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# Unravelling temporality and environmental drivers of jellyfish presence in an urban beach

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**Abstract**

Jellyfish blooms affect human activities, causing negative socio-economic impacts. Many questions regarding the presence of these invertebrates remain unknown, including when and why they appear. The aim of this study was to unravel when and which environmental drivers drive the arrival of jellyfish to the urban beach of Las Canteras ( Canary Islands), by taking advantage of a long-term temporal series on jellyfish stings and semi-qualitative abundances of three jellyfish species (*Physalia physalis*, *Velella velella* and *Pelagia noctiluca*), provided by the Red Cross rescue service. First, we described inter- and intra (seasonal) annual patterns. Then, daily patterns in stings and monthly jellyfish abundances, by means of a model selection strategy, were connected with daily and monthly environmental drivers (zooplankton biomass, Sea Surface Temperature, SST, wind intensity, as well as climatic indices related to El Niño and La Niña events). We detected a strong seasonal trend in the number of jellyfish stings, with larger values in spring and summer relative to autumn and winter. *Physalia physalis* and *Velella velella* appeared during winter, which was also revealed by the model selection approach on the effect of environmental predictors (SST, in particular) on their abundances. In contrast, *Pelagia noctiluca* -the most abundant species - was present all year round, with the summer months as those with the highest abundances. There was a significant correlation between the daily number of stings and the daily presence of *Pelagia noctiluca* over time. In brief, the

occurrence of the three jellyfish species, in the study area, is seasonally partitioned, with SST over time as the most relevant environmental predictor of both the number of stings and the abundances of the three jellyfish species.

**Key words**: abundance, seasonality, outbreaks, stings, Atlantic Ocean, Canary Islands

## 1. Introduction

Jellyfish are animals belonging to the phylum Cnidaria, which include the classes Anthozoa, Scyphozoa, Cubozoa and Hydrozoa. Most of these animals spend all or part of their life cycles suspended or drifting in the sea water, i.e., medusa phase. Cnidarians are also significant components of the plankton, with large medusae – popularly called jellyfish – and colonial forms, such as the Portuguese man-of-war (*Physalia physalis*), using their fishing tentacles (dactylozooids) equipped with stinging cells to prey on a variety of organisms, including small-sized fish (Richardson et al., 2009).

The presence of jellyfish often has a negative impact on several economic activities (Gueroun et al., 2021). Blooms and massive onshore arrivals of jellyfish, while often perceived as spectacular and enigmatic phenomena, disrupt multiple sectors, interfering with tourism and leisure activities by stinging swimmers, with even fatalities, and forcing beach closures (Bordehore et al., 2015). They impact fishing by clogging nets, sometimes even capsizing boats, and harm aquaculture by killing fish in net-pens. Coastal industries, including power plants, face operational challenges as jellyfish block cooling-water intake systems (Purcell et al., 2007). Moreover, jellyfish blooms can shift ecological community structure and energy transfer within marine ecosystems (Condon et al., 2011; Fernández-Alias et al., 2022). Understanding the environmental drivers of these blooms and their cascading impacts on marine ecosystems and human activities is crucial for effective coastal management and conservation (Condon et al., 2013; Castro-Gutierrez et al., 2024). As jellyfish expand their habitats and increase their presence in coastal areas, they pose growing economic and ecological challenges to communities worldwide (Qui, 2014).

The scientific and social interest on jellyfish has increased in recent decades, evidenced by a rise in the scientific literature and media coverage. This interest stems from the perception of a global increase in jellyfish blooms, which has various impacts on human activities and ecosystems (Edelist et al., 2021). However, there is no consensus among scientists regarding whether jellyfish populations are actually increasing globally, as this issue remains unexamined and may result from misinterpretations of existing publications (Gueroun et al., 2022). In brief, there is a lack of knowledge on patterns of spatial and temporal variation across most of the world's oceans (Marambio et al., 2021). With the recent advent of Citizen Science and Local Ecological Knowledge programs across the globe, several citizen science projects emerged, where users can record any type of sighting, with the aim of monitoring different species. Some examples include the CIESM Jelly watch program in the Mediterranean (https://www.ciesm.org/marine/programs/jellywatch.htm), the Infomedusa facility across southern Spain (Castro-Gutierrez et al., 2024), or the REDPROMAR in the Canary Islands (https://redpromar.org/).

Environmental variables, such as water temperature, wind patterns, and ocean currents, significantly influence the dynamics of jellyfish populations and their coastal presence. Elevated sea surface temperatures have been associated with increased jellyfish densities, as warmer waters can enhance reproductive rates and extend the habitable range for various species (Song et al., 2024). Wind direction and speed also play a crucial role in jellyfish distribution. Onshore winds can drive jellyfish towards coastal areas, leading to higher concentrations near beaches, while offshore winds may disperse them away from the shore. Additionally, ocean currents facilitate the transport of jellyfish larvae and adults, influencing their spatial distribution and the timing of bloom event (Geshwin et al., 2014).

In the Canary Islands, studies on jellyfish populations around the islands are scarce. However, this scenario has been changing, as a result of the large concerns because of the massive arrivals of jellyfish (*Pelagia noctiluca*) that occurred in 2012, when around 10 tons of jellyfish were removed, only in Las Canteras beach (in the capital city of Las Palmas de G.C.) in just one day (lower inset in Fig. 1). As a result, improving the possibility to predict the blooms of jellyfish species, i.e., identifying environmental drivers governing such massive ashore arrivals, is crucial to minimize potential economic and social impacts.

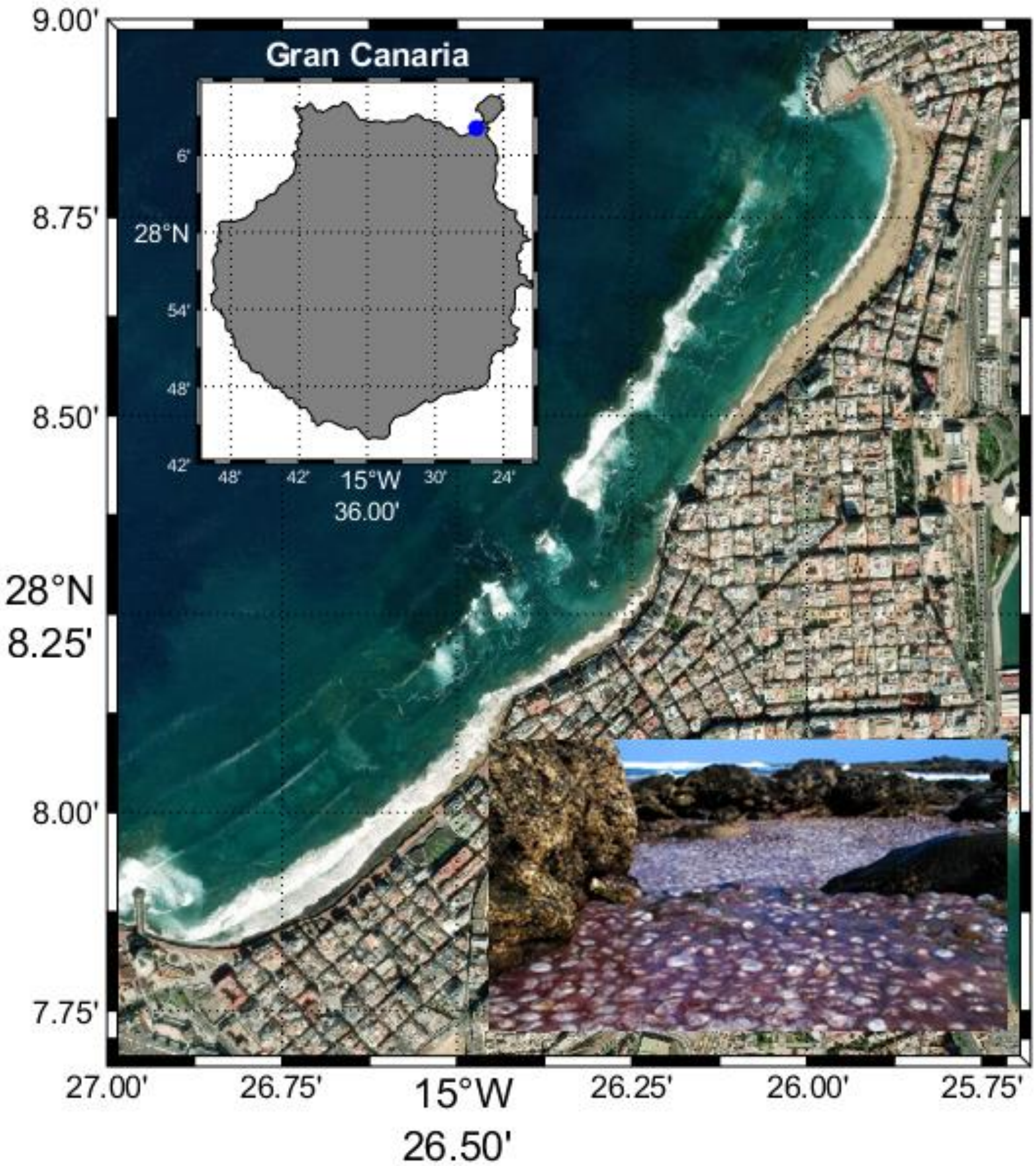


**Figure 1**. Aerial view of Las Canteras urban beach. The blue dot in the upper inset highlights its location on the island of Gran Canaria (Picture © Esri, DigitalGlobe,

GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN and GIS User Community"). The lower inset shows the bloom of *Pelagia noctiluca*, in 2012. Source: ElDiario.es.

