UNIVERSITAT ROVIRA I VIRGILI

DEVELOPING CLIMATE SERVICES FOR SURFING ACTIVITY

Anna Boqué Ciurana

UNIVERSITAT ROVIRA i VIRGILI

Developing climate services for surfing activity

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DOCTORAL THESIS
2022

Ph.D. Dissertation

Developing climate services for surfing activity

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September 2022

Ph.D. Program in City, Territory and Sustainable Planning

Departament de Geografia

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FAIG CONSTAR que aquest treball, titulat "Desenvolupant Serveis Climàtics per l'activitat del surf" que presenta Anna Boqué Ciurana per a l'obtenció del títol de Doctor, ha estat realitzat sota la meva direcció al Departament Geografia d'aquesta universitat.

HAGO CONSTAR que el presente trabajo, titulado "Desarrollando Servicios Climáticos para la actividad del surf"que presenta Anna Boqué Ciurana para la obtención del título de Doctor, ha sido realizado bajo mi dirección en el Departamento Geografía de esta universidad.

I STATE that the present study, entitled "Developing Climate Services for surfing activity", presented by Anna Boqué Ciurana for the award of the degree of Doctor, has been carried out under my supervision at the Department of Geography of this university.

Vila-seca (Tarragona, Espanya), [1 de setembre del 2022]

Vila-seca (Tarragona, España), [1 de septiembre del 2022]

Vila-seca (Tarragona, Spain), [1st of September, 2022]

El/s director/s de la tesi doctoral

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Enric Aguilar Anfrons

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PREFACE

There is a growing need to improve resilience in society relating to climatic hazards and to better manage risks and opportunities deriving from climate variability and change. Several countries are currently attempting to address changes by providing Climate Services (CS, from now onwards). CS provides climatic information in a form that assists decision-making (Hewitt et al., 2012).

Tourist destinations must adapt to climate change to reduce associated risks. Hence, access to CS will be an essential prerequisite for successful adaptation in the tourist sector. For the adaptation to climate variability and change, it CS must be: (1) quality made and suitable; (2) a tool for decision-making; (3) an incentive for social benefits; and (4) communicated adequately (4) (Scott et al., 2011).

This dissertation aims toward the development of a Surfing Climate Service (SCS) activity. Specifically, it explores how a surfing climate service should be built. Different data sources and methods have been used and implemented for this purpose, and we have developed a methodology to define a SCS.

This research project is based on the compilation of three academic publications developed during the Ph.D. course in the Program of City, Territory, and Sustainable Planning at the Centre for Climate Change, C3 and the Department of Geography of the Universitat Rovira i Virgili. Accordingly, the present dissertation is structured as follows:

PART I: consists of two chapters. The first chapter presents the research introduction, describes the working hypothesis and objectives, shows the thesis' structure, and explains the research design and methodology implemented. The second chapter details the general theoretical framework of the dissertation.

PART II: is the central core of the thesis, based on three studies. These studies cover important research directions related to: 1) the definition of the surfing climatology for surf spots around the Iberian Peninsula; 2) the exploration of users' needs for Surfing Climate Services; and 3) the development of SCS users' needs on a local scale.

In this line, the three studies are detailed below:

1) **Boqué Ciurana, A**., & Aguilar, E. (2020). Expected distribution of surfing days in the Iberian Peninsula. *Journal of Marine Science and Engineering*, *8*(8), 599. https://doi.org/10.3390/jmse8080599 [JCR Q1 IF: 2.744]

2) **Boqué Ciurana, A**., & Aguilar, E. (2021). Which Meteorological and Climatological Information Is Requested for Better Surfing Experiences? A Survey-Based Analysis. *Atmosphere*, *12*(3), 293. https://doi.org/10.3390/atmos12030293 [JCR Q3 IF: 3.110]

3) **Boqué Ciurana, A**., Ménendez, M., Suárez Bilbao, M., & Aguilar, E. (2022). Exploring the Climatic Potential of Somo's Surf Spot for Tourist Destination Management. *Sustainability*, 14(14), 8496. https://doi.org/10.3390/su14148496 [JCR Q2 IF: 3.889]

PART III: presents the discussion, conclusions about the main findings of the dissertation, and future research directions.

This doctoral thesis was supported by the Secretariat of Universities and Research of the Department of Business and Knowledge of the Generalitat de Catalunya, the European Union (UE), and the European Social Fund (ESF) predoctoral research grant (2019FI_B_00493, 2020FI_B1_00103, 2021FI_B2_00147). This grant has allowed dedication to the research project for three years and five months of full-time commitment. It has further provided complementary funding to conduct a research visit to:

- **Instituto de Hidráulica Ambiental—Universidad de Cantabria** (Spain).
  Research group: Marine Climate and Climate Change
  Period: 14th June—12th September 2021
  Funding institutions: Secretariat of Universities and Research of the Department of Business and Knowledge of the Generalitat de Catalunya, the European Union (UE), and the European Social Fund (ESF).

During my doctoral thesis development, I have had the opportunity over the years to develop additional research and relationships with international co-authors who have opened up the possibility of establishing future collaborations. Accordingly, here is a scientific article and a book chapter, which do not form the doctoral thesis but nevertheless support it:

1) Font Barnet, A., **Boqué Ciurana, A**., Olano Pozo, J. X., Russo, A., Coscarelli, R., Antronico, L., & Aguilar, E. (2021). Climate services for tourism: An applied methodology for user engagement and co-creation in European destinations. *Climate Services*, *23*, 100249.

2) Coscarelli R., Antronico L., De Pascale F., **Boqué Ciurana A**., Font Barnet A., Russo P.A., Saladié Borraz Ò (2021), Tendenze climatiche e flussi turistici: prime analisi tratte dal Progetto europeo "INDECIS. In: Tagarelli G., Torchia F. (a cura di), Turismo, Paesaggio e Beni Culturali. Prospettive di tutela, valorizzazione e sviluppo sostenibile, Vol. 2, Quaderni della Società Italiana di Scienze del Turismo, Aracne Editrice, Roma, 275-292.

I have presented research outputs in five international congresses, conferences, and workshops, which are listed as follows to the degree of the related link to the thesis:

1) **Boqué Ciurana, A**., & Aguilar, E. (2020, May). How Climate Services can provide the knowledge of the expected surfing days on surf-spots in the Iberian Peninsula. In *EGU General Assembly Conference Abstracts* (p. 9440).
2) **Boqué Ciurana A**. (2021, December). Climate Services for surfing tourism. In *Global ecoforum: tourism and climate.*
3) Olano Pozo, J. X., **Boqué Ciurana, A**., Font Barnet, A., Russo, A., Saladié Borraz, Ò., Anton-Clavé, S., & Aguilar, E. (2020, May). Co-developing climate services with local agents: The INDECIS Snow Tourism Index. In *EGU General Assembly Conference Abstracts* (p. 8926).
4) Coscarelli, R., Antronico, L., **Boqué Ciurana, A.,** De Pascale, F., Font Barnet, A., Russo, A. P., & Saladié Borraz, Ò. (2020, May). Climate trends and tourist flows: first results of the case study in the Sila National Park (southern Italy) within the INDECIS Project. In *EGU General Assembly Conference Abstracts* (p. 2978).
5) **Boqué Ciurana, A**; Font Barnet, A.; Olano Pozo, J. X. (2021, September). " CO-CREATION OF CLIMATE SERVICES WITH LOCAL AGENTS" COURSE:

ADAPTING WMO CLIMATE SERVICE COMPETENCIES IN THE FRAME OF BACHELOR DEGREE ON GEOGRAPHY OF ROVIRA I VIRGILI UNIVERSITY. In *I 73 International Research-to-Practice Conference on Climate Services: Science and Education: Conference Proceedings. Odesa: Odessa State Environmental University, 2021. 144 p. ISBN 978-966-186-162-5* (p. 67).

I have also participated as a facilitator of capacity-building training organized by the World Meteorological Organization (WMO) for different meteorological services in South American countries. Specifically, showing climate services for the agriculture sector inside the ENANDES project: improving the adaptive capacity of Andean communities through Climate Services in Peru, Colombia, and Chile:

1) IDEAM, Bogotá, Colombia: 04/04/2022–11/04/2022
2) SENAMHI, Lima, Perú: 06/06/2022–10/06/2022
3) DMC, Santiago de Chile, Chile: 04/07/2022–08/07/2022

At the beginning of the thesis, the main project related to the dissertation was the INDECIS project due to its particular relation in developing CS for the tourism sector. In this vein, the INDECIS project has created the opportunity to start new projects, and I have the chance to join them as a predoctoral researcher in the Centre for Climate Change, C3, led by Dra. Manola Brunet. All of these projects have contributed to my development and knowledge of Climate Services and practical learning by carrying out specific co-creation processes applied in different sectors: tourism; education; infrastructure; energy; and agriculture (Figure 1).

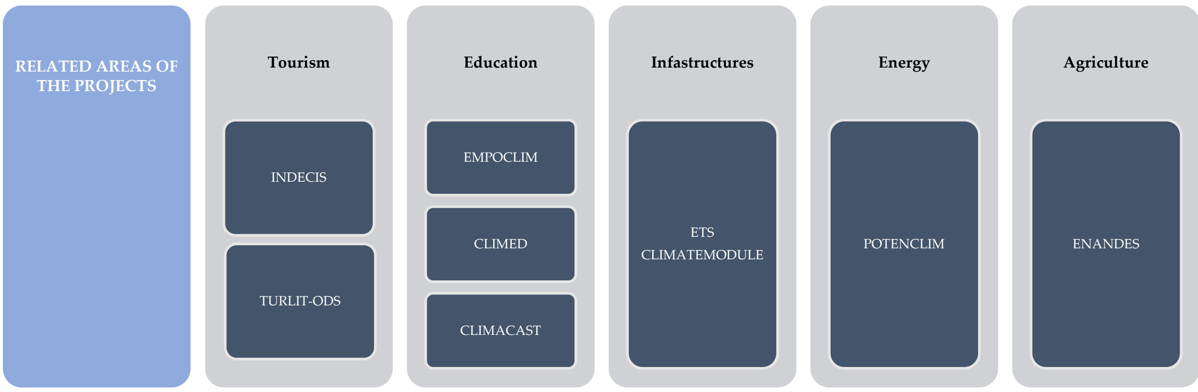

Figure 1. Related areas of the projects.

Source: author's own production

Characteristics of the aforementioned projects:

1) **Integrated approach for the development across Europe of user-oriented climate indicators for GFCS high priority sectors: agriculture, disaster risk reduction, energy, health, water, and tourism (INDECIS)**
Funds: 6,487,647 €
Period: 2017–2020
PI: Dr. Enric Aguillar, Centre for Climate Change, C3, Geography Department, Universitat Rovira i Virgili
Funding Institution: ERA4CS Cofund Grant Agreement nº 690462

2) **Multilevel Local, Nation- and Region-Wide Education and Training in Climate Services, Climate Change Adaptation, and Mitigation (CLIMED)**
Funds: 834,332 €
Period: 2020-11-15, 2023-11-14
PI: Dra. Hanna K. Lappalainen, University of Helsinki
Funding Institution: ERASMUS+KA2: Cooperation for innovation and the exchange of good practices. Capacity building in higher education CBHE 2020.

3) **Empowering educational community to adapt to Climate Change (EMPOCLIM)**
Funds: 13,690 €
Period: September 2021–June 2022
PI: Dra. Gisela Cebrián, Pedagogy Department, Universitat Rovira i Virgili
Funding Institution: Diputació de Tarragona

4) **Determination of the present and future climatic potential of the province of Tarragona for the generation of wind energy (POTENCLIM)**
Funds: 16,407.87 €
Period: September 2021–June 2022

PI: Dr. Enric Aguillar, Centre for Climate Change- C3, Geography Department, Universitat Rovira i Virgili
Funding Institution: Diputació de Tarragona

5) **Co-creation of Climate Change indicators for ETS Risk Management Services for tunnels (MIRET) and infrastructures (MIRETS)**
Funds: 60,500 €
Period: 2022
PI: Dr. Enric Aguilar, Centre for Climate Change, C3, Geography Department, Universitat Rovira i Virgili
Funding Institution: Engineering Technical Services (ETS), private company

6) **Improving the adaptive capacity of Andean communities through Climate Services in Perú, Colombia, and Chile**
Funds: NA
Period: March 2022–July 2022
PI: Dr. Enric Aguilar, Centre for Climate Change, C3, Geography Department, Universitat Rovira i Virgili
Funding Institution: World Meteorological Organization (WMO)

7) **CLIMACAST- Understanding and exposing climate misinformation on podcasts**
Funds: 17,800 €
Period: June 2022–May 2023
PI: Dr. Enric Aguilar, Centre for Climate Change, C3, Geography Department, Universitat Rovira i Virgili
Funding Institution: International Fact-Checking Network (IFCN)

8) **Co-creation of Climate Services for the deseasonalization and diversification of tourist activities on the coast of Tarragona (TURLIT- ODS)**
Funds: 8,500 €

Period: March 2022–December 2022

PI: Dr. Enric Aguilar, Geography Department, Universitat Rovira i Virgili

Funding Institution: Diputació de Tarragona

ACKNOWLEDGEMENTS

I am truly grateful for:

The support and mentoring of Dr. Enric Aguilar, from completing the degree in geography to completing my doctoral studies.

Dr. Javier Sigró's advice, which encouraged me to develop the PhD and motivated me to apply for the predoctoral research grant that allowed me to develop the thesis with specific funds.

The excellent collaboration and support, especially during the INDECIS project, with Dr. Antonio Russo, Dr. Salvador Anton, Dr. Òscar Saladié, and Alba Font.

The welcome from Dra. Manola Brunet in the research group she leads, and all my colleagues in the Centre for Climate Change, special mention to Dr. Jon Olano, Alberto Hueso, Dr. Oleg Skrynyk, Caterina Cimolai, and Luc Yannick Andréas Randriamarolaza.

Thanks to all the surfers and companies from different surf spots in Spain and Portugal, who have followed my research and assisted my study by answering the survey explaining which meteorological and climatological information is needed for a better surfing experience.

Also, the other colleagues of the geography department who shared concerns about developing the Ph.D. as the professors of the faculty, who I have had during the completion of my bachelor's and master's degrees. They inspired me to achieve my objective of developing and defining my Ph.D.

The kind reception and support received in the research stay from Dra. Melisa Ménendez, María Suárez Bilbao, and Dr. Manuel del Jesus at the Hydraulic Institute of the University of Cantabria.

The Secretariat of Universities and Research of the Department of Business and Knowledge of the Generalitat de Catalunya, the European Union (UE), and the European Social Fund (ESF) for supporting this research through a Doctoral Research Grant (2019FI_B_00493, 2020FI_B1_00103, 2021FI_B2_00147).

ABSTRACT

This thesis represents a methodological contribution and a step forward towards the development of climate services for surf. Climate services aim to deliver climate information their users. The information provided must help individuals and organizations to implement climate-smart decisions. The Global Framework for Climate Services states that it equips decision-makers in climate-sensitive sectors to help society to adapt to climate variability and change.

This global framework established five priority areas of action: agriculture and food security; disaster risk reduction; energy; health; and water. However, climate services can be developed for other sectors, such as tourism.

In this thesis we focus on the development of a climate service for surf tourism, which has not attempted before, to our best knowledge. To do so, we first identify the atmospheric and oceanic conditions influencing the practice of surfing. This relies on the previous research and, as a result, we obtain the expected surfing days per year are for the most relevant surf spots in the Iberian Peninsula. This is indicator is validated constructing a citizen science based benchmark, integrated by recorded surfing sessions.

Next, to apprehend the actual needs for meteorological and climatic information by users and companies involved in surfing activity we develop and analyze an online survey.

Finally, responding the necessities identified in the previous steep, an atmospheric-oceanic database with high spatial resolution is developed through a hybrid downscaling approach. A series of indicators are also designed to advise on the activity in tourist destinations. To ascertain the potential application of these indicators, we test them over Somo (Cantabria, Spain), a pioneer and world-known surf Spot in Spain.

RESUM

Aquesta tesi representa una contribució metodològica i un pas endavant cap al desenvolupament de Serveis Climàtics pel surf. Els serveis climàtics pretenen entregar informació climàtica als seus usuaris. La informació que s'entregui ha d'ajudar als individuals i a les organitzacions a implementar decisions climàticament intel·ligents. El Marc Global pels Serveis Climàtics afirma que equipar als *decision makers* dels sectors climàticament sensibles ajuda a la societat a adaptar-se a la variabilitat i al canvi del clima.

Aquest marc global va establir cinc àrees d'actuació prioritària: agricultura, seguretat alimentària; reducció de riscos, energia, salut i aigua. Tot i amb això, els serveis climàtics es poden desenvolupar per altres sectors, com ara el turisme.

Aquesta tesi es centra en el desenvolupament d'un servei climàtic pel turisme del surf, fet que no s'ha intentat abans, segons el nostre coneixement. Per a fer-ho, primerament s'identifiquen les condicions atmosfèriques i oceàniques que influeixen la pràctica de surf. Això segueix la recerca anterior i, com a resultat, s'obtenen els dies esperats de surf per any per aquells *surf spots* més rellevants a la Península Ibèrica. Aquest indicador es validat a través de la construcció d'un *benchmark* basat amb ciència ciutadana, integrat per sessions de surf registrades.

Després, per comprendre les necessitats actuals d'informació climàtica i meteorològica per part d'usuaris i empreses involucrades amb l'activitat del surf, s'ha desenvolupat i analitzat una enquesta en línia.

Finalment, responent a les necessitats identificades en el pas anterior, un *dataset* amotsfèric- oceànic amb alta resolució espacial s'ha desenvolupat a través d'un *downscaling* híbrid. També s'han dissenyat una sèrie d'indicadors per recomanat sobre l'activitat en les destinacions turístiques. Per a veure el potencial d'aplicació d'aquests indicadors, s'han testejat a Somo (Cantabria, Espanya), un pioner i reconegut *surf spot* d'Espanya.

RESUMEN

Esta tesis representa una contribución metodológica y un paso hacia delante para el desarrollo de Servicios Climáticos para el surf. Los servicios climáticos pretenden entregar información climática a sus usuarios. La información que se entregue tiene que ayudar a los individuales y a las organizaciones a implementar decisiones climáticamente inteligentes. El Marco Global por los Servicios Climáticos afirmar que equipar los *decisión makers* de los sectores climáticamente sensitivos ayuda a la sociedad a adaptarse a la variabilidad y al cambio del clima.

Este marco global estableció cinco áreas de actuación prioritaria: agricultura, seguridad alimentaria, reducción de riesgos, energía, salud y agua. Aun así, los servicios climáticos se pueden desarrollar para otros sectores, como ahora el turismo.

Esta tesis se centra en el desarrollo de un servicio climático para el turismo de surf, hecho que no se ha intentado antes, según nuestro conocimiento. Para llevarlo a cabo, primeramente, se identifican las condiciones atmosféricas y oceánicas que influyen en la practica de surf. Esto sigue la investigación anterior y, como resultado, se obtienen los días esperados de surf por año para aquellos *surf spots* más relevantes en la Península Ibérica. Este indicador es validado a través de la construcción de un *benchmark* basado con ciencia ciudadana, integrado por sesiones de surf registradas.

Después, para comprender las necesidades actuales de información climática y meteorológica por parte de los usuarios y las empresas involucradas con la actividad de surf, se ha desarrollado y analizado un cuestionario en línea.

Finalmente, respondiendo a las necesidades identificadas en el paso anterior, un *dataset* atmosférico-oceánico con altra resolución espacial se ha desarrollado a través de un *downscaling* híbrido.

También se han diseñado una serie de indicadores para recomendar sobre la actividad en las destinaciones turísticas. Para ver el potencial de aplicación de estos indicadores, se han testeado a Somo (Cantabria, España), un pionero y reconocido *surf spot* de España.

CONTENTS

TABLES

FIGURES

LIST OF ACRONYMS

Abbreviation	Definition
AO	Alternative offers
BDS	Buoys dataset
CS	Climate Service
D_{md}	Mean wave direction
E	East
GAC	Glassy App Citizen data
GAS	Glassy App Site
GFCS	Global framework for Climate Services
H_{m0}	Significant wave height
H_{max}	Maximum wave
N	North
NE	North east
NW	North west
O_{sd}	Optimal swell direction
O_{wd}	Optimal wind direction
S	South
SCS	Surfing Climate Service
SD	Surfing days
SDS	Surfing days stratified by surfers' skills
SE	South east
SUP	Stand Up Paddle
SUP waves	Stand Up Paddle with waves
SuS	Surfers' safety
SW	South west
SWOP	Surfing waves occurrence probability
SwS	Swimmers' safety
T_p	Peak period of the wave
W	West
Wd	Wind direction
We	Wave energy
WMO	World Meteorological Organization
Ws	Wind speed
obs_m	Total number of observations per month
obs_{crm}	Number of hourly observations that meet the required conditions
n_m	Number of days in that month
I_m	Monthly indicator

PART I. INTRODUCTION

1. Research presentation

This first chapter is focused on presenting the general context and the basic conceptual framework of the research and describing the aims, research objectives, and hypotheses. The thesis structure, research design, and methodology are also shown.

1.1 Introduction

Nowadays, the systematic evaluation of the extension and nature of the use of climatic information for tourism subsectors and/or specific destinations is limited or non-existent. Here we face different challenges: (1) the relation between weather/climate and the viability of specific tourism activities, (2) the knowledge of the role of the use of climatic information in decision-making processes, and (3) the efficiency of the communication with to end users.

A thorough investigation of these knowledge gaps may lead to significant opportunities to promote the improvement of decision-making in the tourism sector and consequently reduce the climatic risk to that sector.

