Environmental drivers of lesser weever stings on the northeast Atlantic coast (A Lanzada beach, Spain)

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ABSTRACT

Many marine species, including anemones, snails, jellyfish, coral and fish, are venomous to humans, causing serious injuries or even death. Most of these animals live in warm, shallow waters, which increases the chances of an encounter with them. The majority of these interactions with humans are accidental; however, it is not well known under which circumstances (if any) these encounters are more likely to happen. A smart-city initiative was launched for A Lanzada beach (NW Spain) in the summer of 2014. As part of this initiative, lifeguards collated data on all incidents occurring on the beach, including weever fish stings. Additionally, a number of environmental parameters were monitored. Using this unique information, statistical models were developed to evaluate under which environmental conditions beach users would be more likely to be stung by lesser weevers. The optimal model showed that stings were more likely at the southern end of this 2.7 km long beach, pointing to differences in sediment composition along the beach as a key factor. Moreover, warmer sea water and

higher air temperature increased the chances of being stung. Furthermore, stings increased at low tide and decreased under strong meridional wind conditions. Finally, the number of stings increased with beach occupation up to a levelling-off point. All this suggests that a combination of fish behaviour and favourable climate conditions for beachgoers increases the chances of suffering an accidental encounter with lesser weever fish. Our results, based on basic environmental information, constitute a simple tool that could be used to provide precautionary advice to beach users in order to avoid accidental encounters with lesser weever fish.

Keywords: beach, warning services, lesions, lesser weever, poisonous fish, fish sting, northeast Atlantic coast, A Lanzada beach.

1. Introduction

Tourism on the coastline of the Iberian Peninsula is of huge economic importance due to the climate conditions on this coast and the increase in recreational and sport-related services, which makes it one of the favourite tourist destinations in Europe (Eurostat, <http://ec.europa.eu/eurostat/web/tourism/data/main-tables>). One of the inconveniences that tourists can find on the coast and, therefore, a threat to this industry is the potential presence of poisonous marine animals whose stings have a large impact on public health and leisure in coastal areas; for instance, jellyfish in the Mediterranean Sea (Ghermandi *et al.*, 2015).

The hazard of jellyfish is widely recognised and has attracted great attention from the marine research community. In recent years, many studies have suggested that jellyfish populations are increasing in some areas of the world as a consequence of a combination of several factors, such as overfishing, acidification and global warming

(Richardson *et al.*, 2009; Purcell *et al.*, 2007, 2012, but see Condon *et al.*, 2012), and these booms might cause public health issues. For instance, the number of jellyfish stings along the Mediterranean coast increased by 50% from 2010 to 2012, reaching a total of 118,346 people stung (Bordehore *et al.*, 2016) that far exceeded previous estimations of >14,000 people receiving medical treatment on the south and east Spanish coasts in August 2006 (Pingree and Abend, 2006). This huge number of people affected is an increasing problem with important socioeconomic costs (Mills, 2001; Hay, 2006; Purcell *et al.*, 2007; Canepa *et al.*, 2014; de Donno *et al.*, 2014; Nunes *et al.*, 2015; Ghermandi *et al.*, 2015). This has led to the development of various early-warning systems, from remote-sensing observations and coastal circulation models to different in-situ observations designed to study jellyfish outbreaks (Bentlage *et al.*, 2009; Bernard *et al.*, 2011; Marambio *et al.*, 2013).

Apart from the research on jellyfish, few studies have quantified the presence or impact on public health of other poisonous marine taxa, such as the blue-ringed octopus (*Hapalochlaena* spp.), cone snails (*Conus* spp.) or certain species of fish (Fenner *et al.*, 2004). The lack of ecological and ethological knowledge (Lewis, 1980; Tortonese, 1986) about weever fish is particularly surprising in view of the fact that they are among the most venomous specimens along the Atlantic European coast and are quite common on the coasts of the Iberian Peninsula (Vasconcelos, 2001; Prista *et al.*, 2003). Even though weever fish stings are popularly known to users of certain Spanish beaches, only one scientific paper, to our knowledge, has dealt with weever fish stings, detailing 414 cases along the 164 kilometres of the southern Spanish coastline during the summer of 1999 (Portillo *et al.*, 2008). Based on the poor attention received, the trouble generated by weever fish seems to be minor compared to that caused by jellyfish. However, this impact could be more acute on specific beaches; accordingly, improving our knowledge

of the factors that might be related to the incidence of weever fish stings is important.