Understanding the interplay between environmental factors is essential for predicting jellyfish bloom occurrences and mitigating their impacts on coastal ecosystems and human activities. Recent studies have emphasized the need for integrated monitoring approaches that consider multiple environmental variables to accurately forecast jellyfish dynamics (de la Fuente-Roselló et al., 2024).

In this study, we initially aimed at describing inter- and intra-annual temporal patterns in the arrival (i.e., appearance) of jellyfish in Las Canteras beach (Las Palmas de G.C., Gran Canaria Island, Canary Islands, Fig. 1). Such temporal patterns took advantage of two databases provided by the Red Cross rescue service, including daily injuries (stings) and a proxy to the abundance of the three main species: *Physalia physalis*, *Velella velella* and *Pelagia noctiluca*. Then, we analysed whether some environmental elements contribute to explain both the daily number of stings and the abundances of the three jellyfish species over time. We hypothesized that temporal patterns in the appearance of the three jellyfish species over seasons and years would be predicted by a range of environmental drivers operating at a range of temporal scales, from those with clear seasonal patterns in the study region (i.e., zooplankton biomass, Sea Surface Temperature, wind intensity), to climatic indices (i.e., El Niño and La Niña events) that mostly vary over years.



## 2. Material and methods

### 2.1. Study area

This study was carried out at Las Canteras beach, a nearshore semi-enclosed lagoon system located in the metropolitan area of Las Palmas de G.C., at the northern side of Gran Canaria Island (northeastern Atlantic Ocean, Fig. 1). The city has approximately 400,000 inhabitants and the beach is a pivotal core for its social and economic progress, with more than 300,000 tourists, on average, visiting the beach every year (www.grancanaria.com/turismo/es). The beach is about 3 km long and has capacity to accommodate more than 70.000 users per day, mainly for sunbathing, swimming, snorkelling, diving, paddling or surfing (www.lpamar.laspalmasgc.es) (Tuya et al., 2020). Sandy bottoms and rocky reefs are interconnected as irregular mosaics, typically between zero and three m depth (Tuya et al., 2019). An offshore sedimentary bar (ca. 2 km long) delimits the system's seaward extent; the bar is fragmented at several places and ranges between 200 and 300 m offshore. At low tide, the bar is above the surface, providing protection against swells. At high tide, however, the system is open to offshore waters (Tuya et al., 2019). The study site is protected within the framework of a ''Special Area of Conservation'' (code ES7010037, EU ''Natura 2000'' framework) (www.miteco.gob.es/es/costas). Commercial and recreational fishing is banned across the entire beach. In addition, the beach holds the environmental quality certification UNE-EN ISO 14001 (AENOR). Due to mild temperature all year round, the beach is frequented irrespective of seasons (Tuya et al., 2020). On average, it receives between 25,000 and 35,000 visitors daily. During weekends, this number can increase significantly, reaching between 60,000 and 84,000 visitors per day (Canarias7, 2022). Seasonal peaks, such as holidays, further highlight its popularity; for instance, during Easter 2023, a total of 540,276 individuals visited the beach and its promenade over the holiday period (La Provincia, 2023).

## 2.2. Data compilation

Data on jellyfish presence, on a daily basis, was provided by the local Cruz Roja (Red Cross) rescue service; two different datasets were used. The first dataset recorded the total number of jellyfish stings per day, from January 2009 to December 2023, irrespective of the species; this was an indirect way to account for the presence of jellyfish on the beach. The second dataset recorded the presence of three main jellyfish species (*Physalia physalis*, *Velella velella* and *Pelagia noctiluca*), from January 2014 to December 2021, by means of a semi-quantitative scale, ranging from 0 to 3, with 3 corresponding to the highest abundance and 0 to a total lack of presence (1 corresponded to 1-2 ind, 2 to 3-5 ind and 3 to > 5 ind). Typically, jellyfish are deposited onshore, so a quick checking (a 5 min walk along ca. 200 m of the beach shoreline) was sufficient to allow the rescue service crew to annotate such values. Typically, the same beach stretch was inspected at low tide within the northern side of the beach. Sampling days were random each month, with 5 to 8 annotations per month, so this dataset provided pooled monthly abundances per species over time.

2.3 Environmental drivers

Environmental variables, which may directly or indirectly correlate with jellyfish presence, were majorly downloaded from the EU Copernicus Marine Service (https://data.marine.copernicus.eu/), for the study area, between January 2009 and December 2023. Daily zooplankton biomasses were downloaded from the GLORYS reanalysis product: cmems_mod_glo_bgc_my_0.083deglmtl PT1D-i (Fig. S1, spatial resolution data in a 1/12º model, which corresponds to a distance of 8

13 Km between adjacent nodes at the local latitude). Daily mixed layer thickness data were downloaded from the GLORYS reanalysis product GLOBAL_MULTIYEAR_PHY_001_030 (Fig. S2). Daily sea surface temperature (SST) was obtained from the OSTIA product, using the METOFFICE-GLO-SST-L4-NRT-OBSSST-V2 database (Fig. S3). Daily wind velocity data were downloaded from the ERA5 reanalysis model (Fig. S4), which was subsequently filtered for the NW to the NE component, which includes those winds directions that may advent jellyfish species to the study beach (Fig. 1b). As the arrival of dust storms ("calima") may contribute to explain the dynamics of jellyfish, as calima enrich the ocean surface with minerals, we quantified such events over time (Rodriguez et al., 2001). We used the PM10 measurements over time from an official air quality monitoring station of the Canary Islands Government (https://www3.gobiernodecanarias.org/medioambiente/calidaddelaire/ica.do), which is specifically located at ca. 400 m from Las Canteras beach. The PM10 is considered the air quality variable that best correlates with dust storm events (Rodriguez et al., 2001). In our case, we calculated daily PM10 values that accounted for the potential cumulative effect of calima over the previous 90 days (Fig. S5, where peaks correspond to calima events).

Two climatic indices, which summarize the state of the atmosphere over time, were here also considered. Firstly, the North Atlantic Oscillation (NAO) index, calculated according to the NOAA (https://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao.shtml), was calculated. Positive NAO values are associated with increased atmospheric dynamics that bring cool waters to the Canary region, while negative values are linked to reduced dynamics and high temperature values (Fig. S5). Secondly, the El Niño / La Niña (ENSO) variability metric, widely used as a global index for describing climate variability patterns on a global scale, was also accounted, via the NOAA ONI (Oceanic Niño Index, https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONIv5.php).

While the positive phase of ENSO (El Niño) is characterized by relatively warm global temperatures, the negative phase (La Niña) is characterized by relatively cool global temperatures (Fig. S6).

Because lagged environmental conditions may also contribute to explain the arrival of jellyfish to the studied beach, we considered 4 additional lagged environmental predictors, in terms of the zooplankton biomass (lagged 93 days), the mixing layer thickness (150 days), wind intensity (20 days) and SST (89 days). Lagged days were selected as those that maximized the correlation with the daily number of stings.

2.4 Statistical analysis

All statistical routines were here implemented in the Rstudio (2023.9.1.494) package. Temporal patterns in the number of stings through months were initially described by fitting a non-linear Generalized Additive Model (GAM) to data pooled through years; we aimed to detect any seasonal pattern in the appearance of each species. The GAM was fitted using 'cubic regression' splines and a 'negative binomial' family for the residuals distribution, via the R "mgcv" package (Wood, 2003); the basis dimensions 'k' of the smoothers was limited to three, to avoid overfitting and ensure monotonic relationships. We assessed model performance using the 'gam.check' function, which produces graphical diagnostics (QQ-plot, residuals histogram, residuals versus fitted values and fitted values versus observed values). A Generalized Linear Model (GLM), fitted using a 'negative binomial' family error distribution and a 'log' link function in the R "MASS" package (Venables & Ripley, 2002), then tested for significant differences in the number of stings among the four annual seasons, with data pooled through years; this was another way to detect seasonality in the appearance of each species. The same model and associated statistical routines were implemented to test for significant differences among seasons for the semi-quantitative abundances of the three species from 2014 to 2021. For all fitted models, graphical inspection of residuals (QQ-plots, histograms, and residuals versus fitted values) provided evidence for the suitability of fitted models. Finally, we measured the strength of the correlation between the mean monthly number of stings, between January 2014 and Decembre 2021, and the mean total abundance of the three jellyfish species through Pearson product moment correlations.

