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Expected Distribution of Surfing Days in the Iberian Peninsula

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Abstract: This study presents, for the first time, a comprehensive characterization of the surf spots around the Iberian Peninsula and provides surfers and stakeholders an evaluation of the expected surfing days per year on each region and spot. The provision of this climate information can help to decision-making and limit the economic and social damages caused by climate-related disasters. This product aligns with the concept of climate services, increasingly requested to help economic activities to achieve optimal performances. We employ use in our study of two sources of data: meteorological buoys (Redcos, Redex and Costeira) and citizen science data, specifically information mined from surfers reanalyzed, namely the information contained in the Glassy app for smartphones (GAC & GAS). The surf spots are characterized using bottom type, surf break type and optimal wind (O_{wd}) and optimal swell direction (O_{sd}). Then, we define a surfing day as the ones in which optimal swell direction and waves bigger than 0.9 m occur; using three parameters mean swell direction (D_{md}), significant wave height (H_{m0}) and optimal swell direction for each surf spot (O_{sd}) and compute the expected frequency of surfing days per year. Once this is done, we attempt to validate the approach taken to characterize a surfing day using buoys parameters (H_{m0}, H_{max}, T_p and D_{md}) and information about actual surf sessions for a small subset of our spots (i.e., Costa Tarragona). Our findings confirm that the area of western shore is the best suited for surfing, with over 300 days/year, followed by northern shore (300, 200 days/year) and southern and southeastern shores (<100 days/year). We expect that these values may modestly contribute to a climate-informed planning and management of the surfing activities.

Keywords: buoy data; surf; surfing; Iberian Peninsula; surf spots; significant wave height; ocean waves observation

1. Introduction

Surfing is a coastal sport practiced in many spots across the Iberian Peninsula. These surfing spots require specific environmental conditions, which produce surfable waves. This includes swell size, swell direction, swell quality (spectral width and peak period), wave-grouping characteristics (number of waves in a set, wave-height distribution within the set and time between sets), wind direction and wind strength [1]. Surf spots are the specific nearshore locations where surfing occurs and which surfers use regularly and loyally and about which surfers often develop expert local knowledge [2]. Surfing tourism has increased in popularity as a form of active sport tourism, with surfers bringing economic benefits to a destination [3].

Although all surf spots are used for the same recreational purpose, each spot is unique given its oceanographic, coastal, social setting and cultural history [4]. Successful surf spots require good waves. Their definition can be approached from different standpoints, often combining cultural, purely physical elements and the fact that surfers seek different waves according to their surfing skills.

Hutt et al. [5] defined a ranking of the skill level for surfers, grouped in ten categories which are differenced by the peel angle limit (deg) and the minimum and the maximum wave height (m). Hence, different surfing waves attract different surfers to either match or challenge their abilities [5,6].

Waves knowledge is central to any attempt to describe surfing spots, more specifically the organization of the waves (swell) and the way they break and peel. When the wind blows over the ocean's surface, it creates wave energy. Wave characteristics depend on the wind speed and directional constancy, the time the wind is blowing and the extent of the oceanic area affected by the flow. As wave energy travels through the open ocean, it becomes an organized train of waves or swell. Swells present typical wave periods (T), depending on their origin. Ocean swell, also known as ground swell, is the best type for surfing, as it produces non mixed waves with large values of T. Groundswell is generated by storms and the stronger the swell, the larger tend to be the wave periods.. Wind swell is created by wind local winds acting near shore. As a result, it is not as powerful as groundswell and relates to short wave periods. Surfers' seek well organized wave trains with large wave periods, so ocean swells are preferred over wind and coastal swells. Nevertheless, the perception of swell period for surfing depends on the oceanic basin. For example, in the Mediterranean, local surfers call low periods those smaller than four seconds, medium between four seconds and eight seconds and high periods are those larger than eight seconds. This contrasts with the typical values for the Atlantic, where low periods are those smaller than eight seconds, medium range between 8 s and 13 s and high, larger than 13 s [7].

When waves approach the shore, they eventually break. Breaking characteristics depend on the shore morphology, wind strength and direction. Offshore winds increase breaking intensity and onshore or cross-shore winds reduce it [8]. The perfect conditions for surfing are light offshore winds or no wind [9]. These wind conditions delay wave breaking, causing the wave to break in shallower water and increasing the breaking intensity. Strong offshore winds make waves hard to catch [10]. When there is no wind, it is called glassy conditions and is regarded as the best condition for surfing in terms of coastal winds.

Furthermore, surfing requires a steep unbroken wave face to create board speed for performing maneuvers, referred as peel [11]. The peel angle, related to the break angle and the wave obliquity at the breaking depth, determines the speed that the board must adopt to stay ahead of the breaking section of the wave [12]. A minimum peel angle of 30° is generally required for surfing, large peel angles are generally associated with nonuniform bottom contours [13].

In the previous paragraphs we described the importance of the characteristics of the wave breaks and the factors influencing them. These factors can be monitored using four parameters: breaking wave height, wave peel angle, wave breaking intensity and wave section length. Wave height–defined as the vertical distance between the trough of a wave and the following crest is perhaps the most important; wave peel angle is defined as the angle between the trail of the broken whitewater and the crest of the unbroken wave as it propagates shoreward. The wave breaking intensity is defined by the orthogonal seabed gradient and it is the dominant variable controlling the wave breaker intensity. The wave section length–defined as the distance between two breaking crests in a wave set–occurs when the wave breaks and, depending on the characteristics of the sections originated, surfers can perform different maneuvers [14]. According to the values of these parameters, the waves will be useless for surf, adequate for beginners, for intermediate level or for advanced surfers [5].

The seabed morphology plays an important role in creating wave breakers. Planar beaches with parallel contours do not produce good surfing breaks [14]. The peel angle is too low for surfing, Waves simply closeout as the crest breaks all at once rather than peeling. Other bathymetric configurations—i.e., sandbar and reef break, see Section 3 for further description—are needed to cause waves to break along the wave crest rather than all at once. Most surfing spots are near prominent morphologic features which create rough seafloors, such as river mouths, with ebb deltas, coral/rock reefs, points, rock ledges, piers, jetties or beaches where large scale bar/rip features [15,16].

Depending on the characteristics of the seafloor, three different types of surf breaks are defined: beach break, point break and reef break. In beach breaks, the wave breaks on a sand bottom. Wave shape and size will vary depending upon the interaction of the incoming wave field with the underlying sandbar morphology. In a point break, the wave breaks at a rocky point which can be natural or artificial, for example, a dike. In a reef break, the wave breaks on shelves of rocks or coral and are the most consistent in terms of wave shape and peak location.

In this context of fragility of the surf spots—if their environment is modified by the building of a harbor or a jetty—the surfing conditions will also be modified somehow. In order to preserve the surfing resource, it is believed that consideration must be given to the coastal management of these spots because, historically, many surfing breaks have been altered or destroyed by coastal development [17]. Moreover, as said by Caldwel, M.R. et al. [18] and Corne, N.P. et al. [19], coasts—and specifically surf spots—are highly dynamic and often fragile environments, particularly susceptible to local and global environmental threats. Nevertheless, on a global level, some engineers are inspired by natural reefs to not only protect the shore, but also to provide good surfing spots.

Thus, not all surfing breaks are entirely natural. They can be created, modified or destroyed by human activities, such as building seawalls (e.g., Saint Clair, Dunedin, New Zealand), jetties (e.g., Mission Bay jetties, San Diego, California), boating infrastructure (e.g., Manu Bay, Raglan, New Zealand), piers (e.g., Oil Piers, Ventura, California) and beach nourishment (e.g., "The Cove" Sandy Hook, New Jersey). It is not surprising that many existing surfing breaks are unnatural because there are few environments that have not been impacted to some degree by human activity [20,21].

As our previous discussion suggests, the determination of the characteristics of existing or potential surfing spots is complex and requires surf quality studies at different scales [22]. While several global studies are available in the literature [23–25] this is not the case for regional and local studies which consider higher resolution and more localized variability, with the exception of [26,27]. In this regard, we are not aware of any study which describes the distribution of the number of surfing days per month for each spot in the Iberian Peninsula. In fact, what is known is that it is difficult to have a spot where favorable surfing conditions occur every day of the year–which means that wave, wind, tide and bathymetry conditions would be conducive to surfing. In this study, we pursue the following objectives: (1) to investigate the wave parameters needed to classify surfing days thus obtain wave climate (2) thus, this specific wave climate allows us to assess the dependence on these parameters to know the expected surfing days per year in different surf spots around the Iberian Peninsula. Surf-crafts considered for the study are shortboards and longboards.

The remainder of this paper is organized as follows: study site, data and methods are presented in Section 2; we present our results at Section 3, to finish with discussion and conclusions (Section 4).

2. Study Area, Data and Methods

2.1. Study Area and Data

The study area covers the coast of the Iberian Peninsula, located in the southwest corner of the European continent. The countries which form the peninsula are Spain, Portugal, a small area of France, Andorra and the United Kingdom (Gibraltar). For this study, the Iberian Peninsula coast is divided into 14 regions regarding NUTS2 classification—nomenclature of territorial units for statistics from the European Union, which contains a total of 872 surfing spots, from which we will concentrate on the 46 that can be directly related to available buoy data (see Section 2.2). Both NUTS2 regions and selected spots are shown in Figure 1.

The Iberian Peninsula is studied in four main categories: western shore, northern shore, southern shore and southeastern shore-taking as reference the cardinal points. Each main group is formed by territorial subcategories divided in NUTS2. Each NUTS2 region has several specific spots.

This study uses different data sources to study the characteristics of waves. Historical wave data are extracted from 25 buoys managed by *Puertos del Estado* (http://www.puertos.es/es-es/oceanografia/Paginas/portus.aspx.) (Spain) and integrated in the REDCOS network (coastal buoys) and REDEXT network (open ocean buoys) and the Nazaré buoy from the *Instituto Hidrográfico Marinha Portugal* (https://www.hidrografico.pt/boias.) (Portugal) (see Figure 2 and Table 1). The buoys from the REDEXT network are characterized by being located offshore in areas with depths over 200 m, to ensure that the measurements are not perturbed by local effects and are representative of large littoral areas. The REDCOS buoys, installed in depths of 100 m more less, complement REDEXT measurements highlighting local conditions in specific areas of interest for harbor activities or for the validation of wave models. Their measurements are conditioned by the shore's profile and by the effects of the bottom on the surge. The buoy data are quality controlled in origin.