Recent data on lesser weever fish stings seen on A Lanzada beach (northwest of Spain, Fig. 1) during the summer of 2014 suggested a potential impact on public health and leisure on Spanish beaches that was significantly greater than thought, taking this unusual problem to the level of that caused by jellyfish. Consequently, our objective was to evaluate the factors that might have driven weever fish stings in a typical summer season. By gathering information on interventions by lifeguards and in-situ environmental data through a smart-city initiative, we aimed to improve beach management. Statistical modelling was used to understand to what extent oceanographic and meteorological conditions drove lesser weever stings to beach users. This unprecedented analysis could become an early-warning system based on environmental variables and designed to provide online precautionary information to beachgoers.

2. Methods

2.1. Study site and its lifeguard service

O Grove is a small coastal town located in southern Galicia (NW Spain, Fig. 1). Its population was 10,851 in 2014 (Instituto Galego de Estatística, www.ige.eu), although the population usually triples during summer. O Grove is a former island that is connected with the mainland by an isthmus whose western side is a beach called A Lanzada that is, on average and at high tide, 2.7 kilometres long and 40 meters wide (Fig. 1). Its sedimentary morphology is primarily influenced by the topography of the bottom regions and the incidence of wave energy, which is concentrated in the central and southern areas when the waves come from the northwest (Durán *et al.*, 2001). The surface of the beach is composed of fine white sand, with quartz being the main component, whose grain increases in size towards the ends of the beach. At the southern

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103 Fig. 1. Location of A Lanzada beach (NW Spain) and position of the lifeguard stations,
104 the meteorological station, the buoy and the restaurants.

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end, the grain size is larger and of biogenic origin. This is also an area of the beach where a field of ripples and a shallow rocky outcrop are seen (Durán *et al.*, 2001). The tide in this area of the Spanish coast is semi-diurnal, with a range of 2.5 meters on average, generating tidal currents that are practically negligible on this beach.

A Lanzada is used by large numbers of local people and tourists and has a maximum capacity of roughly 12,000 people. In addition to its popularity among beachgoers, A Lanzada beach was one of the first beaches in Spain to be awarded different distinctions for water quality and environmental management, such as the Blue Flag (<http://www.blueflag.global/>), in the last decades. During the summer season, first-aid, surveillance and lifeguard services are provided daily from 11:00 to 20:00, local time, by the O Grove Maritime Search and Rescue Unit (Unidade Marítima de Salvamento e Rescate, UMSR), based in three lifeguard stations located in the north, centre and south of the beach (Fig. 1). These locations follow the distribution of beachgoers, with each zone concentrating approximately 20%, 50% and 30% of the users of A Lanzada beach from north to south, respectively, according to the UMSR team.

2.2. *The lesser weever fish and its stings*

The weever fish occurs from the northeastern Atlantic to Morocco and throughout the Mediterranean Sea (Lewis, 1980; Tortonese, 1986). The two main species occurring on the Galician coast are the greater weever (*Trachinus draco* Linnaeus, 1758) and the lesser weever (*Echiichthys vipera* Cuvier, 1829). These species have significantly different bathymetric distributions. While the greater weever prefers deeper offshore waters, the lesser weever inhabits shallow inshore waters from the low-tide mark to a depth of 50 metres (Wheeler, 1978). Therefore, bathers are mainly stung

by the lesser weever, while the greater weever is responsible for most of the stings suffered by fishers and divers.

The lesser weever (Fig. S1) is a short, stout fish that can reach up to 150 mm in standard length (Tortonese, 1986) and lacks a swim bladder (Jones and Marshall, 1953). This considerable adaptation to a demersal habitat allows them to stay close to or lie on the bottom, where water movement is strongly reduced. Lesser weevers move up the beach with the tide, and down with the outgoing tide, even though some individuals may remain buried in the sand during the low-tide period. In winter, as temperature falls, lesser weevers also move into deeper waters, hibernating until the onset of warmer weather (Heinke, 1913). The lesser weever displays nocturnal activity, lying buried during the day and emerging to forage at night (Lewis, 1976; Wheeler, 1978). Its diet is essentially carnivore, with the lesser weever preying preferentially upon crustaceans (Quiniou, 1978; Sorbe, 1981) and fish (Dauvin, 1988), and secondarily on polychaetes and bivalves (Collignon and Aloncle, 1960).