To assess the effect of the range of considered environmental predictors on both the total number of stings over time, and the semi-quantitative abundances of the three jellyfish species, we initially visualized and tested for correlations (Spearman coefficients) between each pair of predictor variables, using the "corrplot" R package (Wei & Simko, 2017). An initial arbitrary cut-off at r > 0.6 was considered (Harrison et al., 2018). This was necessary to limit the inclusion of over-correlated predictor variables; if two predictor variables were correlated, we chose that one with a larger biological significance (Harrison et al., 2018). Subsequently, the mixing layer thickness was not considered in terms of modelling, due to correlations with a range of predictors (Fig. S8). We then carried out a model selection strategy, for both the total number of stings and the qualitative abundance of each species over time, through the "MuMIn" R package (Bartoń, 2019). This allowed us to perform a multimodel averaging that incorporated model selection uncertainty, after ranking candidate models by the AIC. At the end, this strategy provided estimates of the relative importance of each predictor variable, as the sum of Akaike weights over all possible models. We aimed at assessing the relative weight of each predictor explaining the appearance of each jellyfish species. Such models were fitted by means of GLMs, using a 'negative binomial' family error distribution with a 'log' link function, via the "MASS" R package (Venables and Ripley, 2002), which are ideal for overdispersed count data. Again, visual inspection of model assumptions was performed on selected models.

## 3. Results

### 3.1 Number of stings over time

The averaged monthly number of stings showed a clear annual cycle, with maxima during spring to summer months, progressively decreasing towards winter (Fig. 2). This pattern was statistically significant (GAM: smooth term fitted, $P < 2e^{-16}$, Fig. S9) with a 26% of explained deviance. This seasonal pattern was also observed when the number of injuries were pooled by seasons through years (Fig. 3), with significant differences among seasons (GLM: df = 3, Deviance = 371.02, $P < 2.2e^{-16}$).

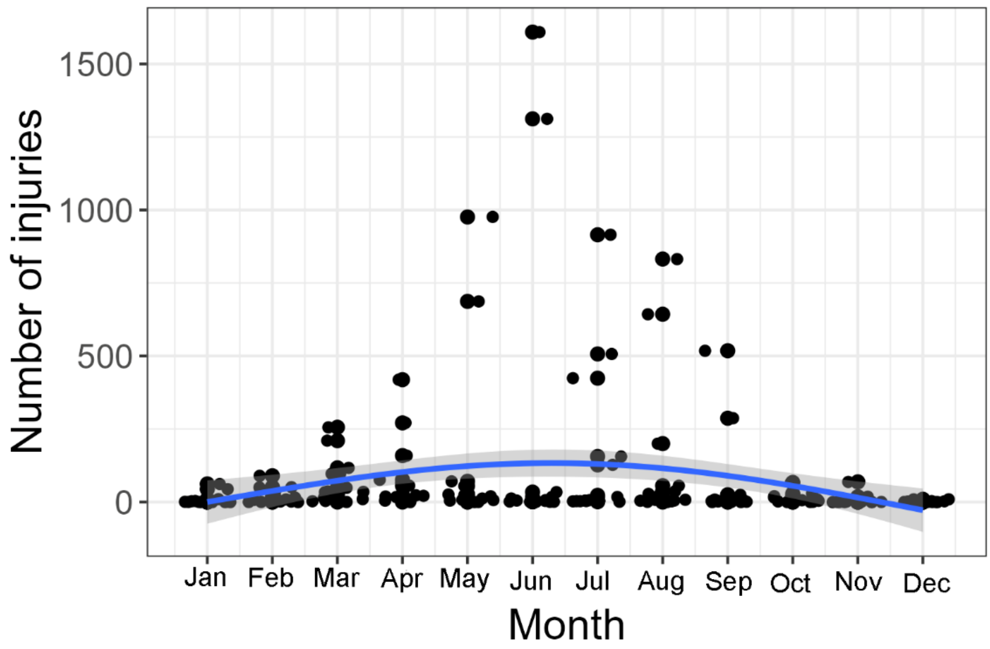


**Figure 2.** Mean monthly number of jellyfish stings from January 2009 to december 2023. The blue line denote the GAM fitted non-linear curve.

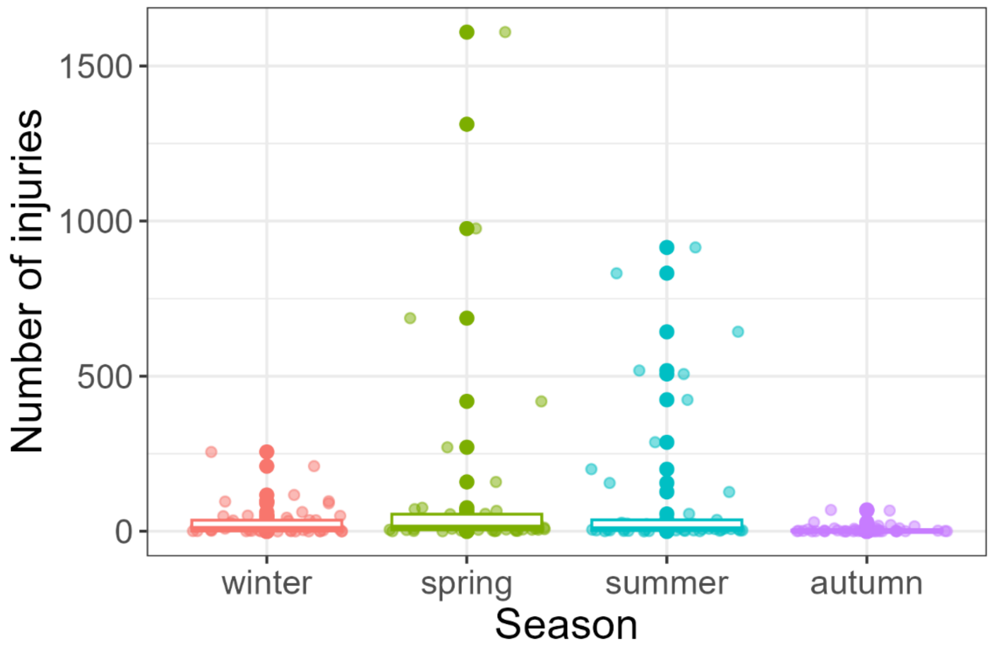


**Figure 3.** Number of jellyfish stings in winter (January, February, March), spring (May, April, June), summer (July, August, September) and autum (October, November, December). Data was pooled from January 2009 to December 2023.

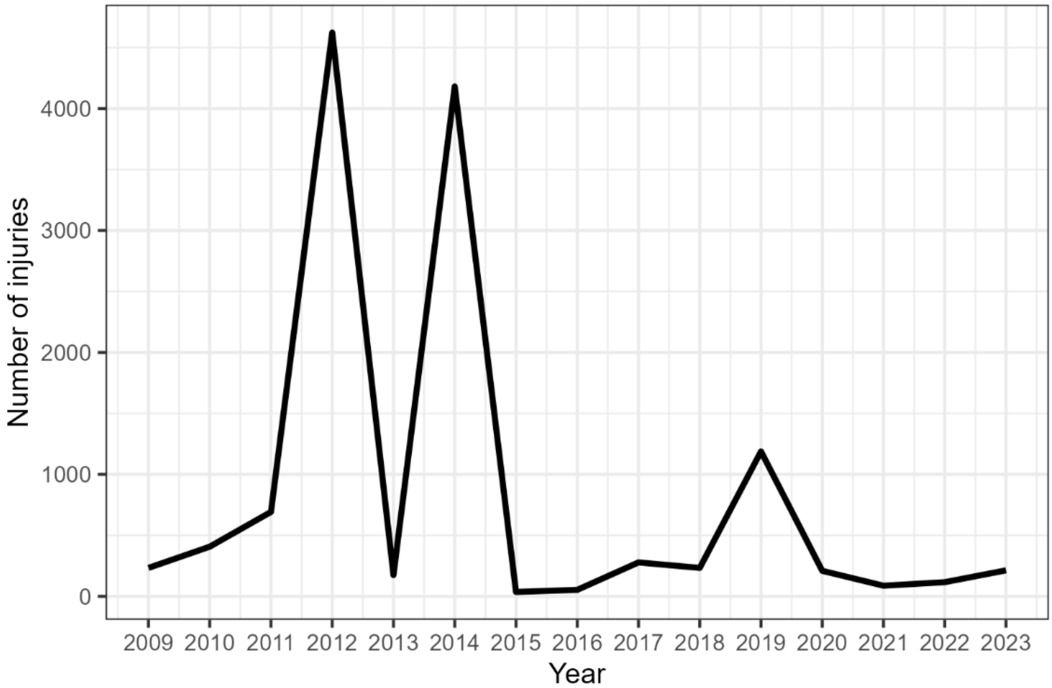


**Figure 4.** Total annual stings from 2009 to 2023.

Through the15-years time series, we observed different annual peaks in the total number of stings, with a considerable number of injuries in 2012, 2014 and 2019 (Fig. 4).