This research explores these three gaps, finding the atmospheric-ocean conditions influencing surfing activity and other water activities such as windsurfing and standup paddleboarding (SUP from now onwards). We explore the role of meteorological and climatological information for surfing activity and we collect and develop the fine-resolution data required to inform the surfers and agents involved in surfing. We finally design a prototype to communicate this information with users.

Understanding the role of climate and weather in tourism is vital to understanding how it can harm or benefit tourist activities. Relating sport tourism, or more specifically the surfing subsector, we can relate the surfing conditions of a particular territory to the coast morphology, climate and weather patterns, among other factors. Atmospheric variations exert their impact in time scales of days, months, and years and condition the viability of surfing as well as the skills require to surf in a given day and place.

To understand the occurrence of surfing days, researchers must explore the climate system, how the atmosphere exchanges energy with the ocean, and how this affects low and high pressure systems. Once these processes are examined, understanding the occurrence of favourable surfing conditions will be easier (Espejo et al., 2011).

To better manage tourist activity and enhance resilience in front of climate variability and change, a climate service (CS) can work as a practical tool to provide users with usable and actionable information on climate variability, climate change impacts, and related risks, opportunities, and uncertainties. With this aim, the purpose of a CS is to develop, translate and customize climate information to the various user needs, considering all related stakeholders, such as academics, NGOs, decision-makers in enterprises and administrative bodies, policy-makers at multiple levels of government, and citizens (JPI Climate, 2016; Lechozky, 2017). Proficient use of this information is meant to offer essential benefits to society. According to the World Meteorological Organization (WMO, 2015), effective use of climate information has the potential for reducing the effects of natural hazards, as well as conveying a broader range of societal benefits, like the avoidance of injury or loss of life, the protection of property, or increasing the safety and comfort of everyday life. Moreover, the information can bring profitability and productivity that strengthen national economies by providing a solid base for future planning.

As the present thesis aims to define a methodology to develop a "surfing climate service "(SCS), user–provider engagement is considered a fundamental element in preparing, developing, and using climate information as a CS for decision-making. Collaboration between decision-makers and climate scientists is key to leveraging expertise from both parties to solve problems better (Briley et al., 2015; Golding et al., 2017). Research demonstrates (Bruno et al., 2018; Golding et al., 2017) that stakeholders' participation in the production of a CS is a necessary condition for the successful implementation of the CS, and effective user engagement in the co-production of climate services is vital to guarantee their value and impact. To enable society to better manage the risks and opportunities arising from changes in climate, engagement between the users and the providers of climate information needs to be much more effective and should more efficiently link climate information with decision-making (Hewitt et al., 2017). The present investigation engages end users by employing an online survey.

As this research generates the foundation for an SCS, it must have its current societal relevance, value, and expected benefits. A climate service's values should exist at local, national, regional, and international levels and are implemented in a range of different sectors, including agriculture, healthcare, forestry, fisheries, transportation, energy, disaster risk reduction, water resources management, and tourism (Vaughan et al., 2014). This research paves the way for specific CS for the surfing tourist sector.

Tourism is one of the economic activities that can be most affected by climate change. Along this same line, tourism is a vulnerable activity in a variable exposition, depending on the kind of tourism located in a specific place (Olcina, 2012).

Some forms of tourist activity are more sensitive and dependent on climate and meteorological conditions than others (e.g. outdoor, snow-based, rural tourism). All tourist destinations are to some extent at least climate sensitive, reacting to weather and intra/interannual climate variability or to extreme meteorological phenomena. These factors influence competitiveness and sustainability in both the short and long term (Gómez-Martín et al., 2017). For this reason, it this thesis will explore for the first time how surfing destinations at regional and local levels are climate sensitive.

Similarly, accurate geographically specific meteorological information is essential for tourism operations. That means that each location has its own particular conditions, so there is a need to create a CS focused on the reality of the territory. Likewise, reliance on general regional forecasts, which may differ substantially from specific conditions of destinations that are often characterized by a unique weather/microclimate, could cause mistaken decisions to be taken, thereby damaging the destination. Thus, producing a CS at an appropriate, often tailor-made, geographical scale (which may overcome administrative and even geographical boundaries or be restricted to a few stations) is also a key component of their value. Regarding the results of the online survey developed for this research, a hybrid downscaling method has been applied to achieve high-resolution data on both spatial and temporal scales.

Nowadays, the actual uptake and application of climate services are limited as the studies in this area remain low (Skelton et al., 2019). The need to provide climate information to society has been recognized for many decades. For example, the first World Climate Conference held in 1979 by the WMO called for establishing the World Climate Programme to improve our understanding of climate systems and their impact on society (Vaughan et al., 2014). More recently, climate services have become a standard practice to describe user-oriented approaches to making climate information available (Weisse et al., 2015). Due to this context, this work aims to explore climate as a subsector of tourism activity.

Surfing tourism takes part in coastal tourism and recreation and contributes substantially to national economies while at the same time providing pleasure and joy to people through beneficial physical and mental stimulation (White et al., 2010; Barbier, 2017), as well as other significant social benefits (Irvine et al., 2013; Rocher et al., 2020). At the same time, the research interest in nature-based activities is growing (Coventry et al., 2021). Still, the development of climate services for these activities has been largely unexplored (Font Barnet et al., 2021), and surfing tourism constitutes one of the nature-based activities dependent on climate-related information.

The sustainability of these coastal destinations may be compromised by recreational marine activities if carried out unsustainably, harming the ecosystems (Rees et al., 2010; Wyles et al., 2014). Tourists may jeopardize the sustainability of surfing destinations. As surfing is one of the many recreational activities supported by the marine environment, that is, it is a human activity that depends on natural capital (e.g. wave break) or environmental features (e.g. water quality). Therefore, it can be studied as a cultural ecosystem service benefit that contributes to human mental and physical health. The influence of this sport spreads throughout different sectors (e.g. economic, environmental, and sociocultural), being one of the world's most popular marine recreational activities (Orams & Towner, 2012).

Because of this popularity, the capacity of marine and coastal ecosystems to supply recreational benefits such as surfing depends on the sustainable use and integrated management of those ecosystems to guarantee that they remain clean and healthy. Framing the activity into sustainable tourism development is essential to ensure a balance of the effects between the economic, social, and environmental dimensions

(Carbone, 2005). In this context, studies that analyse the performance of touristic and recreational activities in the marine realm are urgently needed (Román et al., 2022) to measure if they occur sustainably and in line with the UN's 2030 Agenda for Sustainable Development (United Nations, 2015).

Nowadays, the increasing social interest in surfing has brought with it an increase in scientific interest and an expansion in the number of publications and topics covered in the literature (Román et al., 2022). In this context, this dissertation emerges from the need to delve into the knowledge of surfing climatology and understand the users' needs for a surfing climate service. The present work raises several research objectives. The existing literature tends to show that tourism is closely related to weather, climate, and climate change. This thesis is also focused on exploring the importance of stakeholders' engagement and ability to adapt and mitigate climate change in tourist destinations. Also, from the literature emerges an opportunity to develop climate services for climate-sensitive sectors, even though we are unaware of any research on developing specific climate services for surfing activity.

1.2 Working hypothesis and research objectives of the thesis

The purpose of this section is to detail the working hypothesis and research questions as wells as to present our main objective. This objective is achieved through different specific objectives associated with the three research articles which compile this dissertation.

The hypothesis of this research (Figure 2) proposes that tourist management for coastal destinations can be improved through the development and use of a co-created surfing climate service (SCS). If the hypothesis is true, tourist destinations can be better managed, planned, and promoted by knowing the information that may address decision-making in the surfing tourism sector. The hypothesis implies that transforming atmospheric–oceanic data into information promotes resilient climate actions. To achieve this goal, it is necessary knowing which data needs to be converted and in what way in cooperation between scientists, surfers, and surfing schools, among others. This cooperation is gained through user engagement and co-creation during the climate service development.

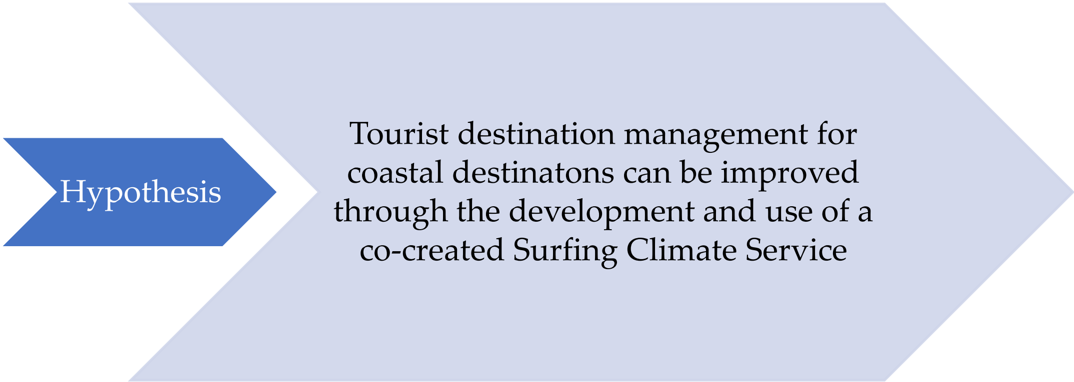

Figure 2. Research hypothesis

Source: author's own production

This thesis's research design and development were motivated by the following questions: which is the number of expected surfing days for each surf spots in the Iberian Peninsula? Which are the atmospheric–oceanic conditions that make surfing possible? How can climate services provide better information to surf-destination managers and surfers? Would surfers or surf schools benefit from the development of specific services derived from their specific needs to foster better surfing? Do surfers have different preferences in receiving the information depending on their surfing skills? Can climate data assess an alternative surfing offer when conditions prevent surfing? How may this climate-resilient information be communicated to end users? How can we develop a surfing climate service?

The principal research objective (Figure 3) is to develop a methodology to define a surfing climate service that equips decision-makers in the surfing tourism sector to help the destination to better adapt to climate variability and change. That means that the research may address the challenges of developing an accurate climate service in a specific sector that has not been previously explored. As a starting point, the study follows the global framework of climate services guidelines (WMO, 2015). We also explore and consider the most recent literature explains about tourism, weather, climate, and oceanic conditions.

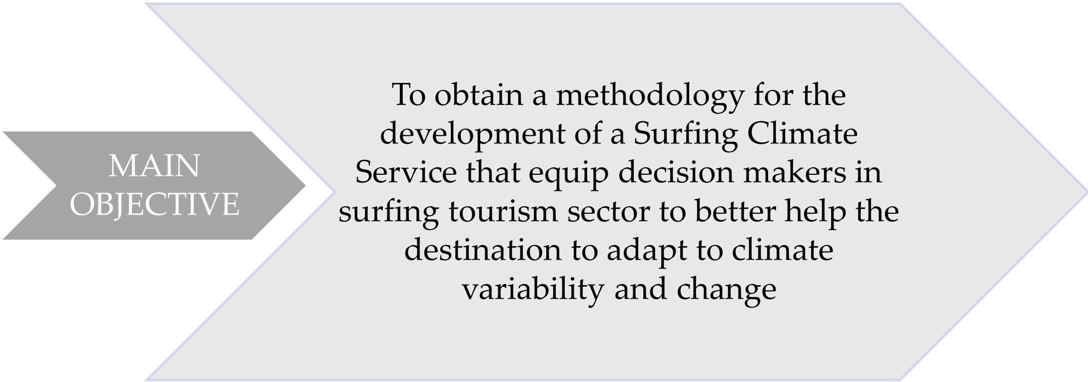

Figure 3. Main objective

Source: author's own production

With the goal to define a methodology to develop a surfing climate service (SCS), this research project is highly interdisciplinary and has as its foundation the pre-existing knowledge of (1) relations between weather, climate, and tourism and (2) the development of a CS. Thanks to the literature review, it is possible to design and develop a methodology to establish surfing climatology on a regional scale.

This research starts with the definition, for the first time, of a the Iberian Peninsula's surfing climatology, explicitly focusing on specific surf spots located near oceanic buoys offshore. The exploration and study of the atmospheric–oceanic conditions that influence surfing to facilitate their knowledge of local expected surfing days across the Iberian Peninsula.

Thus, the first specific research objective (Figure 4) involves identifying the atmospheric–oceanic conditions that make surfing possible and relate them to climate variables. It is possible to comprehend surfing wave spatial behaviour in surf spots in the Iberian Peninsula and design a methodology to establish the expected surfing days per year in specific surf spots. This first objective emerges from Scott et al., 2005 who demonstrated that climate and weather conditions for outdoor recreation construct the basis to identify which activities are or are not viable in certain territories and moments. We also considered what Buckley et al. (2002) who indicated that surf, snow, and white water provide natural resources for adventure tourism. The resources themselves and their tourism access depend on the weather; hence, climate change affects them.

We consider Butt et al., (2009) to understand the science of surfing waves, where waves are formed, and how they travel to the shore. The present dissertation pays attention to Espejo et al., (2014) and Peñas de Haro (2015), who previously explored surfing climatology on both a global and a regional scale. The authors are the primary references for how to develop surfing climatology indicators.

In this context, and as the correct management of surfing activity requires the analysis of the primary resource that makes the activity possible, the present research aims to explore surfing wave climatology by using oceanic buoy data.

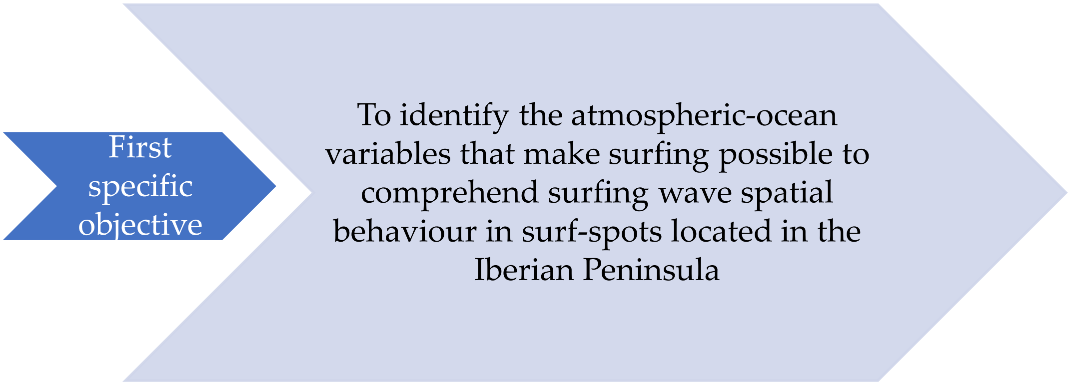

Figure 4. First specific objective of the research.

Source: author's own production

Secondly, in consonance with our goal to define a service, we refine our knowledge through the online exploration of users' needs. The second specific objective (Figure 5) is focused on exploring and understanding which meteorological and climatological information is requested for a better surfing experience. As surfing activity generates impacts and benefits in social, economic, and environmental spheres, with consequences for a diverse group of stakeholders beyond surfers (Román et al., 2022), we explored the perceptions of surfers and businesses that offer this activity.

Previous research has explored through an online survey instrument the examination of serious surfers and the implications for the surf tourism industry (Sotomayor et al., 2015). However, that study was not focused on what climatological and meteorological information surfers could consult for a better surfing experience and that examination surveyed a sample size of only 52 surfers.

Farmer (1992) explored the different types of surfers, and Dolnicar et al. (2003) identified five segments of surfers in Australia with distinct demographic and surf-related preferences (e.g. types of waves and challenges), and travel behaviours. Existing studies (Farmer, 1992; Dolnicar et al., 2003; Dolnicar & Fluker, 2004; Moutinho et al., 2007; Nourbakhsh, 2008) have provided strong evidence that surfers need to be differentiated in their travel behaviour. This can be done, for example, by profiling surfers who are more lucrative from the industry perspective. Thus, knowing the profile of surfers is essential for understanding their needs in assisting decision-making. The present research has included exploring what atmospheric–ocean conditions influence the activity. For this purpose, the design and implementation of an online survey have been applied.

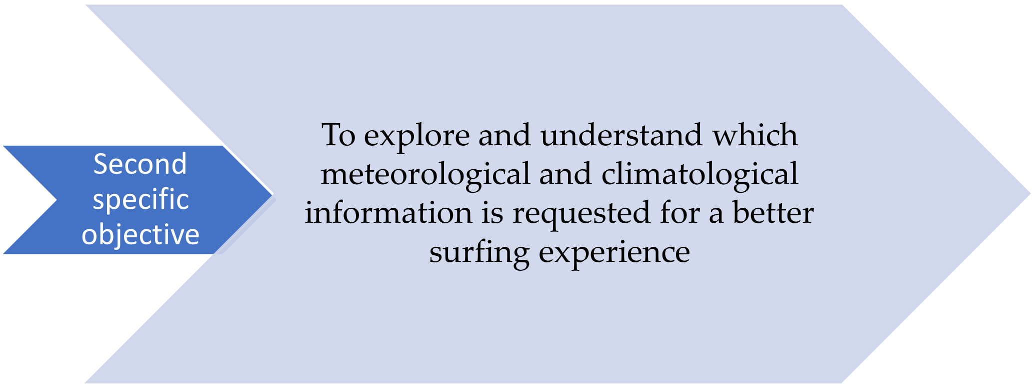

Figure 5. Second specific objective of the research

Source: author's production

Our second specific objective helps us to obtain indicators of value for tourist destination management at specific surf-spot destinations developed answering a third objective. The indicators are computed for Playa de Somo surf spot, located in the north of the Iberian Peninsula. The indicators constitute a piece of climate information that can assess the surfing activity on the local scale.

The third specific objective (Figure 6) emerges from the needs identified by the future climate service users (examined through the second objective). The third objective focuses on generating indicators for better surfing destination management. Surfing has become a prominent activity in many coastal areas, and there is an increasing worldwide demand for surfing resources as participation levels in the sport grow (Lazarow, 2007).

Several studies made quantitative assessments of the surfing wave climate. Rally (1991) defined and quantified a 'good' surf break. A rudimentary analysis of surfing mechanics demonstrates that conditions can be examined in terms of the joint statistical climate of 1) breaker peel rate and 2) attainable board speed as characterized by the Iribarren Number (Iribarren & Nogales,1949). Applying such a numerical algorithm to Duck Beach, North Carolina, for instance, indicates that the waves are suitable for surfing roughly 25% of the time. Dally (2001) attempts to measure surfing climate by developing a model for the joint probability density function of surfer board speed and wave break rate; this study relates board speed directly to breaker height. Hutt et al., (2001) employed a numerical wave refraction model to examine the surfability of Narrowneck Beach, in Australia, and an offshore submerged reef designed to be constructed at the same site. The modelling indicated that the site's surfing suitability would be improved significantly with the addition of the reef. Tausía (2020) added bathymetry in his study of Cantabria's regional surf spots, which helped obtain more detailed information about the surfing resource along the Cantabric coast.

Even with the attempts to characterize the climatic potential for surfing at different sites, it is important to understand the main parameters needed for surfing, which are the wave parameters. Thus, to characterize a surf spot's climatic potential, the following questions arise: How is wave height measured? and Do we have wave data at the requested resolution? In this context, the guide to wave analysis and forecasting of the WMO (Laing et al.,2018) states that useful visual observations of wave heights can be made at sea from ships. Visual observations from land are meaningful only at the observation site because the waves change dramatically over the last few hundred meters as they approach the shore and the observer is too far away from the unmodified (offshore) waves to assess their characteristics. To a coastal observer, waves usually appear to approach almost normal to the shore because of refraction and may, therefore, be more likely to be oblique to the wind than is the case further offshore. Shore-based observations normally apply only to that particular location, and although relevant to a study of local climatology or a site-specific forecast, they are rarely meaningful for any other meteorological purpose. However, they may be helpful for specific user groups such as surfers. Even so, it is not possible to cover all of the shore by visual observations.

For this reason, hindcasts are playing an increasing role in marine climatology. The opposite of forecast, hindcast is a backward projection calculating past wave conditions at a certain place. Most recent wave climatology, especially regional climatologies, are based on hindcast data. The same applies to design criteria produced by offshore oil and gas exploration and production companies and the regulatory authorities in many countries worldwide. The reason is simple: the costs involved in implementing a measurement program, especially on a regional basis, and the period spent waiting for a reasonable amount of data to be collected are unacceptable (Laing et al., 2018).

Besides, over the past few decades, wave retrospective analysis or reanalysis databases have become a powerful source of information for wave climate research and ocean applications. These databases have good spatial coverage and provide a continuous time series of offshore wave parameters over significant periods (of more than 40 years), allowing the description of wave climate in locations where instrumental data is unavailable. However, 1) they are not quantitatively perfect, 2) waves are poorly described in shallow water areas because the spatial resolution is not sufficiently detailed, and 3) wave transformations due to the interaction with the bathymetry are not usually modelled (Camus et al., 2013). These problems can be solved using calibration methods employing instrumental observations and modelling of the transformation processes and the increase of the spatial resolution, a process known as downscaling.

Therefore, the literature concludes that when analysing wave data, hindcast data is required to be processed with downscaling methods. As seen before, the link between surfing and climate is crucial. As stated by Scott and Lemieux (2010), the interface between climate and tourism is multifaceted and complex, as climate represents both a vital resource to be exploited and an essential limiting factor that poses risks to be managed by the tourism industry and tourists alike. All tourism destinations and operators are climate-sensitive to a degree, and climate is a crucial influence on travel planning in the travel experience (Scott & Lemieux, 2010).

Combined, surf forecasts and observed natural conditions impact surf travel behaviours in nuanced ways that deserve further attention to better understand destination and hospitality management. Host and guest satisfaction and how they relate to seasonal and regional travel patterns (Mach et al., 2020) also impact surf travel behaviours. Surfers form a sensory relationship with the local weather patterns, sea floors, jetties, and rock walls. Nevertheless, they need additional information about surf spots they have never previously visited (Anderson, 2014).

As defined by Fluker (2003), surf tourism involves travel and temporary stays undertaken by surfers with the primary expectation of surfing waves.