Under threat, this fish responds by either moving deeper into the sand or rising the venomous spines located on the first dorsal fin, which is totally black (Fig. S1). The lesser weever is considered to be the most dangerous of European weevers due to its poison and its frequent occurrence at beaches (Tortonese, 1986). The dorsal spines and a single spine on each main gill cover contain venomous thermolabile proteins (Davies and Evans, 1996). The most common symptoms when bathers suffer a sting are a sharp stab as the spine penetrates the skin, followed by pain shortly afterwards which begins in the site of the puncture and expands around it, usually affecting the whole foot. The victim may also experience itching, minor swelling, irritation, dizziness and even fainting. Headache, nausea, vomiting, sweating, and syncope may occur rarely (Cain, 1983; Fener, 2004; Portillo-Strempel *et al.*, 2009; Duran and Duran, 2014).

There are various treatments for weever fish stings. Given that the toxin is thermolabile, immersion in hot water should be applied (Gweta *et al.*, 2008; Lopacinski *et al.*, 2009). Other treatments include the application of warmed stale urine to the wound and even prophylactic antibiotics to avoid the possibility of infection (Cain, 1983; Fener, 2004; Portillo-Strempel *et al.*, 2009; Duran and Duran, 2014). As a commercial antiserum is not available (Cain 1983; Mayser *et al.*, 2003), basically empirical treatment (Mayser *et al.*, 2003) is usually sufficient for pain relief, even though severe cases might require specific treatment (Maretic *et al.*, 1973; Linares del Río *et al.*, 1989; Williamson *et al.*, 1996). In particular, the protocol followed by the O Grove UMSR service consists of the following four steps: 1) locate the sting and wash with diluted ammonia while checking that no part of the spine remains inside; 2) put the affected foot or body part into hot water; 3) apply some antihistamine cream and cover with bandage, and 4) walk on a hot area.

2.3. Data sources

During the summer of 2014, the O Grove UMSR decided to carry out an experiment implementing new technologies as coastal management tools, namely a specific web application designed to digitalise every event (e.g., accidents, requests for materials, different types of care given to bathers), services provided in the lifeguard stations, including health care after lesser weever fish stings, and a smart-city initiative that temporarily provided online real-time meteorological and oceanographic information for A Lanzada beach during that summer. The web application installed on tablets located in each lifeguard station was used to record the daily number of lesser weever fish stings attended to in the three different lifeguard stations along the beach (Fig. 1). We assumed that there was no confusion with other lesions caused by jellyfish

or inert objects because of the particular symptoms of these fish stings and the lifeguards' expertise.

Environmental information for the study area was transmitted online through a website and gathered by a monitoring system formed by a buoy and a meteorological station. The buoy, designed by Marine Instruments (www.marineinstruments.com) for being used near the coastline, was discreetly moored as part of a set of barrage buoys (Fig. 1). This float measured wave height continuously by means of accelerometers and water temperature at a depth of 10 cm using an industrial thermometer with resolutions of 0.1 m and 0.2 °C. Values were transmitted every 10 minutes by a GPRS system. A professional weather station (Oregon Scientific model WMR200) recorded meteorological parameters from wind, temperature, humidity and ultraviolet radiation sensors and a self-emptying rain gauge with a frequency of every 5 minutes (Fig. 1). Therefore, meteorological and oceanographic information was obtained for a single location at the beach that we consider representative of the entire beach in view of the length of the study area. The dataset was completed with ocean tide height estimated using the software IOS Tidal Package, developed by the Institute of Ocean Sciences, Canada. In order to have the same temporal frequency that daily lesser weever fish stings, environmental data were recorded during the open hours of the lifeguard stations, that is, from 11:00 local time to 20:00 local time, and averaged daily.

As the number of users of the beach was not available, the daily number of customers of two nearby restaurants was used as a proxy for beach occupation (Fig. 1). More specifically, both restaurants provided information on the number of customers at lunch time each day during the summer season. The data from both restaurants were highly related (Fig. S2); accordingly, we used the number of costumers of the closest restaurant as an indicator of daily beach users during the whole study period. We

assumed that 100% beach occupation corresponded with the maximum number of clients in the restaurant, which coincided, in both cases, with the 16th of August, while the occupation for the other days was estimated as a proportion of people in relation to the maximum. Given that the theoretical maximum capacity of the beach is 12,000 people per day, we estimated the daily number of beach users relative to that maximum. Furthermore, users are not evenly distributed along the beach, as mentioned above; consequently, we assumed that on a given day 20% of beach users were located in the northern part of the beach and 50% in the centre, while 30% of the users of A Lanzada stayed at the southern end of the beach.