3.2 Abundances over time

Over the 8 years (2014-2021), a total of three different species were recorded: *Physalia physalis*, *Velella velella* and *Pelagia noctiluca*, which showed varying seasonal patterns throughout the sampling period (Fig. 5). *Physalia physalis* generally appeared in winter (i.e., January to April, GLM: 'seasons', df = 3, Deviance = 360.01, $P < 2.2e^{-16}$), with February as the month of largest abundance (Fig. 5A). *Velella velella* was the least abundant jellyfish species, with the largest abundances also occurring in winter and early spring (Fig. 5B, GLM: 'seasons', df = 3, Deviance = 17.37, P = 0.00059). In contrast, *Pelagia noctiluca* was present all year round, despite the summer months (i.e., May to July) were those with the highest abundances (Fig. 5C, GLM: 'seasons', df = 3, Deviance = 7.22, P = 0.0649).

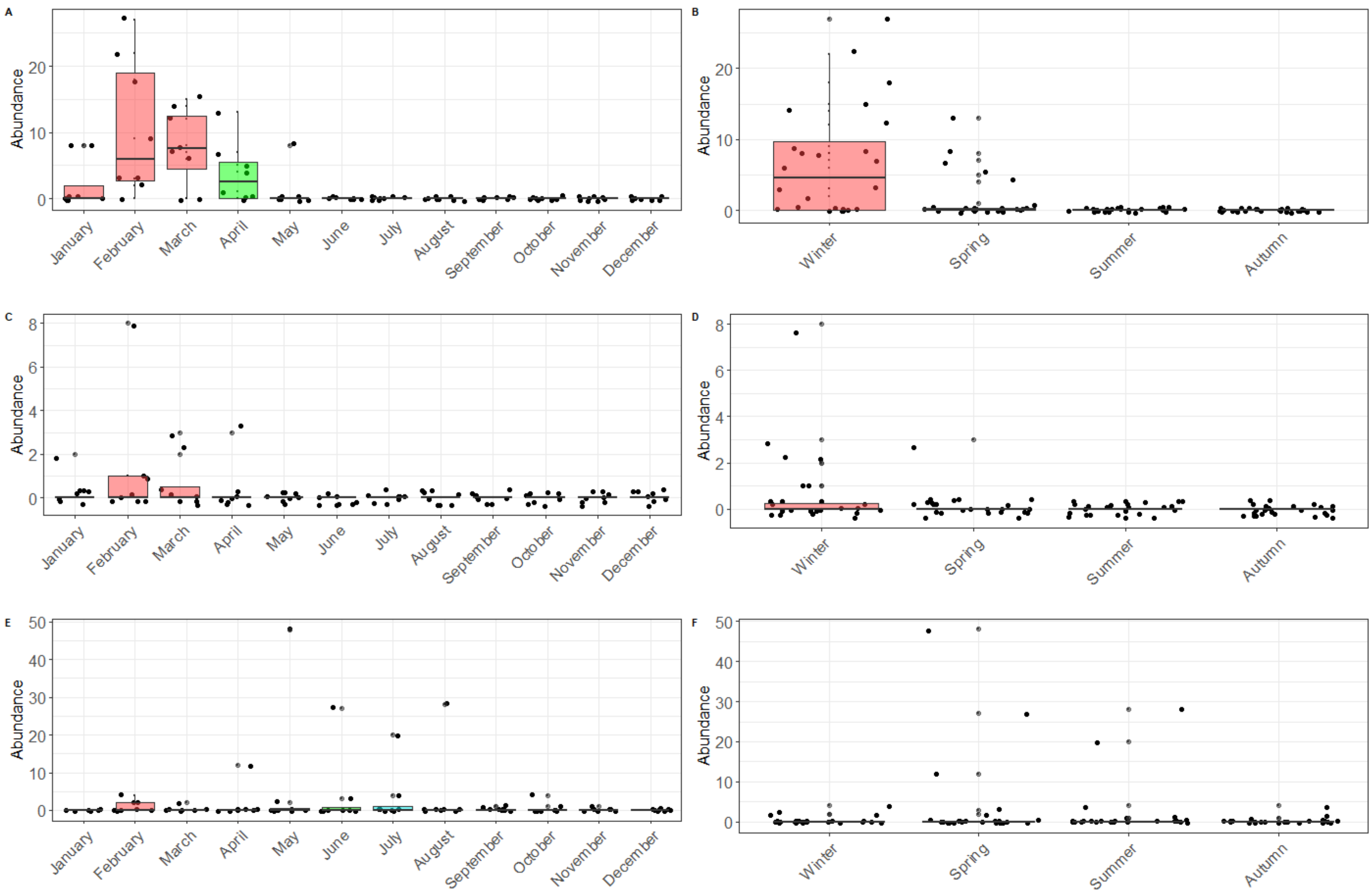


**Figure 5**. Monthly and seasonal abundances (abundances per species were pooled over months and seasons) for (A, B) *Physalia physalis*, (C, D) *Velella velella* and (E, F) *Pelagia noctiluca*. Data was pooled from 2014 to 2021. Different colours of boxplots denote different seasons (salmon: winter; green: spring.

In terms of the mean total number of jellyfish species over time (Fig. 6), *Physalia physalis* regularly appear every year (Fig. 6A), while the other two species had a more random abundance, with even years with no presence at all (Fig. 6B, 6C). It is worth mentioning that large abundances of the three species were registered in 2014.

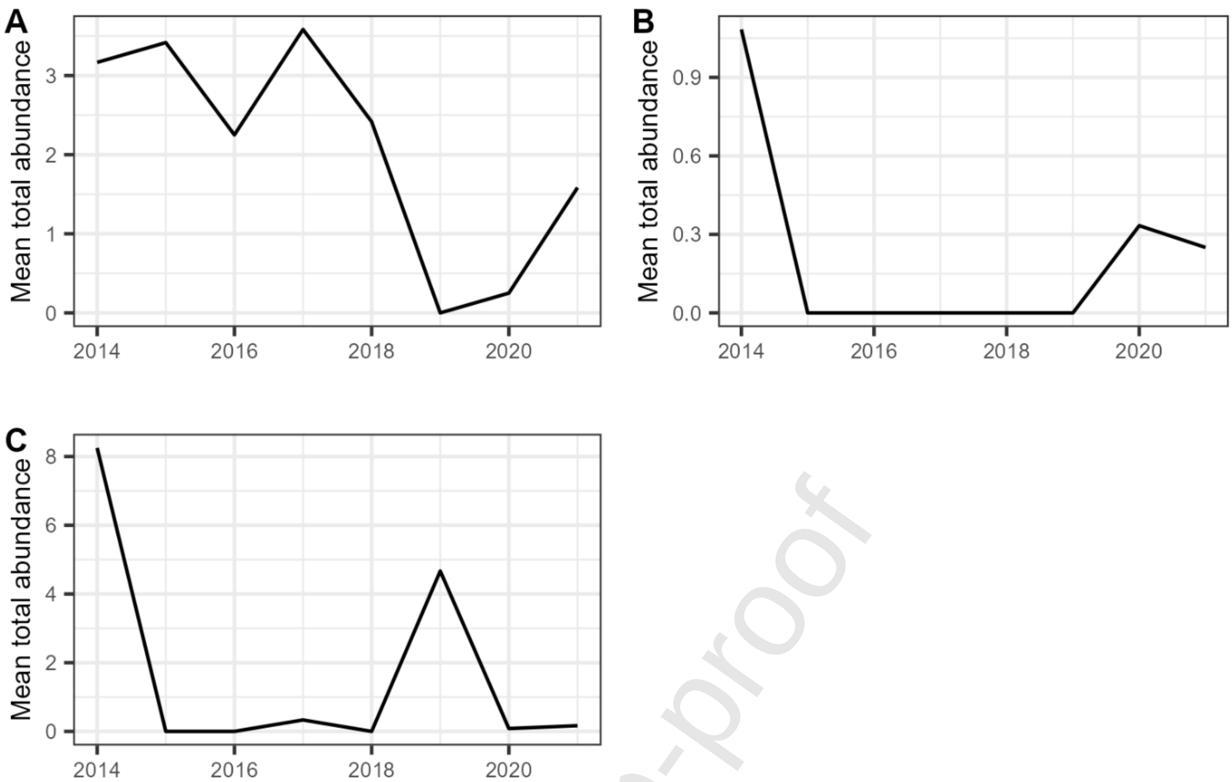


**Figure 6**. Total annual abundances (pooled over each year) for (A) *Physalia physalis*, (B) *Velella velella*, and (C) *Pelagia noctiluca* over time.