Previous studies have failed to fully capture whether associations between the surfing skill level and destination preferences exist in developing a psychographic-based profile. These results suggest that further attention is needed to explore destination preferences across different types of surfers, including those at different levels in the casual–serious continuum (Sotomayor & Barbieri, 2016).

Climate services must meet users' needs, capabilities, and decision framing (Vaughan & Dessai, 2014). Collaboration with potential users from an early stage of the design process, and a human-centred design approach, can lead to products and services that are usable, useful, and likely to be used (Earthy et al., 2001*)*. The design process – through engaging users, gathering requirements, focusing on users' experience, and judging user-centred evaluations – can contribute to a thorough understanding of users, tasks and environments to inform product or service development (Christel et al., 2018).

In this context, this research objective is focused on bridging the gap between users and producers of climate information. This objective explores the possibility of having high-resolution atmospheric–ocean data and then generating a series of climatic indices that will assess tourist destinations according to their climatic potential.

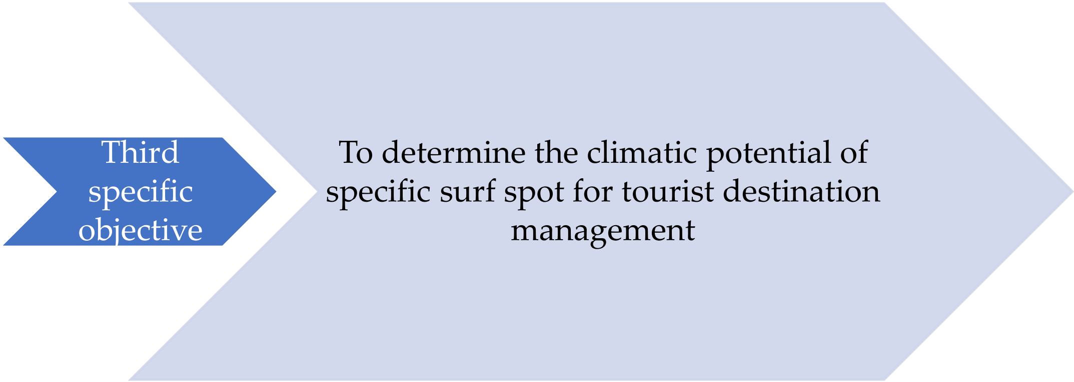

Figure 6. Third specific objective of the research.

Source: author's own production

The principal research objective and its specific objectives have been established to achieve all those contributions to science previously mentioned.

The specific research objectives mentioned above are related and contribute to the three research areas (presented in Figure 7), which are associated with the three articles that constitute this dissertation's core. Different research areas cover the following topics: (1) the definition of surfing climatology, (2) the exploration of surfers' and surf schools' behaviour, preferences, and needs in checking sea-state information, and (3) the development of the SCS users' needs for a climate-resilient tourist destination management.

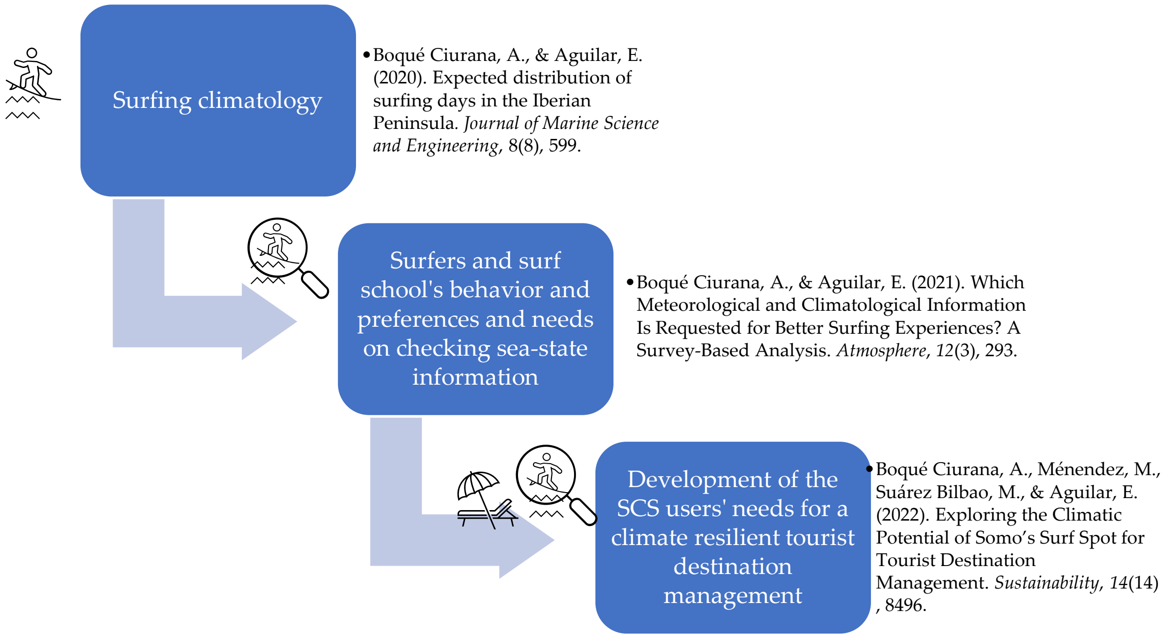

Figure 7. Research areas to which this dissertation contributes

Source: author's own production

1.3 Structure of the thesis

The structure of the thesis is illustrated in Figure 8. The first part of the thesis corresponds to the research presentation (Chapter 1) and general theoretical framework (Chapter 2). Chapter 1 outlines the introduction, the working hypothesis, and the research objectives and presents the research methodology and design.

Chapter 2 presents the background of the research areas relevant to the thesis and conceptual frameworks. We discuss three main topics - related to the three specific objectives: (1) the definition of a tourist activity climatology, (2) the climate service co-creation to face climate variability and change, and (3) the sustainable surfing destinations panorama. The first objective gives a general concept of how climate, weather, and tourism are related. It also explores the literature that assesses the climatic potential for tourism from a climatological perspective. It further presents the different approaches to determining the climatic potential of tourist activities. At the end of this section, as the thesis explores how atmospheric–oceanic conditions influence surfing, it presents the leading theory about this topic.

The second objective, as this study aims to develop a methodology to create an SCS, discusses how climate service co-creation can help to face climate variability and change. To do so, theory and practical examples of climate services co-creation in other sectors are presented.

The third objective pays special attention to surf destination management and the role of surf forecasts. For this purpose, the growth of tourism in society is outlined, particularly emphasizing surfing tourism. Finally, this area also explains the importance of surf forecasting and its limitations.

The second part of the thesis is contained in Chapters 3, 4, and 5, each one related to a publication in an international scientific journal. In turn, each of these publications answers the thesis's first, second, and third objectives, respectively. The union of the development of the three goals helps to achieve the general objective of this thesis. Thus, Chapter 3 presents the definition and results of surfing climatology in the Iberian Peninsula. Chapter 4 explores the users' needs of the future SCS, identifying which meteorological and climatological information helps achieve a better surfing experience. Then, Chapter 5 explicates the climatic potential of a specific surf spot for tourist destination management.

The third, Chapter 6, includes the discussion and conclusions to this thesis. The main findings are highlighted in this section, and further research lines are mentioned.

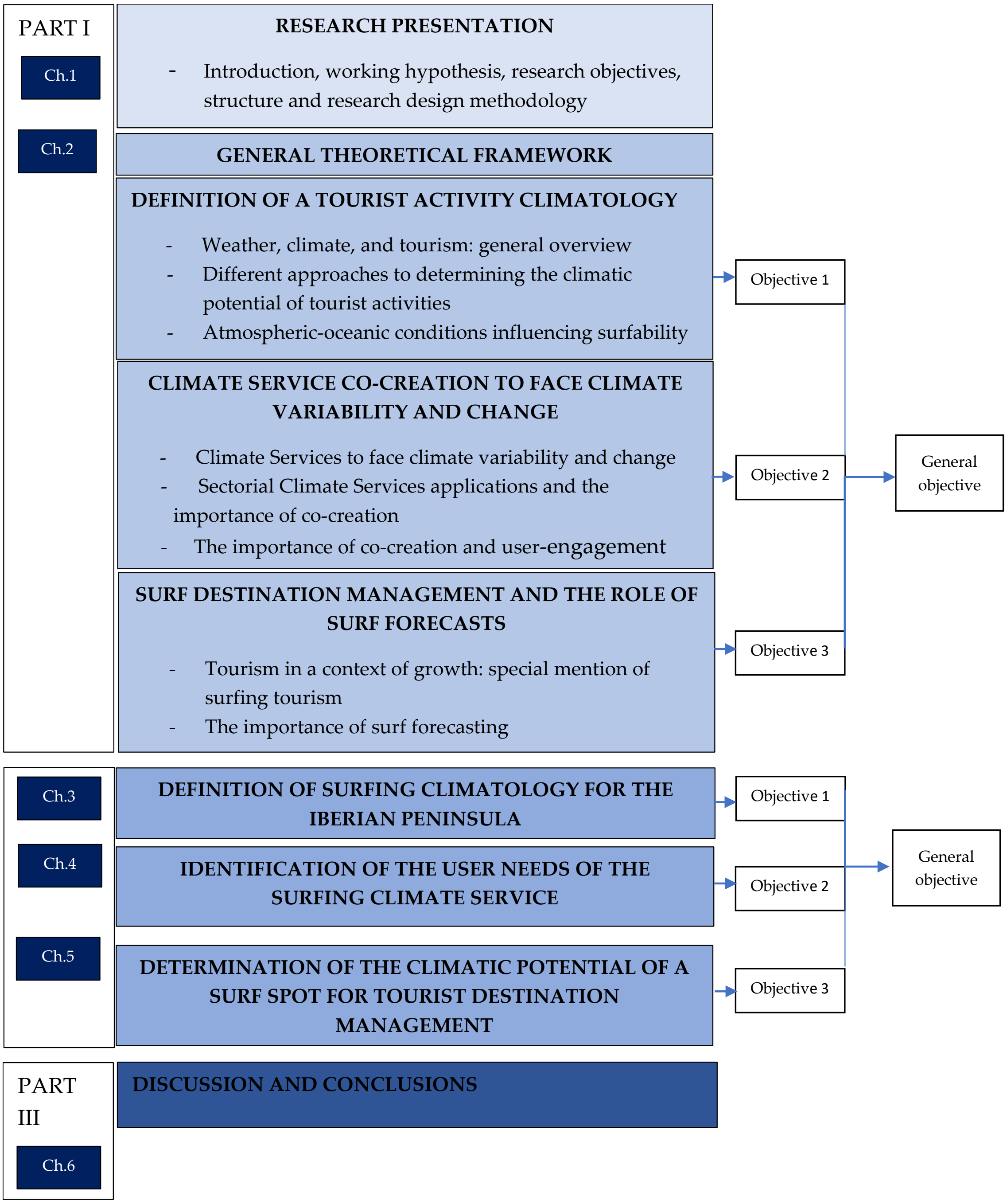

Figure 4. Structure of the thesis.

Source: author's own production.

1.3 Research design and methodology

This dissertation is based on a compendium of articles designed as successive steps for developing a surfing climate service. This section provides a general perspective on the project's research design and the contribution of each article to this manuscript's structure (Table 1).

Table 1. Methodological details for each case study

Source: author's own production

	Chapter 3	**Chapter 4**	**Chapter 5**
Objective	1	2	3
Case study	Iberian Peninsula surf spots (regional scale)	Surfers and surf schools related to Iberian Peninsula surf spots (global scale)	Somo surf spot, located in Cantabria, northern Iberian Peninsula (local scale)
Data sources	Oceanic buoy register	Surveys (470 responses)	Global ocean waves 2 (GOW2) → for wave data Global CFSR re-analysis → for wind data
Year of data	1985–2019 -when data is available-	2020	1985–2015
Study area	Iberian Peninsula		Somo surf spot (Cantabria, Spain)

The first paper identifies the factors that make surfing possible and uses an ad hoc-developed methodology to compute the local expected surfing days per year across the Iberian Peninsula's surfing spots. The data source is oceanic buoy data from both coastal and external networks from *Puertos del Estado* and *Instituto de la Marinha Portugal*. To validate the indicators, we compare the expected surfing days' results with the recorded surfing sessions with *Glassy app* in the benchmark area of Tarragona's coast. The data covers the period from 1985 to 2019. Note that not all buoys cover the entire period.

The second study focuses on collecting the requirements of future users of the SCS. To gather data, an online survey was sent to surf schools and surfers who have been surfing in the Iberian Peninsula at least once. Four hundred seventy people answered the survey. The results revealed which information was checked before surfing and what users believe can be improved. The survey also allowed an understanding of the perspective of business' incomes related to surfing and wave surfing conditions.

Finally, the third study uses atmospheric-ocean data from 1985 to 2015 for one of the most famous surf spots, Playa de Somo in Cantabria. Data with the fine spatial resolution is computed by hybrid downscaling and using the SWAN model for wave propagation. Once the database was developed, indicators to assess the activity were generated and calculated for the whole period.

Table 2. Chapters of the thesis and knowledge areas of contribution

Source: author's own production

Area	Chapter 3	Chapter 4	Chapter 5
Surfing climatology definition	✓	✗	✓
Communication of CS	✗	✓	✓
Identifying and understanding users' needs	✗	✓	✗
Developing users' needs	✗	✓	✓
Exploring alternative surfing options	✗	✓	✓

Source: author's own production

Each research article aims to contribute to the main facets of the needs of the proposed climate service. At the same time, each article is focused on contributing to a specific area of knowledge (Table 2). In this regard, the first article, forming Chapter 3, explores the definition of surfing climatology. Chapter 4 makes an effort to understand how to design the communication of the SCS and explores, identifies, and understands the users' needs. Chapter 5 then contributes with the definition of surfing climatology in fine resolution, the communication of the SCS, the development of the users' needs, and the exploration of alternative surfing options.

The general methodology developed in this thesis is shown in Figure 9. From the beginning of our research, we constructed the basis of the development of a surfing climate service. First, this research explores and understands the climatology and weather patterns in the Iberian Peninsula's surf spots. After achieving this goal, the thesis explores the essential awareness of how atmospheric-ocean conditions impact surfing activity. Then, the knowledge of how end users require information has been extracted through the user-engagement process and co-creation methodologies. Thanks to this, it is possible to generate an SCS prototype. To make the prototype real, developing new scientific applications regarding both scientific and users' knowledge is necessary.

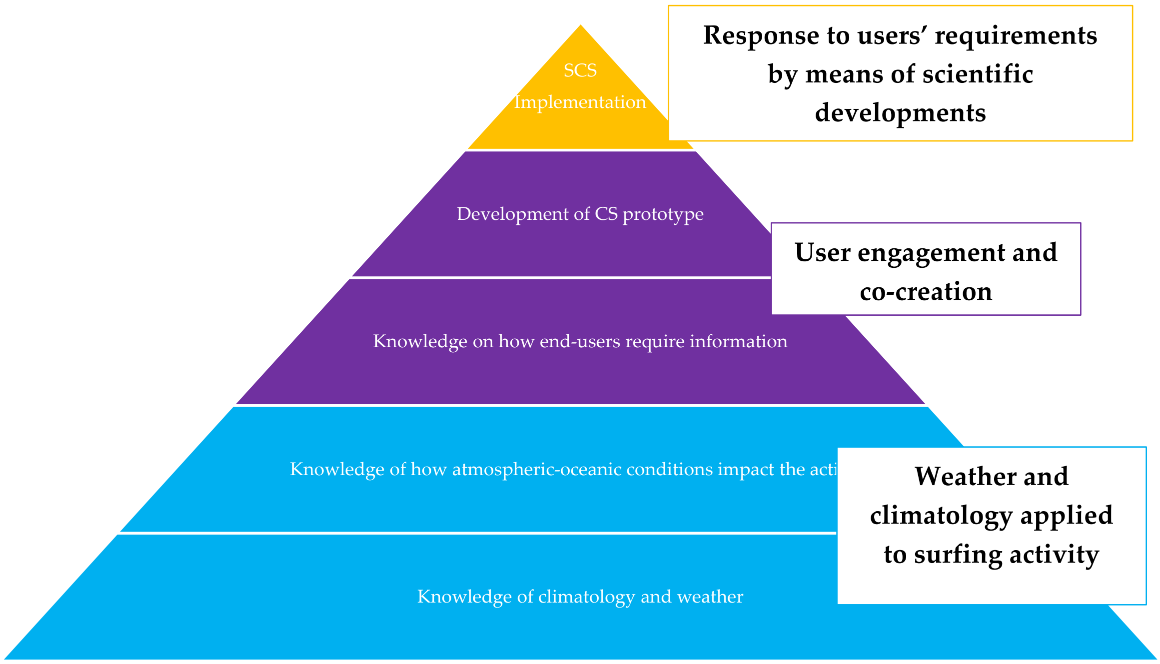

Figure 5. Pyramid of the growing methodology for developing the SCS.

Source: author's own production

2. General theoretical framework

In the research presentation, we have introduced the background of the research as a context to understand from what literature we depart for developing the surfing climate service. In this section, we explore deeply the topics introduced in section 1.

In this line, this second chapter presents the general theoretical background of this research. It is divided into three subsections, linked with each of the three objectives of the present research.

This section first exposes how to define a tourist activity climatology by explaining: (1) how weather, climate, and tourism are related; (2) how the different approaches to determine the climatic potential of tourist activities are defined; and (3) the atmospheric-oceanic conditions that influence surfability.

Second, we introduce the concepts associated with CS co-creation. This line exposes how climate service can face climate variability and change; we also see sectorial climate services applications.

Thirdly, we present surf destination management and the role of surf forecasts by providing literature about the growth of tourism, with special mention of surf tourism. The specifications of surf forecasting is also shown, and considered essentially important for developing the SCS.

2.1 Definition of a tourist activity climatology

As mentioned in the introduction, weather and climate moderate tourist activities. There is no general approach to computing climatologies for the different tourist activities. Even so, exploring how climate and weather modulate a tourist activity and generating a specific climatology for detailed places and specific tourist activity is possible.

For this reason, the present section will describe how weather, climate, and tourism relate. Afterward, the present thesis focuses on exploring the climatic potential for surfing activity (following objective 1), so atmospheric-oceanic conditions that influence surfability are detailed. As the current research attempts to define specific indicators for surfing climatologies, different approaches are explored to determine the climatic potential of tourist activities.

2.1.1 Weather, climate, and tourism: general overview

Climate is one of the factors that influence travel planning (Figure 10). The concept of "climate" influences travel plans made months in advance. Climatology contributes to the destination choice, travel timing, activity planning, and insurance needs. Weather forecasts influence short-planned travel and is considered in the selection of last-minute holidays. Once tourists are on the trip, weather strongly impacts their activity selection and behaviour at the destination. Weather will also indicate when trip activities need specific action such as to use, avoid, change, adapt and/or accept alternate options. Weather also implies spending behaviour and trip satisfaction (Becken, 2010).

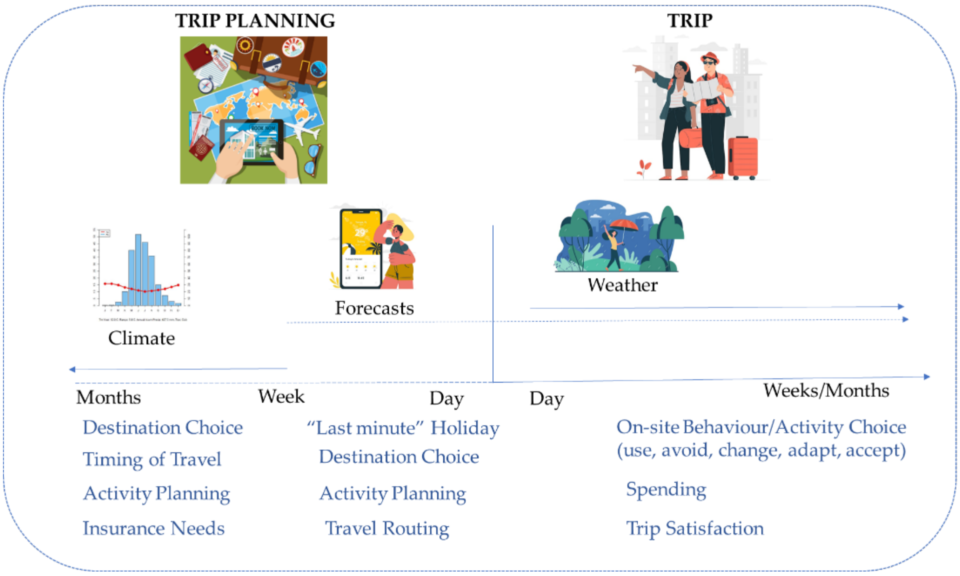

Figure 6. How climate, forecasts, and weather influence travel patterns.

Source: author's own elaboration adapted from Becken, 2010.

Even though the tourism sector declared the state of climate emergency in 2020, it is a common perception that the last three decades of research have failed to prepare the sector for the net-zero transition and climate disruption that will transform tourism over the next three decades. The climate change imperative demands more of the tourism academy (Scott & Gössling, 2022).

Gómez-Martín (2005) suggests that climate can support tourist activity either as a basic resource or as a necessary complement. At some destinations—together with geographical location, topography, landscape, flora, and fauna—weather and climate constitute the natural resource-base for recreation and tourism (De Freitas, 2003). As Becken (2010) stated, any tourism activity or product has ideal atmospheric conditions, which correspond to those providing the maximum level of comfort for visitors engaging in such activities for the longest time. At the destination level, these conditions should be projected to different products throughout the year, i.e., in the summer; or a city on the coast could offer ideal conditions for sand and beach tourism and cultural tourism and events in cold seasons. Many destinations, however, specialize in one tourist product; they typically can offer ideal conditions for such activity in one season, while the other seasons are dead periods.