2.4. Data analysis

We modelled the sting rates using generalised linear models (GLMs) with a negative binomial distribution and a log link function. The stings were highly skewed, with many days having zero stings, one and two stings recorded on a few days, and so on (Fig. 2). Therefore, the observed stings S on day i were assumed to follow a negative binomial distribution with a mean μ_i and variance $\mu_i + \mu_i^2 / k$, where k is the dispersion parameter. The negative binomial distribution is appropriate for overdispersed data like this, where the variance is larger than the mean.

The optimal model was selected using a backward model selection procedure based on the Akaike Information Criteria (AIC). We started with a full model which included all spatial and environmental variables that could potentially drive sting rates; accordingly, the expected mean number of stings μ on a day i can be formulated as follows:

$$\log(\mu_i) = \alpha + \beta_1 LS_i + \beta_2 BO_i + \beta_3 BO_i^2 + \beta_4 SST_i + \beta_5 AT_i + \beta_6 TH_i + \beta_7 WH_i + \beta_8 V_i$$

where α is an intercept, β_n are the coefficients of the linear terms, and ε_i is a vector of residuals assumed to be independent. Covariates were defined as follows: LS is the lifeguard station, BO is beach occupation, SST is the mean sea surface temperature during the lifeguards' working hours, AT is the mean air temperature during the lifeguards' working hours, TH is the mean tide height during the lifeguards' working hours, WH is the mean wave height, and V is the speed of the meridional wind component. Before model fitting, variance inflation factors (VIFs) were calculated to detect collinearity issues (Zuur *et al.*, 2007). The calculation of VIFs revealed no signs of collinearity among the explanatory variables, with all values below a cut-off level of 3. Finally, each model coefficient was transformed to percentage change in the number of stings for ease of interpretation using the formula $(\exp^{(\beta)} - 1) \times 100$. Model residuals were inspected for model misspecification or any remaining structure not accounted for in the above equation. All analyses and the treatment of the data were performed with R language version R-3.4.3 (R Development Core Team, 2017) and using the MASS_7.3-47 package (Venables and Ripley, 2002).

3. Results

3.1. Environmental conditions

During the study period, winds with a northerly component prevailed at Lanzada beach from the 1st of July to the 13th of September 2014 (Fig. 2). This general dominance was interrupted by short events of southwesterly winds (Fig. 2c), especially between the 1st and the 13th of August and when sea surface temperature reached maximum values (around 21 °C) (Fig. 2b). Sea surface temperature showed large oscillations throughout the summer, with pulses of warm waters under the influence of

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270 Fig. 2. Daily records of medical care provided for lesser weever fish stings, fluctuations
271 in meteorological and oceanographic conditions at the beach, and percentage of beach
272 occupation during the summer of 2014.

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southwesterly winds and cooling events under north wind regimes; the coldest day recorded was the 10th of July, with an average value of 14.1 °C (Fig. 2b). On those days, northerly winds were the most intense, reaching 32 km · h⁻¹ (Fig. 2c). However, they did not cause the highest waves due to the orientation of the beach; instead, such waves were seen under the influence of southwesterly winds, with a daily average value of 1.6 m (Fig. 2b).

3.2. *Lesser weever fish stings*

The staff of the three lifeguard stations of A Lanzada beach provided medical care to a total of 1,005 cases of lesser weever fish stings during the summer of 2014 (Fig. 2a). This figure represents 0.3% of all the people who visited the beach during that summer. A significantly higher incidence of stings was recorded in the southern lifeguard station, where 517 people were attended to, whereas the cases in the centre and at the north end of the beach were almost a half of that figure in both stations, namely 273 and 215 stings, respectively. The stings followed a similar temporal distribution regardless of the station (Fig. 2a). The maximum daily occurrence of lesser weever fish stings was seen in the southern station, with 27 interventions on the 31st of August. On the same date, a maximum of 24 stings was also recorded in the central area. Although the number of weever fish stings at the northern end of the beach was also high on that day, a maximum of 18 people stung was reached on the 5th of August. The number of medical interventions due to stings during maximum occupancy of the beach was 8 in the northern and central medical stations, and 9 interventions in the southern station.

