seasonal distribution of the pleustonic siphonophore *P. physalis* in the southeastern Pacific, from January 2016 to December 2017. The northernmost and southernmost records for the southeastern Pacific were recorded in this study, from Arica (18°26'S; 70°18'W) to Quellón (43°21'S; 74°07'W) in Chile, respectively. During the surveyed period, the greatest strandings of this species were recorded both in the north (23°S) and south of Chile (36–38°S) during the austral summer months, coinciding when sea surface is relatively warmer. The number of strandings registered in 2017 was more than 4 times the number of strandings during 2016; this is 17339 colonies in 2017 and 3910 colonies in 2016. The association between the maximum observed strandings and the time of appearance of Coastal El Niño event during summer 2017 are also discussed. Our findings can be used as guidance in the monitoring of *P. physalis*, in order to prevent encounters and therefore possible accidents with humans in coastal waters and beaches by strandings.

1. Introduction

Physalia physalis Linnaeus, 1758, commonly called Portuguese man-of-war or blue bubbles, is a pleustonic siphonophoran widely distributed in the Pacific, Atlantic and Indian oceans (Elston, 2007). They are commonly found floating in near-shore waters or stranded along the beaches (Ferrer and Pastor, 2017). The Portuguese man-of-war is easily recognizable by its bright bluish pneumatophore, with an apical crest. The pneumatophore allows this species to float in the air/water interface. As well as other cnidarians, *P. physalis* has multiple dactylozoids that can discharge thousands of cnidae to capture preys or as a defense (Munro et al., 2019). Toxins discharged by this siphonophore can cause necrotic, neurotoxic and cardiotoxic effects in humans. For this reason it is considered a public health issue in several countries (Bastos et al., 2017).

P. physalis is one of the most known siphonophores around the world, with a large amount of studies about this species, mostly dealing with cases of envenomations, and with its ecology, occurrence and distribution (Purcell, 1984; Edwards et al., 2002; Castriota et al., 2017). This siphonophore is common in the tropical and subtropical areas of the Indian, Atlantic and Pacific Oceans, between 55°N and 40°S. Due to distended pneumatophores (a gas-filled float), colonies can be transported many kilometers away from its origin, mainly by strong winds. However, others oceanographic factors, as open-ocean currents, can influence their displacement (Prieto et al., 2015; Rodrigues et al., 2020).

There are only a few records of *P. physalis* in the southeastern Pacific. In the South American coasts they have only been reported from Ecuador off The Santa Clara Island (3°S) (Andrade, 2012) and recently in the eastern tropical Pacific Ocean off Colombia (3°N) (Uribe-Palomino et al., 2018). In Chile *P. physalis* has been reported from Pan de Azucar (26°S) in the north to Bahia Ancud (41°S) in the south, and off the oceanic islands of Juan Fernandez and Easter Island (Leloup, 1935; Fagetti, 1958; Moyano and Valdovinos, 1984; Brito, 2002; Araya et al., 2016).

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https://doi.org/10.1016/j.rsma.2020.101557
2352-4855/

The frequency of appearance of this species varies throughout the year (Canepa and Palma, 2015), as well as the number of colonies that reach the coast, with the highest number of sightings being recorded during the summer months. Regionally, there are limited studies concerning to the factors that influence the distribution of this species, with most of the sightings having been associated with El Niño Southern Oscillation events (Araya et al., 2016).

We report the monthly distribution and frequency of occurrence of *P. physalis* in the Southeastern Pacific coasts of Chile from January 2016 to December 2017. Also, we analyze possible explanations of the maximum observed strandings recorded in summer 2017 associated to the atypical and unprecedented event in the Pacific sea surface temperature anomaly, the Coastal El Niño.

2. Material and methods

2.1. *P. physalis* data collection

Data regarding the number of individuals stranded on the beach, and the localization of massive strandings was provided by the Ministry of Health of Chile and the Chilean Navy, using the National database of *P. physalis* sightings. This database provided the following data: location, date, and number of recorded colonies from January 2016 to December 2017 along the entire Chilean coast.

2.2. Sea surface temperatures

Daily records and monthly data of sea surface temperature (SST) were obtained from a NOAA high-resolution blended SST on a 0.25 × 0.25 degrees latitude-longitude grid (Reynolds et al., 2007). A representation of anomalous SST observed during coastal El Niño along the eastern Pacific was shown by Garreaud (2018). A similar approximation was used in this study to show a positive anomaly of SST along the northern-central Chilean oceanic and coastal area. The spatial distribution of SST was obtained from the difference between the averaged SST of the period 25–30 January 2017 and the averaged SST period 15–20 January 2017. Additionally, the surface advection of warmer oceanic water was represented using the GLOBAL Ocean Sea Physical Analysis and Forecasting Products managed by Copernicus Marine Environment Monitoring Services (CMEMS). Surface ocean currents at 1/12-degree resolution for the study area were obtained for January 2017 and averaged to obtain surface current anomalies using the same periods used to obtain SST anomalies. Monthly climatologies (monthly averages) were obtained between January 1985 and December 2015 and presented using Latitude-Time plots, in order to show the seasonal variability of SST along the eastern Pacific.