The vital issue, thus, will be the endowments with climatic attributes that boost their competitiveness on top of other (geographical or anthropic/organizational) features. Global climate change can alter the distribution of climate assets among destinations, with implications for tourism seasonality, demand and travel patterns, and consumer behavior. Changes in the length and quality of the tourism season have considerable consequences for the long-term profitability of tourism enterprises and competitive relationships between destinations (Scott et al., 2004). This means that tourism is highly dependent on the climatic conditions of a given destination, their variability, and change. Grillakis et al. (2016) examined the impact of two degrees of global warming on European summer tourism from a climate comfort perspective. Results show that the change in climate will positively affect central and northern Europe, increasing the potential for further economic development in this direction. Mediterranean countries will likely lose favorability during the hot summer months but will become more favorable in the early and late summer seasons.

As seen, climate constitutes an essential resource for tourism since it influences the range of tourism activities and the development of the tourism supply. Tourism is highly sensitive to changes in climate elements. Adaptation strategy-making needs to explore whether the tourism climate condition in a given region at a specific time is appropriate and how it may change in the future (Kovács & Király, 2021). Day et al. (2021) examined the implications of climate change for tourism and outdoor recreation in a specific case study in the state of Indiana in the USA. The direct impacts of climate change in Indiana include increases in the number of hot and sweltering days each summer, fewer mild days, more rain, and less snow. Each direct impact will affect tourism and recreation. Additionally, various indirect impacts are anticipated, including climate-related changes in health issues and new infrastructure needs among others.

Similarly, Zajck et al. (2022) compared future climatic suitability to shoreline loss for recreational beach use for five Japanese beaches. Coastal tourism is impacted by regional environmental change, including sea-level rise and climatic change. Future climate conditions and projections of shoreline changes due to sea-level rise were used to assess the historical and future climatic suitability. Diminished beaches with improved climate conditions were observed at all sites except Yonehara, which had diminished beach and climate conditions. Results highlight that beach tourism suitability at the study sites will likely exhibit more remarkable changes due to sea-level rise than those driven by changing atmospheric conditions.

In this context of changing climate and weather, the availability and sharing of knowledge and information is an essential requirement for the successful planning of the tourism sector regarding this phenomenon. Lopes et al. (2022) explored pathways for adapting tourism to climate change in an urban destination by a Modified Delphi Approach. The evidence from different stakeholders demonstrates that there is an ambiguous process of understanding the problem, information needs, and a weak interaction between actors-resources-tasks. The options for more sustainable practices must be based on three axes: (1) solutions based on the energy sector in the hotel industry; (2) improvement and expansion of green infrastructure for tourist enjoyment; and (3) network participation through the collaboration of various stakeholders with relevance in tourism and urban planning.

For this reason, there are a lot of studies (Lise & Tol, 2002; Hall & Higham 2005; Amelung et al., 2007) that analyze and warn of the possible impacts that climate change can produce on tourism as a result of the alteration of the initial conditions of the natural resources.

2.1.2 Different approaches to determining the climatic potential of tourist activities

As introduced in the previous section, one of the economic activities that can be more affected due to climate change effects is tourism. In this sense, tourism is a vulnerable activity in a variable exposition, depending on the kind of tourism located in a specific place (Olcina, 2012). Moreover, the relationship between tourism and climate change is bidirectional. This implies that tourist activity is possible due to the existence of specific resources in a territory. These resources explain the displacement of the human being in the research of experiences, evasion of pleasure, or enjoyment (Tuan, 2003). However, simultaneously, there are changes in the territorial resources in the climate change scenario. In this context, it is known that, mainly due to thermic and pluviometry conditions (Olcina, 2012), climate change will modify tourist flows and travel patterns in terms of visited places and seasonality and, therefore, will affect the current configuration of the tourist marketplace. This relationship has been integrated into analyses of the dependence of tourism performance on climatic conditions. Mieczkowski (1985) created a method for evaluating world climates and their bearing on tourist attractiveness. The process consists of calculating the Tourist Climatic Index (TCI). This index is one of the most widespread within climate studies applied in tourism. This is because the combination of various meteorological parameters directly influences human well-being. In detail, TCI uses a variety of seven parameters that can be obtained from weather station data. Three of these parameters are independent (precipitation, wind, and insolation), and two come from a bioclimatic combination: hourly comfort index and daily comfort index.

Since then, several scholars have used TCI to analyze specific tourist destinations. Amiranashvili et al. (2008) have used this approach to evaluate the climate in the Georgian resort town of Batumi. In this case, data from the hydrometeorological department of Georgia was used for the TCI calculations. The results determine the climatic potential of tourism to Batumi. It is further found that, similar to New Orleans, Charleston, New York, St. Louis, and Tbilisi, Batumi relates to the cities with bimodal-shoulder peak TCI distribution. Therefore, the first peak of TCI falls in May and June, and the second in September and October (Amiranashvili et al., 2008). Mushawemhuka et al. (2020) quantified climate suitability for Zimbabwean nature-based tourism using TCI. Cracu et al. (2016) analysed climate-tourism potential in the Mamaia Resort area using TCI; Khaledi (2017) calculated the TCI for baluchestan region of Iran. The TCI was also used to analyse the vulnerability to climate change of the Mediterranean as a destination region by Amelung et al. (2007), also suggesting that stakeholders need to be engaged in tourism to explore the vulnerability of their businesses and policies to climate change.

Other studies have extended the use of TCI to other variables. For instance, Scott et al. (2016) produced a different index, the Holiday Climatic Index (HCI), and compared its use with the TCI in Europe. They argue that while much research has been devoted to quantifying optimal or unacceptable climate conditions—both generally, or for specific, tourism segments or activities—over the last ten years, this knowledge is not incorporated in the TCI. Similarly, Yu et al. (2021) made a comparison of the holiday climate index: beach and the tourism climate index across coastal destinations in China; Rutty et al. (2020) explored the values of TCI and HCI in the Caribbean to explain the arrival of tourists in that region. Demiroglu et al. (2020) calculated the performance of HCI of Urban and Beach Destinations in the Mediterranean. Alonso-Pérez et al. (2021) evaluated the TCI in the Canary Islands and linked the values with the number of visitors; they found that TCI assesses the importance of climate as a primary attribute of the Canary Islands as a tourist destination for sightseeing and other light outdoor activities through the year. However, climate comfort in the archipelago can be affected by a meteorological situation not considered in any tourism climate index. Harydai et al. (2019) calculate the TCI and correlate it with the number of visitors in Samosir district in North Sumatra Province, finding no correlation between climate comfort and the number of visitors. Similarly, Russo et al. (2012) analyse climate resources as one of many 'territorial capital endowments,' which could explain migration flows, using an index based on an elaboration of the TCI, the difference between values of the TCI in 'warm' and 'cold' months. It is found that the relationship with migration flows is significantly strong and negative (Europeans tend to migrate where climate conditions are less uneven according to the season, and this behaviour is more accentuated for the 25-49 age cohort).

In the field of urban studies, Gholamreza et al. (2009) correlate metropolitan sprawl with climate comfort in Teheran and find that sprawl has a negative effect on TCI. In the line of cross-analyzing TCI with other variables, Hossein (2015) conducts a risk assessment of precipitation through a mathematical approach to the tourism climate risk, using different probabilities of excessive precipitation. Another example of evolution in the uses of TCI is the combination of two climate change scenarios with the TCI (Amelung et al., 2007).

Many scholars did engage with the limitations presented by the TCI approach. For instance, Gómez-Martín (2017) identifies two main limitations. On the one hand, the index does not refer to any particular geographic or socio-demographic segment. On the other hand, the index has a low empirical contrast: the hierarchy of variables and the establishment of favorable and unfavorable thresholds have been determined based on the author's judgment, without being referenced to the behaviour or the atmospheric preferences of tourists. These limitations are found to have prompted uncorrected interpretations of research results.

New tools have been created, probably because of these limitations. Thus Matzarakis et al. (2010) introduced a Climate Tourism Information Schemes (CTIS) assessment method for climate and tourism based on daily data. The innovative aspect of the CTIS is that it considers different parameters depending on specific regions or specific tourism uses. Other authors thoroughly redefine the TCI. Kovács and Unger (2014) modified the TCI in two ways: on the one hand, physiologically equivalent temperature (PET) is applied instead of effective temperature (ET). On the other hand, the TCI is adjusted to a ten-day scale and not in monthly averages of climatic parameters as in the original TCI.

Tang et al. (2012) implemented a new Tourism Climate Suitability Index (TCSI) to evaluate the tourism climate suitability in Qinghai Province, China. The climate suitability index uses different impact factors: temperature and humidity, wind chill, solar radiation, atmospheric oxygen, and barrier weather. Results found that there is a clear distributional characteristic of spatial-temporal variability of TCSI values in Qinghai Province, tourism climate suitability has significant seasonal and regional differences and the key factor that influences regional differences in tourism climatic suitability, which is atmospheric oxygen. Also, the key factors that influence seasonal differences are temperature and humidity, the wind chill factor, and barrier weather (Tang et al., 2012).

Other researchers tackle the relationship between climate and tourism without considering the TCI. For instance, Álvarez- Díaz et al. (2010) present for the first time, the statistical relationship between the North Atlantic Oscillation (NAO)—value computed considering the difference of sea level pressure value produced between low pressures from Iceland and the high pressures from the Azores—and tourism movement, corroborating the result that NAO has a significant effect on the number of tourists arriving in the Balearic Islands from the UK and Germany. In a similar way, but for the global surfing tourism field, Espejo et al. (2014) investigated interannual variability by comparing occurrence values with global and regional modes of low-frequency climate variability such as El Niño and the North Atlantic Oscillation, revealing strong influence at both the global and the regional scale. Martínez et al. (2019) adopt a different approach in their study of the climatic preferences for trekking tourists in Spain, which is based on a survey aimed to gauge the weight of different atmospheric facets on aspects such as enjoyment, comfort, health, and risk. Morgan et al. (2000) have created their index to evaluate the relationship between climate and, in this case, beach tourism based on users' preferences in terms of climate and bathing water temperature. In the same vein, Ren (2004) created the human body comfort index to evaluate the comfortableness in the framework of the tourism climate in Wuati Mountain. The application of this index suggests that the comfortableness of the human body varies with different months according to the analysis and assessment of the tourism climatic comfortableness of each month. At the same time, De Freitas et al. (2004) introduced a Climate Index for Tourism (CIT) relying on actual observations rather than on average data. In that way, the index rates the climate resource activities that are highly climate/weather-sensitive, such as beach holidays, resort tourism, and water-based sporting holiday. The same author introduced 'A second generation climate index for tourism' in which he uses the application of this index (De Freitas et al., 2008).

Hamilton et al. (2005) identified that literature on tourism and climate change lacks an analysis of the global changes in tourism demand. For this reason, they created a simulation model of international tourist flows using 1995 data on departures and arrivals for 207 countries. The matrix of bilateral tourism flows is perturbed with scenarios of population growth, economic growth, and particularly climate change. It was found that climate change would imply that the currently dominant group of international tourists—sun and beach lovers from Western Europe—would stay closer to home, with an altogether slight decrease in total international tourist numbers and distances travelled.

Kapetanakis et al. (2022) developed the Urban Climate Comfort Index (UCCI) to cover the gap in climate indices that are urban tourist destinations. UCCI integrates critical climate variables for urban tourism and is formed by empirical data from an *in situ* survey conducted in southern Europe, close to the Acropolis Museum in Athens, Greece. The new index can be applied to other similar urban tourist destinations and assist impact assessment studies and tourism management measures, including climate change adaptation.

Wang et al. (2022) stated that in the context of global warming, how to measure summer climate suitability at the local scale is important for meteorological services. In this line, considering meteorological and ecological conditions, body comfort, and the atmospheric environment, an assessment method for summer climate suitability was proposed and applied for Zhejiang Province. The research established Summer Suitable Index (SSI), including four secondary indices: a summer cool index (SCI), a comfort days index (CDI), a good air days index (GADI), and a vegetation cover index (VCI).

New challenges are facing society today, and so does tourism; severe air pollution in China has caused significant tourism transformation for pursuing fresh air in microclimate tourism markets. For this reason, Yang et al. (2022) proposed a multidimensional index, the fresh air-natural microclimate comfort index (FAI-NMCI), connecting the fresh air index with the natural microclimate comfort index of scenic spots together from transdisciplinary and multidisciplinary perspectives.

The Coastal Tourism Climate Index (CTCI), developed by Gao et al. (2022), was designed to assess the tourism climate suitability of Chinese coastal cities. The CTCI was developed to include five variables: thermal comfort, sunshine, precipitation, wind, and air quality. They applied HCI and CTCI in China, finding that CTCI is more suitable.

Ma et al. (2020) introduced the Camping Climate Index (CCI); this index addressed a gap in the literature by providing a camping-sector climate tourism index.

Kóvacs et al. (2014) modified the TCI to central European climatic conditions in two ways. On the one hand, one of the most popular, widely used bioclimatic indices, Physiologically Equivalent Temperature (PET) is applied instead of effective temperature (ET) in the part of the index related to thermal conditions. Furthermore, the TCI is adjusted to a ten-day scale since it is more relevant to tourism than the original monthly averages of the climatic parameters.

In a similar context, the Tourism Climate Comfort Index (TCCI) is an attempt to evaluate climate comfort for tourism purposes (Adelkovic et al., 2016).

As in many coastal resort areas of the world, it is likely that optimal climatic conditions for beach use might occur outside the peak of tourist season, an Improved user-based beach climate index (IUSBCLI) was developed by Morgan et al. (2000). Investigation of this issue together with associated publicity might help to spread the tourism load and hence reduce undesirable social and environmental effects of extreme seasonality in tourist demand. For the purpose of developing this index, questionnaire surveys were carried out in Wales, Malta, and Turkey to establish the preferences of north European beach users for thermal sensation and bathing water temperature, plus priority levels for other climatic attributes.

Yu et al. (2009) developed and tested a Modified Climate Index for Tourism (MCIT). The index measures climate as a tourism resource by combining several tourism-related climate elements. The authors defend that it improves previous methods by incorporating variables more relevant to tourism activities and hourly observations rather than simple daily averages.

Table 3 presents a summary of the mentioned climate indices in chronological order.

Table 3. Climate index list sorted by year of creation

Source: author's own production

Abbreviation of the Index	**Name of the Index**	**Developed by**	**Year of creation**
TCI	Tourist Climatic Index	Mieczkowski	1985
IUSBCLI	Improved user-based beach climate index	Morgan et al.	2000
CIT	Climate index for tourism	De Freitas	2004
CIT (2)	Second generation of climate index for tourism	De Freitas	2008
MCIT	Modified Climate Index for Tourism	Yu et al.	2009
TCSI	Tourism Climate Suitability Index	Tang et al.	2012
UTCI	Universal Thermal Climate Index	Błażejczyk et al.	2013
TCImodified	Tourist Climatic Index modified	Kóvacs	2014
HCI	Holiday Climatic Index	Scott et al.	2016
TCCI	Tourism climate comfort index	Andelkovic et al.	2016
CCI	Camping Climate Index	Ma	2021
SSI	Summer Suitable Index	Wang et al.	2022
UCCI	Urban Climate Comfort Index	Kapetanakis et al.	2022
FAI-NMCI	Fresh Air- Natural Microclimate Comfort Index	Yang et al.	2022
CTCI	Costal Tourism Climate Index	Gao et al.	2022

Present and future steps in the tourism climate research not only focus on the generation of specific tourist climate indices but also aim to develop specific climate services; this is the case of the generation of Climate Services for tourism in the Caribbean in which Matthews et al. (2020) generate a comparative analysis of climate push and pull influences using climate indices. Their study uses an optimization algorithm to develop two indices: (1) an optimized in-situ index that estimates the climatic pull factor of the destination and (2) an optimized ex-situ index that estimates the climatic push factor from the source market.

2.1.3 Atmospheric-oceanic conditions influencing surfability

We have seen how climate and weather influence tourist activities in previous sections and also how climatic potential for tourist activities can be determined. But this thesis is of vital importance to understand which atmospheric-oceanic conditions influence surfability. For this reason, the present section will present which conditions influence surfability.

For example, and as many social science researchers indicate, the recreational use of the sea breeze is an important factor for the development of water activities, conditioning the practice of sports such as windsurfing, kitesurfing, surfing, paragliding, and usage of all types of sailboats in certain coastal hot spots (Alomar-Garau & Grimalt-Gelabert, 2022).

The seasonal availability of wind resources represents and added value for a specific location. For example, elite sports competitions search optimal locations. King's Cup sailing competition takes place in the summer and uses the Bay of Palma as a regatta course because of its wind aptitude for sailing: constant, benevolent winds that are easy to predict. On the contrary, in the specific case of surfing, which depends on the prevailing swell, the breeze is considered a short-period, low-energy sea wind, which 'fouls' the swell and eliminates its effectiveness in generating low-height, low-energy coastal waves, degrading the surf (Alomar-Garau & Grimalt-Gelabert, 2022).

To comprehend wave resources for surfing is essential to define the following concepts: fetch, swell, and surf. Fetch is the area in which the wind generates ocean waves; that means the area of water the wind has acted upon in creating waves. After leaving a fetch or generating area, waves travel to a point some distance away from a coast, for example, with speeds proportional to their periods (Griswold, 1964).

Swells appear in the ocean when the wind transfers its energy from the air into the water. Swell is the collection of waves moving away from a storm in the ocean. As swell arrives at the beach, shallow water forces waves to slow down and rise up above the surface, morphing as it goes through a process known as shoaling. Swell corridor means the region offshore of the surf breaks where ocean swell travels and transforms into a surfable wave – understanding a surfable wave as the one that can be caught and ridden by a surfer – (Mead & Atkin, 2019).

The very definition of ocean swell is ambiguous: while it is usually perceived as former wind-generated waves, in fact, it may reconnect with the local wind through nonlinear interactions (Babanin & Jiang, 2017). Often, messy swells produce clean surfing; this happens if swells are filtered out as waves refract on the wedge of the headland, resulting in clean, organized, long-period waves at surfing locations (Scarfe et al., 2003).

Surf is swell that has arrived in shallow enough water to rise up above the surface and break (Mead & Black, 2001).

To understand wave resource availability is necessary to illustrate how swell is generated and travels to the shore. As shown in Figure 11, the farther away the swell-generating wind is, the cleaner the swell will be once it arrives. Distant ground swells end up with cleaner, long-period waves. But in the case of close-proximity wind swell, the chop does not have as much time and distance to clean up, making for shorter periods and peakier conditions (Cool, 2003). So, for surfing, a generation area is necessary where the wind blows and generates possible surfing waves that will reach the shore faster or slower depending on their period. Waves generated in the same fetch area will arrive at the shore ordered by their period; first, with the ones that present more wave period, and at the end, the ones with smaller periods. As a general rule, the larger the wave period, the better for it will be for surfing. Also, the furthest the fetch area is generated, the better, so waves will be clean and not mixed (Butt et al., 2004).

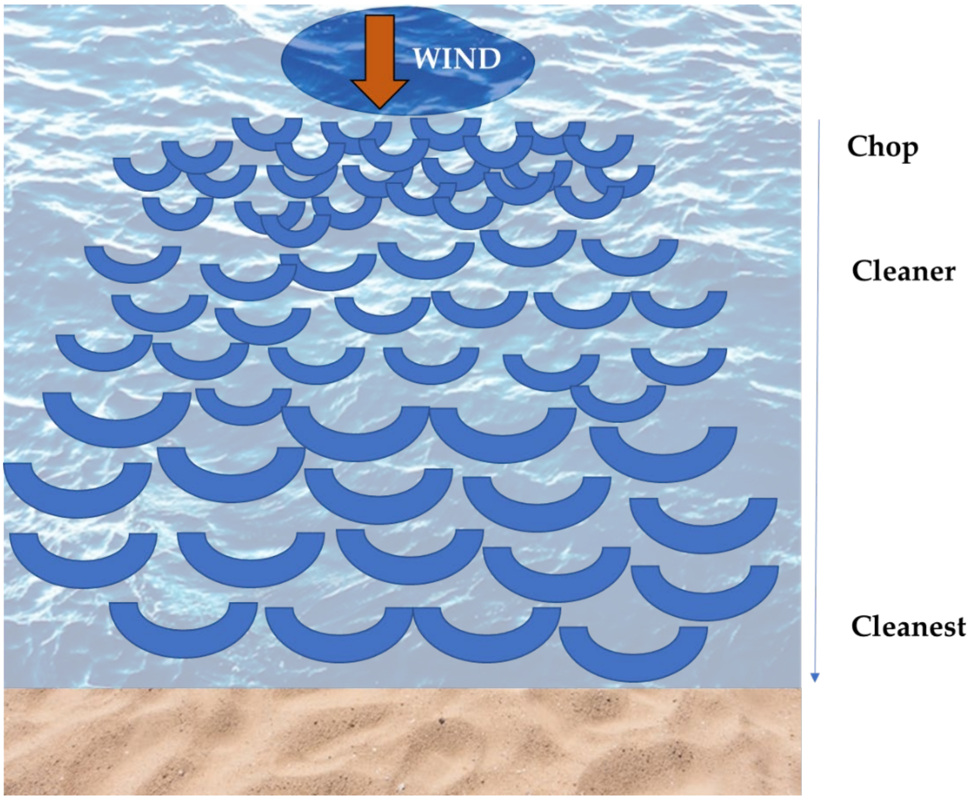

Figure 7. Swell generation and travel.

Source: author's own production adapted from Cool, 2003.

International surfing destinations are highly dependent on specific combinations of wind-wave formation, thermal conditions, and local bathymetry (Espejo et al., 2014).