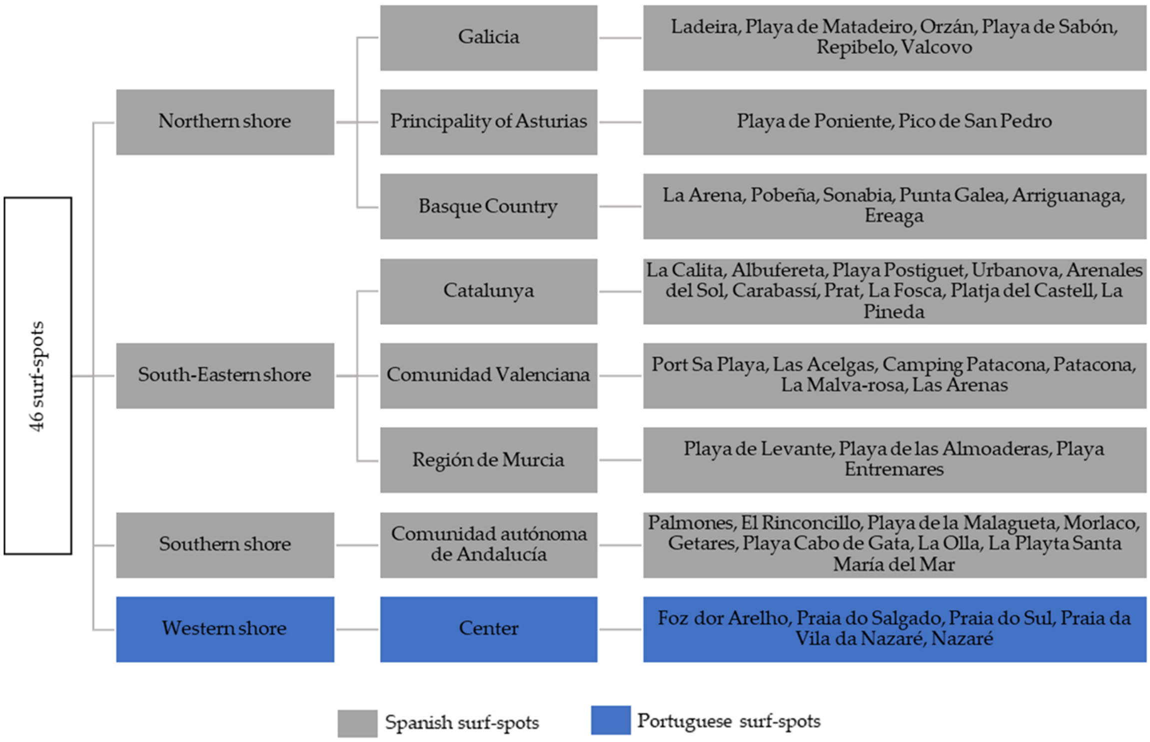

Figure 1. Selected 46 surf spots structure, organized by section and political region (Autonomous Communities for Spain; statistical regions (NUTS2), managed by the regional coordination and development commissions (CCDRs) for Portugal).

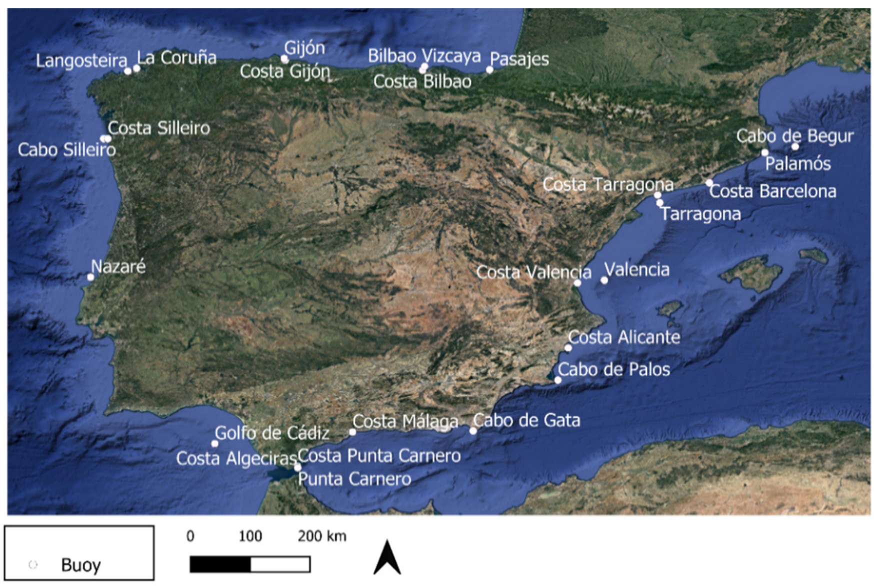

Figure 2. Nearshore BDS distribution around the Iberian Peninsula.

Table 1. Studied buoys.

Name of the Buoy	Period of the Dataset	Network Buoy	Variables Provided and Measure Units
Costa Algeciras	2004-03-17 to 2005-07-29	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Costa Alicante	1985-09-26 to 2014-01-15	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Costa Barcelona	2004-03-08 to 2019-09-12	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Costa Bilbao	2004-02-26 to 2019-09-12	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Costa Gijon	2001-02-02 to 2019-09-12	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Costa Malaga	1985-11-19 to 2019-09-12	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Costa Punta Carnero	2010-11-12 to 2019-09-12	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Costa Valencia	2005-06-08 to 2013-10-30	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Palamos	1988-04-26 to 2012-04-12	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Pasajes	2010-03-15 to 2012-05-23	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Tarragona	1992-11-12 to 2019-09-12	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Langosteira	2013-09-06 to 2019-09-12	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Punta Carnero	2013-08-19 to 2019-09-12	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Bilbao Vizcaya	1990-11-07 to 2019-09-12	REDEXT	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Cabo Begur	2001-03-27 to 2019-09-12	REDEXT	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Cabo de Gata	1998-03-27 to 2019-09-12	REDEXT	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Cabo de Palos	2006-07-18 to 2019-09-12	REDEXT	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Cabo Silleiro	1998-07-06 to 2019-09-12	REDEXT	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Golfo de Cadiz	1996-08-27 to 2019-09-12	REDEXT	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Tarragona	2004-08-20 to 2019-09-12	REDEXT	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Valencia Copa	2005-09-15 to 2019-09-12	REDEXT	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Gijon	1994-03-22 to 2010-08-13	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
La Corunha	1982-07-14 to 2012-12-03	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Silleiro	1991-02-22 to 2006-10-09	REDCOS	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$
Nazaré Costeira	2010-03-23 to 2018-12-31	COSTEIRA	$H_{m0\,(m)}$, $H_{max\,(m)}$, $T_{p\,(s)}$, $D_{md\,(°)}$

This study analyzed historic wave data recorded between 1982 and 2019 (see again Table 1 for details). The data were collected hourly in most of the network, except for La Coruña, where data were collected every four hours and Costa Alicante, Costa Málaga and Bilbao–Vizcaya where data were collected every three hours. The variables analyzed in this study were significant wave height H_{m0}, maximum wave height H_{max}, peak wave period T_p and average swell direction D_{md}.

To identify the specific characteristics needed for surfing in the specific surf spots, we make complementary use of information obtained from the Glassy app (The app is no longer in service, but it is possible to download the *apk* if needed https://glassy-pro.es.aptoide.com/app.). This app is made for surfers use and it contains more than 18,000 surf spots around the world. It allows one to store the surfing session. The application was developed thanks to a startup in Valencia (Spain). In this regard the project it was first launched as an app for the mobile phone open to all users. However, nowadays it allows an individual user to log a surfing session experience.

The application provides knowledge on the best conditions for each surf spot (897 across the Iberian Peninsula, including 46 on our database) and we extract from there optimal swell direction (O_{sd}), optimal wind direction (O_{wd}), surf break type and bottom type. The app provides access to the forecasted conditions and allows the users to track their sessions, information that we will use for validation purposes (see Section 2.2 for further explanations).

2.2. Methods

To achieve the objectives described in Section 1, we combine the two data sources previously introduced (buoy data and Glassy App data) as described in Figure 3. Our analysis is split in three steps:

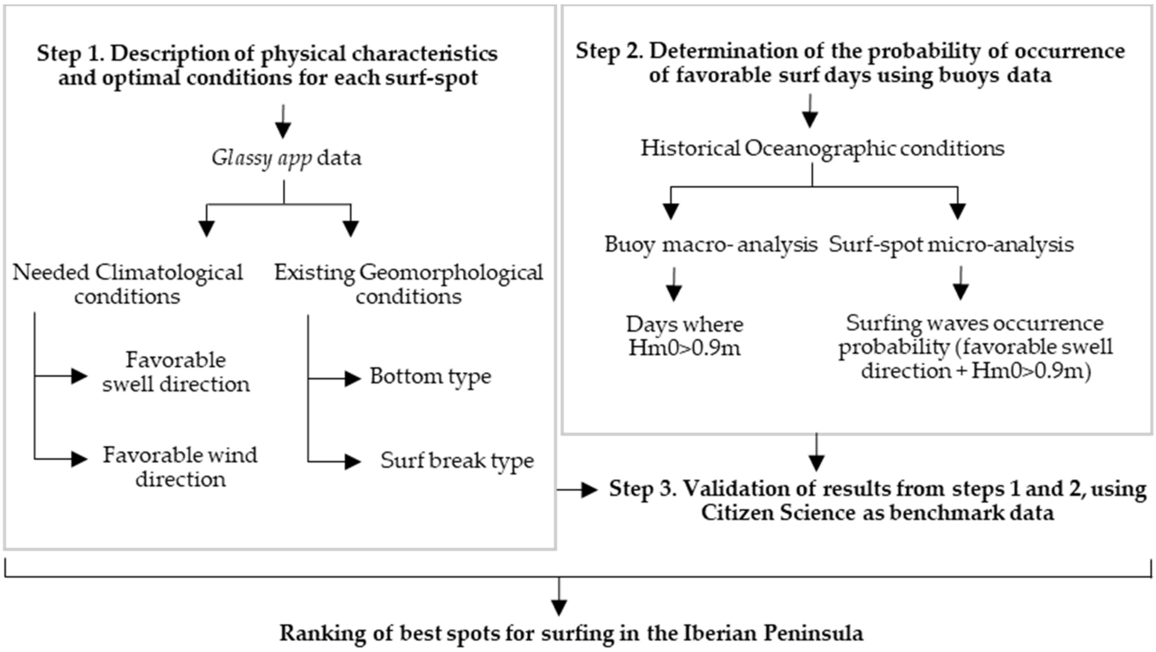

Figure 3. Methodology flow: from *citizen science data* and buoy network data to the expected surfing days per year in the Iberian Peninsula.