3. Results and discussion

During our survey, the Portuguese man-of-war was reported from Arica (Playa Las Machas 18°26'S; 70°18'W) to Quellón (Caleta Inio 43°21'S; 74°07'W) along a large sea surface temperature gradient (Fig. 1a). It was previously stated that this species has a geographical range in the Pacific Ocean from 18°27'S to 45°S (review paper-Oliveira et al., 2016). However, this may constitute an error, because the southernmost documented record was informed at Bahia Ancud 41°52'S; 73°49'W, with no previous records of *P. physalis* at latitude 45°S (Moyano and Valdovinos, 1984; Canepa and Palma, 2015; Araya et al., 2016). Therefore, this study provides the northernmost and southernmost confirmed records of this species in the Eastern Pacific, thus extending its previously known latitudinal range in about 1.8 km to the north, and 170 km to the south (Fig. 1a).

In the present study, the areas with the highest number of sightings were in the north (23°S) and center-south (37–42°S) of Chile, with up to 1200 colonies recorded at certain locations (Fig. 1b). The Portuguese man-of-war was reported throughout the year, having a consistently higher abundance in the austral summer months: January, February and March (Fig. 1b), with a number of sightings ranging from 2748 colonies in January to 6262 colonies in March. The highest local abundance was reported on March 23rd 2017, with 1200 colonies stranded in the locality of Lebu (37°S). The increase in the surface water temperature and number of hours of sunlight through the day can positively influence the amount of jellyfish along the coast (Guillén Nieto et al., 2013). Thus, our results agree with similar records for other jellyfish species, such as *Muggiaea atlantica* (Siphonophore) or *Solmundella bitentaculata* (Hydromedusae) (Palma et al., 2011), which have been reported in southern Chile year-round, but increasing their abundances during the spring–summer seasons (October and March), when the sea surface is relatively warmer (Fig. 2a, b). Besides, the highest abundances of *P. physalis* in these months agree with the maximum biological production, which is enhanced by the upwelling due to favorable winds during austral spring and summer seasons (Daneri et al., 2000). Moreover, the highest number of sightings of these jellyfishes has been previously related to El Niño Southern Oscillation events (Palma and Rosales, 1995; Vera et al., 2004; Oliva et al., 2010). Numerous strandings of *P. physalis* were reported during 2015 along the northern Chilean coastline (26–27°S), clearly related to a strong El Niño Southern Oscillation event (2015–2016) (Araya et al., 2016). Subsequently in 2016 and 2017 a weak La Niña event was observed to be active in the central Pacific (defined by the Oceanic Niño Index — ONI, https://ggweather.com/enso/oni.htm), causing an anomalous cooling in surface waters of the eastern Pacific, along the coasts of Chile, Peru and Ecuador. La Niña scenario was not clearly observed along the east equatorial Pacific; instead, an anomalous and unprecedented event in this century called Coastal El Niño developed in January 2017 (Garreaud, 2018). Last time this phenomenon was reported was in 1925 and previously in 1891 (Takahashi and Martínez, 2017). Coastal El Niño events have a spatial surface warming pattern that differs from eastern or central Pacific El Niño events (Garreaud, 2018). These events are characterized by warming of the coastal equatorial region, not necessarily connected to a warming of the oceanic equatorial region.

Warming during the 2017 event was higher farther south of the equatorial region where the onset occurs; between 5°S and 30°S the sea surface temperature increased by more than 1 °C in only 7 days, extending 1500 km offshore (Fig. 2c reproduced using methodology by Garreaud, 2018). A relaxation of the westerly winds between 10–30°S impinging the Andes lead to a decrease of the southeastern trades off the coast at lower levels of the atmosphere, producing a relaxation of coastal upwelling followed by warming of the eastern Pacific (Rodríguez-Morata et al., 2018). *P. physalis* distribution is controlled by wind due to distended pneumatophores, but also by surface sea currents, which drag their colonies due to their long filaments (Prieto et al., 2015), which can measure up to 50 m long (Elston, 2007). Analysis of surface ocean currents showed the advection of oceanic flow towards the coastal region of northern and central Chile (Fig. 3), most likely as the result from westerly wind relaxation within this latitudinal band, and that favored the advection and possible arrival of *P. physalis* to the shore. This species was found mainly during the first months of 2017, extending as far south as 43°S and concentrated mainly between 23–42°S (Fig. 1b) consistent

