Predicting Jellyfish Strandings in the Moroccan North-West Mediterranean Coastline

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Abstract

In the recent years, the frequency and the geographic distribution of jellyfish blooms have been increased in the Mediterranean north-west coastline of Morocco. Since 2011 this area has been subjected to successive blooms and stranding of ***Pelagia noctiluca***. Our research was aimed to study the reasons of jellyfish blooms and to predict their stranding in our coastline. We have evaluated three parameters that we are suspecting to be responsible of Jellyfish blooms and stranding on the northern coast of the Mediterranean Sea in Morocco. The evaluation of the relations between sea surface temperature, waves height and the wind direction causing the stranding of Jellyfish, demonstrated that the correlation scores were found to be statistically significant with $r(33) = 0.445$, $p < 0.01$, for sea surface temperature (°C) and $r(33) = 0.694$, $p < 0.001$ for waves height (m). Moreover a one-way analysis of variance (ANOVA) was calculated on wind direction causing stranding of jellyfish; the analysis was found to be very significant, $F(1, 31) = 25.823$, $p = 0.001$.

Keywords: *Pelagia noctiluca*; Jellyfish; Stranding; Morocco; Mediterranean north-west coastline.

Introduction

Trends in ***P. noctiluca*** populations in the Mediterranean have been recently reviewed (Broth et al. 2012, Condon et al. 2013). The periodic occurrence of P. noctiluca in the western Mediterranean was first reported by Goy et al. in 1989, Dr. Goy reconstructing a time series of the occurrence of ***P. noctiluca*** dating back to 1775. Long-term climate fluctuations have been correlated with jellyfish abundance in Mediterranean waters (Molinero et al. 2005, 2008). The North Atlantic climate variability is significantly related to long-term changes in zooplankton functional groups, including ***Pelagia noctiluca***, in the NW Mediterranean (Molinero et al. 2008). Physical forcing has also been responsible for coastal or inshore stranding in the Adriatic Sea (Maretic et al, 1987; Benović 1991; Legović1991; Zavodnik 1991; Malej and Malej 2004). In shallow coastal waters wind, currents and tides have been the main drivers, allowing for huge accumulations of medusae (Zavodnik D, 1987). Jellyfish spatiotemporal dynamics are highly variable, as well the blooms which occur irregularly are difficult to predict (Boero et al. 2008, Brotz and Pauly 2012). ***Pelagia noctiluca*** (Forsskål 1775) is the most common jellyfish species in the Mediterranean waters; it is widely distributed from the warm subtropical waters of the Gulf of Mexico and the Mediterranean Sea to the temperate waters of the North Sea (Russell 1970; Graham et al. 2003; Purcell 2005; Licandro et al. 2010) and up to 4°C of latitude (Doyle et al. 2008; Bastian et al. 2011).

Pelagia noctiluca is an important non selective planktonic predator (Larson 1987; Morand et al. 1987; Sandrini and Avian 1989; Giorgi et al. 1991; Daly Yahia et al. 2010; Rosa et al. 2013) feeding on almost all types of zooplankton and ichthyoplankton (Giorgi et al. 1991; Zavodnik 1991; Malej et al. 1993). In fact, many fish compete for the same zooplankton prey as jellyfish (Purcell and Arai 2001, Purcell et al., 2007); moreover, fish are also predators of jellyfish, with benthic including reef fish species ingesting polyps, as well as pelagic fish species eating ephyrae and small individuals (Graham, 2001). However, the declination of such fish opens up ecological space for jellyfish proliferations. Moreover, coastal eutrophication encourage phytoplankton blooms that can ultimately lead to jellyfish outbreaks (Purcell et al. 2007). The greater tolerance of polyps and medusa than fish to low-oxygen conditions ensures that jellyfish survive, even reproduce during hypoxic events, which fish are unable to do; such 'dead zones' are thought to favor jellyfish (Lynam et al. 2004). Higher temperatures also accelerate medusa growth and ephyrae production (Kevin and Raskoff 2001). Jellyfish appear to be sensitive to climate variability, with their abundance being related to large-scale climate indices such as the North Atlantic Oscillation (NAO) (Lynam et al. 2004), El Nino Southern Oscillation (Kevin and Raskoff 2001), and the Pacific Decadal Oscillation (Anderson and Piatt 1999).