Description of the physical characteristics and optimal conditions for each surf spot, using Glassy App Site data (GAS, from now onwards): bottom type, surf break type, optimal wind direction (O_{wd}), optimal swell direction (O_{sd}).

Determination of the probability of occurrence of optimal surf days using buoys dataset (BDS, from now onwards). First, we identify at the buoy scale (macroanalysis) the number of days with $H_{m0} > 0.9$ m.; second, we combine the previous information with swell direction data and compare it with the optimal swell values (see step 1) to make inference at the surf spot level. This analysis is limited to the 46 surf spots which can be directly linked to one of the 25 available buoys (see Table A1).

Results from steps 1 and 2 are validated using a citizen science as benchmark data, extracting information (more than 1000.000 hourly observations from the BDS) on real surf sessions from Glassy App Citizen data (GAC, from now onwards). Contrasting how surfers perceived and qualified their experience.

The benchmark is constructed using information from the buoy, attributing H_{m0} and D_{md} registered to the close by surf spots (see Figure A1). Then days are grouped in surfed days and non-surfed days.

This three steps approach allows us to rank the studied surf spots in the Iberian Peninsula according to the probability of occurrence of good surfing days.

Step 2 is split into buoy level analysis (macro) and surf spot level (micro). The buoy macroanalysis is based on the standard significant wave height (H_{m0}) [28]. As measured and provided by buoy, H_{m0} refers to the height (from the trough to the crest) of the waves following in the third quartile of the empirical wave height distribution. We adopt this variable, originated in the field of navigation, because it is a good proxy of the state of the sea, reflecting the height of the surge that an observer would perceive. However, for the assessment of the actual surfability of the sea, we introduce second parameter, the mean height, *MeanH*, informs on the expected height of the surfable waves. It is not directly provided by the BSD, but it is duly approximated using Equation (1), from Breatschneider et al. [29].

$$MeanH = 0.64\ Hm0 \quad (1)$$

where *MeanH* is the mean height, *Hm*0 is signficant wave height.

The number of days with $MeanH > 0.5$ ($\sim H_{m0} = 0.9$) will be considered as surfing days [30] and we will compute the number of exceedances for each buoy and provide the monthly normal. In this sense, we only use this simple wave height criterion to approach surfed days. That values are taken from BDS.

At the surf spot level or microanalysis, we introduce the surfing waves occurrence probability indicator (*SWOP*, Equation (2)) defined as the ratio of favorable swell observations to the total number of swell observations.

$$SWOP = \frac{\sum cosd}{\sum n_{osd}} \quad (2)$$

where *cosd* is counted optimal swell mean direction, *osd* is counted observations of swell direction and n_{osd} is the number of counted observations of swell direction.

The indicator is calculated for the surf spots attributable to a nearby buoy (Table A1). The reason information from the buoys can be attributed to specific spots is the propagation of the free-traveling swell. The storm center is where swell propagation starts to travel from the ocean/sea to the shore. The swell moves away from the generating area (storm center) with circumferential dispersion and radial dispersion. In this respect, waves are just messengers of energy. The further from the storm center the swell travels, the more it expands in both radial and circumferential directions.

In this case, only the swell direction is considered for calculating the SWTOP indicator. It is important to remember that having the necessary swell direction in the surf spot will not necessarily mean having surfable waves, as there are more variables that also play an important role, such as wind direction, peak period or significant wave height.

In Step 3 (Figure 4), we attempt to validate our results using citizen science data for the 2006–2019 period as a benchmark. All the data registered by citizen sensors correspond to days when there is at least one observation of a surf session. These days are considered surfed days and are pooled to compared them with data from the nearest buoy. Buoys measure the sea state by observing a series of instantaneous elevations of the sea level during a minimum time interval (depending on type of the buoys). This sample is considered representative of the waves at that time. Next, Series of elevations the standard zero crossing and spectral analyses are used to obtain the most representative parameters of the waves.

We derive means and standard deviations for H_{m0}, maximum wave height (H_{max}), peak period (T_p) and mode for mean swell direction (D_{md}), which represent the typical values for surfed days. These values are also computed using data for the whole 2006–2019 period for comparison. We do not use wind direction as REDCOST buoys do not collect that variable.

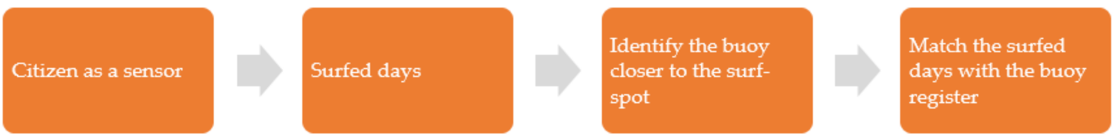

Figure 4. Conceptual explanation of the benchmarking/validation approach by using citizen science data (Step 3). Once the validation process proves the methodology of attributing surfing days to surf spots, it is possible to create a ranking for expected surfing days per year in the studied surf spots. To identify this, days where $H_{m0} > 0.9$ m and O_{sd} are selected.

3. Results

In this section, we present an overview of the 872 surf spots characteristics of the Iberian Peninsula, namely: bottom type, surf break type, optimal swell (O_{sd}) and wind direction (O_{wd}). Then the natural frequency of waves is presented for 46 selected surf spots, directly attributable to BDS. Afterwards, validation process is made by using GAC, GAS and BDS for Tarragona's coast. Finally, we show the frequency of good surfing conditions for the previously 46 selected surf spots. In this section, we see new a contribution to wave climate science thanks to citizen science data and BDS.

3.1. Optimal Wind and D_{md} Conditions for Surfing

We extract optimal swell direction (Osd) and optimal wind direction (Owd) for each surf spot from GAS (Figures 5 and 6). The results confirm, as expected, that the location plays an important role in the direction of the necessary Dmd for surfing. The optimal Dmd rotates from W–NW on the western and northern shores to NE–S on the southeastern shore. The two regions in the southern shore, present a larger spread, although dominant directions range from SW to E. Favorable wind direction corresponds to the opposite direction of optimal swell direction. The optimal wind rotates from NE/SW on the western shores to NE–SW in northern shore. For southeastern and southern shores, the optimal wind direction rotates to SW–NE.

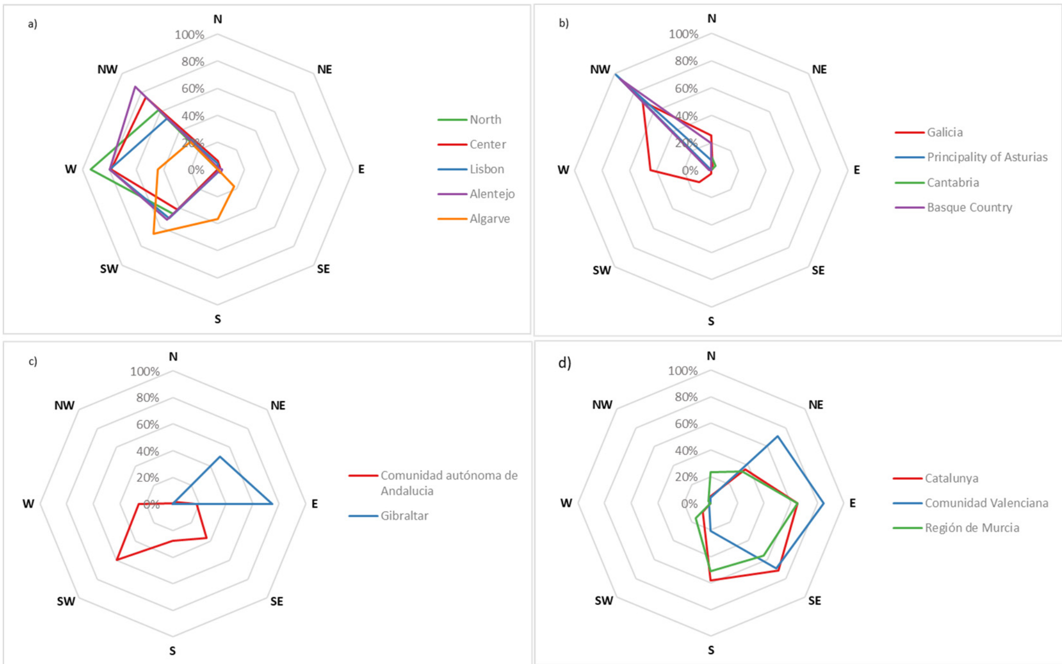

Figure 5. O_{sd} in the Iberian Peninsula's surf spots. (**a**) Western shore; (**b**) northern shore; (**c**) southern shore; (**d**) south-eastern shore.