One of the most technical branches associated with the study of surfing is the detailed understanding of the processes experienced by waves spreading and interacting with the seabed to finally break properly in coastal areas. These complex processes usually manifest themselves naturally as a product of various factors, such as the local climate (waves, wind, and sea level), the different bathymetric configurations, and the type of material of the coastal bottoms, which, to a greater or lesser extent, control the quality, level, and difficulty for the practice of surfing. These natural conditions are usually scarce in the coastal area and highly dependent on local and seasonal climatology (Espejo et al., 2014).

Few studies have explored surfing climatology. Espejo et al. (2014) explored surfing wave climate variability on a global scale using an objective-standardized index to evaluate surf conditions. Finding climate patterns help to explain interannual variability of the surf resource. According to general atmospheric circulation and swell propagation patterns, results show that west-facing low to middle-latitude coasts are more suitable for surfing, especially those in the Southern Hemisphere. The resulting maps provide useful information for surfers, the surf tourism industry, and surf-related coastal planners and stakeholders. Similarly, but on a regional scale, Peñas de Haro (2015) analyzed the surfing and bodysurfing resource based on climatology for the Balearic Island of Mallorca. Pattiaratchi et al. (1999) analysed the surfing climate of the Perth Metropolitan coastline by using offshore wind and wave data together with a wave refraction/diffraction and shoaling model. Results show the spatial distribution of surfability in this place.

Gamble and Leonard (2005) developed a test coastal climatology product for recreation and tourism end users in southeastern North Carolina. The product was designed so that it can offer guidance and serve as a model to the Coastal Services Center and National Climatic Data Center of the National Oceanic and Atmospheric Administration for further development of climatology products useful to coastal managers across the southeastern U.S. Since most coastal recreation and tourism occurs outdoors, information about weather and climate can be very important to managers and participants in determining when to offer or participate in an activity, the duration of that activity, and the activity's success or enjoyment (Smith 1993; Boniface & Cooper, 1994; de Freitas 2001). Further, weather and climate information can aid in planning, scheduling, promoting, and participating in alternative activities during periods of adverse weather (Perry, 1997).

Coll et al. (2014) examined the role of climate on seasonality tourism and emerging tourist product configurations in Mallorca. They also defined that the climate (natural resource) becomes a tourist attraction when it is positively valued by tourists to influence the purchase decisions. However, the resource value changes according to social changes (the value that society gives, according to the tastes and fashions of the moment), in addition to the influence that advertising and social media can produce from it. For example, certain atmospheric elements, such as high (strong) winds or isolation, were formerly conceived as limiting factors for tourism development. In contrast, today, there is crucial attraction for certain types of tourism, such as the sun and sand or water sports (surfing, windsurfing).

2.2 Climate Service co-creation to face climate variability and change

Climate Services equip decision-makers to face climate variability and change. This section exposes the importance and value of a co-created Climate Service for a specific sector. This topic is of critical importance as, as of today, we are not aware of any existing Surfing Climate Service.

As a background, this section explores what climate services are and how the co-creation process can lead to tailored-made CS. In this vein, several approaches to CS development for different sectors are detailed and work as parallelisms—if it proceeds—for developing the SCS. The background of this section also aligns with the second objective of this research, which focused on exploring users' needs of the SCS.

2.2.1 Climate services to face climate variability and change

The Global Framework for Climate Services (Lúcio & Grasso, 2016), or GFCS, was defined at the World Climate Conference held in Geneva in 2009 to present a coordination mechanism, built on existing initiatives and infrastructure. The intention was to address the entire value chain from observations, research, products development, service delivery, and applications of these services in support of decision-making in climate-sensitive sectors.

Climate Services are understood as the transmission of processed information from meteorological and climatological data in a way that becomes useful for the end-user in the decision-making process. This can apply both for the short, medium, and long term and should be helpful to activate action that adapts tourism activity into long-term trends and sudden changes in the competitive context or to mitigate the effects tourism generates on climatic conditions.

The provision of CS must be understood as a necessary dimension of destination planning for resilient communities that allow adaptation to climate change, among other challenges. Reliable and ready-to-use information on weather, water, and climate will enable individuals, households, organizations, businesses, and governments to make informed and aware decisions, maximizing gains from current and future climate conditions (Golding *et al*., 2017; Gómez-Martín 2005; Vicent *et al.*, 2018).

There is a growing and urgent need to improve society's resilience to climate-related hazards and to better manage the risks and opportunities arising from climate variability and climate change. Society has always had to deal with climate variability, including extreme weather and climate events, but can no longer assume that past climatic conditions indicate current and future conditions (Hewitt et al., 2012). For this reason, CS can work as a tool for managing those challenges.

In summary, the Global Framework for Climate Services established five priority areas: agriculture and food security; water; health; energy; and disaster and risk reduction. For the development of the CS, the roles of five specific sections are essential: (1) the user interface platform; (2) research modelling and prediction; (3) capacity development; (4) climate services information system; and (5) observations and monitoring (Figure 12).

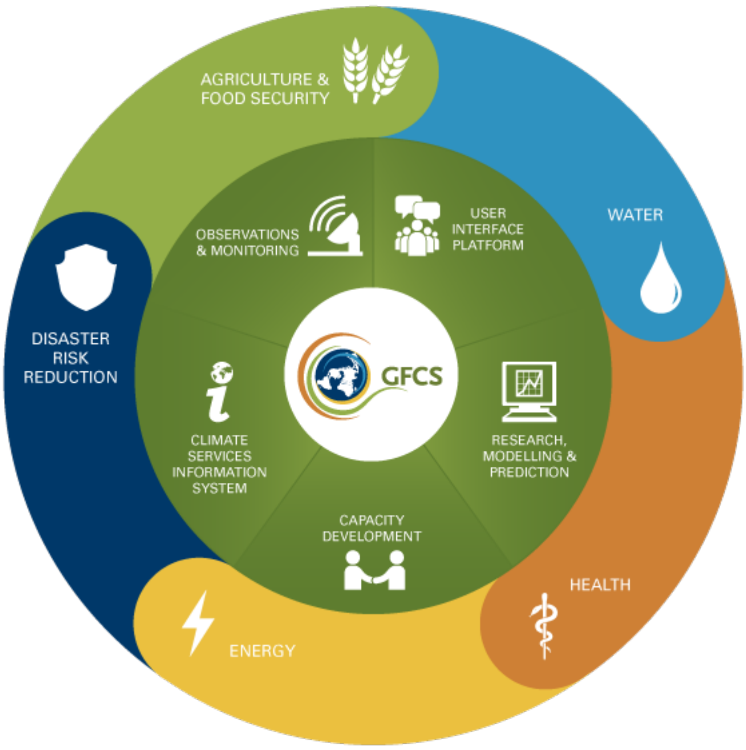

Figure 8. Priority areas of CS applications.

Source: Global Framework for Climate Services, 2014

2.2.2 Sectorial Climate Services applications and the importance of co-creation

As seen in previous sections, in the 21st century, the world's population will encounter multifaceted challenges from climate variability and climate change. These require wise and well-informed decision-making abilities at every level, from households to international fora. In parallel to the need to understand recent climatic changes and tendencies of extreme weather events, there is a need to know their impacts (Font Barnet et al., 2021). Many recent examples of impact-based forecasts in different disciplines are either from the priority defined areas related to risk reduction strategy (Speight et al., 2021), agriculture (Malhi et al., 2021), health (Davis et al., 2021), energy (Gil et al., 2021), and water (Liu et al., 2021). In this sense, there is an increasing demand for customized, climate-related tools, products, and information to enable climate-smart strategic decisions at various levels for various end-users. In this context, these reasons have led to the development of actionable climate science and specific climate services (Van der Hurk et al., 2018; European Commission, 2015).

Research has explored sectorial climate service applications with different approaches in this connection. Still, with the following similar aims, Viel et al. (2016) examined how seasonal forecasts could help a decision maker, with for example, climate service for water resource management. Also, in the water sector, Tudose et al. (2022) developed climate services for sustainable resource management, the water, energy, and land nexus in a specific river basin in Romania.

Dinku et al. (2014) bridged critical gaps in climate services and applications in Africa, finding four critical gaps: (1) gaps in the integration of climate into policy; (2) gaps in the integration of climate into practice at scale; (3) gaps in climate services; and (4) gaps in climate data.

For the agriculture sector, Naab et al. (2019) examined the role of climate services in agricultural productivity in Ghana, from the perspectives of farmers and institutions. Similarly, Dayamba et al. (2018) developed a new approach to extension and climate information services: Participatory Integrated Climate Services for Agriculture. This approach uses historical climate records, participatory decision-making tools, and forecasts to help farmers identify and better plan livelihood options suited to local climate features and farmers' own circumstances. This approach was implemented in two sites in Senegal and Mali. This process stimulated farmers to consider and then implement a range of innovations, which included: (1) changes in the timing of activities such as sowing dates; (2) implementation of soil and water management practices; (3) selection of crop varieties; (4) fertilizer management; and (5) adaptation of plants for the season to actual resources available to them.

Vogel et al. (2017) established a framework for climate services evaluation and its application to the Caribbean Agrometeorological Initiative. The evaluation model helps evaluators address all elements of the provision of climate services—including the quality of weather and climate forecasts and agronomic advisories, the distribution of that information, the uptake of that information, and actions taken by farmers.

Even so, for the development of CS, Buontempo et al. (2020) stated that it is essential to have access to consistent and reliable data and information products to understand better and manage climate risks in climate-sensitive sectors such as agriculture. Tailoring these products to the needs of the users they want to serve facilitates informed decision-making and downstream applications. This requires an in-depth understanding of users' needs and the context in which these users operate.

Weisse et al. (2015) bring together climate service providers and users to discuss their experiences and needs. Using a range of user examples, they demonstrate that historical climate information is often as important as future projections and should receive more attention in future frameworks for climate services. In particular, we concentrate on climate services for marine applications in Europe, where we have a long experience (Weisse & Von Stroch, 2009).

Examples of climate services for the health sector are also found in the literature; for example, Lowe et al. (2017) framed climate services for health specifically for predicting the evolution of the 2015 dengue season in Machala, Ecuador.

A high-level expert panel discussed how climate and health services could best collaborate to improve public health. Key recommendations to merge health and climate services included: a move from risk assessment towards risk management; the engagement of the public health community with both the climate sector and development sectors, whose decisions impact health, particularly the most vulnerable; to increase operational research of the use of policy-relevant climate information to manage climate-sensitive health risks; and to develop in-country capacities to improve local knowledge (including a collection of epidemiological, climate and socio-economic data), along with institutional interaction with policymakers (Jancloes et al., 2014).

Studies about the real development of Climate Services are done, Tall et al. (2014), in their report, presented lessons learned from 18 case studies across Africa and South Asia that have developed and delivered weather and climate information and related advisory services for smallholder farmers. The case studies were examined from the standpoint of how they address five key challenges for scaling up effective climate services for farmers: salience; access; legitimacy; equity; and integration.

To conclude, climate services involve the timely production, translation, and delivery of useful climate data, information, and knowledge for societal decision-making. They rely on a range of expertise and are underpinned by research in climate and related sciences, sectoral applications (e.g., agriculture, water, health, energy, disasters), and a number of social science fields, including political science, sociology, anthropology, and economics. Feedback and engagement between these research communities and communities involved in developing and/or using climate services is thus critical, ensuring that climate services are built on the best available science and providing researchers with guidance regarding priority challenges in the development of climate services that should warrant their attention (Vaughan et al., 2016).

Visbek (2008) indicated that needs complementary climate services that provide continuous climate information for all regions and they are critical to help in adapting and mitigating climate change.

Even so, the development of successful climate services face several challenges, including the identification of the target audience and their needs and requirements, and the effective communication of complex climate information, through engagement with a range of stakeholders (Goodess et al., 2019).

In this vein, increasing numbers of scholars and practitioners appeal to procedural theories of co-production as they work to transform climate science into climate services (Bremer et al., 2019). To do this, stakeholders' participation is the basis for a productive and effective application of CS where effective user engagement and the co-production of climate services are key. That has been a core recommendation of the GFCS and several published studies. This application is not only used in priority areas—agriculture and food security, disaster risk reduction, energy, health, and water—but also in the tourism sector (Turton et al., 2010; Moreno & Becken, 2009; Pandy & Rogerson., 2018; Hopkins, 2014; Morrison & Pickering, 2013).

Vincent et al. (2018) stated that co-production develops credible, salient, and legitimate knowledge for climate services. CS can learn from long traditions of co-productions in other science policy fields. In this line, co-produced climate services are increasingly recognized as a means of improving the effective generation and utilization of climate information to inform decision-making and support adaptation to climate change.

There are examples of research in this field, Costa et al. (2022) examined 16 experiences of ERA4CS projects to define and recommend good practices for transdisciplinary knowledge co-production of climate services to researchers, users, funding agencies, and private sector service providers. They developed a guide mapping the diversity of stakeholder identification, involvement, and engagement methods.

In this context, Golding et al. (2017) stated that engagement between providers and users is well acknowledged as one of the most fundamental activities in providing, developing, and using climate information for decision-making or climate services. Yet there is little guidance in the literature on the most effective and demonstration methods of engagement; their study presented experiences of effective engagement between providers and users to understand the climate information requirements of decision-makers in China. There is a need to develop specific climate services for particular areas and sectors, Nkiaka et al. (2019) identify: (1) the barriers that impede the delivery and uptake of climate services; and (2) the potential strategies for overcoming them to enhance resilience to climate shocks in sub-Saharan Africa.

Depending on the sector in that the Climate Service is developed and depending on the end users, there are different ways of providing CS. Thanks to the GFCS, we know some tips to follow for their development (Figure 13). CS should be composed of directly accessible climate products. CS must be targeted climate products delivered through appropriate media. They have to be directly accessible climate databases, with the option to download specific datasets if users require it. They should publish climate data statistics in a channel and format that is comprehensible to the users (Figure 13).

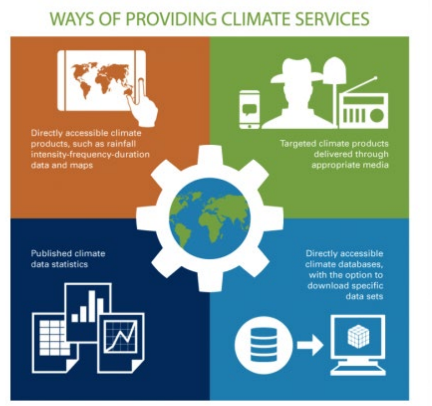

Figure 9. Ways of providing Climate Services

Source: Global framework for Climate Services, 2014.

2.3 Surf destination management and the role of surf forecasts

This section aligns with objective 3, which focuses on developing indicators to assess the management of a sustainable surfing destination. In the practical part of the research, it is necessary to apply most of the theories explained in the previous theoretical sections to understand how to build those indicators.

To think about the management of surfing destinations, it is first required to understand the growth of tourism, paying special attention to surfing tourism. It is also indispensable to understand the principles of surf forecasting and use the high quality specific data to design and compute the specific indicators for surfing destination management. We find in the literature that surf forecasting requires some improvements in the future to obtain more precise forecasts not only modelled for open sea but also modelled for the shore, where surfing is practiced. Establishing surfing climatologies for the nearshore will act as first steps for designing similar nearshore forecast models for surfing; for this reason, a section about surf forecasting is included.

2.3.1 Tourism in a context of growth: special mention of surfing tourism

Tourism is one of the largest global economic sectors, a vital contributor to the economy of many nations, and is highly promoted as an important means of future development and poverty reduction in developing countries. The interface between climate and tourism is multifaceted and complex, with broad significance for tourist decision-making and expenditures and industry marketing and operations worldwide. With the close relationship of tourists to the environment and climate, the integrated effects of climate change are anticipated to markedly affect tourism businesses and destinations, as well as the destination choices and mobility of individual tourists in the decades ahead. Recent major natural, political, and economic shocks have demonstrated that the tourism sector has relatively high adaptive capacity. Improved climate services will be vital for travellers and tourism businesses, and destinations to adapt to climate change economically, socially, and environmentally sustainable (Scott et al., 2011).

Buckley et al. (2002) exposed that commercial surf tourism is recent in origin but is now a significant component of the worldwide adventure tourism sector. There are more than 10 million surfers worldwide; one-third of these are cash-rich, time-poor, and potential tour clients. Martin et al. (2012) stated that surf tourism is a rapidly expanding market segment of the wider sports tourism and focused on providing an analytical interpretation of surf tourism research for 1997-2011. Outputs show a genesis in sports tourism literature, representing a new and available body of surf tourism research. In this vein, surfing events, artificial surf reefs, and the sustainability of surf sites and host communities are among the most prolific areas under discussion. Key arguments include socioeconomics, coastal management, and sustainable tourism. Approximately 10% of countries in the world with coastal surfing resources have been studied, and this and other findings indicate the potential for new research areas in domestic and international tourism. In this line, Martin (2022) uploaded his previous research by looking for surf research for the 2011-2020 period. The study postulates that the field has entered a period of academic professionalization.

Marine ecosystems contribute to human well-being, e.g., through the promotion of nature-based recreational activities, such as surfing, which is a benefit obtained from Cultural Ecosystem Services. Román et al. (2022) focused on identifying the benefits and impacts associated with surfing and who are the main affected subjects and/or objects, achieving a better understanding of the sustainability status of this recreational activity. Results found that implications of surfing go beyond direct users (i.e., surfers) and have consequences in diverse dimensions (environmental, socio cultural, and economic), involving many stakeholders.

Surf tourism is an increasingly popular niche in tourism that sparks economic development in many coastal regions around the world. Surfers use surf breaks, which can be considered natural resources that thus experience carrying capacity issues (Knaap & Vanneste, 2021).

The sustainability and conservation of coastal surfing resources have gained considerable attention in the twenty-first century. Martin and Assenov (2014) investigated the significance of 27 social, economic, environmental, and governance indicators outlined in the Surf Resource Sustainability Index, a contemporary methodology for measuring the conservation aptitude of surf sites. Results of the research contributed to surfing tourism planning and development through the clarification of sustainability indicators. A surf resource conservation action matrix is developed for future policy design and management.

Buckley (2002) also explored sustainability problems, in this line of research exposed that Indo-Pacific surf destinations with cheap and open access and no capacity management have experienced crowding, crime, pollution, and price collapses.

O'Brien et al. (2013) analyzed a strategic approach to managing tourism in Papua New Guinea with a similar aim to manage better surfing tourist destinations. As surf tourists often travel to remote destinations to ride surfboards, earlier research suggests the mismanagement of surf tourism in some destinations has significantly harmful impacts on host communities. Primary data came from semi-structured interviews and participant observation. The derived knowledge from this research may decrease host communities' reliance on less sustainable commercial activities and inform policy and practice on sustainable approaches to using sports tourism for community building and poverty alleviation.

Surf tourism presents its economic impact. Mach and Ponting (2021) stated that international surf tourism expenditure was valued between $31.5 to $64 billion USD per year, and surfers reported being willing to pay between $1.99 and $4.1 billion USD more annually for sustainable surf tourism products. These results suggest surfing tourism deserves a more significant place in funding initiatives, discussions, and research on fostering sustainable development of ocean resources in the rapidly changing world.

Krause (2012) defined surf tourism as a largely ignored mode of touristic behaviour in the academy. His investigation added to a very limited body of work by providing explorations of the significance of surf tourism for surfers and by bringing forward data and observations of the impacts surf tourism has had on Playas Jacó and Hermosa in Costa Rica.

Even so, it is necessary to remember what Mach and Ponting (2018) defined as that surf resources are critical to thousands of coastal communities as the natural resource base for many tourism services that spur development. There is almost a total lack of formal surf-break management worldwide, despite many surf resources becoming crowded, which leads to nuanced resource conflicts with social, economic, and environmental implications.

2.3.2 The importance of surf forecasting

Combined surf forecasts and observed natural conditions impact surf travel behavior in nuanced ways that deserve further attention to better understand destination and hospitality management, as well as, host and guest satisfaction and they relate to intra-seasonal and intra-regional travel patterns (Mach et al., 2020).

To plan the 'perfect' session, every surfer, windsurfer, and bodyboarder needs to be familiar with the ever-changing state of the ocean. Sea-sport activities are done in the ocean, which is a different playing field. Skiing has a predictable hill and slope that stays somewhat constant. Water-skiing has some varying conditions, but it is fairly still a sport of constant value regarding Mother Nature. Wave riding sports, however, have many more variables to deal with (Cool, 2003).

Besides knowing when swells will arrive and how big waves will be, wind, tidal depths, hazards, water temperatures, and other fluctuations all need to be taken into account. Events that occur thousands of miles away affect surfing days later. Thanks to the advancement of science and technology, we can visually see what is occurring on the entire ocean surface in the winds, swell heights, and other data that is useful to surf forecasting. Satellites and other means of analysis of recent ocean events forecasting computers crunch into a visual representation of what is happening on the open sea. These representations are called models (Cool, 2003).

Models play a vital role in forecasting surf conditions. However, that is typically not the intention for many of the models generated today. For the most part, models showing open ocean systems are primarily intended for the maritime industries and naval interests (Cool, 2003).

As models in general were computed in the open sea, it is important to take into consideration mitigation factors as: shoaling, refraction, swell angles, swell windows and angular spreading, diffraction, island blockage, opposing winds and currents, and storm course (Cool, 2003).