The mean monthly number of stings, between January 2014 and Decembre 2021, significantly correlated with the mean total abundance of *Pelagia noctiluca* ($r_s = 0.77$), whereas correlations were unsignificant for the other two jellyfish species ($r_s < 0.1$).

3.3 Effect of environmental drivers over time

SST, including a lagged SST component, was revealed as the most relevant environmental driver significantly contributing to explain the total number of stings over time (weight = 0.83 and 1, respectively); increased temperatures positively influenced the number of stings (Table 1). The total number of stings were also positively affected by the abundance of zooplankton (weight = 0.97) and the lagged component of wind intensity (weight = 0.96) (Table 1). The ENSO index of climatic variability also contributed to explain some variation (weight = 0.83, Table 1).

Abundances over time of both *Physalia physalis* and *Velella velella* were only significantly affected by SST, with a clear negative effect of SST on their abundances (weight = 1 and

0.72, respectively, Table 1). For *Pelagia noctiluca*, the NAO climatic variation was revealed, however, as the most relevant driver (weight = 0.89, Table 1), with also a relevant (but positive) contribution of the lagged component of the SST (weight = 0.61, Table 1).

| | Estimate | SE | Z | P | Akaike weight |
|---|---|---|---|---|---|
| **Total stings** | | | | | |
| Intercept | -2.8649 | 0.3396 | -8.436 | < $2e^{-16}$ *** | |
| ENSO | -1.0313 | 0.2839 | -3.633 | 0.000280 *** | 0.83 |
| Lagged SST | 5.6650 | 0.2740 | 20.675 | < $2e^{-16}$ *** | 1 |
| Lagged Wind | 1.0521 | 0.3654 | 2.880 | 0.003983 ** | 0.96 |
| SST | 0.7400 | 0.3487 | 2.122 | 0.033799 * | 0.83 |
| Wind Intensity | -0.6437 | 0.3720 | -1.730 | 0.083542 | 0.60 |
| Zooplankton biomass | 2.7289 | 0.7971 | 3.423 | 0.000618 *** | 0.97 |
| ***Physalia physalis*** | | | | | |
| Intercept | 4.471 | 0.536 | 8.343 | < $2e^{-16}$ *** | |
| SST | -17.329 | 2.542 | -6.817 | 9.29e-12 *** | 1 |
| ***Velella velella*** | | | | | |
| Intercept | 1.637 | 1.790 | 0.915 | 0.36041 | |
| PM10 | 3.765 | 2.840 | 1.326 | 0.18495 | 0.55 |
| SST | -12.391 | 4.777 | -2.594 | 0.00948 ** | 0.68 |
| ***Pelagia noctiluca*** | | | | | |
| Intercept | 5.059 | 2.171 | 2.330 | 0.0198 * | |
| Lagged SST | 6.782 | 2.705 | 2.507 | 0.0122 * | 0.61 |
| Lagged Zooplankton abundance | -6.782 | 3.276 | -2.070 | 0.0384 * | 0.45 |
| NAO | -2.999 | 2.378 | -4.017 | $5.89e^{-05}$ *** | 0.89 |
| SST | -2.999 | 1.806 | -1.660 | 0.0969 | 0.45 |
| Wind Intensity | 3.125 | 1.980 | 1.578 | 0.11452 | 0.38 |

**Table 1**. Results of multi-model averaging from model selection of predictive environmental variables most contributing to explain variation on the number of stings and the semi-quantitative abundances of the three jellyfish species over time. ***: P< 0.001 **: P< 0.01, *: P < 0.05.

## 4. Discussion

Considerable records of stings and sightings of three jellyfish species, in conjunction with varying environmental conditions over time, have been worked here to understand temporality driving jellyfish occurrences on Las Canteras Beach. Despite both databases (i.e., stings and semi-quantitative abundances) covered different years, it is worth noting that the large number of stings through 2014 and 2019 was connected to large amounts of just one jellyfish species, *Pelagia noctiluca*, with a very significant correlation between both metrics. Hence, variation in the number of stings over time is connected to variation in the arrival of the most conspicuous jellyfish species on the beach. Considerable variation in the temporal occurrence of jellyfish, e.g., years and months with high numbers of jellyfish advected onto beaches, alternating with low-density periods, has been also recorded in the Atlantic (Lilley et al 2009; Fernández-Alias et al., 2024; Long et al., 2024) and the Indican Ocean (Syazwan et al., 2020;; Syazwan et al., 2025). It is worth mentioning that this urban beach, with a consistent influx of visitors throughout the year, ensures that swimmer presence is not confined to specific seasons, such as spring or summer (Canarias7, 2022; La Provincia, 2023). Consequently, the observed rise in jellyfish stings during warmer months cannot be only attributed to increased beachgoer numbers. Still, the use of wetsuits by surfers, which is less common in summer, may also contribute to explain the increase in stings in summer.

Notably, daily records of people affected by stings indicate larger jellyfish numbers in spring and summer relative to autumn and winter months. In turn, our results showed that the three species of jellyfish showed distinct seasonal patterns. During winter and spring, *Physalia physalis* and *Velella velella* are the predominant species. *Pelagia noctiluca* is, however, generally present during most of the year, as it has been reported in the northwest of the Mediterranean Sea (Ferraris et al., 2012; Canepa et al., 2013; Ottmann et al., 2021; Mghili, 2022), with peaks in arrivals to the beach in the summer months. This temporal pattern in the presence of both *Physalia physalis* and *Pelagia noctiluca* was also detected, for the entire Canary Islands (Bondyale et al., 2022), when jellyfish sightings from the REDPROMAR (https://redpromar.org/) - a citizenship science monitoring program facility supported by the Government of the Canary Islands – was analyzed.

Initially, varying seasonality in the presence of each jellyfish species could be caused by varying environmental conditions, including onshore winds and coastal currents that transport jellyfish towards beaches, as well as elevated sea surface temperatures that may enhance reproduction and extend habitat ranges (Purcell et al., 2007; Brotz et al., 2012; Canepa et al., 2020). In brief, such environmental variation can affect the natural life cycles of these jellyfish species, but also their appearance on the coasts via drifting. On the one hand, *Physalia physalis* is found across tropical, subtropical and temperate waters of the globe (Ferrer & Pastor, 2017). In the study area, the presence of this species was considerably related to SST, in particular to low temperatures (i.e., winter months). On the other hand, warmer waters are preferred by *Pelagia noctiluca*, with a thermal niche of sea water temperatures between 13.5°C and 26°C (Rosa et al., 2013). The appearance of this species was also significantly connected to STT (in this case to the lagged SST component), but with a positive contribution, as records were dominant in the spring and summer months. Importantly, the NAO index of climatic variation was that environmental predictor most contributing to explain temporal variation in the arrival of this species over time. A negative effect of the NAO index was detected, which is associated to large temperature values. Therefore, there is a clear climatic effect on the presence of *P. noctiluca* in the study area, with high temperatures positively determining the presence of this jellyfish. There is literature suggesting that the NAO affects the abundance of this species (Lyam et al., 2004). While the NAO affects fluctuations of the abundance of *P. physalis* (Canepa et al., 2020, Prieto et al., 2015), our study did not reveal any significant influence in this sense.

It is worth mentioning that wind intensity (in particular, its lagged component) only had a statistically significant effect on the total number of stings, with high wind intensities positively increasing the number of stings. This is clear evidence that the overall arrival of jellyfish, indirectly measured through the number of stings, is locally affected by increased wind intensities that passively drift jellyfish onshore. In this sense, wind has been identified as a key mechanism controlling the direction and coastal arrival of *P. physalis* across a range of latitudes (Ferrer et al., 2017). Initially, the lack of a significant effect on the semi-qualitative abundances of the three species was puzzling. However, this may be caused by lagged wind intensities, at a range of temporal scales, as a relevant mechanism that was otherwise not accounted by our analysis. In any case, it is worth noting that wind intensities, mostly associated to the trade winds in the study region (Tuya et al., 2019), are particularly high in summer relative to winter. This fact may also to understand the larger number of stings in summer.

The complexity of the ecological and environmental processes influencing jellyfish occurrences and associated stinging incidences, such as Las Canteras beach as a case-study, deserves attention to better predict massive arrivals. Seasonal trends, human activity, biological cycles and climatic conditions play intertwining roles. Understanding the interplay of these elements is crucial for effective coastal management, in particular in urban beaches (Rodriguez et al., 2015). The significant role of oceanographic conditions in jellyfish aggregation emphasizes the need to prioritize ecological and climatic drivers over anthropogenic influences when interpreting sting patterns, at least at Las Canteras beach. By integrating local monitoring data with broader environmental analyses, this study provides a robust framework for predicting and mitigating jellyfish blooms in urban coastal areas (Condon et al., 2013; Castro-Gutierrez et al., 2024). This insight is essential for balancing the ecological significance of jellyfish with their socioeconomic impacts on tourism, fisheries, and other coastal activities.