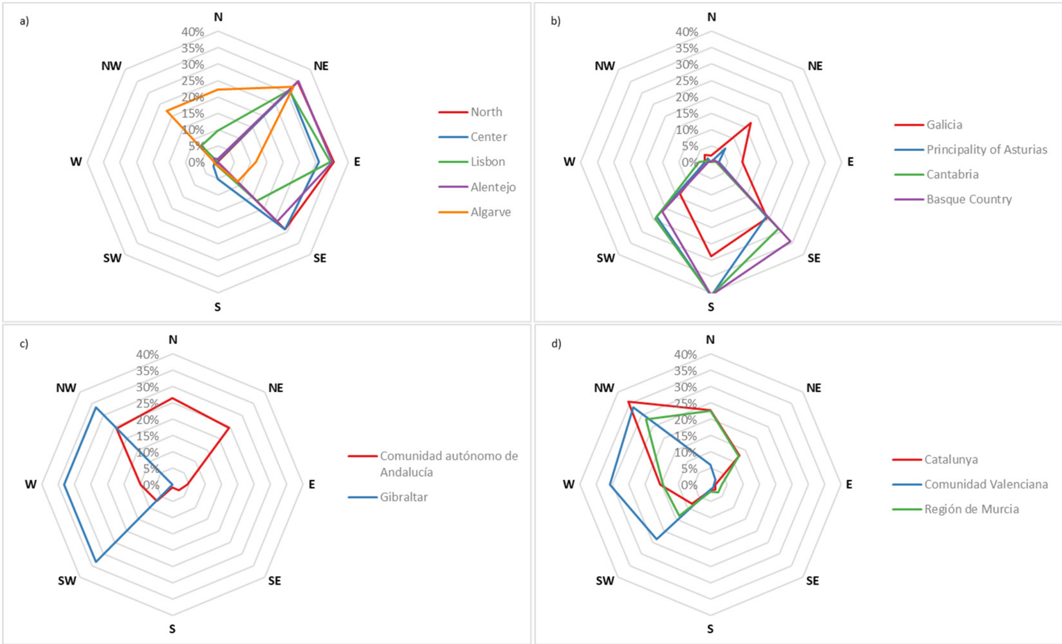

Figure 6. O_{wd} in the Iberian Peninsula's surf spots (%). (**a**) Western shore; (**b**) northern shore; (**c**) southern shore; (**d**) south-eastern shore.

3.2. Historical Oceanographic Conditions.

In this section, we present the distribution of the significant wave height using data from 25 from buoys (macroanalysis) attributed to 46 surf spots (microanalysis).

3.2.1. H_{m0} Distribution

Figure 7 presents the analysis of $H_{m0} > 0.9$ m. The Atlantic Coast (northern and western shores) is characterized by a larger number of days with significant wave height, $H_{m0} > 0.9$ m. The mean values, calculated as the arithmetic average of all the spots within a region, of 26.65 days/year (western), 24.72 days/year (northern) nearly double those obtained around the Mediterranean (12.87 days/year, South Eastern; 12.04 days/year southern). In addition, Atlantic spots present smaller seasonality compared to the Mediterranean shore, which presents minimum values in spring and summer and smaller variations across the studied spots (see standard deviations in Figure 7. Even though these considerations may be biased by the different number of spots on each category, it is worth to mentioning that the smallest monthly value in the Atlantic regions is larger than 15 days, compared to many spots in the Mediterranean that present fewer than 5 days with $H_{m0} > 0.9$ m during spring and summer months.

Seasonality in wave results is obvious in Figure 7c and little in Figure 7d, but interestingly there is no strong seasonality in Figure 7a,b. These wave results patters can be associated with the swell producing systems. The main generators of surfing wave are low pressures, so atmospheric travel patterns will contribute to wave surfed days patterns. Then, the requirements of having surfing days on Iberian Peninsula's shore will depend on surf spots location and orientation. Situations of low pressures coming from N, NE, NW, S and SW represent the maximum occurrence of surfed days in the occidental Mediterranean. The swell production systems required for surfing on the northern shore of the peninsula are low pressures coming from N, NE, NW—located commonly in Great Britain. Western shore surfing days require low pressures from W.

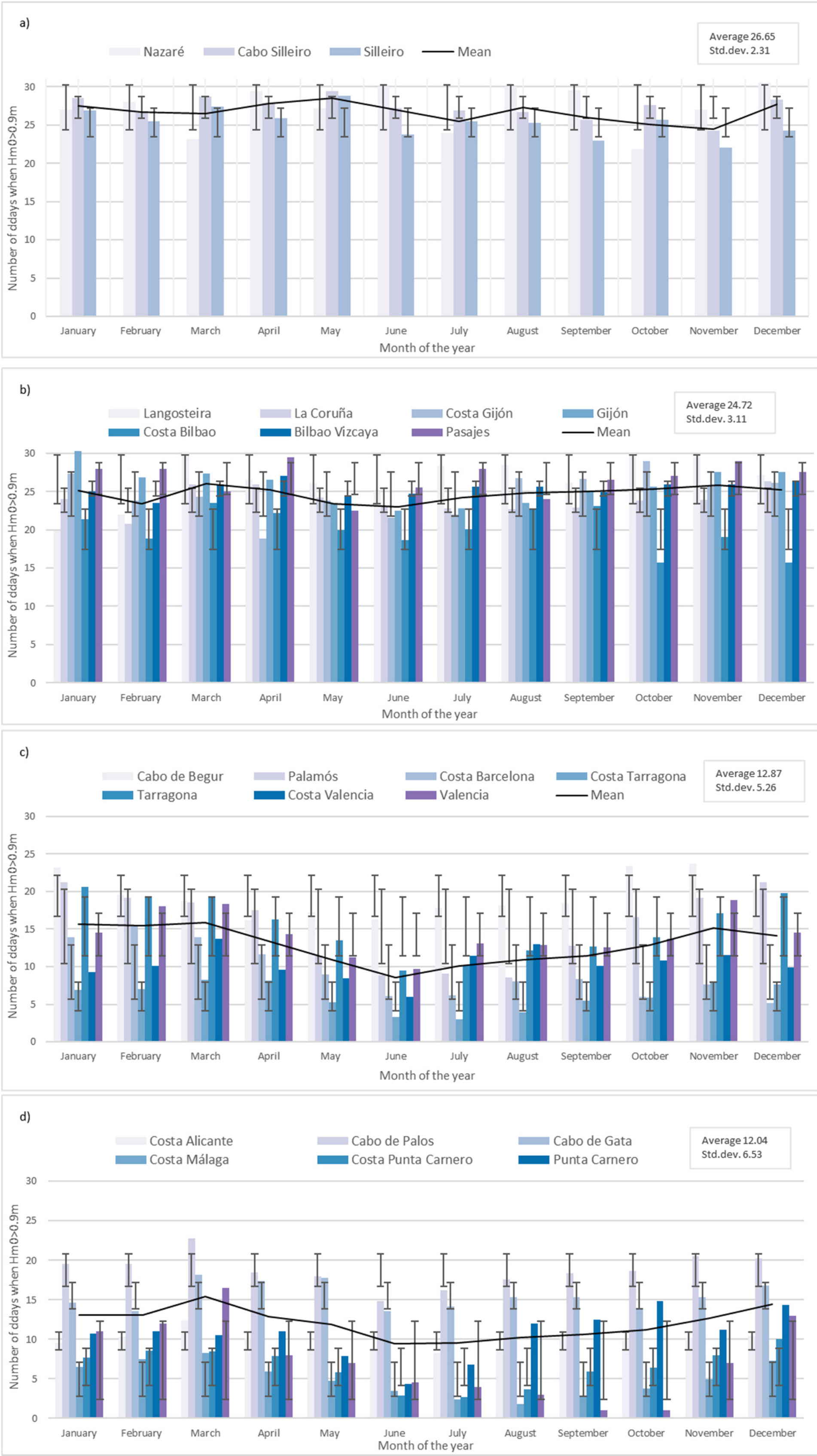

Figure 7. Observed days where H_{m0} > 0.9 m. (**a**) Western shore; (**b**) northern shore; (**c**) south-eastern shore; (**d**) southern shore.

3.2.2. SWOP Analysis

Figure 8 presents the SWOP analysis. Figure 8a shows the SWOP values the western Shore. As described in Section 2.2, SWOP values are computed using buoy data and optimal swell directions for each surf spot. Consequently, surf spots attributed to the same buoys and with the same optimal swell direction, i.e., Nazaré, Praia do Salgado, Praia do Sul and Praia da Vila de Nazaré, present the same SWOP value, 92.38% (337 days) corresponding to SW, W or NW swells. For Foz do Arelho and Nazaré, the value is 91.53% (334 days), associated with a W or NW swells. These high values contrast with Ladeira, where SWOP is 19.42% (71 days) of optimal swell.

Figure 8. SWOP values and expected days per year with O_{sd}. (**a**) Western shore; (**b**) northern shore; (**c**) southern shore; (**d**) south-eastern shore.

Figure 8b presents the surf spots on the northern shore with available swell data. The SWOP values oscillate between nearly 75% (273 days) in Playa de Sabón (W and NW swell), Repibleo and Valcovo (SW, W or NW swells) and La Arena and Pobeña (NW swell); 70% (255 favorable days) in Punta Galea Arriguanaga and Eraga (NW swell); and 55% (201 favorable days) in Gijón, Playa Poniente and Pico de San Pedro (NW swell).

Figure 8c presents the SWOP values for southeastern shore. These values are smaller than the ones representing the areas previously presented. The SWOP values oscillate between 57.92% (212 days) in Playa de la Malagueta (E, SE swell), 56.33% (206 days) in Playa Santa Maria del Mar and la Olla (S, SWE swell), 54.67% (200 days) in Playa Entremares, Playa de las Almoaderas and Playa Levante (N, NE, E swell), 48.27% (176 days) in Palmones (SE, S swell), 47.09% (172 days) in Morclaco (SE swell), 17.15% (63 days) in El Rinconcillo (NE, E, SE, S, SW swell) and 16.38% (60 days) in Getares (SE swell).

Figure 8d presents the SWOP values for southern shore. SWOP biggest value for this region is 93.9% (343 days) in El Prat (NE, E, SE, S swell), followed by La Fosca (NE, E, SE, S swell) 90.07% (329 days); 88.4% (323 days) in las Acelgas, la Patacona, Camping la Patacona, Las Arenas (E, SE swell); 87.23% (319 days) in la Albufereta (E, SE, S swell); 70.48% (257 days) in La Malva-rosa; 69.48% (254 days) in La Calita (E, SE swell); 49.34% (180 days) in Playa Postiguet, Urbanova and Arenales del Sol; 46.06% (168 days) in Platja del Castell (SE, S, SW swell) and 32.14% (117 days) in La Pineda (NE, E swell).