PART II. CASE STUDIES

3. Definition of the Surfing Climatology in the Iberian Peninsula

Expected Distribution of Surfing Days in the Iberian Peninsula

Boqué Ciurana, A., & Aguilar, E. (2020). Expected distribution of surfing days in the Iberian Peninsula. *Journal of Marine Science and Engineering*, *8*(8), 599. https://doi.org/10.3390/jmse8080599

Highlights

- Variables that define surfability are defined
- The significant wave height variable is the most decisive determinant
- An indicator to assess expected surfing days per year is defined
- The wave surfing resource varies depending on the coast of the peninsula
- Northern and western shores present the most expected numbers of surfing days per year

Abstract

This study presents, for the first time, a comprehensive characterization of the surf spots
around the Iberian Peninsula and provides surfers and stakeholders with 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 (*Owd*) and optimal swell direction (*Osd*). Then, we define a surfing day as the ones in which optimal swell direction and waves bigger than 0.9m occur; using three parameters mean swell direction (*Dmd*), significant wave height (*Hm0*) and optimal swell direction for each surf spot (*Osd*) 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 (*Hm0, Hmax, Tp* and *Dmd*) 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

3.1 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 andwind strength (Butt & Russell, 2009). 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 (Reineman, 2016). Surfing tourism has increased in popularity as a form of active sport tourism, with surfers bringing economic benefits to a destination (Reynolds & Hritz, 2012).

Although all surf spots are used for the same recreational purpose, each spot is unique given its oceanographic, coastal, social setting and cultural history (Reineman & Ardoin, 2018). 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. (2001) 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 (Hutt et al., 2001; Scarfe et al., 2003).

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 (Tp), depending on their origin. Ocean swell, also known as ground swell, is thebest type for surfing, as it produces non mixed waves with large values of Tp. Groundswell is generatedby storms and the stronger the swell, the larger tend to be the wave periods. Wind swell is created bywind 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 thosesmaller 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 (Wiegel, 1960).

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 (Cool, 2003). The perfect conditions for surfing are light offshore windsor no wind (Douglass, 1990). 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 (Scarfe et al., 2003). 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 (Mead & Black, 2001). The peel angle, related to the break angle and the wave obliquity atthe breaking depth, determines the speed that the board must adopt to stay ahead of the breaking section of the wave (Mendonça et al., 2012).

A minimum peel angle of 30° is generally required for surfing, large peel angles are generally associated with nonuniform bottom contours (Walker, 1974).

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 (Scarfe et al., 2009). According to the values of these parameters, the waves will be useless for surf, adequate for beginners, for intermediate level or for advanced surfers (Hutt et al., 2001).

The seabed morphology plays an important role in creating wave breakers. Planar beaches with parallel contours do not produce good surfing breaks (Scarfe et al., 2009). The peel angle is too low forsurfing, Waves simply closeout as the crest breaks all at once rather than peeling. Other bathymetricconfigurations—i.e., sandbar and reef break, see Section 3.3 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/rockreefs, points, rock ledges, piers, jetties or beaches where large scale bar/rip features (Hutt et al., 2001; Cinner & Bodin, 2010).

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 themost 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 (Scarfe, 2008). Moreover, as said by Caldwel et al. (2013) and Corne (2009), 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 tonot 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 (Scarfe et al., 2009; Rivera Mateos, 2016).

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 (Dally, 2001). While several global studies are available in the literature (Espejo et al., 2014; McGregor & Wills, 2017; Espejo et al., 2012) this is not the case for regional and local studies which consider higher resolution and more localized variability, with the exception of Lopes and Bicudo (2017) and Peñas de Haro (2015). In thisregard, we are not aware of any study which describes the distribution of the number of surfingdays per month for each spot in the Iberian Peninsula. In fact, what is known is that it is difficultto have a spot where favorable surfing conditions occur every day of the year–which means thatwave, wind, tide and bathymetry conditions would be conducive to surfing. In this study, we pursuethe 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 presentedin Section 3.2; we present our results at Section 3.3, to finish with discussion and conclusions (Section 3.4).

3.2 Study Area, Data and Methods

3.2.1 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 statisticsfrom the European Union, which contains a total of 872 surfing spots, from which we will concentrateon the 46 that can be directly related to available buoy data (see Section 3.2.2). Both NUTS2 regions andselected spots are shown in Figure 14.

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 dataare 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 15 and Table 4). 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.

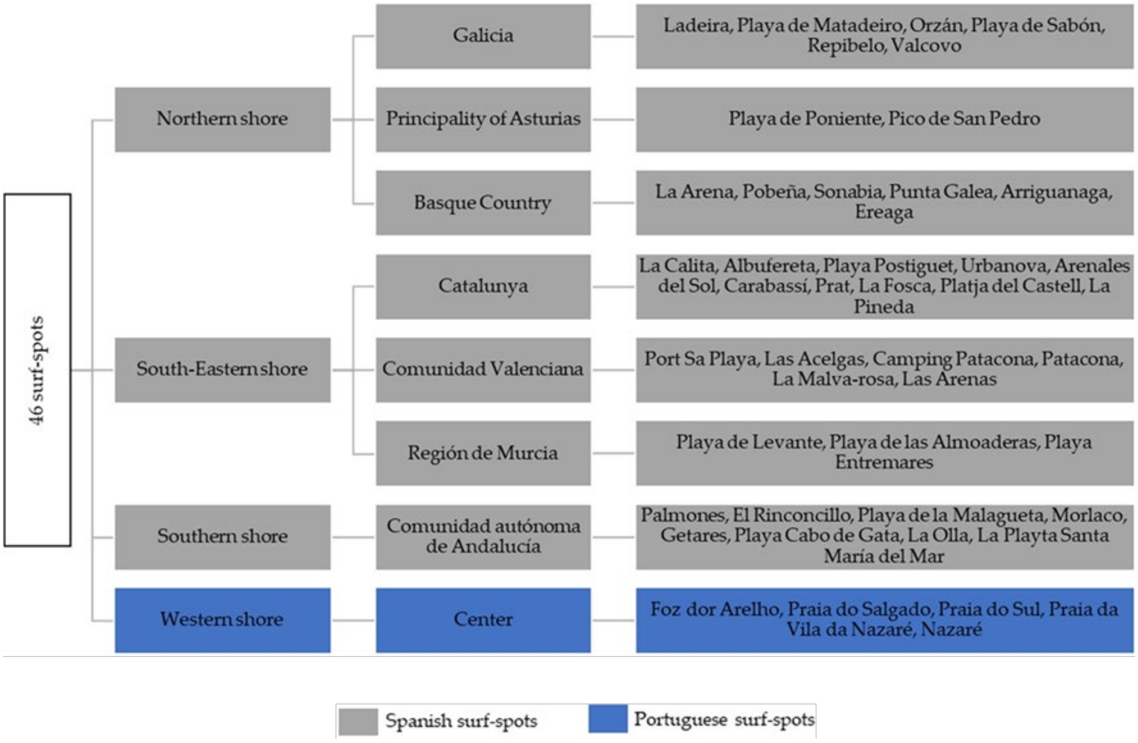

Figure 10. Selected 46 surf spots structure, organized by section and political region (Autonomous Communities for Spain; statistical regions (NUTS2), managed by the regional coordination and development commissions (CCDRs) for Portugal).

Source: author's own production

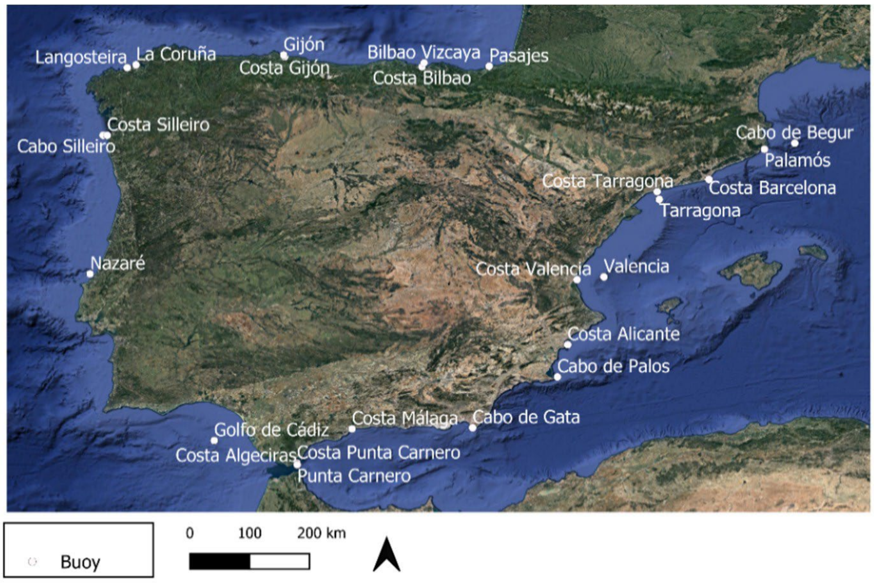

Figure 11. Nearshore BDS distribution around the Iberian Peninsula.

Source: author's own production

Table 4. Studied buoys

Source: author's own production

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

This study analyzed historic wave data recorded between 1982 and 2019 (see again Table 4 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 3.2.2 for further explanations).

3.2.2 Methods

To achieve the objectives described in Section 3.1, we combine the two data sources previously introduced (buoy data and Glassy App data) as described in Figure 16. Our analysis is split in three steps:

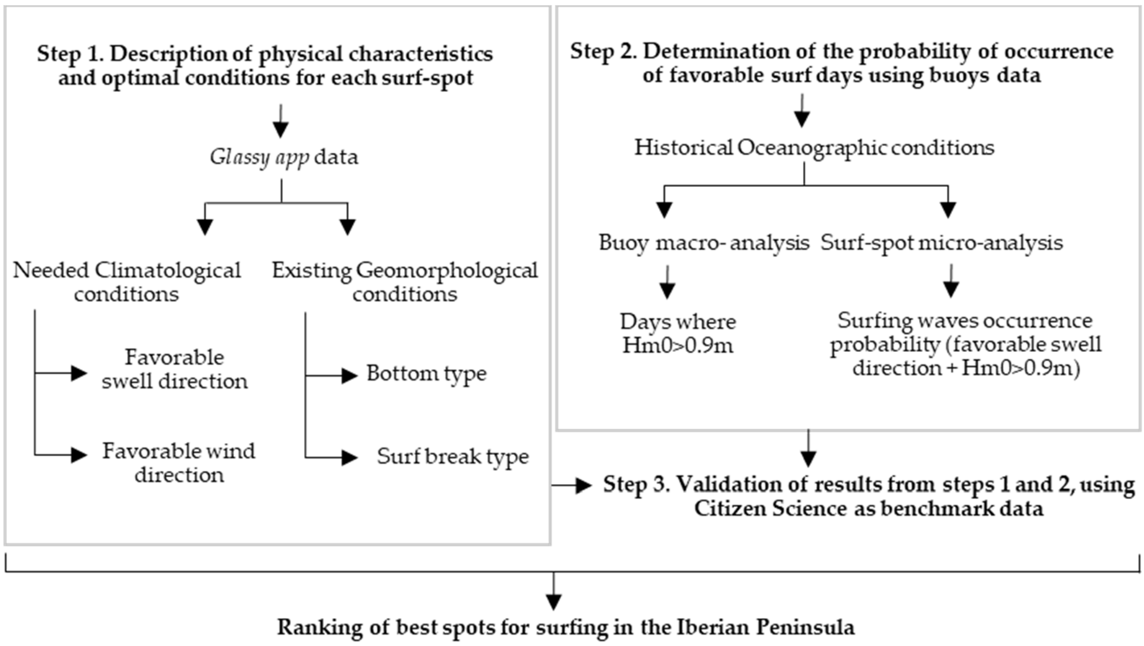

Figure 12. Methodology flow: from citizen science data and buoy network data to the expected surfing days per year in the Iberian Peninsula

Source: author's own production

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}) (Munk, 1944). 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 (1964).

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

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 (Young et al., 1995) 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 numberof swell observations.

$$SWOP = \sum cosd \,\Sigma\, n\,osd \tag{2}$$

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 reasoninformation 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 SWOP indicator. It is important to remember that having the necessary swell direction in the surf spot will not necessarilymean 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 17), 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 ofinstantaneous 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 parametersof 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.

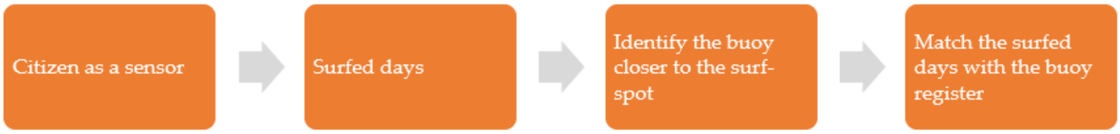

Figure 13. Conceptual explanation of the benchmarking/validation approach by using citizen science data (Step 3). Once the validation process proves the methodology of attributing surfing days to surf spots, it is possible to create a ranking for expected surfing days per year in the studied surf spots. To identify this, days where Hm0>0.9 m and Optimal swell directioon are selected.

Source: author's own production

3.3 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.

3.3.1 Optimal wind and *Dmd* Conditions for Surfing

We extract optimal swell direction (O_{sd}) and optimal wind direction (O_{wd}) for each surf spot from GAS (Figures 18 and 19). 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 optimalwind direction rotates to SW–NE.

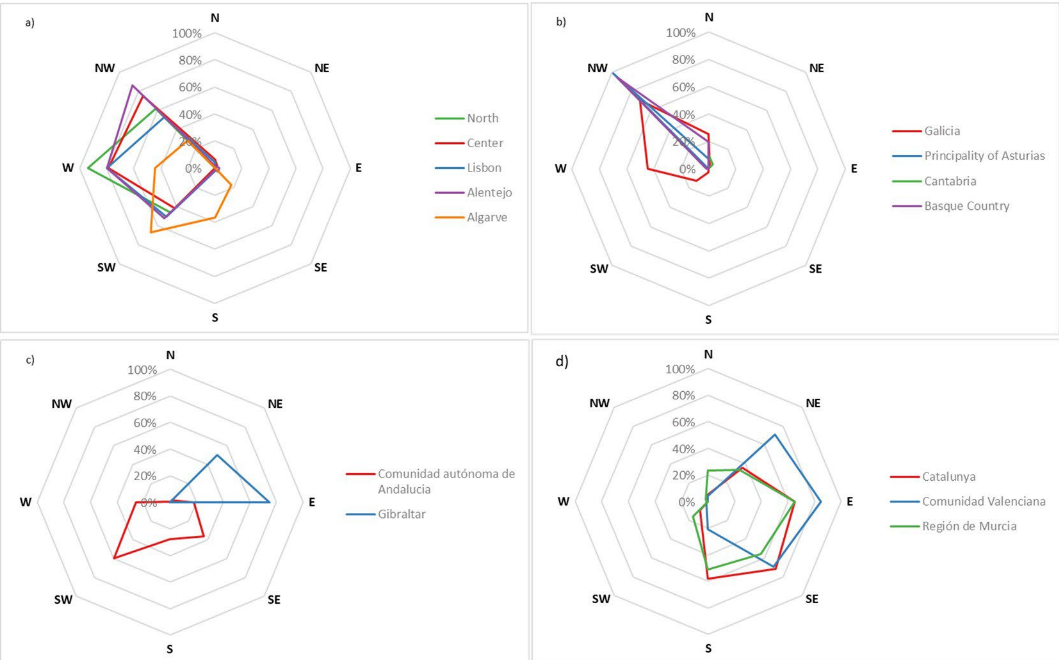

Figure 14. Optimal swell direction in the Iberian Peninsula's surf spots. (a) Western shore; (b) northern shore; (c) southernshore; (d) south-eastern shore.

Source: author's own production

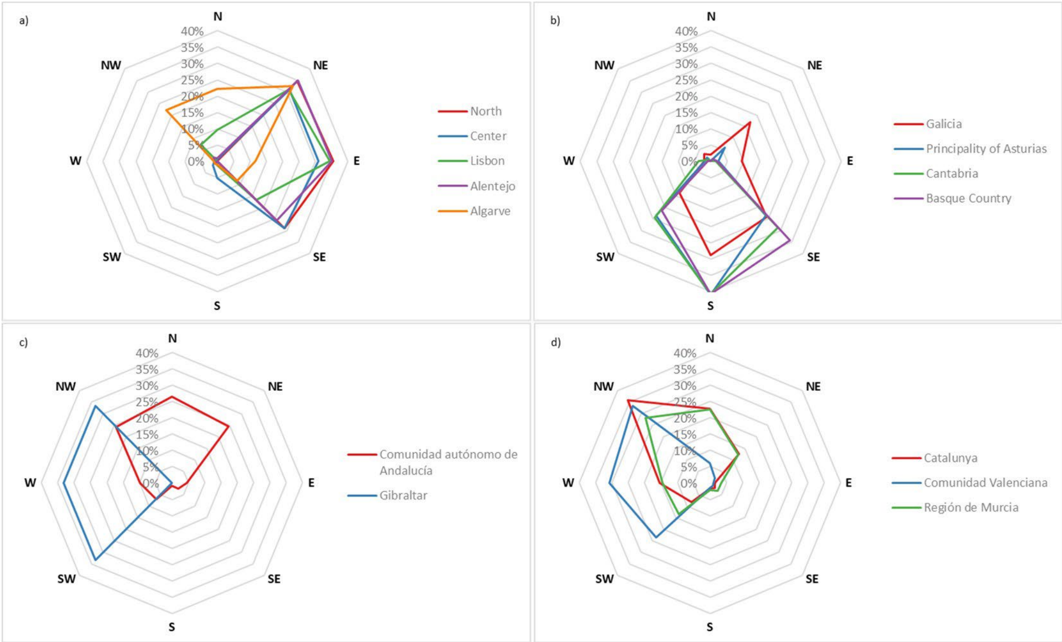

Figure 15. Optimal wind direction in the Iberian Peninsula's surf spots (%). (a) Western shore; (b) northern shore; (c) southern shore; (d) south-eastern shore.

Source: author's own production

3.3.2 Historical Oceanographic Conditions

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

3.3.2.1 H_{m0} Distribution

Figure 20 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 20. 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 tomany 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 20c and little in Figure 20d, but interestingly thereis no strong seasonality in Figure 20a,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 dayson 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.

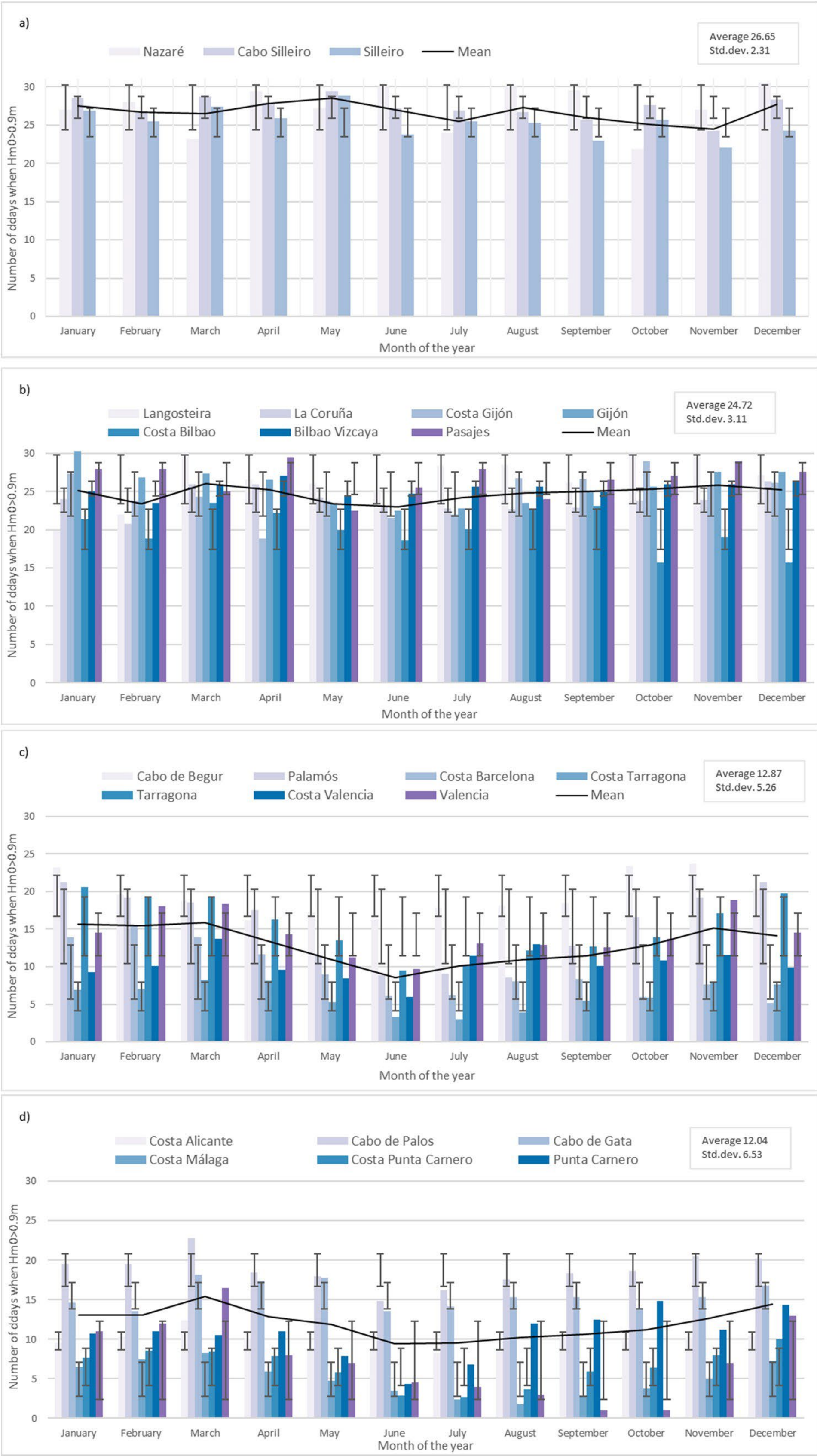

Figure 16. Observed days where Hm0>0.9 m. (a) Western shore; (b) northern shore; (c) south-eastern shore; (d) southern shore.

Source: author's own production

3.3.2.2 SWOP Analysis

Figure 21 presents the SWOP analysis. Figure 21a shows the SWOP values the western Shore.As described in Section 3.2.2, 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 17. SWOP values and expected days per year with Optimal swell diretion. (a) Western shore; (b) northern shore; (c) southern shore; (d) south-eastern shore.