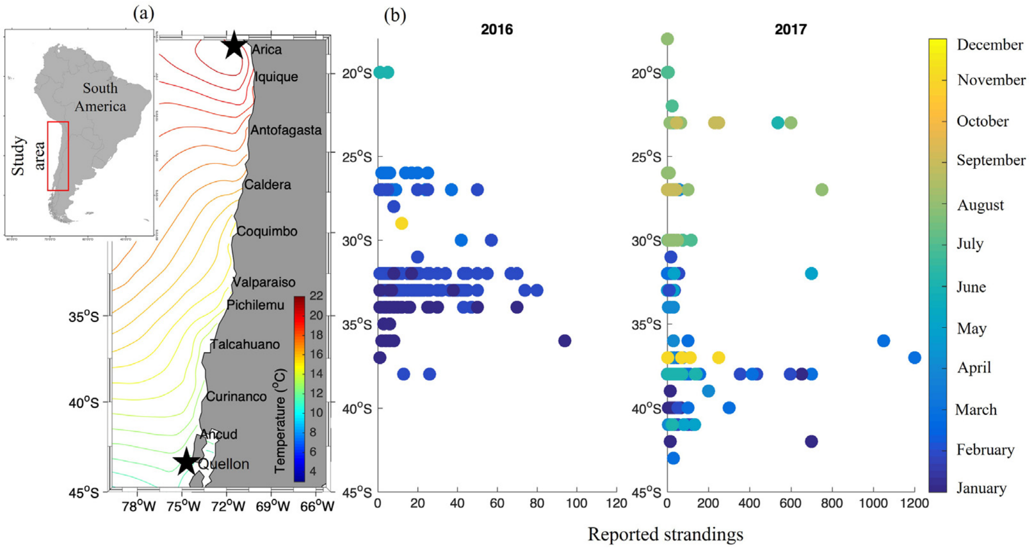

Fig. 1. (a) Study area along the Southeastern Pacific coast with the mean temperatures from 1985 to 2015 between 20°-45°S. Black stars indicate the northernmost and southernmost locations reported for *P. physalis*. (b) Latitudinal and temporal distribution of the total stranding number of colonies of *P. physalis* along the Southern Pacific between 2016 and 2017.

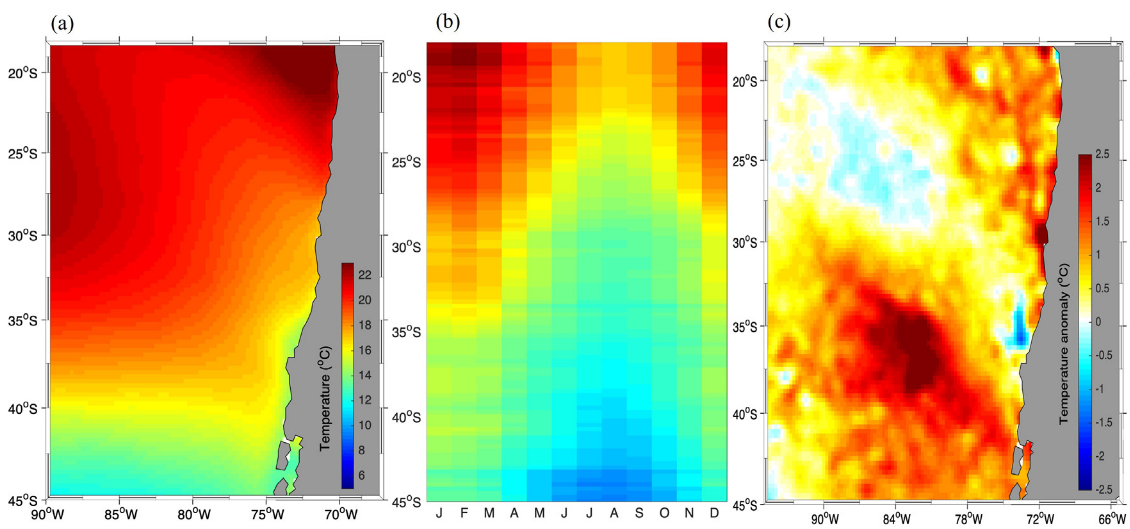

Fig. 2. (a) Latitudinal average of Januaries from 1985–2015 of SST. (b) Latitude-Time plot of SST, the values show 1985–2015 monthly SST from January to December along *x*-axis. Color bar is the same as 2a. (c) Difference in SST averaged between 25 and 30 January minus SST averaged between 15 and 20 January 2017 along the Southeastern Pacific.. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