The SWOP values in the Iberian Peninsula range from 22 days to 329 days. The lowest value corresponds to Carabassí and the highest one to la Fosca in Palamós. It is important to mention that the SWOP indicator is not the only condition needed for surfing, so maybe the necessary swell direction may be reaching a beach, but the wave height is not enough for surfing. Thanks to SWOP indicator is shown that the expected days when the swell is favorable for surfing varies between the different surf spots.

3.3. Validation Trough Citizen Science Data and BDS

In this section, we present the distribution of H_{m0}, H_{max}, T_p and D_{md} for the data from Costa Tarragona's buoy. This buoy's data were compared using a Citizens' Science approach with surfers' observations which identified and tagged surfing days in the past (2006–2019).

Table 2 provides mean values and their standard deviations of surfed days vs. non-surfed days. They confirm the importance of the parameters shown and how they help in the characterization of a good surfing day. As expected, the values of H_{m0} and H_{max} are larger on surfed days (0.96 m; 1.50 m) than on non-surfed days (0.49 m; 0.77 m). Similarly, the standard deviations are larger for the surfed days, although this is for sure influenced by a smaller sample size. In addition, values of T_p are larger for the surfed days (6.99 s) in respect with non-surfed days (5.12 s). It is shown that bigger waves, bigger the periods. In addition, we encounter more constant values of swell, D_{md} in surfed days (E observations represent the 67.29% of total observations) in respect with non-surfed days (SE, 50.13%). Results show how swell direction determine surfability of a day.

Table 2. H_{m0}, H_{max}, Tp and D_{md} values for Costa Tarragona's buoy: 2006–2019.

Period: 2006–2019									
	H_{m0} (m)		**H_{max} (m)**		**T_p (s)**		**D_{md} (Cardinal Points)**		
	SD [1]	**NSD [2]**	**SD**	**NSD**	**SD**	**NSD**		**SD**	**NSD**
Average	0.96	0.49	1.50	0.77	6.99	5.12	Mode	E	SE
Std. dev	0.50	0.30	0.79	0.44	1.78	1.65	% mode n	67.29%	50.13%
Q1	0.60	0.30	1.00	0.5	6.01	4.10	–	–	–
Q2	0.90	0.40	1.40	0.7	6.90	5.09	–	–	–
Q3	1.30	0.60	2.00	1	8.11	6.20	–	–	–
Min	0	0	0	0	0	0	–	–	–
Max	3.50	3.90	5.80	7	12.60	23.40	–	–	–

[1] surfed day. [2] non-surfed day.

Figure 9 illustrates the frequency of H_{m0} and H_{max} split on surfed-days and non-surfed days. As expected, general trends of figure show that for surfed days the median is always larger than for non-surfed days for both parameters. H_{max} and H_{m0} distribution are quite similar. These patterns respond to the definition of each parameter [29]. Boxplots show that the distribution of H_{m0} and H_{max} variables are different for surfed and non-surfed days.

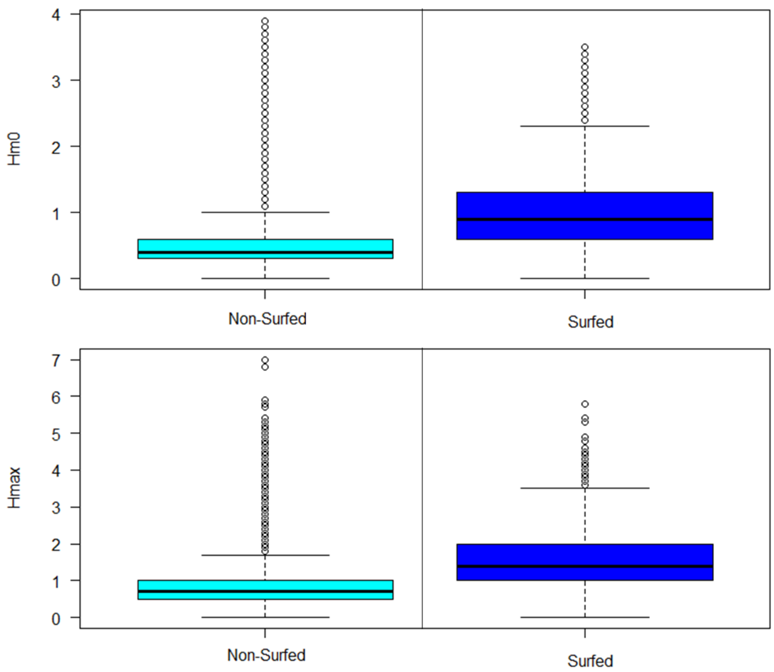

Figure 9. H_{m0} and H_{max} distribution for non-surfed and surfed days in Costa Tarragona's buoy (2006–2019).

Table 2 shows, significant wave height distribution presents for surfed days values of percentile 25 (0.6 m) higher than for non-surfed days (0.3 m). Median for surfed days (0.9m) is higher than for non-surfed days (0.4 m). The same for percentile 75, surfed days present higher values (1.3 m) than non-surfed days (0.6 m).

Maximum wave height distribution shows that on surfed days values are higher than in non-surfed days. Specifically, for surfed days percentile 25 corresponds to 1 m, the median is 1.4 m, and percentile 75 is 2 m. For non-surfed days values of the boxplot are smaller: lower quartile (0.5 m), mean (0.7 m), and the upper quartile are smaller (1 m). Contrary, maximum values occur on non-surfed days.

Contrary, for H_{m0} and H_{max} maximum values occur on non-surfed days instead of on surfed days.

For surfed days most of H_{m0} values correspond to the ones greater than 0.9 m. Nevertheless, there are some days identified as surfed days in which H_{m0} values are smaller than 0.9 m. The reason values of 0 m to 0.4 m exist on surfed days, is explained by the days when, for example, there are no waves in the morning [0 m, 0.9 m] and then in the afternoon the wave height starts to increase [>0.9]. This fact occurs because the Mediterranean shore is characterized to present small values of surfing days per year. In most cases, swells come from generation areas close to the coast so that coming swell do not stay on the surf spots for so long.

We count days as surfed days when citizen science data verify it. The validation process is made in Tarragona's buoys, so it is normal that in a surfed day appear some hour in which significant wave height is smaller of 0.9. This can be explained by two reasons: (1) the swell did not arrive yet or (2) the swell is not coming anymore. Peak period determines when surfing swell is coming or leaving. this means that the swell is coming when periods tend to be bigger and bigger and thus bigger waves. It happens the other way around when it goes from big periods to smaller periods, this means that surfing waves are probably not coming anymore at that moment. Smaller the period, smaller the wave.

Figure 10 shows the percentage of T_p distribution on surfed and non-surfed days. General distribution patterns of peak period always show higher periods in surfed days compared with non-surfed days, in exception of maximum values of the peak period in non-surfed days (23.4 s) instead of lower values on non-surfed days (12.6 s). surfed days peak period values are higher for percentile 25, median and percentile 75 (6 s, 6.9 s, 8.1 s) than for non-surfed (4.1 s, 5.1 s, 6.2 s).

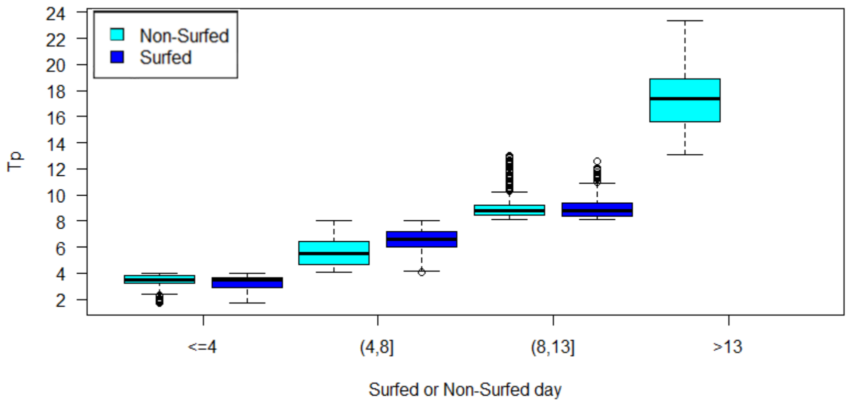

Figure 10. T_p distribution for non-surfed and surfed days in Costa Tarragona's buoy (2006–2019).

Periods > 13 s are identified in non-surfed days, but not in surfing days. This result can probably imply that periods > 13 s relate to bigger waves that citizen data collectors do not try to ride. For periods ≤ 4 it is clear that surfed days present lower values than non-surfed days. These patterns can be explained that probably the day was categorized as surfed day, but big swell did not arrive the entire day. Finally, we see that for surfed days the T_p which fit better are the ones defined as medium (4, 8] and high (8, 13] periods for the Mediterranean. This can be explained because surfing needs high periods, as that way surfers have more time between waves, waves are tidier and do not overlap each other.

Figure 11 plots D_{md}, distribution by cardinal points for surfed and non-surfed days. The most frequent direction on surfed days is east and southeast. Moreover, surfing is less frequent with south, but still possible. Surfing is also viable with a southwest swell direction, but it is less frequent compared with the other directions mentioned before. Furthermore, in surfed days the D_{md} most relevant is [E]. This range of direction matches with the orientation of the surf spots in Tarragona's area. The next most common D_{md} is the interval of [SE] which cover the surf spots that are more oriented to the S. From this information it is possible to say that the most common origin of swells in this area will be the swells coming from (1) the east. Then, it is possible to have surfing days when the swell is coming from (2) SE or S. The surfed days on which is identified another D_{md} of these two mentioned would probably be attributed to being those on which the swell is too big (m) and the diffraction does not lose much energy and can arrive to surf spots. Nevertheless, the D_{md} is not directly focused to the surf spot orientation. The graph of non-surfed days allows us to determine that for surfing purposes in the Costa Tarragona area values of E D_{md} fit better than SE D_{md} values. Note that this is studied grouping surf spots and it is possible once they were desegregated, that maybe there is one surf spot which does not fit correctly with E D_{md} values.