Material and Methods

Study area

M'Diq having as geographical coordinates 35 ° 41'N 5 ° 19 '31 W, is a seaside resort; the population lives almost exclusively on fishing and summer tourism activities and it hosts more than 100,000 tourists each year. M'Diq is located 7 km from Tetouan city, and it's bounded on the north by Fnideq municipality, on the south by Mellaliyine commune, on the west by Alleyine commune and on the east by the Mediterranean Sea. M'Diq covers an area of 480 hectares of which 153 hectares is urbanized (Figure 1). The selection of this area is based on the presence of jellyfish blooms along the beaches.

Figure 1: Geographical location of our study area **(**Source Google Map)

Sampling Strategy

Jellyfish survey strategy used for our study was inspired of the method used by Doyle (**D**oyle et al. 2008) for the study of jellyfish species repartition across the Irish and Celtic Sea shores. In this study, the survey method consisted of walking along a beach transect during low tide. We walked along the water edge to the end of the transect and returned along the tide upper limit, while counting and identifying stranded Jellyfish. In order to have consistency between surveys, this transect situated between low tide and high tide limit was chosen for each survey. Transects start and end points were recorded and are described as it follows: Start point: 35.683040"N, -5.318971"W End point: 35.817096"N, -5.351673"W Length (m): 989. We did use the Quadrate method to calculate the density of jellyfish stranded per square meter. The study was conducted from June 2011 until December 2017 (Figure 2).

Jellyfish identification & Environmental variables

Pelagia noctiluca is the only jellyfish species found stranded in the Mediterranean north-west coastline of Morocco. We have used Russell (Russell, 1970) taxonomic for the identification of the jellyfish we have found. Sea surface temperature was recorded in situ (independent points) for each survey. Temperature has been recorded from June 2011 until December 2017. These readings were recorded every day and a monthly average was used for correlation analyses with jellyfish abundance.

In addition, measures of wave's height as well as wind direction were obtained from PREVIMER web-sites. These tow parameters have been recorded every day of the six years and they were used for correlation analyses to find out if they are causing Jellyfish stranding in our coastline.

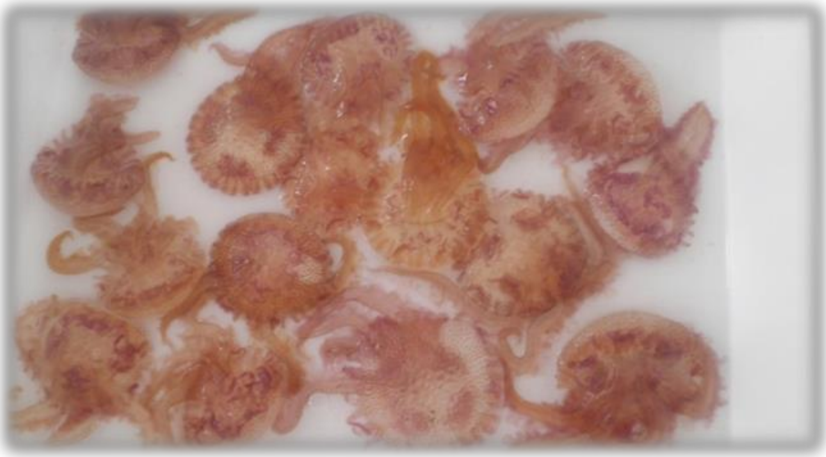


Figure 2: *Pelagia noctiluca* sample (source Majda AOUITITEN)