Source: author's own production

Figure 21b 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 21c 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) inPlaya 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 21d presents the SWOP values for southern shore. SWOP biggest value for this regionis 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 directionmay 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.

3.3.2.3 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 5 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 thesurfed 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 5. Hm0, Hmax, Tp and Dmd values for Costa Tarragona's buoy: 2006-2019

Source: author's own production

	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 22 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 (Bretschneinder, 1964). Boxplots show that the distribution of H_{m0} and H_{max}

variables are different for surfed and non-surfed days.

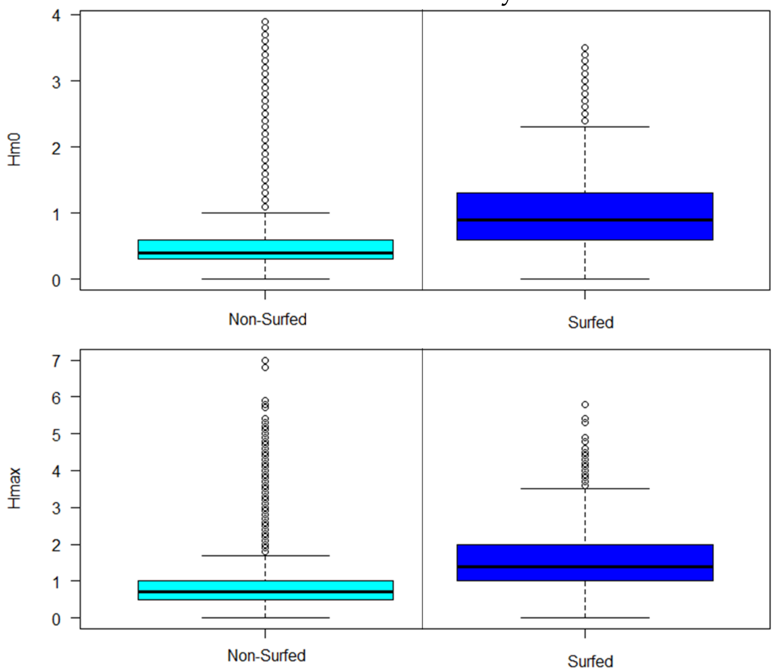

Figure 18. Hm0 and Hmax distribution for non-surfed and surfed days in Costa Tarragona's buoy (2006-2019).

Source: author's own production

Table 5 shows, significant wave height distribution presents for surfed days values of percentile25 (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 valuesof 0 m to 0.4 m exist on surfed days, is explained by the days when, for example, there are no waves inthe morning [0 m, 0.9 m] and then in the afternoon the wave height starts to increase [>0.9]. This factoccurs 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 notstay 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 23 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).

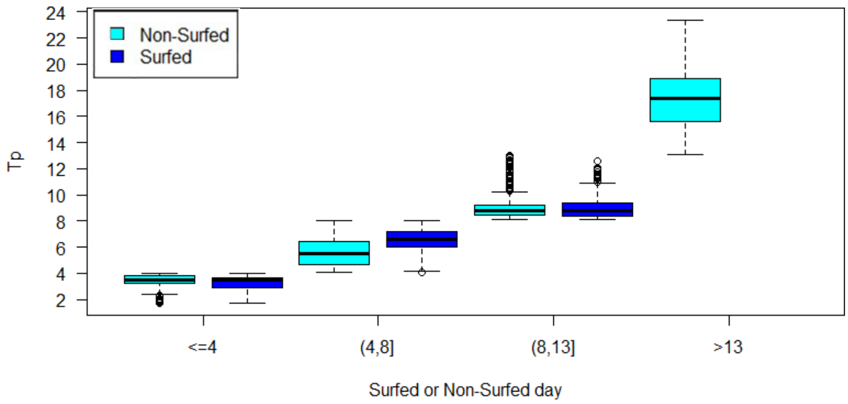

Figure 19. Tp distribution for non-surfed and surfed days in Costa Tarragona's buoy (2006-2019)

Source: author's own production

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 entireday. 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 24 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.

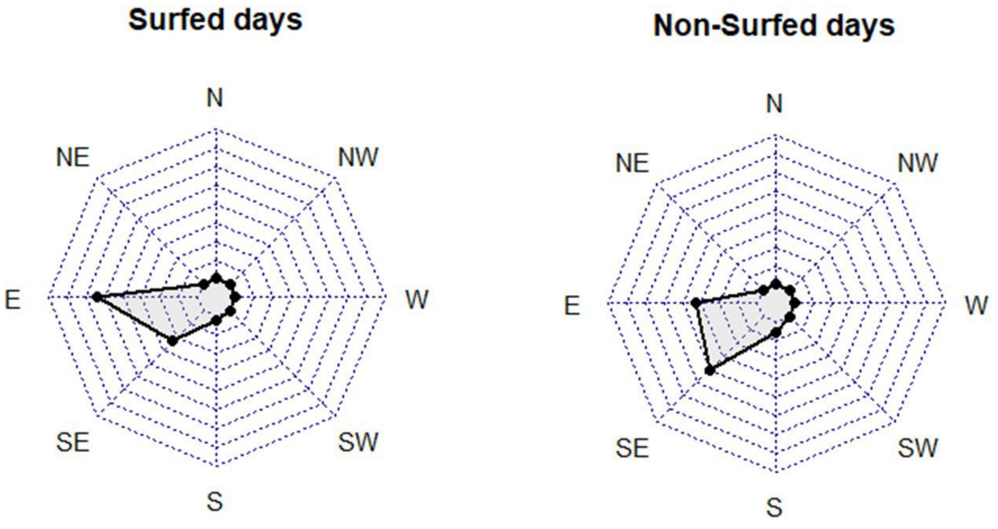

Figure 20. Percentage of Dmd distribution grouped by surfed and non-surfed days hourly observations in Costa Tarragona's buoy (2006-2019)

Source: author's own production

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 6 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 6. Wilcoxon-Mann-Whitney test for Hm0, Hmax and Tp parameters with surfed and non-surfed days

Source: author's own production

	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.

3.3.3 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 24 and Table 7). Figure 25 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 valuescorrespond to southern and southeastern shores. As expected, it is clear that the areas of the AtlanticOcean 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 7, 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 7. Ranking of best spots for surfing in the Iberian Peninsula

Source: author's own production

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.

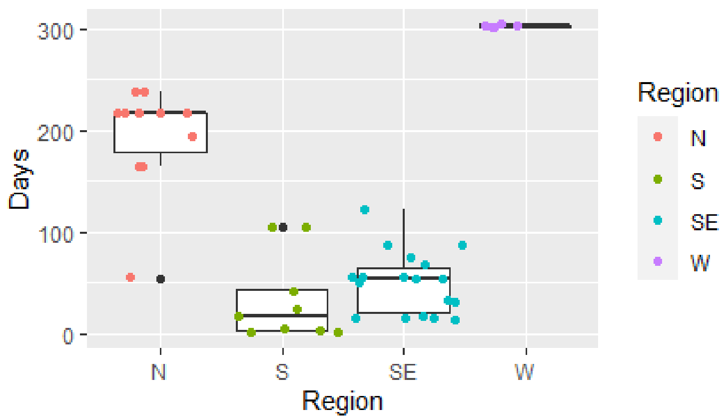

Figure 21. Jitter plot of expected surfing days per year by regions in the Iberian Peninsula

Source: author's own production

3.4 Discussion and Conclusions

Buckley (2017) 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 (GFCS, 2016), 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 (2009) and Butt et al. (2004), 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 Haro (2015) identified the distribution of surfing days in Mallorca and the research of Espejo et al. (2014) and Espejo et al. (2012) 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 et al. (2014) and Espejo et al. (2012) 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 ofcitizen 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 strongwinds 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 (2010) who criticized the "wonderland" in Mentawai Islands in Indonesia. Martin (2010) and Buckley (2017) 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 and Franzidis (2018) 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 thesurf 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 buoysto 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 dataand 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.)

4. Exploring users' needs

Which Meteorological and Climatological Information Is Requested for Better Surfing Experiences? A Survey-Based Analysis

Boqué Ciurana, A., & Aguilar, E. (2021). Which Meteorological and Climatological Information Is Requested for Better Surfing Experiences? A Survey-Based Analysis. *Atmosphere*, *12*(3), 293.

Highlights

- Surfers and businesses that offer this activity around the Iberian Peninsula's surf spots have been surveyed
- Meteorological and climatological information plays a relevant role in planning the activity
- The environmental problem that impacts the more is the extreme erosion of surf spots
- Knowing the expected surfing days can help to regulate business plan and so the business' income
- The need for high-resolution sea state data is detected

Abstract

This paper extends the work of previous research by investigating surfing practices and surf-recreation companies from a behavioral perspective. The study's main aim is to gain insights into the role of meteorological/climatological information in decision-making related to the surf-tourismactivities market. This information was gathered employing an online survey that asked respondents about where they surf and how they check forecasts for surfing. Climate services (CS) are promoted to support the decision-making process to better prepare for and adapt to the risks and opportunities of climate variability and change. The current market for CS is still in its early stages. In this paper, we report the findings from our recent investigation into the actual and potential market for CSfor the Iberian Peninsula surf-tourism sector. Based on surfers' and surf companies' demands, it was found that an improved surfing climate service (herein, SCS) will have clear implications in the management of these tourism areas and provide insights into whether surfing activities may besuccessful. At the same time, such services can help to manage adaptive actions in regard to the impacts of climate change in surfing areas.

Keywords: climate services, tourism, surfing, waves, adaptation, mitigation

4.1 Introduction

Climate services (herein, CS) are promoted to support decision-making process in order to better prepare for and adapt to the risks and opportunities of climate variability and change (Damm et al., 2020). According to the World Meteorological Organization (WMO), the role of CS in climate change mitigation and adaptation has been the subject of research, especially in the four areas of focus for the Global Framework for Climate Services (GFCS) (Hewitt et al., 2012) : (i) health (Jancloes et al., 2014; Connor et al., 2010); (ii) agriculture (Williges et al., 2017; Coulibaly et al., 2017; Vaughan et al., 2019; Rosas et al., 2016); and food security; (iii) water and energy; and (iv) disaster risk reduction. Examples of CS for agriculture can be found in Mali and Senegal, among other countries, where a new approach has been created to develop climate information services. This approach uses historical climate records, participatory decision-making tools, and forecasts to help farmers identify and better plan livelihood options suited to local climate features and farmers' varied circumstances (Dayamba et al., 2018). In addition, several programsaddressing climate services for improving public health can be found in Brazil Lowe et al., (2013) and Ethiopia (Dinku et al., 2011).

Nevertheless, CS can also be developed for other sectors (Soares et al., 2018) such as tourism. For this sector, climate is identified as a factor of location; every economic activity requires a territorial base, and this applies to geographic spaces acting as supports for tourism activities. The kind of terrain in the support area also influences where activities are conducted. Climate is one of the geophysical elements that comprise geographic space (Gómez-Martín, 2005), and it also works as a tourism resource. In this respect, climate is a basic resource for various activities that depend on the climate/weather, which can include sun and beach tourism,winter sports such as skiing and snowboarding, health tourism, and water sports (Smith, 1993).

Aligned with this, it has been affirmed that local climatology and the succession of different weather types influence the location of resorts, the calendar of tourism activities, the use and efficiency of the infrastructure, and the return on investments. Indeed, many resorts have prospered thanks to their ability to turn favorable local climatic conditions to their advantage (Aguilar Anfrons & Gónzalez Reverté, 1995; Barbier, 1984; Becker, 2000; Besanecot, 1974).

The most widely applied approach for quantifying climatic resources is the Tourism Climate Index (TCI). The TCI was developed by Mieczkowski (1985) and was designed to integrate the main climatic variables relevant to tourism into a single numerical index. Other tourism climate indexes have also been developed, including the Daily Comfort Index (CIA), the Daytime Comfort Index (CID), the Climate Index for Tourism (CIT), the Holiday Climate Index (HCI) (Scott et al., 2016), the Beach Comfort Index (BCI) (Becker, 1998) and the Modified Climate Index for Tourism (MCIT) (Scott et al., 2011).

Related to this, several studies have demonstrated the impact of climate on tourism demand. The information provided by such research has made it possible to identify optimal temperatures at travel destinations for different kinds of tourists and various tourism activities (Lise & Tol, 2002). Climate change and tourist comfort on Europe's beaches during the summer have also been analyzed. The main results found that destination managers in Mediterranean tourism destinations should focus part of their attention on climate change impacts such as potential sea level rise and water availability. Furthermore, they should include environmental quality and diversification of activities in their deliberations. In non-Mediterranean regions, a promising strategy may be to focus on short- and medium- distance visitors who can take advantage of new opportunities for beach tourism and explore the merits of seasonal climate forecasting (Moreno & Amelung, 2009).

Climate change can affect tourism. When considering the implications of an increase of 2 ◦C in global warming for European summer tourism, the main results showed that climate change will positively affect Central and Northern Europe, thus increasing the potential for further economic development in this direction. Mediterranean countries, by contrast, stand to lose favorability as tourism destinations during the hot summer months but will tend to gain favor during the early- and late-summer seasons (Grillakis et al., 2016). Therefore, improved climate services will become even more vital for travelers, the travel and tourism industries, and destinations and will be required to adapt services and activities to meet the challenges of climate change in an economically, socially, and environmentally sustainable manner (Scott et al., 2011).

In regard to sun and beach tourism, beaches are the principal attraction. Quantitative and qualitative assessments illustrate that most of the world's sandy shorelines are in retreat (Gable et al., 1997). In this framework, it has been shown that coastal zones are particularly in need of climate services for adaptation. This field of research has analyzed how annual to multidecade sea level projections can be used within coastal climate services (Le Cozannet et al., 2017).

Climate and weather conditions for outdoor recreation construct the basis to identify which activities are viable in certain territories and moments, and which are not (Scott et al.,2005).

Surf, snow, wind, and white-water provide natural resources for adventure tourism. Both the resources themselves and their access for tourism are dependent on weather and, hence, are affected by climate change (Buckley, 2017). As defined by different authors, surf tourism involves travel and temporary stays undertaken by surfers with the primary expectation of surfing waves (Ponting, 2009; Fluker 2003). Such travel includes at least one night away from the region of their usual domicile. The growth of surfing activities and surf tourism has gained significant attention in academia. The Surf Resource Sustainability Index (SRSI) was developed as a conceptual model to study the sustainability of surf-tourism sites. It focuses on the importance of social, economic, environmental, and governance factors in the conservation process (Martin & Assenov, 2013). Referring to studies about wave climates and surfing, Espejo et al.

(2014) studied the spatial and temporal variability of surfing resources around the world. Peñas de Haro (2015) identified the distribution of surfing days in Mallorca, and Boqué Ciurana & Aguilar (2020) defined the expected number of surfing days per year on the Iberian Peninsula.

Some research has identified behavioral market segments among surf tourists based on past destination choice. One study was conducted through an online survey, and the results show six market segments that take into consideration different ages, various levels of surfing ability, length of stay, preferred wave type, and the regularity of undertaking trips with the aim of surfing at the chosen destination (Dolnicar & Fluker, 2003). Other studies have examined the natural component of seasonality in relation to surf tourism, using survey responses collected globally and analyzing how surfers report using forecasts to make travel decisions. In addition, occupancy data is analyzed in relation to surf-forecast data to empirically assess intraseasonal fluctuations. The results found that most international travel is booked months in advance based on climatic factors (Mach et al., 2020. Works focusing on identifying surfers' profiles have also been explored in the Mentawai Islands of the western coast of Sumatra (Towner, 2016).

The need to understand how surf tourism works is aligned with the need for surf- break preservation. Indeed, Reiblich, who researches legal and policy implications of coastal adaptation, has stated that surfbreaks include three components: the submerged lands under the wave zone; a wave corridor that allows an unimpeded right of way for swells to reach the wave zone; and beach access. In this sense, sufficient surfbreak protection requires that policymakers employ a strategy that takes all three components into consideration (Reiblich, 2013; Scheske et al., 2019). In some surf spots such as the Bahía de Todos Santos World Surfing Reserve, surfbreak preservation has been applied. In addition, some studies in Peru, Chile, and the US have focused on the link between surfing and marine conservation, thus highlighting representative surfbreaks and the need for their protection not only for their value to surfers but also for the ecosystem services they provide, as well as other benefits for marine conservation (Scheske et al., 2019).

In the field of CS for surfing, studies about the efficient delivery of forecasting to a nautical sports mobile application (hereafter, app) with semantic data services have demonstrated that weather and sea-related forecasts provide crucial insights for the practice of nautical sports such as wave surfing and kite surfing. Moreover, mobile devices are appropriate interfaces for the visualization of meteorology and operational oceanography data (Amorim et al., 2016). Scott et al. (2011) found that private-sector climate service providers have been innovators in the use of emerging communication technologies designed to deliver specialized climate information to tourists and other tourism-sector end-users. Several examples can be found on weather applications tailored to specific tourism-related activities such as skiing, surfing (e.g., the Oakley Surf Report) and fishing. Meanwhile, several items have been de- signed to track surfing sessions and to register different variables. Pontes Caselli & Ferreira (2018) developed a systematic proposal for UX-centered mobile apps for tracking performance in sports through an app in recreational surfing. Another case of a technological design for surfing is the creation of Smart Fin, which records temperatures and GPS for surf science. In addition to the creation of this technology, a survey was designed to identify groups within the surfing community that would surf for science (Scott, 2019).

A range of communication channels exists for the delivery of climate information to tourists and the tourism sector. Successful attempts have been made to provide understandable, familiar, and consistent international meteorological information that can be used by tourists, but how climate information is communicated to tourists and tourism subsectors remains largely unexplored (Scott et al., 2011).

As stated, while several studies about surfing forecast apps and surfbreak preservation are available in the literature (Edwards & Stephenson, 2013), we are not aware of any study that has designed a surfing-climate service (hereafter, SCS). As previously discussed, the relationship between climate, weather, and tourism must be understood so that tourism planning can be more effective. In this regard, CS can be a tool for achieving effective surf-tourism planning. For this reason, this paper strongly focuses on the design of an SCS tailored for surfers and other surf tourism-sector end-users on a regional scale, specifically, in the Iberian Peninsula framework.

The creation of CS for surf tourism is still in an early and premature stage of development. For this reason, the present study aims to establish the basis of the SCS design, specifically by understanding which meteorological and climatological information is re- quested for a better surfing experience. In this research, we pursue the following objectives: (1) to explore and define what meteorological and climatological information is used nowadays; (2) to discover which meteorological and climatological information can be improved for a better surfing experience; (3) to understand what environmental problems negatively affect surf activities; and (4) to understand surfing tourism flows on the Iberian Peninsula.

4.2 Data and Methods

4.2.1 Survey Description and Target Audience

This research created an online survey with the aim of better understanding how a surfing-climate service (SCS) should be designed for surfers and other surf-tourism sector end-users for surfing on the coast of the Iberian Peninsula. In this regard, the study area covers the coast of the Iberian Peninsula, located in the southwest corner of the European continent. The countries that comprise the peninsula are Spain, Portugal, France, Andorra, and the United Kingdom (Gibraltar). The target population corresponds to surfers older than 16 years of age who have surfed somewhere on the Iberian Peninsula.

Currently, there is no identified number of how many people actually engage in surfing activities; as Esparza (2011) presented, this is because many surfers are not registered in any federation, and in some cases, surfers practice this sport only sporadically, making it difficult to identify them as tourists. For the purposes of this study, we will identify surf tourism using two criteria: (1) surfers stay at a location for at least one night that differs from their usual place of residence in order to surf, and (2) the travel is conducted by active surfers, meaning experts and other practitioners of the sports as well as beginners who travel with the main purpose of surfing. For this reason, the target population is considered infinite for calculating the sample (Equation (3)). We have obtained 470 samples; as there are no previous studies of prevalence in this field, values of probability are considered the same: p (0.5) and q (0.5). We establish z = 95% through Equation (1) to calculate the value of d (4.52%).

$$d = \square\ z\square 2\square pq\square\ n\square s\square\square\square \qquad (3)$$

d = maximum allowable error

z = level of confidence

p = probability of success

q = probability of failure

n□s□ = sample number

First, a pilot survey was launched (Álvarez Esteban, 2003) on SCS; then, the study survey was revised and redesigned according to the answers and feedback from the pilot survey.

Secondly, to achieve the sample, surveys were distributed to surfers via social networks, i.e., Twitter, Instagram, and Facebook, and a surfing radio program. For this reason, results may be biased, and previous parameters should be taken as approximate values. The survey distribution was conducted from 19/05/2020 to 17/10/2020. It included 34 questions in different formats: open-ended, closed-ended, rating, and multiple choice (Table 8). The text for the survey can be found in the Appendix A3.

Table 8. Format of survey questions and topic of interest

Source: author's own production

Question Number	Format of Survey Question	Topic of Interest
0	Filter	Ever surfed on the Iberian Peninsula
1	Closed-ended	Demographic information
2, 3, 4	Open-ended	Demographic information
5, 16	Closed-ended	Behavior information
6	Open-ended	Surfer profile
7, 8, 9	Closed-ended	Surfer profile
10	Open-ended	Local surf spot
11	Multiple choice	Environmental changes
12	Open-ended	Environmental changes
13	Closed-ended	Surfing tourism mobility behavior
14	Open-ended	Surfing tourism mobility behavior
15, 19, 21, 25	Multiple choice	Request for meteorological/climatological information
17	Rating	Request for meteorological/climatological information
18, 22, 24	Closed-ended	Request for meteorological/climatological information
20, 23	Open-ended	Request for meteorological/climatological information
26	Open-ended	The perceptions of meteorological and climatological information use by entrepreneurs, managers or workers at surf schools or similar
27	Multiple-choice	The perceptions of meteorological and climatological information use by entrepreneurs, managers or workers at surf schools or similar
28, 29, 30, 31, 32	Closed-ended	The perceptions of meteorological and climatological information use by entrepreneurs, managers or workers at surf schools or similar

4.2.2 Survey Analysis

The survey analysis allowed the identification of different facets that will contribute to the design of the SCS. These aims are (1) the identification of preferred sea information to assess decision-making before surfing; (2) the identification of future needs for surf-forecast delivery; (3) to understand surfers' perceptions of the environmental problem; and (4) to understand surfing tourism locations on the Iberian Peninsula. Each facet is related to the specific topic. Using all the information gathered, it is possible to design an SCS prototype (Figure 26).