Our results were based on data provided by the red cross rescue service, a type of citizenship science program. Of course, accurate temporal patterns on the presence of jellyfish cannot totally rely on stings and semi-quantitative abundances. Despite the large temporal scale of our data is remarkable, it would be necessary more quantitative, for example via regular trawling in offshore waters, to unambiguously unravel temporality in the appearance of jellyfish species. Moreover, our data comes from just one beach. Ideally, a range of beaches should be monitored to have robust inferences on temporality in the arrival of jellyfish to coastal waters.

## 4.1 Conclusions

There is substantial variability in the temporal occurrence of three jellyfish species, i.e. from year to year, on an urban beach. Still, there is a clear seasonal partitioning, with *Physalia physalis* and *Velella velella* mainly occurring in winter and spring, while *Pelagia noctiluca* appears all year round. The appearance of this species, which is the most conspicuous, is largely affected by climate variation, with high temperatures positively affecting the presence of this jellyfish.

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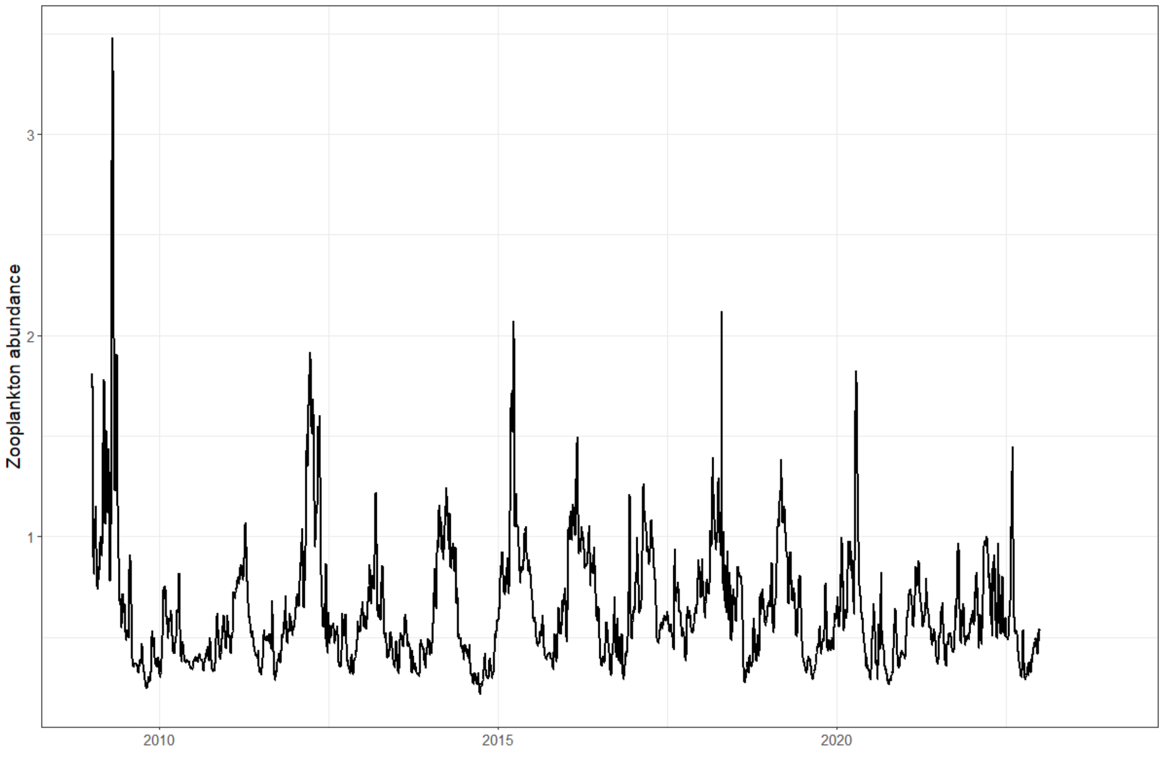


Fig. S1. Zooplankton biomass (g $m^{-2}$) over time in the study area.

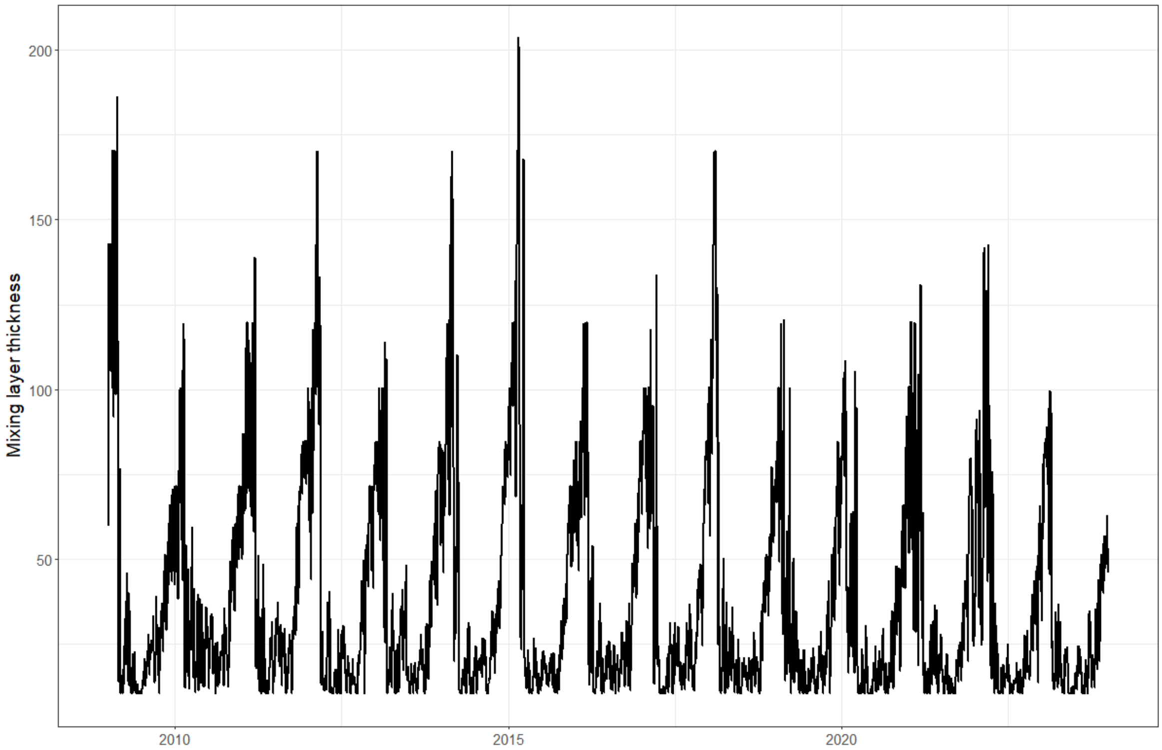


Fig. S2. Mixing layer thickness (m) over time in the study area.

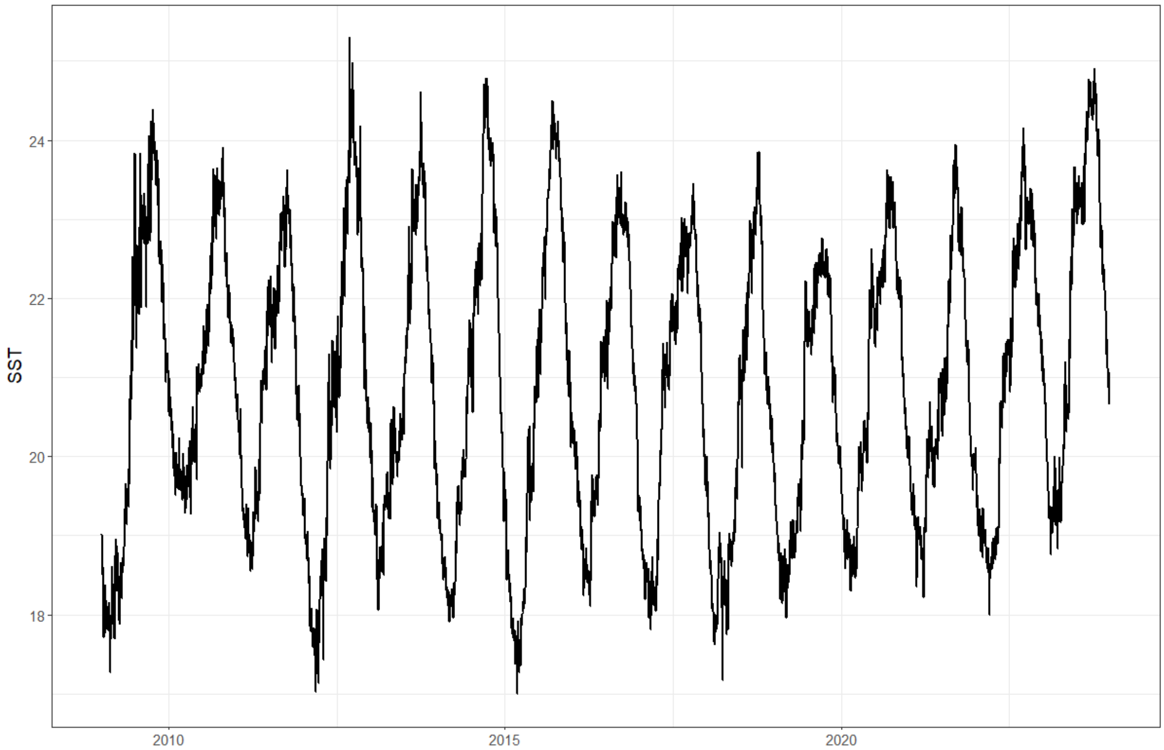


Fig. S3. Sea surface temperature (SST, ºC) over time in the study area.