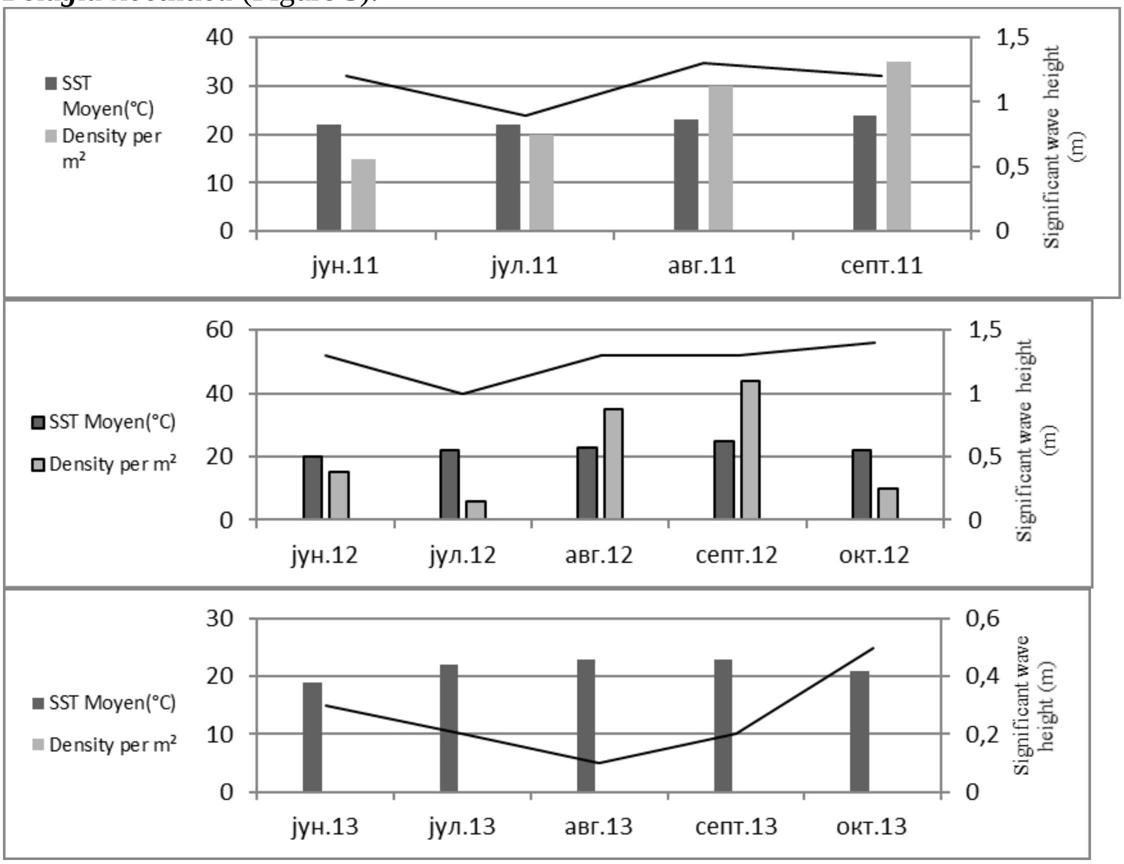
Cluster analysis

Part of the data obtained from the samples was statistically calculated and analyzed using Microsoft Excel software. However Pearson Correlation analysis were used to determine whether there is a relationship between the quantitative variables which are sea surface temperature, waves height and Jellyfish stranding. In addition, ANOVA test was used to determine if there is a relationship between the quantitative variable wind direction with Density of jellyfish stranded; this tow test was statistically calculated, analyzed and compared using SPSS software.

Results

Physical parameters of water

Analysis of the samples of water in our zone of study has yielded several physical and chemical characteristics of the environment where ***Pelagia noctiluca*** stranded. Between June 2011 and December 2017 one type of Jellyfish species was encountered during beach surveys, which is ***Pelagia noctiluca*** (Forsskål 1775). The total number of stranded jellyfish observed each year was: 1000 ind between June and September 2011, 1100 ind between June and October 2012, no blooms or strandings found in 2013, 170 ind between April and October 2014, 990 ind from Jan- August till October 2015, 270 ind from August till September 2016 and 2610 ind from June till December 2017. The overall abundance of encountered stranded ***Pelagia noctiluca*** demonstrated a fluctuating pattern during summer. Actually physical water measurements including the temperature show that the appearance of the jellyfish ***Pelagia noctiluca*** starts in our coastline at a sea surface temperature of 21°C, the maximum abundance is reached at a sea surface temperature of 25.61°C, then ***P. noctiluca*** starts to disappear at a sea surface temperature of 16°C; moreover we have observed that when the waves have the height between 1.20m to 2m, we have probably appearance of ***Pelagia noctiluca*** (Figure 3).