3.3. *Statistical modelling*

Based on AIC (Table S1), the most parsimonious model included LS, BO, SST, AT, TH, and V as explanatory variables (Table 1). The probability of suffering a lesser number of lesser weever fish stings at the A Lanzada beach in summer 2014. S.E.: standard error. N = 225, Dev. Expl. = 45.5%.

Parameter	Estimate	S.E.	z-value	p-value
Intercept	-2.43	1.09	-2.2408	0.0250
LS (B)	6.30	1.07	5.8821	<0.0001
LS (C)	-1.84	0.84	-2.2005	0.0278
BO	-0.27	0.18	-1.5411	0.1233
BO²	0.74	0.15	5.0567	<0.0001
SST	0.19	0.04	4.6402	<0.0001
AT	0.11	0.03	4.1329	0.0000
TH	-0.010	0.002	-5.3842	<0.0001
V	-4.41	1.29	-3.4076	0.0007
V²	-3.87	1.07	-3.6149	0.0003

weever fish sting varied significantly depending on the location at the beach, with the south part of A Lanzada being the zone that showed the highest probability of an injury (Table 1 and Fig. 3a). Relative to the north part of the beach, the chances of being stung were 23% lower in the middle part, while the chances of being injured were 108% higher in the southern part. Beach occupation showed a non-linear relationship with the number of stings (Table 1) which increased linearly with the number of people and levelled off at around 4,000 people (Fig. 3b). Both sea surface temperature (Fig. 3c) and air temperature (Fig. 3d) were positively related to the number of stings (Table 1). A rise of 1 °C in sea water temperature increased the number of stings by 20.2% (from 10.2% to 31% C.I.) in all locations, while an increment of 1 °C in air temperature resulted in an 11.1% (from 5.4% to 17.2 % C.I.) increase in weever fish stings in all zones. Additionally, low-tide situations were significantly more favourable for fish stings (Table 1 and Fig. 3e), revealing 1% fewer stings by each additional centimetre of mean tide height (from -1.4 to -0.7% C.I.). Furthermore, the V showed a non-linear relationship with weever fish stings, with the maximum number of stings occurring at around $-6 \text{ km} \cdot \text{h}^{-1}$, and showing a rapid decrease with more intense upwelling conditions (Table 1 and Fig. 3f). Finally, normalised residuals did not show any departure from normality, any sign of heterogeneity or any remaining misspecification issues (Fig. S3).

4. Discussion

Envenomation caused by stings of marine creatures is a common hazard for humans that might have important health and social implications. Most serious injuries are considered to occur in the temperate or tropical waters of the Indo-Pacific region, although cases of marine envenomation have been described in multiple other regions

Fig 3. Model output assuming a number of 1,000 beach users and fixing the rest of the parameters at their mean values. Predicted number of stings for each beach zone (a) and relationships with sea surface temperature ($^{\circ}\text{C}$) (b), air temperature ($^{\circ}\text{C}$) (c), tide height (m) (d) and meridional wind component (d) and side view of lesser weever fish.

of the world (Williamson *et al.*, 1996). Among venomous sea creatures, jellyfish and other cnidarians have aroused great public concern and scientific interest in recent decades because of the postulated increase in blooming of these species due to anthropogenic disturbance and climate changes (e.g., Dong *et al.*, 2010). However, research on other poisonous taxa is much more scant, and the factors that might determine the pattern of incidents and encounters with these animals are hardly known.

The weever fish is among the most venomous marine fishes, although encounters with this fish have been considered unusual and injuries are assumed to be relatively rare (e.g., British Isles, Cain, 1983). On the southern Spanish coast, however, Portillo-Strempel *et al.* (2009) reported 15 fish stings per 100,000 inhabitants, considering this rate as a non-negligible risk. In spite of this, detailed studies exploring the factors that may drive the rates of weever fish stings are lacking. At A Lanzada beach, we found an average rate of 4.12 stings per 1,000 people, ranging from 0 to 35.5 stings. This suggests that such an extraordinary value and the considerable fluctuations during summertime may be caused by fish behaviour and favourable weather for bathing.