The above study shows that with H_{m0} values from the buoys, it is possible to consider the monthly distribution of surfing days around the Iberian Peninsula coast with a macroanalysis (buoy-by-buoy). In addition, with swell direction it is possible to convert that macroanalysis into a microanalysis, downscaling buoy data to the surf spots. In this way, it is possible to attribute the surfing waves occurrence probability to the surf spots which are closer to the analyzed buoys.

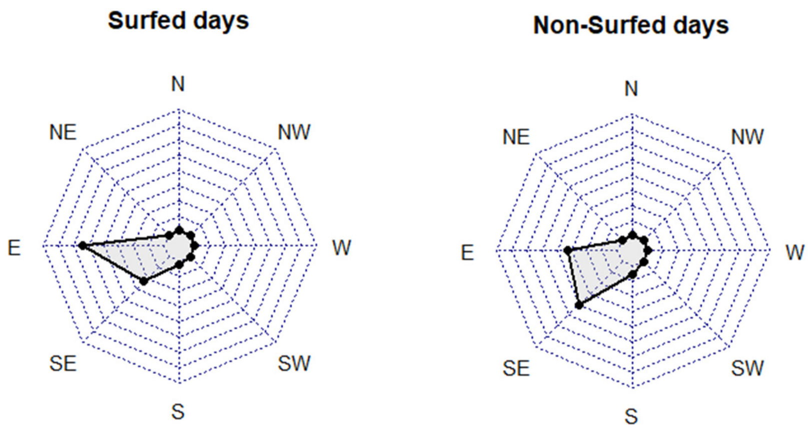

Figure 11. Percentage of D_{md} distribution grouped by surfed and non-surfed days hourly observations in Costa Tarragona's buoy (2006–2019).

Afterwards, thanks to the validation process it is possible to know whether surfing days will correspond to periods of observation when: H_{m0} is higher than 0.9 m (1) and D_{md} corresponds to the O_{sd} on *Glassy app* (2). The validation process is possible thanks to BDS on the Tarragona coast, GAC and GAS.

Table 3 presents Wilcoxon-Mann–Whitney, nonparametric statistical hypothesis test, used to compare two related samples–surfed days and non-surfed days-results show significance for H_{m0}, H_{max} and T_p with surfed and non-surfed days within 0.95 confidence interval.

Table 3. Wilcoxon-Mann–Whitney test for H_{m0}, H_{max} and T_p parameters with surfed and non-surfed days.

	H_{m0} (m) vs. Surf		**H_{max} (m) vs. Surf**		**T_p (s) vs. Surf**	
P-value	$p < 0.01$		$p < 0.01$		$p < 0.01$	
Alternative hypothesis	True location shift is not equal to 0					
95% confidence interval	−0.49996 [1]	−0.40001 [2]	−0.69999 [1]	−0.60004 [2]	−1.89998 [1]	−1.70008 [2]

[1] surfed day, [2] non-surfed day.

3.4. Ranking of Expected Surfing Days Per Year in the Iberian Peninsula

Our previous analyses allow us to rank the surf spots in the Iberian Peninsula according to the expected frequency of surfing days (see Figure 12 and Table 4). Figure 12 shows the distribution of expected surfing days per year for 46 surf spots sorted by regions. Regions with more frequency of expected surfing days are the western shore and northern shore. Shores which present smaller values correspond to southern and southeastern shores. As expected, it is clear that the areas of the Atlantic Ocean present more frequency of surfing days than the shore of the Mediterranean Sea in the Iberian Peninsula. The main results validate the idea that location of surf spots plays an important role in the sense of surfing days frequency. Specifically, following the findings in Table 4, the top-5 surfing spots are on the western shore (>300 days). Values of [300, 200) correspond to surf spots located on the northern shore, specifically into Langosteira and Costa Bilbao Vizacaya placements. Values of [200, 100) are recognized on the northern shore except for Palamós (123, southeastern shore) and La Olla (105, southern shore). Values of <100 are distributed around the southern and south-eastern shore, highest values of this interval correspond to Cadiz's surf spots; this can be explained by the special location, in the vicinity of both the Atlantic Ocean and the Mediterranean Sea.

Table 4. Ranking of best spots for surfing in the Iberian Peninsula.

Surf-spot	Nearest Buoy	% of Expected Surfing Days Per Year [1]	Expected Surfing Days Per Year
Praia do Salgado (43)	Costeira Nazaré	83.28%	304
Praia do Sul (44)	Costeira Nazaré	83.28%	304
Praia da Vila da Nazaré (45)	Costeira Nazaré	83.28%	304
Foz do Arelho (42)	Costeira Nazaré	82.52%	301
Nazaré (46)	Costeira Nazaré	82.51%	301
Repibelo (26)	Lagosteira	65.23%	238
Playa de Sabón (26)	Lagosteira	65.23%	238
Sonabia (29)	Bilbao Vizcaya	59.30%	217
Punta Galea (30)	Bilbao Vizcaya	59.30%	217
La Arena (31)	Bilbao Vizcaya	59.30%	217
Arriguanaga (32)	Bilbao Vizcaya	59.30%	217
Ereaga (33)	Bilbao Vizcaya	59.30%	217
Pobeña (11)	Costa Bilbao	53.25%	194
Playa de Poniente (12)	Costa Gijón	44.79%	164
Pico de San Pedro (13)	Costa Gijón	44.79%	164
La Fosca (23)	Palamós	33.74%	123
La Olla (39)	Golfo de Cádiz	28.80%	105
La Playita Santa María del Mar (40)	Golfo de Cádiz	23.93%	87
Playa de Levante (35)	Cabo de Palos	23.93%	87
Playa de las Almoaderas (36)	Cabo de Palos	23.93%	87
Playa Entremares (37)	Cabo de Palos	23.93%	75
Prat (9)	Costa Barcelona	20.63%	67
Ladeira (38)	Cabo Silleiro	18.22%	55
Port Sa Playa (17)	Costa Valencia	15.09%	55
Las Acelgas (18)	Costa Valencia	15.09%	55
Camping Patacona (19) Patacona (20)	Costa Valencia	15.09%	55
Las Arenas (22)	Costa Valencia	15.09%	55
La Pineda (25)	Tarragona	13.90%	51
Playa de Cabo de Gata (34)	Cabo de Gata	11.77%	43
Platja del Castell (24)	Palamos	9.32%	34
La Malva-rosa (21)	Costa Valencia	8.72%	32
Playa de la Malagueta (14)	Costa Málaga	6.53%	24
Morlaco (15)	Costa Málaga	4.65%	17
Albufereta (4)	Costa Alicante	4.56%	17
La Calita (3)	Costa Alicante	4.23%	15
Playa Postiguet (5)	Costa Alicante	4.01%	15
Urbanova (6)	Costa Alicante	4.01%	15
Arenales del Sol (7)	Costa Alicante	4.01%	15
Palmones (1)	Costa Algeciras	1.70%	6
Carbassí (8)	Costa Alicante	0.88%	3
Getares (16)	Costa Punta Carnero	0.68%	2
El Rinconcillo (2)	Costa Algeciras	0.14%	1
Valcovo (28)	Lagosteiraa	No data	No data
Playa de Matadeiro (41)	La Corunha	No data	No data
Orzán (42)	La Corunha	No data	No data

[1] considering $H_{m0} > 0.9$ m & favourable D_{md}.

The four extreme cases of low values, of expected surfing days per year are El Rinconcillo (1), Getares (2), Carbassí (3) and Palmones (6). El Rinconcillo, Getares and Palmones are in the same gulf; its geomorphological structure influence waves arrival obstructing waves propagation.

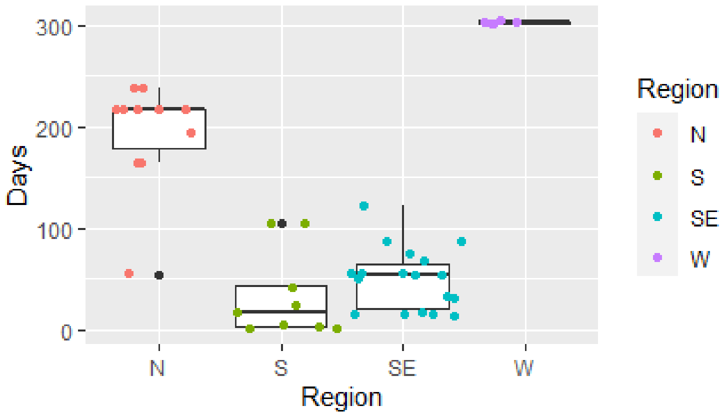

Figure 12. Jitter plot of expected surfing days per year by regions in the Iberian Peninsula.

4. Discussion and Conclusions

Buckley, R [31] explained that waves and snow provide natural resources for adventure tourism and, therefore, these activities are affected by changing weather patterns—and most strikingly by those associated with climate variability and climate change. The global framework for climate services [32], presents climate services as a way to provide climate information to help individuals and organizations to make informed decisions adapted to the varying and changing climate conditions.

Our research represents an advance in the knowledge of the expected surfing conditions in the Iberian Peninsula through a new methodology which characterizes the number of expected surfing days per year in specific surf spots. Following Butt, T [33,34], we attribute buoy wave data to wave height in nearby surf spots, approaching the propagation mechanisms of free-traveling swell and the radial dispersion once the swell reaches shallow water. Our results clearly define how the surfing potential in terms of weather, oceanographic and geomorphologic conditions, is not homogeneous around the Iberian Peninsula's coast. This has obvious implications in the management of these touristic areas and provides insights into whether the surf activity may be successful. Previous studies by Peñas de Aro, P [27] identified the distribution of surfing days in Mallorca and the research of Espejo, A [23–25] studied the spatial and temporal variability of surfing resources around the world. We agree with them in calculating the expected surfing days for specific surf spots from BDS, we add GAS and GAC in order to validate more directly waves parameters to necessary conditions for surfing.