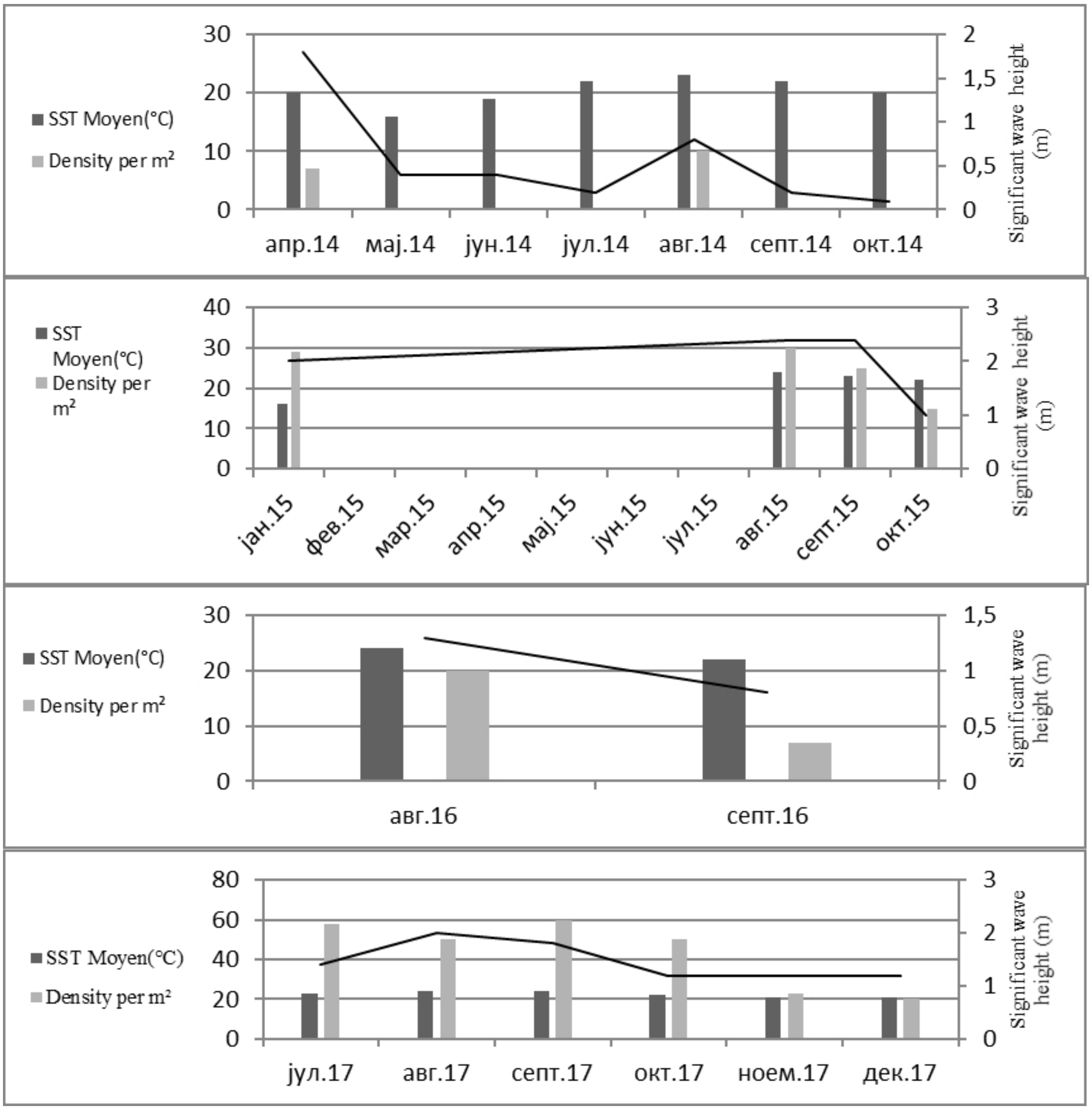


Figure 3: Monthly variation of (SST) sea surface temperature (°C), waves height (m) and the density of jellyfish stranded per m²; (from 2011 until 2017).

Wind direction

We have observed that when the east wind blows on our beach, we have probably appearance of ***Pelagia noctiluca*** and if it's not, we will not found any jellyfish stranding. This was observed in the year of 2013: no jellyfish blooms or stranding have been recorded in to our coast, even if the sea surface temperature was [in June: 18.7°C, July: 22°C, August: 23°C, September: 24°C, October: 22°C] high enough to have blooms of jellyfish (Figure 4).