Presumably, the rate of stings should be greater when more people bathe, as suggested for the south coast of Britain in comparison with the north (Cain, 1983). We found that the number of stings at A Lanzada increased linearly with beach occupation up to a value of around 4,000 people, at which point this relationship levelled off. Unfortunately, detailed information on beach occupation per day and beach zone was not available; therefore, our occupation index was built using data on customers of a nearby restaurant and assuming a specific distribution of beach users along the beach. The use of this proxy might have implications for the final model results (e.g., size effects); however, we believe that the shape of lesser weever stings in the statistical

model, regardless of the used beach occupation index, would be limited by fish abundance. Nonetheless, we are aware that data on beach occupation should be improved and more accurate.

The concentration of medical interventions by lifeguards varied spatially along the beach, with the south station of A Lanzada attending to half of the injured despite covering 30% of users. Moreover, the number of stings was significantly lower in the central zone, where 50% of beach users are located. Environmental monitoring at a single point of the beach did not allow us to interpret this spatial variability. In view of the small area studied and the fair summer weather, we can speculate that the differences in medical interventions in the three stations may be related to beach morphology, sedimentology and/or current dynamics. In this regard, the southern end of the beach is characterized by having a field of ripples of biogenic origin and large grain size as well a shallow rocky outcrop close by, while fine-grain quartz dominates in the other areas of the beach (Durán *et al.*, 2001). Therefore, weever fish might have a preference for coarser sediments, resulting in greater abundance of fish in these habitats. The presence of sand banks might also play a substantial role (Ellis *et al.*, 2007). Furthermore, a non-homogeneous distribution of the availability of prey on the feeding grounds might explain the variability along the beach as well (Braber and de Groot, 1973; Dexter, 1984).

Good weather conditions seem to influence the rate of stings, as indicated by the direct correlation with sea surface temperature and air temperature. These relationships suggest that more benign weather conditions would lead beach users to bathe more, thus raising the probability of a sting. In spite of the fact that higher temperatures would determine beachgoers' behaviour primarily, we cannot exclude the possibility that warmer waters might also affect the behaviour of this species of fish. Indeed, it is well

known that temperature controls the ecology of lesser weevers, since they initiate a hibernation process as waters cool down in the winter period (Heinke, 1913). Furthermore, an increase in their populations has been seen which is related to warming conditions in the Bay of Biscay (Parmesan and Yohe, 2003) and the North Sea (Beare *et al.*, 2004; Perry *et al.*, 2005). As in those regions, Galician waters are also undergoing an interannual warming process (Pérez *et al.*, 2010); however, the lack of reliable time series on lesser weever abundance (or on their stings as a proxy for abundance) prevents a thorough analysis of long-term trends.

Both beachgoers' and fish behaviour and distribution might also explain the relationship between tide height and the number of stings. The tidal range seen with the slope of the beach expands the area accessible to beachgoers and also increases the probability of stepping on lesser weevers when they are buried in the sand. In this region, the tide has a semidiurnal cycle, with primarily a period of around 12 hours and 25 minutes. As a result, there are days when a low tide coincides with a maximum influx of beachgoers at around 16:00 local time and maximises the intertidal area accessible to users. This situation where the number of stings is expected to be high coincides, due to tidal periodicity, with a high tide towards the sunrise. At this time, lesser weevers are buried in the sand after their nocturnal activity; consequently, they are more likely to move into the intertidal zone at high tide (Lewis, 1976). Therefore, the areas on which beach users step and those in which lesser weevers are buried will be coincident (separated) at low (high) tide in the first hours of the afternoon.

Galician waters, as northern boundary of the Iberian-Canary current upwelling system, are a highly productive ecosystem (Longhurst, 1995; Aristegui *et al.*, 2009). Northerly winds that promote coastal upwelling (Pardo *et al.*, 2011) at these latitudes prevailed at A Lanzada beach during the summer of 2014. The dominance of upwelling-