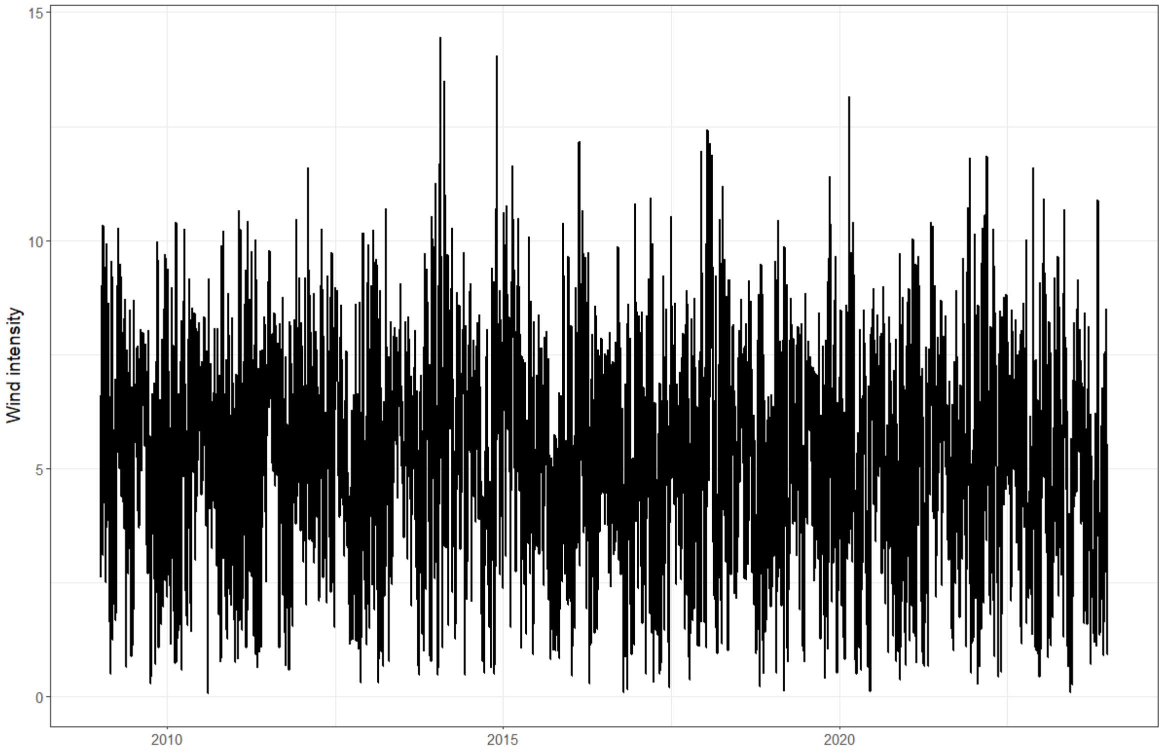


Fig. S4. Wind intensity (m $s^{-1}$) over time in the study area.

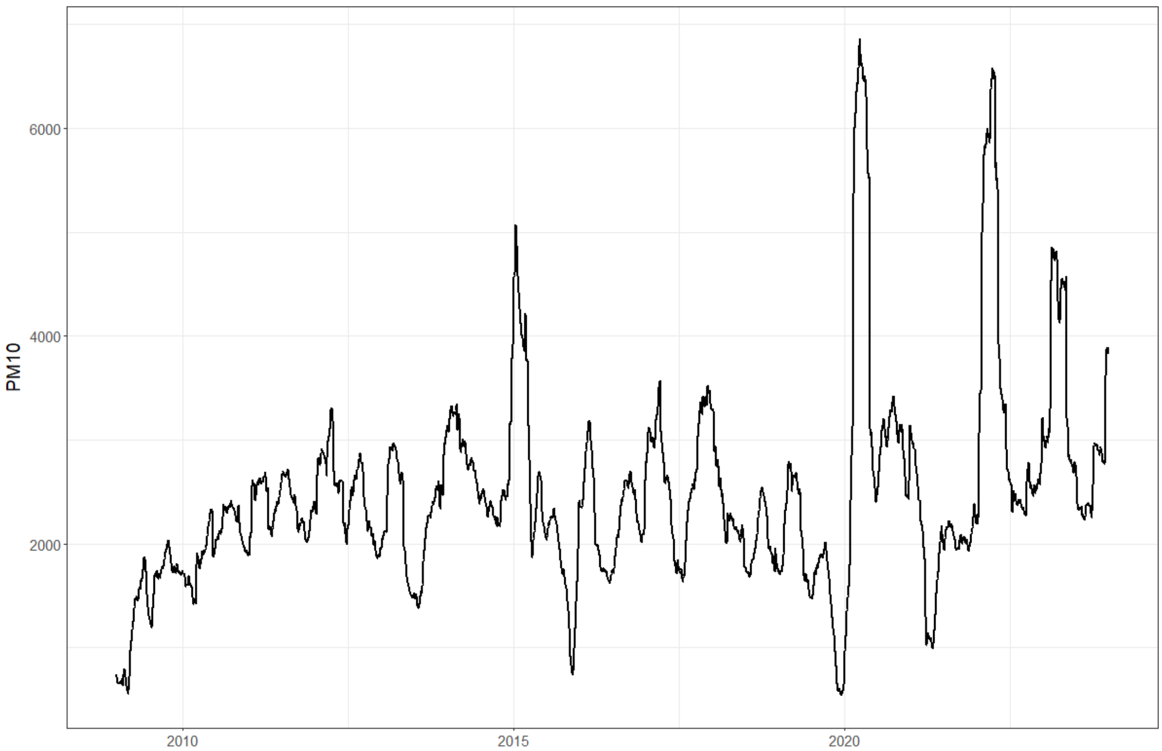


Fig. S5. PM10 ($\mu g\ m^{-3}$) over time in the study area.

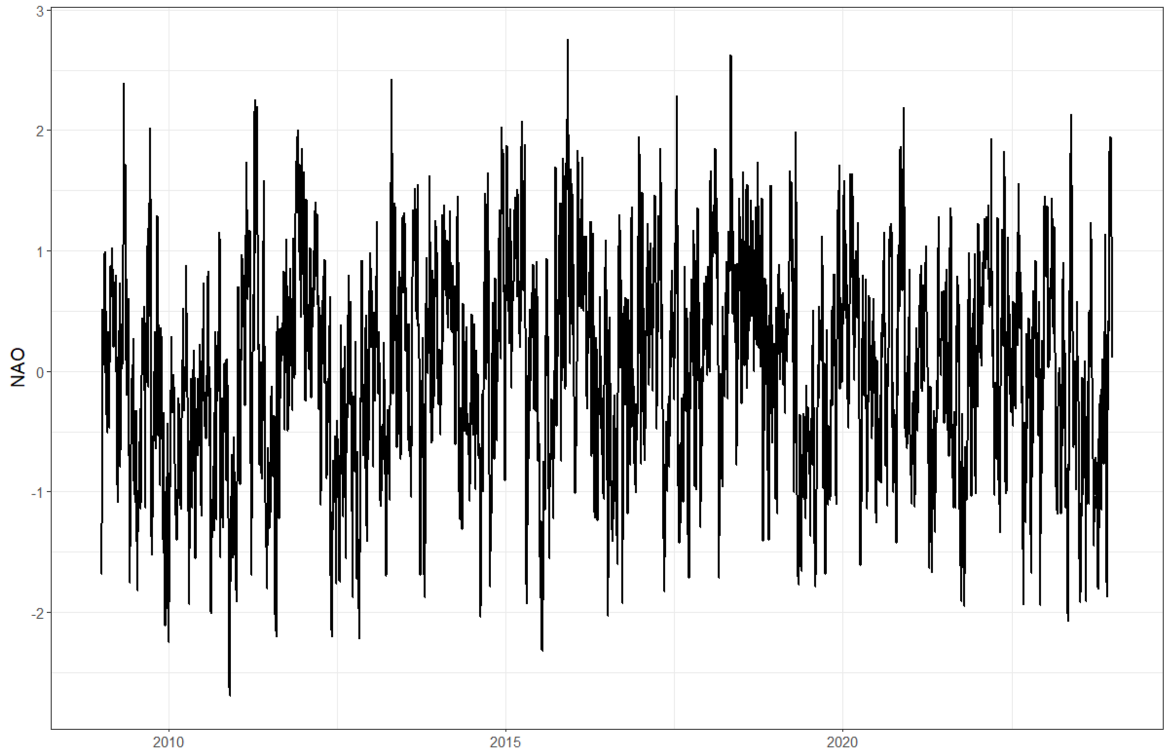


Fig. S6. NAO index over time in the study area.