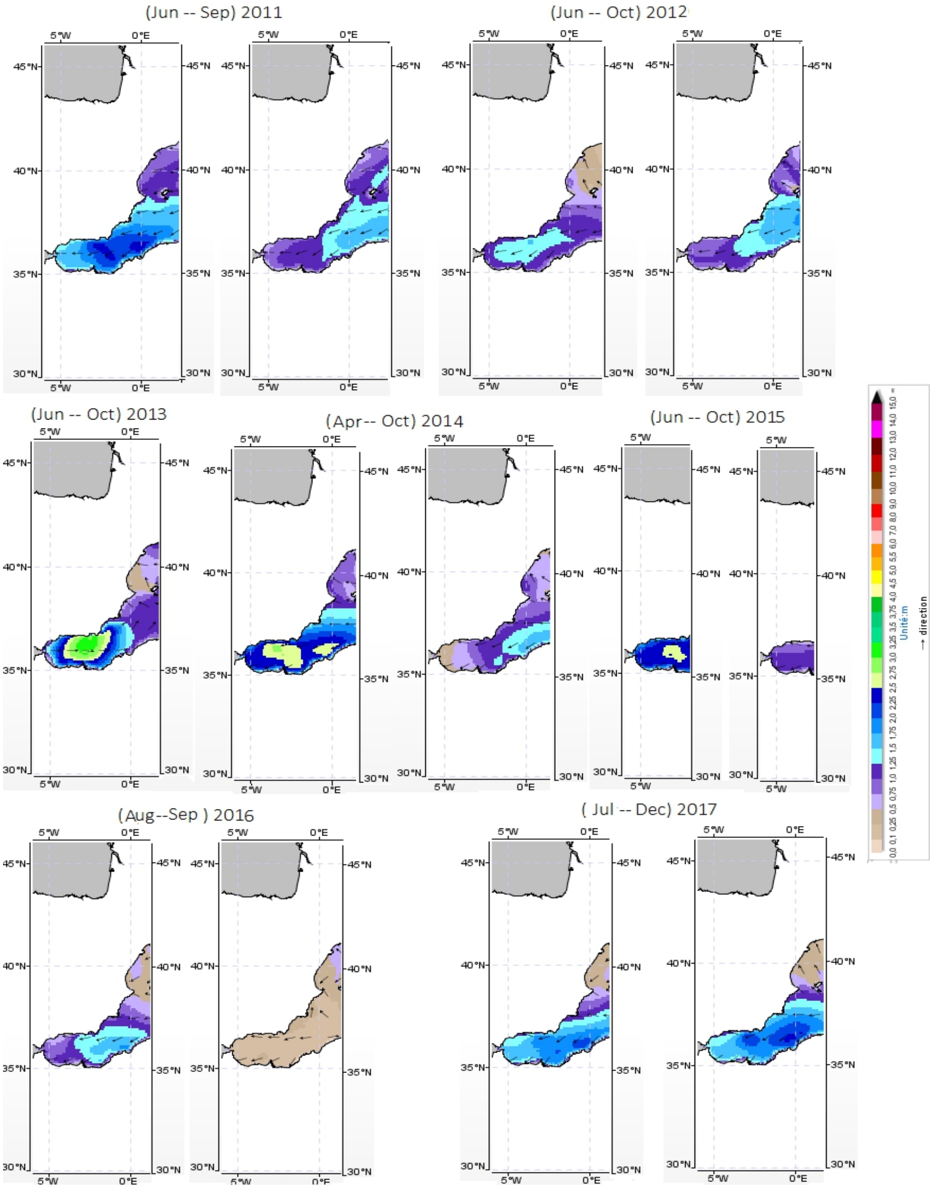


Figure 4: Satellite-derived sea-surface significant wave's height and wind direction (model WAVEWATCH III following Douglas Sea and swell scale protocol, 1921). Instrument for the stranding months from June 2011 to December 2017.

Statistic analysis results

Statistical analysis was carried out using statistical tests software package, with the intention of studying the relation between sea surface temperature, sea waves height and Jellyfish stranding and to determine whether there is a relationship or not. Pearson Correlation test shows that the density of jellyfish stranded and sea surface temperature have a statistically significant linear relationship r (33) = 0.445, $p < 0.01$ (Table 1), meaning that these variables tend to increase together (greater density of jellyfish stranded is associated with greater sea surface temperature). Moreover, we have found that the relationship between the density of jellyfish stranded and sea waves height was a positive correlation between the two variables, r = +0.694, n = 33, p = 0.001 (Table 2).