favourable winds caused the displacement of surface waters along this coast and the consequent upward replacement with cold, nutrient-rich waters. The reverse process, called downwelling, when southerly winds pile up warm surface water towards the coastline, took place in successive pulses. The fluctuations of the meridional wind speed component and the variability of lesser weever fish stings showed a dome-shaped relationship, with a maximum being attained at mild north winds of $-6 \text{ km} \cdot \text{h}^{-1}$, that is, under moderate coastal upwelling conditions. In addition to replacing warm surface water with cool subsurface water, upwelling events also have a potential impact on the fish community fertilising the coastal waters or modifying the coastal currents (Álvarez-Salgado *et al.*, 2009). The change in wind direction to south winds generates a remarkable fall in the number of interventions on the beach, while a lower reduction rate is seen under an intensification of north winds. The coinciding reduction in stings under an intensification of wind speed, regardless of wind direction, could be related to the generation of waves. The limited ability of lesser weevers to face the dragging of the waves due to their lack of a swim bladder makes these fish move away from the surf zone under the action of higher waves. In fact, waves exceeding 1.5 meters reduced the values of people stung to almost zero. The orientation of the beach, much more protected from north winds than from other winds, could explain the impact of the direction of the meridional wind component on the number of lesser weever stings.

The uniqueness of the database analysed here, showing 1,005 people stung by lesser weever fish at a 2.7 km beach during the summer of 2014, does not allow us to compare our findings with the events seen at other summer times at the same beach or other beaches. However, information from other sources pointed out at the summer of 2014 as a year when many interventions were required. For instance, information published in local newspapers reported 9,230 interventions attributed to lesser weever

fish stings along the 30 km coastline of the municipality of Vigo (Galicia, Spain) during the same season. Those beaches and A Lanzada beach, separated by 75 kilometres, are located within the Rías Baixas, four coastal embayments between 42° N and 43° N of NW. A gross extrapolation of these values along the ~500 km of littoral of the Rías Baixas would result in an estimation close to 100,000 people stung by lesser weevers. The magnitude of this figure exceeds the numbers reported for other Spanish zones (Portillo-Strempel *et al.*, 2009) and elsewhere in Europe (Cain, 1983), and it would be even higher than the well-known cases of jellyfish stings seen, for example, in the Mediterranean Sea (Bordehore *et al.*, 2016).

The empirical model described in this study was able to explain ~45% of the lesser weever fish stings attended to on A Lanzada beach (NW Spain) during the summer of 2014. Model performance could be improved by recording the time when the sting occurs and incorporating into the analysis a better beach occupation index measured in situ. This would facilitate a better understanding of the sting dynamics which would be the result of complex interactions between fish and human behaviour with the environment. In any case, the present work shows that basic information gathered by lifeguards and complemented with data on local environmental conditions can be successfully used to evaluate the incidence of weever fish stings. Empirical models at a local scale, such as the one developed here for A Lanzada beach, bring about the possibility of providing public, real-time information to forecast the probability of lesser weever fish stings and minimise the risk for beachgoers. Additionally, these models would help to optimise the working time of lifeguards, who spend at least 30 minutes on each person attended to, with such provision of services representing 90% of all interventions by the lifeguard services. Furthermore, the in-situ collection of information on beaches that is useful and accessible for the scientific

community could be the basis for evaluating large-scale spatio-temporal trends and proposing management measures.

CONCLUSIONS

This database opportunely compiled using information gathered on A Lanzada beach through a smart-city initiative during the summer of 2014 indicates that lesser weever stings are a more common problem than reported by the literature to date. On a 2.7 km beach, a total of 1,005 stings were recorded in three lifeguard stations from the 1st of July to the 13th of September. The provision of medical care was not homogeneous along the entire beach; instead, it was required especially at the southern end (517 cases), while it was needed less frequently in the central area (215 cases). The incidence described for A Lanzada beach using publicly released information suggests that the incidence of lesser weever stings along the northwestern Spanish coast is at least comparable to the incidence of jellyfish stings on the Mediterranean coast.

In addition to the characteristics of the beach (orientation, morphology, etc.), environmental conditions correlated with the number of people stung, which explains almost a half of the lesser weever stings (45%) out of the total variability. Sea surface temperature and air temperature showed a direct relationship with the interventions on the beach, while the correlation with tide height and a northerly wind component constituted an inverse association and a dome-shaped association, respectively. Besides relating to bathers' behaviour on the beach, our results seem to indicate the importance of the spatio-temporal dynamics of lesser weever populations for the total number of stings. It also seems clear that there is a need to improve the studies on the ecology of this little-known fish, especially in response to a potential increase in the populations on the Atlantic European coast.

The coincidence between the habitat of this little-known poisonous marine fish, an important tourist industry and the concentration of population on the coast will have a socioeconomic impact. Based on these results, an appropriate beach monitoring system and new technologies similar to those used on A Lanzada beach would provide information for the prevention of lesser weever stings.

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