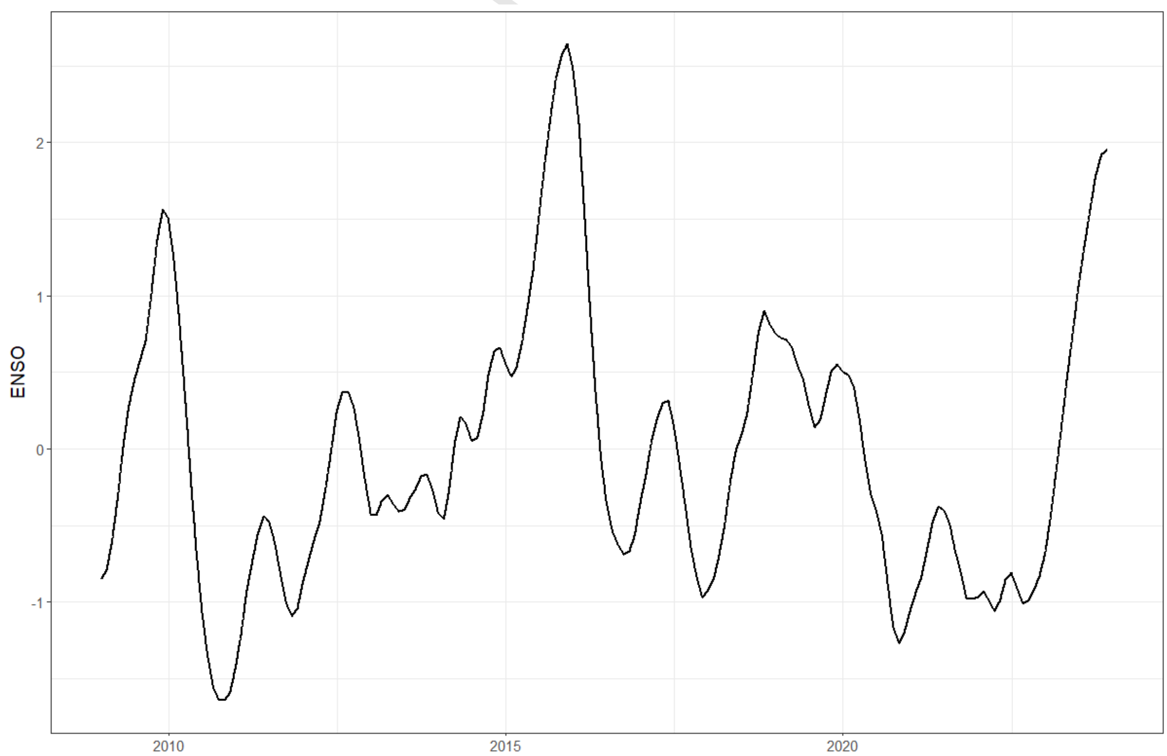


Fig. S7. ENSO index over time in the study area.

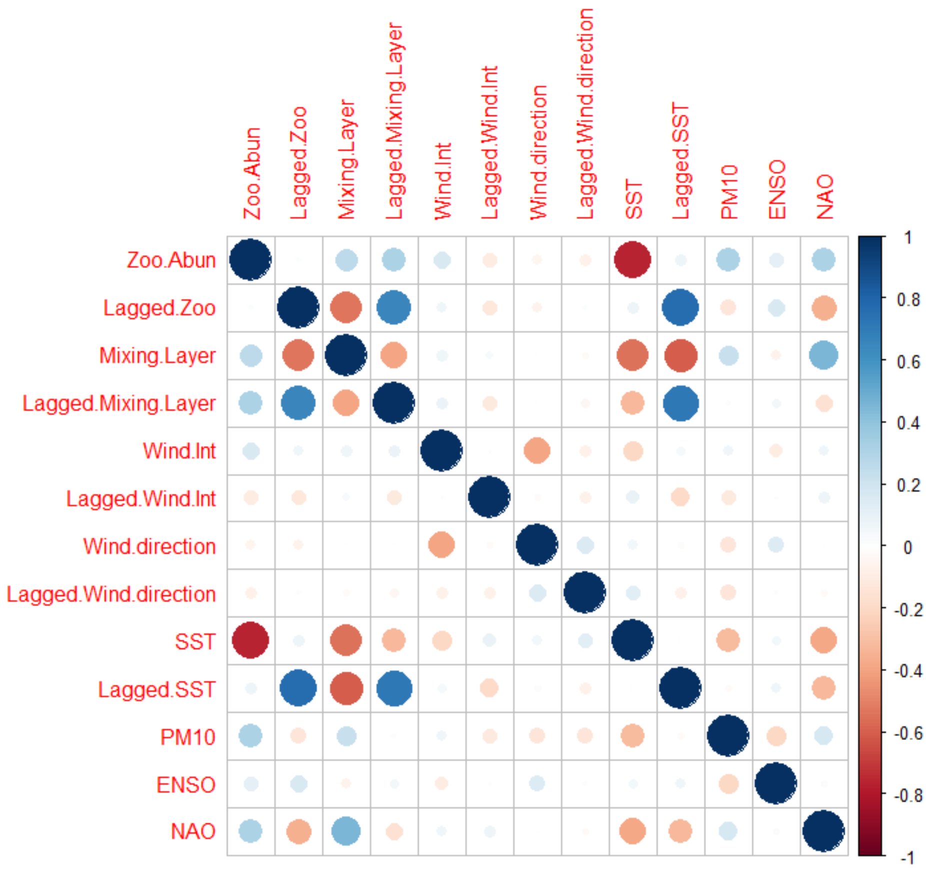


Fig. S8. Pairwise correlations (Spearman coefficients) between predictor variables.

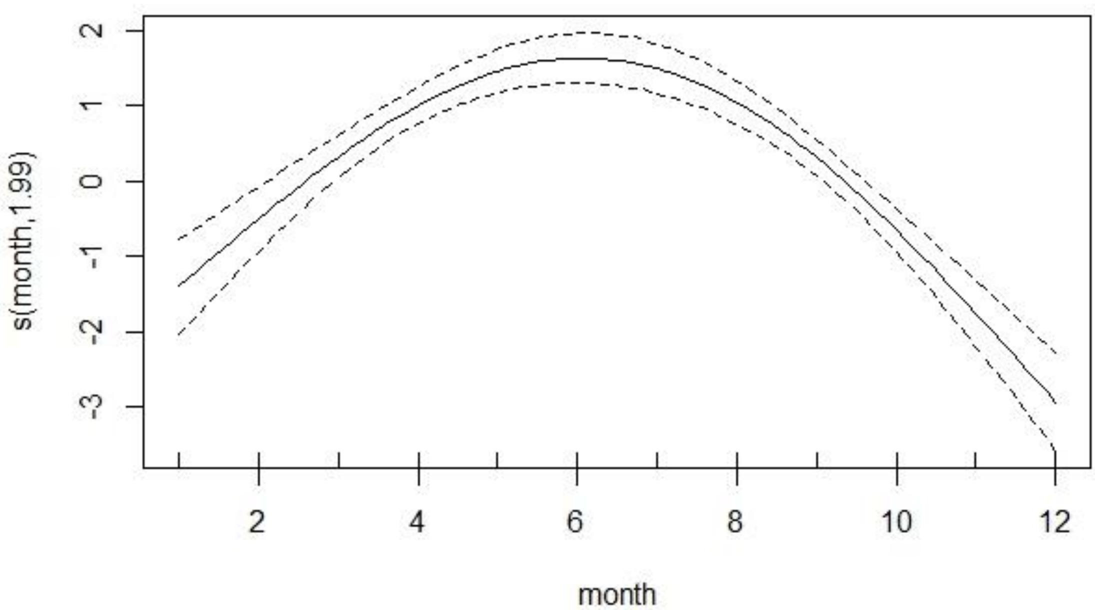


Fig. S9. Smooth curve fitted to the mean monthly number of stings over time.

This paper has no conflict of interest

- Many questions regarding the presence of jellyfish remain unknown
- We unravelled when and how arrivals of jellyfish occur in an urban beach
- Strong seasonal pattern in the number of three jellyfish species and stings
- Correlation between the number of stings and the presence of *Pelagia noctiluca*
- Water temperature as the most relevant environmental predictor of stings and abundances