Espejo, A [23,25] found relevant distribution patterns of surfing conditions on a global scale. Conversely, our study makes a special contribution on a local scale to the science thanks to the use of citizen science data. Our validated methodology allows us to know how H_{m0} distribution matches with expected surfing days distribution around the Iberian Peninsula. We find relevant distribution patterns on surfing conditions which vary spatially and temporally. Knowing how they vary seasonally, annually and in the longer term can help decision-making within the surfing tourism industry. Results allow to evidence how climate variations can harm or benefit the activity of surfing. For example, more storms in terms of frequency and intensity on the southern and southeastern shore area will probably harm sun and beach tourism climatological/meteorological requirements. Nevertheless, this fact can produce more frequency of surfing days per year which can be an opportunity for developing this sector. For western and northern shores, the increase of storms associated with strong winds on the shore can possibly contribute to the decrease of perfect conditions for surfing.

Nevertheless, it is also important to defend the preservation of coastal surfing resources as discussed by Martin, S.A [35] who criticized the "wonderland" in Mentawai Islands in Indonesia. Martin, S.A [35] and Buckley, R [31] argue that with better practice, principles of tourism development may allow new more effective foundations for surfing tourist space in pursuit of sustainable tourism development, and in this respect, the present research provides an introduction to creating a climate service for surfing tourism, which can develop the sustainable development needs for surf tourism.

Hritz, N. et al. [36] highlight the fact that surfing tourism has increased in popularity but has received little attention related to its economic impact. This study is a step towards understanding the surf resources (number of expected surfing days) and helping produce a sustainable economic impact. In this way, the strategies for planning surfing tourism must be different, depending on the location of the surf spots.

Research has explored the advances in climate services in multiple fields but determining the frequency of surfing days around the Iberian Peninsula by attributing data from oceanographic buoys to surf spots has not been done before. Further research could focus on developing a prototype for surf tourism industry translating this historical wave study to tailored wave forecasting. The forecast data and information collected for the future surfing climate services should be transformed into customized products to assist different surfing user communities (tourist destination managers, surf schools, tourist accommodation establishments, particularly surf camps, etc.)

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Buoys Characteristics and Variables Formulas

Figure A1. Surf spots attributed to Costa Tarragona's buoy and used in the benchmarking process.

Table A1. Synthesis of nearshore wave buoy and corresponding surfing location.

ID	Name of the Buoy	Name of the Surf Spot/s	Distance to the Nearest Surf Spot (km)	Average Distance to All Surf Spots (km)	Furthest Surf Spot Distance (km)
1	Costa Algeciras	Palmones (1), El Rinconcillo (2)	1.26	2324.21	4031.70
2	Costa Alicante	La Calita (3), Albufereta (4), Playa Postiguet (5), Urbanova (6), Arenales del Sol (7), Carabassí (8)	5.53	2411.51	4235.20
3	Costa Barcelona	Prat (9)	3.25	2636.72	4578.07
4	Costa Bilbao	La Arena (10), Pobeña (11)	1.96	2682.41	4813.64
5	Costa Gijon	Playa de Poniente (12), Pico de San Pedro (13)	0.96	2700.20	4857.07
6	Costa Malaga	Playa de la Malagueta (14), Morlaco (15)	2.54	2330.16	4088.26
7	Costa Punta Carnero	Getares (16)	1.92	2324.21	4032.13
8	Costa Valencia	Port Sa Playa (17), Las Acelgas (18), Camping Patacona (19), Patacona (20), La Malva-rosa (21), Las Arenas (22)	4.21	2465.36	4368.13
9	Palamos	La Fosca (23), Platja del Castell (24)	1.66	2711.06	4645.74
10	Pasajes	Any surf spot detected	8.49	2697.83	4806.60
11	Costa Tarragona	La Pineda (25)	1.34	2592.93	4549.53
12	Langosteira	Playa de Sabón (26), Repibelo (27), Valcovo (28)	3.75	2736.35	4876.90
13	Punta Carnero	Getares (16)	3.62	2323.73	4028.77
14	Bilbao Vizcaya	Sonabia (29), Punta Galea (30), La Arena (31), Arriguanaga (32), Ereaga (33)	8.80	2699.80	4821.50
15	Cabo Begur	Any identified surf spot	43.30	2740.84	4662.30
16	Cabo de Gata	Playa Cabo de Gata (34)	2.35	2340.01	4071.49
17	Cabo de Palos	Playa de Levante (35), Playa de las Almoaderas (36), Playa Entremares (37)	5.81	2388.21	4169.50
18	Cabo Silleiro	Ladeira (38)	11.37	2657.48	4749.88
19	Golfo de Cadiz	La Olla (39), La Playita Santa María del Mar (40)	52.25	2356.35	4102.31
20	Tarragona	La Pineda (25)	17.39	2585.54	4533.93
21	Valencia Copa	Port Sa Playa (17), Las Acelgas (18), Camping Patacona (19), Patacona (20), La Malva-rosa (21), Las Arenas (22)	40.24	2479.73	4373.70
22	Gijon	Playa de Poniente (12), Pico de San Pedro (13)	3.97	2703.04	4860.72
23	La Corunha	Playa de Matadeiro (41), Orzán (42)	27.75	2736.05	4879.97
24	Costa Silleiro	Ladeira (38)	7.58	2655.04	4748.51
25	Nazaré	Foz do Arelho (42), Praia do Salgado (43), Praia do Sul (44), Praia da Vila da Nazaré (45), Nazaré (46)	9.86	2519.80	4479.34

Wave buoy parameters description: swell is made of a superposition of groups of waves from different periods. The period of the group with the most energy is called the peak wave period denoted T_p, (Equations (A1) and (A2)) [30] where the peak frequency is the frequency which corresponds to the maximum of S(f) [37]. Average of wave mean direction is recognized as D_{md} or θ_m (Equation (A3)) [38] maximum wave height occurring in a record is recognized as H_{max}. (Equation (A4)) [39] this may be estimated from H_{m0} and T_p (which is the medium period of trains of waves superposition). Spectra parameters can be defined from different relations with the density spectra function, r is the momentum (m_r) of spectral density function $S(\omega)$ (Equation (A5)) [37].

$$T_p = {f_p}^{-1} \tag{A1}$$

where f_p is wave frequency corresponding to peak of the spectrum (modal or peak frequency).

$$T_p = \frac{2\pi}{\omega_p} \tag{A2}$$

where ω_p is angular frequency in the peak of the spectrum.

$$\theta_m = \arctan\left[\frac{\int_0^{2\mu}\int_0^{\infty} \sin\theta S\,(\omega,\ \theta) d\omega d\theta}{\int_0^{2\mu}\int_0^{\infty} \cos\theta S\,(\omega,\ \theta) d\omega d\theta}\right] \tag{A3}$$

where $S\,(\omega,\ \theta)$ is full description of the directional wave spectrum from directional buoy register.

$$Hmax = \overline{Hm0}\sqrt{0.5 \ln N} \tag{A4}$$

where $Hmax$ is maximum wave height, $\overline{Hm\text{O}}$ is mean of significant wave height, N is counted observations of waves.

$$m_r = \int_0^{\infty} \omega^r S(\omega) \mathrm{d}\omega,\ \mathrm{r} = 0,\ 1,\ 2\ldots \tag{A5}$$

where ω is angular frequency. This function represents the wave energy averaged over the sea state for each frequency.

Appendix B. Bottom Type and Surf Break Characterization

As described in Section 1, bottom type is an important characteristic for a surf spot as it contributes to define how waves will break. Figure A2 shows the percentage of bottom types in the IP surf spots. Sand is the most frequent type (62.16%), followed by sand and rocks (17.20%) and rocks (17.20%). The remaining 3.44% are unknown.

Figure A3 provides information on the distribution of the different surf breaks around the Iberian Peninsula. The results show that in all the regions, the most common surf break is beach break (78.2%), followed by point breaks (11.8%), the lest frequent being reef breaks (9.6%). The remaining 0.4 are unknown.

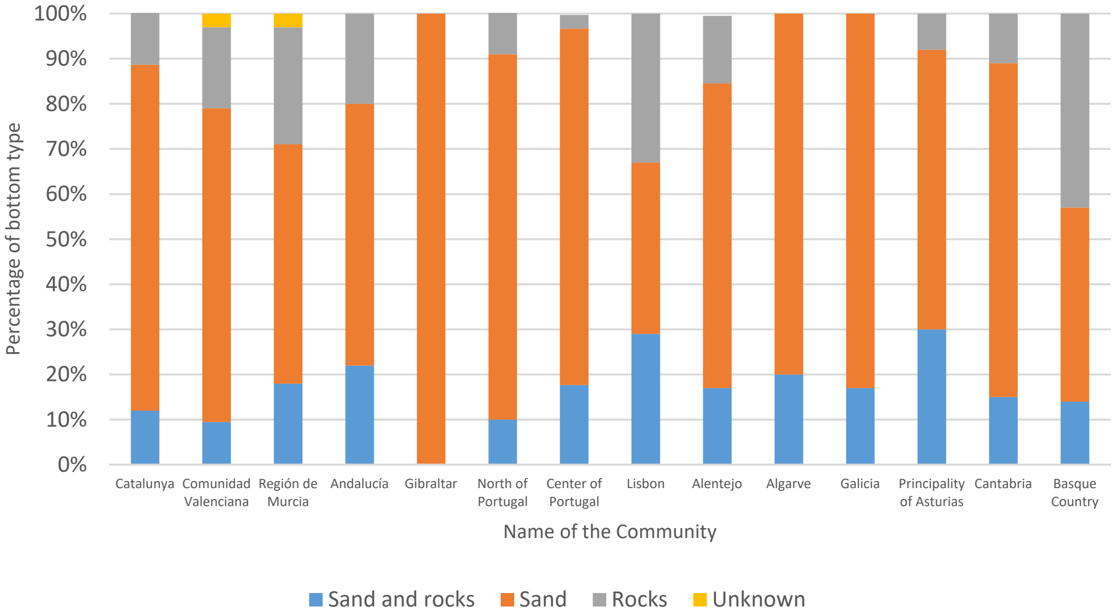

Figure A2. Distribution of bottom type grouped by NUTS2 division (%).