Table 1: Relation of correlation between sea surface temperature and the density of ***Pelagia noctiluca*** stranded

Correlations

		Density of jellyfish stranded per m²	Sea Surface Temperature (°C)
Density of jellyfish stranded per m²	Pearson Correlation	1	.445**
	Sig. (2-tailed)		.010
	N	33	33
Sea Surface Temperature (°C)	Pearson Correlation	.445**	1
	Sig. (2-tailed)	.010	
	N	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

Table 2: Relation of correlation between sea wave's height and the density of ***Pelagia noctiluca*** stranded.

Correlations

		Density of jellyfish stranded per m²	Sea waves height (m)
Density of jellyfish stranded per m²	Pearson Correlation	1	.694**
	Sig. (2-tailed)		.000
	N	33	33
Sea waves height (m)	Pearson Correlation	.694**	1
	Sig. (2-tailed)	.000	
	N	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

A one-way analysis of variance (ANOVA) was calculated on wind direction causing stranding of jellyfish. The analysis was significant, F (1, 31) = 25.823, p = 0.001 (Table 4). East wind cause the stranding of jellyfish (M = 26.70, SD = 16.463) more than the West wind (M = 0.00, SD = 0.000) (Table 3).

Table 3: Descriptive relation between wind direction and the density of ***Pelagia noctiluca*** stranded.

Descriptives

Density of jellyfish stranded per m²

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	Upper Bound	Minimum	Maximum
East	23	26.70	16.463	3.433	19.58	33.81	6	60
West	10	.00	.000	.000	0.00	.00	0	0
Total	33	18.61	18.481	3.217	12.05	25.16	0	60

Table 4: ANOVA test to determine the relationship between wind direction and the density of ***Pelagia noctiluca*** stranded.

ANOVA

Density of jellyfish stranded per m²

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4967.009	1	4967.009	25.823	0.000
Within Groups	5962.870	31	192.351		
Total	10929.879	32			

Conclusion and discussion

The causes of the jellyfish blooms and strandings around Moroccan North-West Mediterranean coastal waters is poorly understood. Starting in 2011 until 2017, our study aimed to evaluate the reasons of jellyfish blooms as well as their strandings, based on the evaluation of three parameters (sea surface temperature, sea waves height and wind direction). We have found that we can combine the observations of sea surface temperature, sea waves height and wind direction to predict whether we will have stranding of ***Pelagia noctiluca*** on our coastline or not. Between June 2011 and December 2017, one type of Jellyfish species was encountered in our area of study which is ***Pelagia noctiluca***. Actually, the appearance of this jellyfish starts on our coastline at a sea surface temperature of 21°C, the maximum abundance is reached at a sea surface temperature of 25.61°C, then ***P. noctiluca*** starts to disappear at a sea surface temperature of 16°C. Experiments reveal that temperature affects the activity (pulsation rate) of this species; specifically extreme temperatures, <11 °C and >26 °C, cause decreased activity (Malej and Malej 2004). Moreover we have observed that when the waves have the height between 1.20m to 2m, and when the east wind blows on our beach, we have probably stranding of ***Pelagia noctiluca.*** Physical forcing (wind and current direction) was thought to determine the presence of ***Pelagia noctiluca*** in inshore and offshore waters in the northern Adriatic Sea (Vucetic T, 1984). But if it's not, we will not found any jellyfish stranding; this was observed in

2013: no jellyfish blooms or stranding have been recorded on our coast, even if the sea surface temperature was [in June: 18.7°C, July: 22°C, August: 23°C, September: 24°C, October: 22°C] high enough to have blooms of jellyfish. The correlation scores for all the parameters were found to be statistically significant with r (33) = 0.445, p < 0.01, for sea surface temperature (°C) and r (33) = 0. 694, p < 0.001 for waves height (m) as well as a one-way analysis of variance (ANOVA) calculated on wind direction found to be very significant, F (1, 31) = 25.823, p = 0.001.

The beach stranding survey method proved to be applicable for the scale of the current research and is an important step in the understanding of jellyfish blooms and strandings predictions around the Moroccan North-West Mediterranean coastal.

As a final conclusion, we consider that the methodology presented in this study could be easily adapted and expanded along the Moroccan North-West Mediterranean coastal to predict Jellyfish strandings which will help us to reduce the number of people stung by jellyfish.

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