with the spatial pattern of anomalous high SST and increased onshore advection during the onset of the 2017 coastal El Niño event (Fig. 2c). The number of strandings after the onset of a coastal El Niño was more than 4 times the strandings registered during 2016 (total recorded in 2016: 3910 colonies; in 2017:17339 colonies). January 2017 was identified as anomalously warmer and also the eastern Pacific experienced the largest northwestern wind positive anomalies (Garreaud, 2018) that could have contributed to the increased onshore advection of *P. physalis* from the warmer subtropical region. Other oceanographic mechanisms (i.e ocean retention within bays and local circulation features that favor local retention) could play a role in the local distribution and advection along the shoreline; however further studies are needed to properly predict the frequency and extension of future strandings.

Stings caused by *P. physalis* have been reported in the Western Pacific, mainly during the summer months, thus coinciding with the greatest number of stranded colonies observed. Considering that the distance between the northernmost and southernmost findings of this species along Chile is approximately 3300 km, with numerous touristic beaches, *P. physalis* is a potential threat to human health, even when air-dried and stranded. Accidents with this species can cause intense systemic effects, including nausea, vomiting, cold sweating, cardiac arrhythmia, syncope, and even death (Resgalla et al., 2005; Bastos et al., 2017). Therefore, a continuous monitoring must be considered to establish an early warning system, as it has already been implemented in other countries when jellyfish blooms occur (Straehler-Pohl and Jarms, 2010).

In conclusion we report the southernmost distribution of the Portuguese man-of-war along the South American coast, expanding its known range of distribution. In addition, we report for the first time the association between a large number of stranded colonies and the anomalous 2017 Coastal El Niño event in Chile. The information presented in this study can provide guidance in the monitoring of *P. physalis* in other regions around the world, in

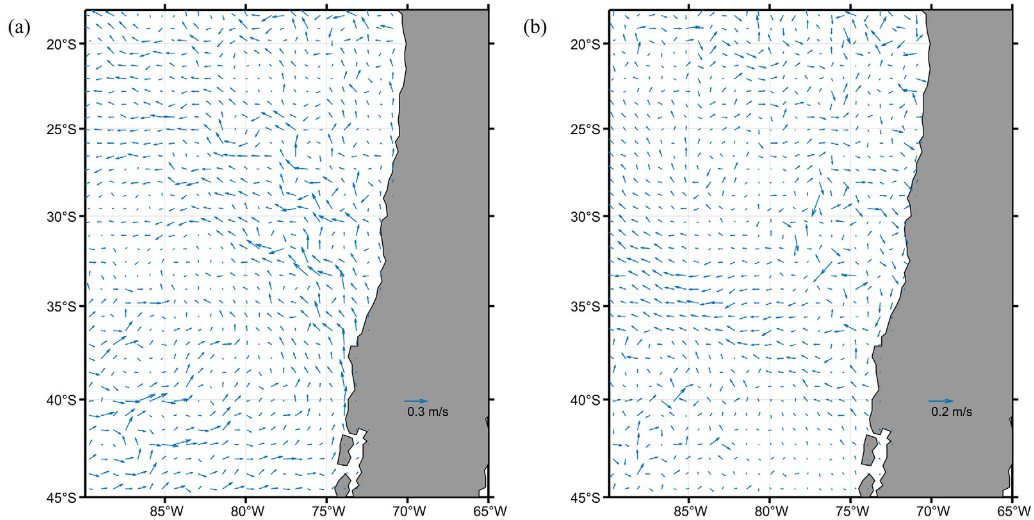

Fig. 3. (a) Ocean surface currents averaged between 15–30 January 2017. (b) Anomalies of ocean surface currents during Coastal El Niño event obtained by the difference between the currents averaged from 25 until 30 January minus currents averaged from 15 until 20 January 2017 along the Southeastern Pacific.

order to prevent encounters with humans in coastal waters and beaches by strandings.

CRediT authorship contribution statement

Pablo Fierro: Conceptualization, Writing - original draft, Writing - review & editing, Supervision, Funding acquisition. **Loretto Arriagada:** Methodology, Writing - original draft, Writing - review & editing. **Andrea Piñones:** Analysis, Writing - review & editing, Visualization. **Juan Francisco Araya:** Writing - original draft, 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.

Acknowledgments

We are thankful to the Ministry of Health of Chile, and to the Chilean Navy, for providing the information of the National database of *P. physalis* sightings. AP thanks COPAS Sur-Austral ANID PIA-AFB170006 and FONDECYT 11170913. Anonymous reviewers provided comments that improved our manuscript.

Funding

This work was supported by CONICYT FONDECYT project 11190631.

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