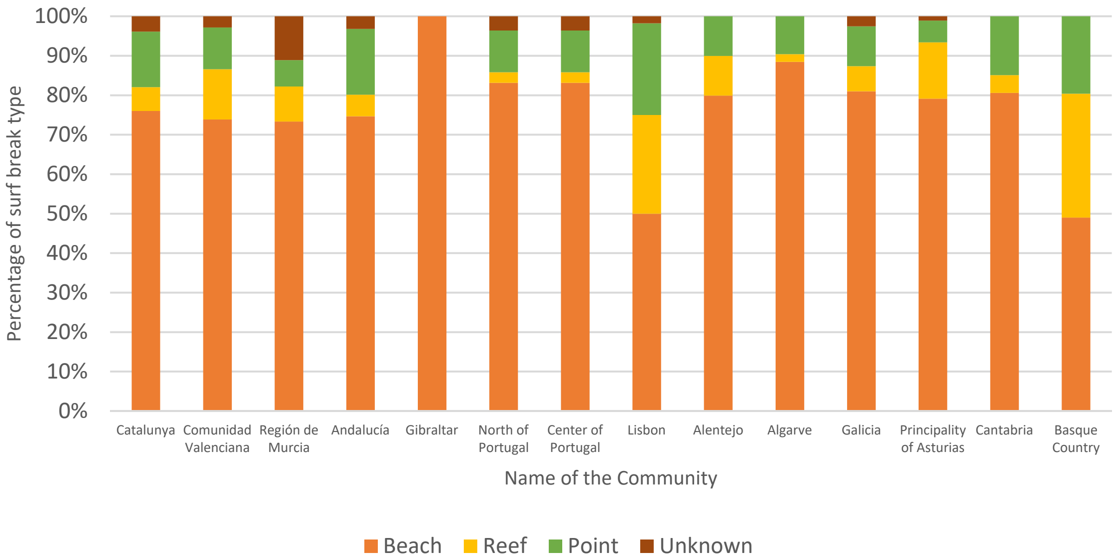

Figure A3. Distribution of surf break type grouped by NUTS2 division (%).

References

1. Butt, T.; Russell, P. Investigating the accuracy of surf forecasts over various time scales. *Reef J.* **2009**, *1*, 112–118.
2. Reineman, D.R. The utility of surfers' wave knowledge for coastal management. *Mar. Policy* **2016**, *67*, 139–147. [CrossRef]
3. Reynolds, Z.; Hritz, N.M. Surfing as adventure travel: Motivations and lifestyles. *J. Tour. Insights* **2012**, *3*. [CrossRef]
4. Reineman, D.R.; Ardoin, N.M. Sustainable tourism and the management of nearshore coastal places: Place attachment and disruption to surf-spots. *J. Sustain. Tour.* **2018**, *26*, 325–340. [CrossRef]
5. Hutt, J.; Black, K.P.; Mead, S.T. Classification of Surf Breaks in Relation to Surfing Skill. *J. Coast. Res.* **2001**, 66–81. Available online: www.jstor.org/stable/25736206 (accessed on 29 March 2020).
6. Scarfe, B.E.; Elwany, M.H.S.; Mead, S.T.; Black, K.P. The Science of Surfing Waves and Surfing Breaks—A Review. 2003. Available online: https://escholarship.org/uc/item/6h72j1fz (accessed on 16 January 2020).

7. Wiegel, R.L. Wind waves and swell. *Coast. Eng. Proc.* **1960**, *1*, 1. [CrossRef]
8. Cool, N. *The Origin of Waves. The WetSand WaveCast Guide to Surf Forecasting: A Simple Approach to Planning the Perfect Sessions*; iUniverse: Bloomington, IN, USA, 2003; Chapter 4, pp. 10–25.
9. Douglass, S.L. Influence of wind on breaking waves. *J. Waterw. Port Coast. Ocean Eng.* **1990**, *116*, 651–663. [CrossRef]
10. Scarfe, B.E.; Elwany, M.; Hany, S.; Black, K.P. UC San Diego Scripps Institution of Oceanography Technical Report Title Surfing Conditions around Jetties Publication Date. Available online: https://escholarship.org/uc/item/28612336 (accessed on 6 March 2003).
11. Mead, S.; Black, K. Predicting the Breaking Intensity of Surfing Waves. *J. Coast. Res.* 2001, pp. 51–65. Available online: www.jstor.org/stable/25736205 (accessed on 6 March 2003).
12. Mendonça, A.; Fortes, C.J.; Capitão, R.; Neves, M.G.; Antunes do Carmo, J.S.; Moura, T. Hydrodynamics around an artificial surfing reef at Leirosa, Portugal. *J. Waterw. Port Coast. Ocean Eng.* **2012**, *138*, 226–235. [CrossRef]
13. Walker, J.R. *"Recreational surf parameters." Technical Rep. 30. Look Laboratory of Oceanographic Engineering*; James, K.K., Ed.; University of Hawaii, Manoa: Honolulu, HI, USA, 1974.
14. Scarfe, B.E.; Healy, T.R.; Rennie, H.G. Research-Based Surfing Literature for Coastal Management and the Science of Surfing—A Review. *J. Coast. Res.* **2009**, *25*, 539–557. [CrossRef]
15. Hutt, J.; Black, K.; Mazeiraud, V. Improving the Surfing Climate of Narrowneck Beach. In *Coasts & Ports 2001: Proceedings of the 15th Australasian Coastal and Ocean Engineering Conference, the 8th Australasian Port and Harbour Conference*; Institution of Engineers, Australia: Barton, Australia, 1 January 2001; p. 114.
16. Cinner, J.E.; Bodin, Ö. Livelihood diversification in tropical coastal communities: A network-based approach to analyzing "livelihood landscapes". *PLoS ONE* **2010**, *5*. [CrossRef]
17. Scarfe, B.E. Oceanographic Considerations for the Management and Protection of Surfing Breaks. Available online: www.mountreef.co.nz (accessed on 4 May 2020).
18. Caldwell, M.R.; Hartge, E.H.; Ewing, L.C.; Griggs, G.; Kelly, R.P.; Moser, S.C.; Woodson, C.B. *Coastal Issues. Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*; Island press: Washington, DC, USA, 2013; Chapter 9; p. 168.
19. Corne, N.P. The Implications of Coastal Protection and Development on Surfing. *J. Coast. Res.* **2009**, *252*, 427–434. [CrossRef]
20. Scarfe, B.E.; Healy, T.R.; Rennie, H.G.; Mead, S.T. Sustainable Management of Surfing Breaks: Case Studies and Recommendations. *J. Coast. Res.* **2009**, *253*, 684–703. [CrossRef]
21. Rivera Mateos, M. Paisaje, patrimonio y turismo de surf: Factores de atracción y motivación en el Parque Natural del Estrecho, España. *Cuad. Tur.* **2016**, *37*, 351. [CrossRef]
22. Dally, W.R. Improved Stochastic Models for Surfing Climate. *J. Coast. Res.* **2001**, 41–50. [CrossRef]
23. Espejo, A.; Losada, I.J.; Méndez, F.J. Surfing wave climate variability. *Glob. Planet. Chang.* **2014**, *121*, 19–25. [CrossRef]
24. McGregor, T.; Wills, S. Surfing a Wave of Economic Growth. CAMA Working Paper No. 31/2017. March 2017. Available online: https://ssrn.com/abstract=2955476 (accessed on 28 March 2020).
25. Espejo, A.; Losada, I.; Mendez, F. Global assessment of surfing conditions: Seasonal, interannual and long-term variability. In Proceedings of the AGU Fall Meeting Abstracts, San Francisco, CA, USA, 3–7 December 2012.
26. Lopes, J.T.; Bicudo, P. Surfing tourism plan: Madeira Island case study. *Eur. J. Tour. Res.* **2017**, *16*, 45–56.
27. Peñas de Haro, P.E. La Geografía del Surf y el Bodyboard en Mallorca, Clima y Turismo Activo. 1. 2015. Available online: https://dialnet.unirioja.es/servlet/tesis?codigo=59522 (accessed on 13 February 2020).
28. Munk, W.H. *Proposed Uniform Procedure for Observing Waves and Interpreting Instrument Records*; Scripps Institute of Oceanography: La Jolla, CA, USA, 1944.
29. Bretschneinder, C.L. Generation of Waves by Wind State of the Art. *Int. Summer Course Lunteren* **1964**, 160. [CrossRef]
30. Young, I.R.; Verhagen, L.A.; Banner, M.L. A note on the bimodal directional spreading of fetch-limited wind waves. *J. Geophys. Res. Oceans* **1995**, *100*, 773–778. [CrossRef]
31. Buckley, R. Perceived Resource Quality as a Framework to Analyze Impacts of Climate Change on Adventure Tourism: Snow, Surf, Wind, and Whitewater. *Tour. Rev. Int.* **2017**, *21*, 241–254. [CrossRef]
32. The Global Framework for Climate Services (GFCS). *Clim. Serv.* **2016**, *2–3*, 52–53. [CrossRef]

33. Butt, T. *The Surfer's Guide to Waves, Coasts and Climates*; Allison Hodge Publishers: Cornwall, Great Britain, 2009; pp. 48–83.
34. Butt, T.; Russell, P.; Grigg, R. *Surf Science: An Introduction to Waves for Surfing*; University of Hawaii Press: Honolulu, HI, USA, 2004; pp. 33–285.
35. Andrew Martin, S. The Conservation of Coastal Surfing Resources in Thailand: The Andaman Sea. 2010. Available online: https://www.researchgate.net/publication/228704778 (accessed on 13 February 2020).
36. Hritz, N.; Franzidis, A.F. Exploring the economic significance of the surf tourism market by experience level. *J. Destin. Mark. Manag.* **2018**, *7*, 164–169. [CrossRef]
37. Tomás Sampedro, A. Metodologías de calibración de bases de datos de reanálisis de clima marítimo. Ph.D. Thesis, Universidad de Cantabria, Cantabria, Spain, 2010.
38. Kellogg Brown & Root. *Submarine Pipeline on-bottom Stability. Vol. 1. Analysis and Design Guidelines*; PRCI Project PR-178–01132; Kellogg Brown & Root: Houston, TX, USA, 2002.
39. Laing, A.K.; Gemmill, W.; Magnusson, A.K.; Burroughs, L.; Reistad, M.; Khandekar, M.; Carter, D.J.T. *Guide to Wave Analysis*; WMO: Geneva, Switzerland, 1998; Volume 1998, No. 702.