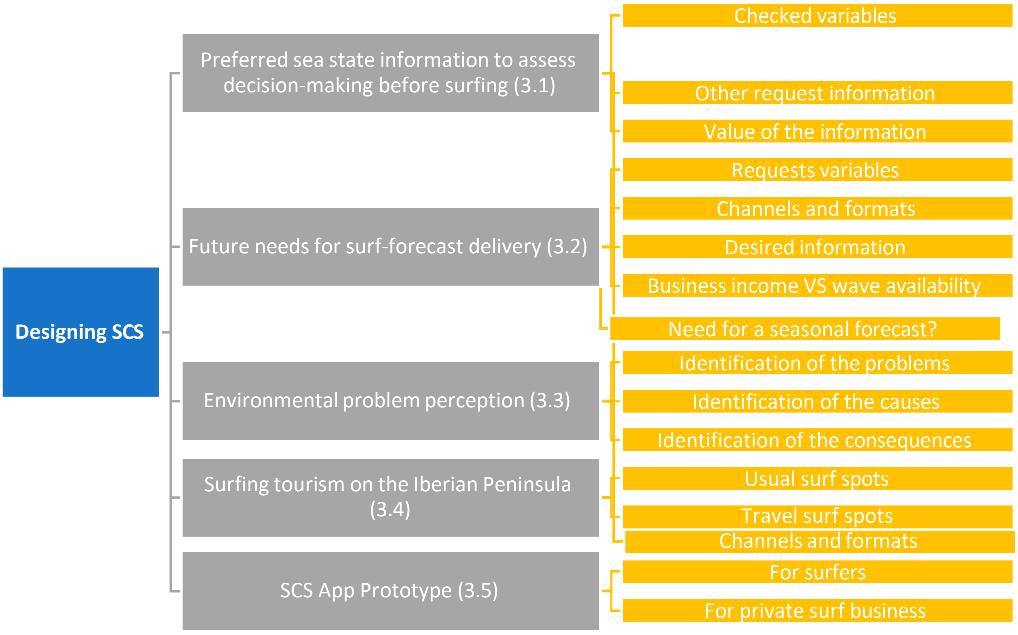

Figure 22. Procedure for designing a prototype of a Surfing Climate Service

Source: author's own production

4.3 Results

The following subsections present the results of the SCS survey and a discussion of the SCS prototype design.

They include: (Section 4.3.1) preferred sea-state -surfing conditions—information to assess decision-making before surfing; (Section 4.3.2) future needs for surf-forecast delivery; (Section 4.3.3) environmental problem perception; (Section 4.3.4) usualsurf spots and surf tourism on the Iberian Peninsula; and (Section 4.3.5) an SCS App Prototype.

In our survey, the male gender represents 75.11% and female 24.89%; the main nationalities are Spanish (66.52%), and Portuguese (17.29%) followed by others (16.19%). Ages are distributed in different intervals: (16–25) 26%; (25–35) 38.90%; (35–45) 24.95%;(45–55), 8.46%, and above 55 years, 1.69% of the respondents. Summary of Survey Responses can be found in Appendix A.4.

4.3.1 Preferred Sea-State Information to Assess Decision-Making before Surfing

Before going surfing, 84.47% of surfers always seek information, 15.53% sometimes seek information, and 0.00% never seek information. Surfers identify two sources of wave prediction: forecasts and nowcasts. The use of forecasts represents most cases; then, nowcasts are used to verify a previously checked forecast. Therefore, nowcasting works as a source of swell confirmation. Thanks to the results of the survey, it is possible to know which kind of wave prediction surfers prefer and use most frequently (Figure 27). In this sense, a ranking about the information consulted before surfing is presented (in which 1 is the lowest and 5 is the highest value, meaning 5 represents more accurate information). This ranking shows seven different categories (*Y* axis) in which different sources of sea-state information can be identified (primary sources forecasts, nowcasts, and secondary sources). As shown, the most preferred sources are internet sites with forecasts (3.98 stars), webcam access (3.71 stars), and information from friends/family (3.54 stars). These are followed by information from buoys in real-time (3.30) and isobaric maps (3.03). The least-preferred source of information is the from surf school/coach (2.59) and social networking sites (2.57). This fact shows that sea-state information quality may be better from the surfers' perspectives, so no evaluations are close to 5.

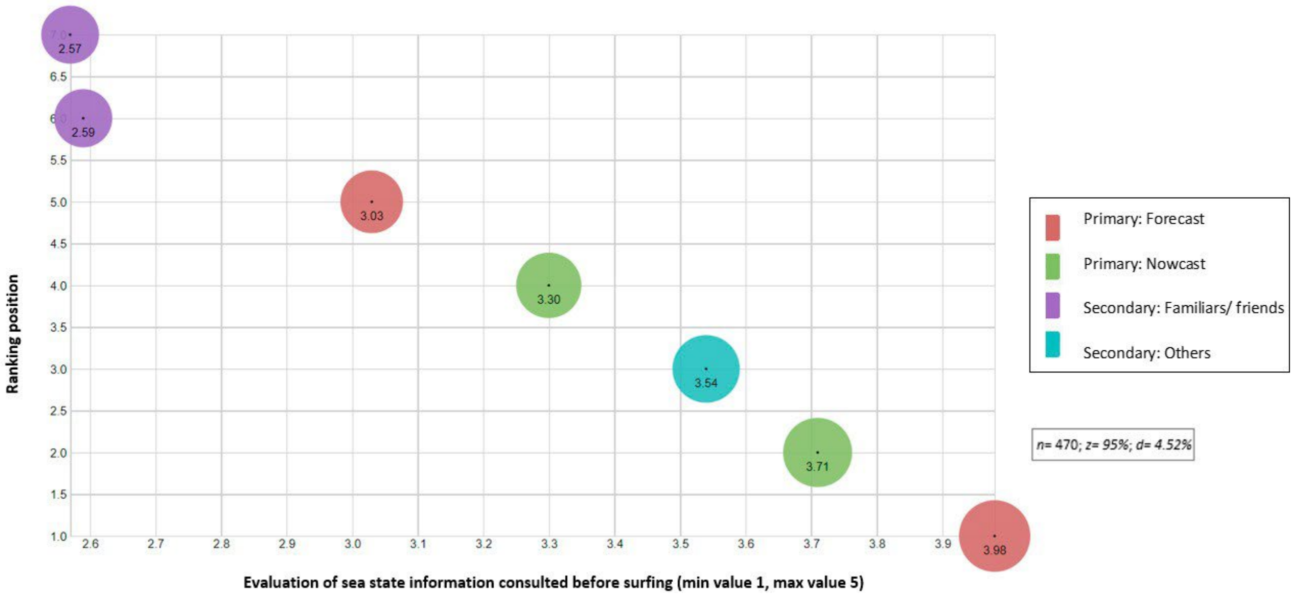

Figure 23. Ranking of sea-state information consulted before surfing.

Source: author's own production

To plan quality surfing sessions, every surfer needs to be familiar with the ever changing state of the ocean. It is known that surfers consult a great variety of sources to anticipate wave conditions in various surf spots. The sources can be found on different forms of communication including websites and applications for mobile devices or both Table 9 presents actual surf-forecast delivery on websites and apps, which represent the combination of the most frequently consulted channels. The range of forecasting for most of these services is 10 days as the maximum; for longer-term forecasts, surfers must purchase a premium version or a forecast app still in beta version such in Todosurf. All the apps and websites are focused mainly on forecasting the following variables: wave height, wav period, wind speed, wind direction, and differentiation between primary swell and other swells. Depending on the source, other complementary variables may also be reported such as surf-quality rating, wave energy, and tidal schedules among others. The prediction models differ depending on resources; some allow making comparisons with different prediction models and others do not. Among these resources, there are some specifically designed to address surfers' requirements, including Todosurf, Wisuki, Magicseaweed MedSwells, and Surfline. Others are specifically designed for windsurfing and include Windfinder and Windguru; they may also report some information useful for surfer that, in some cases, may not be shown in other resources. There is also Windy, which is not specifically designed for sports-related predictions but offers information relevant t surfing predictions.

Other resources can be found only on website channels. Table 10 shows that, in general terms, the range of prediction is shorter than for the resources described in Table 9. In the table below, nowcasting is present, and the most common prediction range is between three and seven days. The information for SurfMediterraneo presents a wider range. Th main variables forecasted are similar to those previously presented. In this kind of resource there are also maritime forecasts designed by local meteorological services, such as those from MeteoGalicia and Aemet. It is interesting to highlight the Camaramar website, which not only provides sea-state forecasts but also offers active tourism information.

Table 9. Websites and app channels for sea-stat information for surfing

Source: author's own production

	Prediction Model	Time of Prediction	Variables	Comments
Todosurf	Nonspecified	7 days, 14 days (new)	Wave height, wave direction, wave period, energy, wind intensity, wind direction. Summary of wind waves, swell 1, swell 2 with the following variables: wave height, wave period, and wave direction. Quality rating.	In the same app/website buoy's data, wind map, and waves map are present from Puertos del Estado. The site allows configuring alarms for the favorite surf-spots.
Wisuki	Nonspecified	7 days	Wind (direction, average, gust), waves (direction, height, period), and tides.	This app is very visual and interactive with satellite images joined with graphs. In the same app/website weather information is shown.
Magicseaweed	NOA WAVEWATCH III, PROTEUS GLOBAL	7 days, 16 days (pro)	Surf height, wind gusts, wave direction, wind intensity and direction, tides. Quality rating. Information about primary and secondary swell can be shown.	In the same app/website weather information is shown. Webcam access with the pro version. It is possible to consult the sea stat historic of the spots.
Windy	ECMWF WAM, Wavewatch 3	10 days	Wind direction, wind average, wind gust, wave height (primary and secondary swell), wave period.	General weather app where there is a specific section for surfing activity.
Windguru	GFS 13, AROME 1.3, AROME 2.5, Zephr-HD3, Zephr-HD4, WRF 9, ICON 7, HIRLAM 7.5, Zephr-HD 9, WRF 27, ICON 13, GDPS 15	10 days	Wind speed, wind gust, wind direction, temperature, cloudiness, tides. Quality rating (in this case is for windsurfing).	There is a pro version that allows access to more maps and models which helps to have a more accurate wind prediction.
Windfinder	GFS and Superforecast (This mixes GFS + horizontal information)	7 days	Wind direction, wind speed, wind gust, cloudiness, kind of precipitation, air temperature, sea level pressure, wave direction, wave height, and wave period. Wind chill, relative humidity (in Superforecast)	The site also provides statistical historic of some variables. The site presents some surf-spot webcams.
Medswells	From FNMOC wave watch 3 model	3 days	Isobaric and surge maps- Wave height, wave direction, and wave period. It also presents variables from wind swell and sea swell and quality rating.	The site also allows surf-spot webcams access and configure alarms for the favorite surf-spots.
			Wave height, direction, and period	The site also allows access to a global navigator where there are regional waves, local

Other resources are available only through the app channel (Table 11); this is the case for Imar and Line App. The first one provides information from Puertos del Estado but is not specifically designed for surfing. However, it offers interesting variables for surfers, and it is possible to search conditions by their list of beaches in Spain and then consult the "nowcast and forecast up to three days" for specific maritime and weather variables. Conversely, Lineapp is designed for surfing with an innovative design that allows not only searching sea-state information but also offers an opportunity to create a community with local surfers, surf travelers, and surf schools.

Table 10. Website channels for consulting sea-stat information for surfing

Source: author's own production

	Prediction Model	Time of Prediction	Variables	Comments
Surf forecast	Nonspecified	7 days	Significant wave height map. Wave height, wave direction, wave period, energy, wind direction, wind intensity, wind state, and tides. Quality rating.	Wave height is in the open sea. In the same app/website information about weather, advanced surf, local wavefinder, and global wavefinder are shown.
Puertos del estado	Wind modelized from Hamnnie-Arome, then wave data is modelized by WAM	3 days and nowcast	Wind speed, wind direction, wave height, wave period, water temperature, atmospheric pressure, salinity level.	It is possible to consult historic data.
Surfmediterraneo	Aemet, Meteocat, FNMOC, UOA Mediterranean, DICCA, laMMA, GFS, MetOffice	7 days, 9 days (isobaric maps), 16 days (wind maps)	There is a link to the table of Puertos del Estado: wind speed, wind direction, wave height, wave direction, wave period. Secondary and primary swell variables.	Webcams. This website collects different cartography about the forecast of different Meteo services for different variables.
Surfcantabria.com	See Windy information See Windguru information	See Windy information See Windguru information	This website collects Windguru forecast and Windy forecast in a visual way.	The website collects links to other sources of forecast (Magicseaweed, storm surf, aemet . . .) with link to surf-spot webcams.
Camaramar	Not applicable. Nowcast	Nowcast	Specification of surf-spot localization, better wind, better season, and surf-spot orientation	This website provides a webcam for different surf-spots as well it links to active tourism offers
Fnmoc	From FNMOC wave watch 3 model	3 days	Significant wave height and direction, swell wave height and direction, wind wave height and direction, swell wave period and direction, wind wave period and direction, peak wave period and direction, white cap probability.	Maps of prediction.
Meteogal	Nonspecified	3 days	Tide time, sky state, wind direction and intensity, sea state, visibility, wave height direction and height, air temperature, water temperature, and maximum UV index.	In MeteoGalicia there is a maritime prediction section.
SurfCatalunya	From FNMOC wave watch 3 model	3 days	See Medswells variables.	The website also presents some surf-spot webcams. The forecast section uses Medswells information.

The main channels of communication (arranged by use) are apps or websites; in a small number of cases, TV weather forecasts are also used.

Referring to the time in advance that a forecast is checked, it has been found that surfers consult the information one day in advance (67.66%), two to three days in advance (67.23%), and on the same day (66.38%). They also check it 4–7 days in advance (45.53%). Further forecasts are less often consulted; specifically, 6.60% consult information two weeks in advance, 0.85% one month in advance, 0.21% one year in advance. Conversely, predictions three months in advance are not consulted. All participants checked the forecast somewhere.

Table 11. App channels to consult sea-state information for surfing

Source: author's own production

Name of The Resource	Prediction Model	Time of Prediction	Variables	Comments
Lineapp	Nonspecified	7 days	Wave height, direction, and period. Wind intensity and direction. Air temperature and cloudiness. Quality rating.	The app includes surf alerts, social and news feed. The app helps to better communication between surfers and surf schools. The app also includes tailored information regarding your profile—surfer or surf school. The app also informs users about spot details—kind of spot, bottom type, best swell, best wind, wave type, and spot level.
Imar	Aemet (wind), Puertos del Estado (other variables)	3 days and nowcast	Wave height, wave direction, wave period, sea level. Wind direction wind intensity. There are the same variables available in real-time. Weather alert.	The main information of sea state from Puertos del Estado in one practical app.

The main parameters checked in the surfing forecast—multiple choice option in the survey-(Figure 28) are wave height (91.91%), wave period (89.79%), wind direction (85,74%), wind intensity (79.36%), and energy (51.28%). Other parameters represent 13.19% and include information such as swell direction (primary and secondary swell direction), water temperature, wave formation, tide schedule, and meteorological maps to see where low pressure and high pressure are originating from and their trajectory. Atmospheric pressure is consulted in 11.70% of cases, and 0.00% do not consult a forecast.

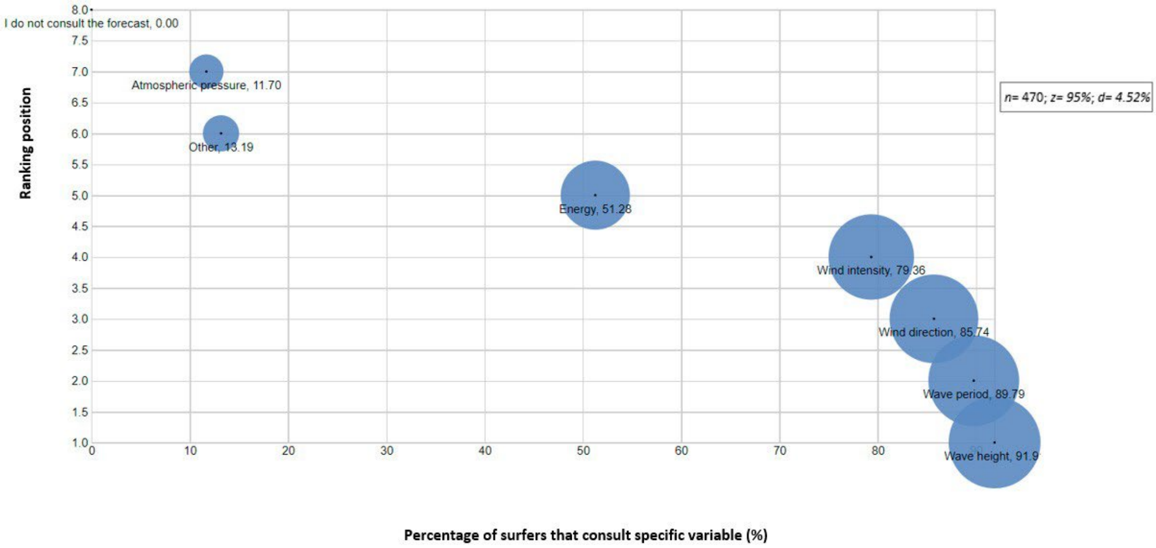

Figure 24. Ranking of variables about sea-state information consulted before surfing

Source: author's own production

The results show a wide variety of resources that help surfers to assess their decisions when planning a surfing trip (Figure 29). Blue dots represent the percentage of surfers that consult specific variables. From this diversity, we can define the following types: designed for surfers, designed for windsurfers, ocean/sea sensors, and weather services. The sources designed for surfers report all the necessary information tailored for specific surfer needs. The sources designed for windsurfers give them better knowledge about wind forecasts than the sources designed specifically for surfers. This is because the main resource needed for windsurfing is wind, and for surfing it is waves. Nevertheless, both variables are relevant for both sports. The sources designed for surfers and windsurfers act mainly as forecasts.

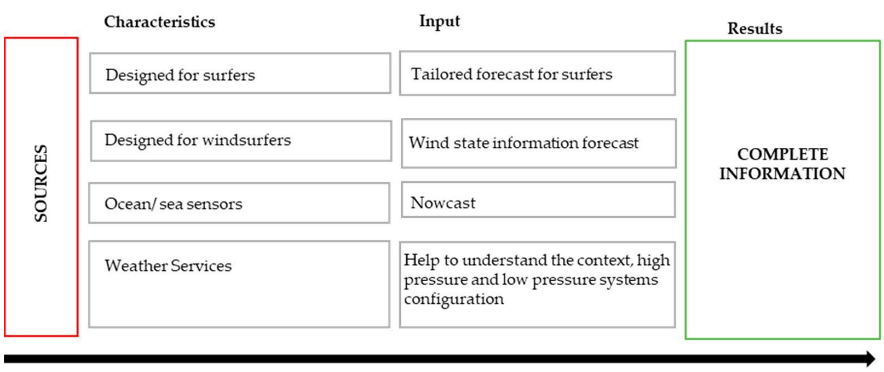

Figure 25. Websites and app channels for sea-state information for surfing

Source: author's own production

Next, weather services help surfers better understand the context in which their desired meteorological variables are developed. Thanks to that source, surfers can understand which generation systems are in action, where they are located, and where are they going. Then, it is possible to interlink the generation systems (high and low pressures) with the behavior of the required variables for surfing such as wave height, wave period, wave direction, wind direction, and wind intensity. Finally, ocean/sea sensors work as nowcast systems that help to validate all the previous information consulted. Depending on the surfers' profiles, they check all kinds of sources, several, or just one.

4.3.2 Future Needs for Surf-Forecast Delivery

Previously, we have observed which resources currently exist that provide the required sea-state and weather information for surfers. We have shown that there is a wide range of information tailored and designed in different ways and presented through multiple channels. We also know which variables surfers require more in their consulted forecasts that will help them figure out how a surfing session will be. Next, it is necessary to present the future needs of surf-forecast delivery for surfers and private surfing businesses. In the following sections, we discuss what can and should be improved in actual forecasts and what surfers' perceptions are in regard to the need for seasonal forecasting related to surfing.

4.3.2.1 Future Needs for Surf-Forecast Delivery for Surfers

The main results in regard to the future needs for surf-forecast delivery are structured by four fundamental pillars (Figure 30): (1) perception about reality, (2) requirements, (3) possible solutions, and (4) results. Perceptions about reality from surfers identify that wave approximation from the fetch area to the shore work differently depending on whether the fetch is generated in the ocean or in the sea. This is the case for the Iberian Peninsula, where waves in northern and western surf spots (Atlantic Ocean) have a lot of space to travel once they arrive at the shore; in this case, the fetch can be monitored with more anticipation than the surfing conditions on the eastern shore (Mediterranean Sea). On the eastern shore, the optimal conditions for surfing are usually created by fetch generation originally located close to the shore; then, there is less space and time to travel until the waves reach the shore, and thus the requirements for prediction are quite different. Surfers affirm that each surf spot is unique and that wave predictions for surfing can be improved. They also state that a number of parameters influence wave availability.

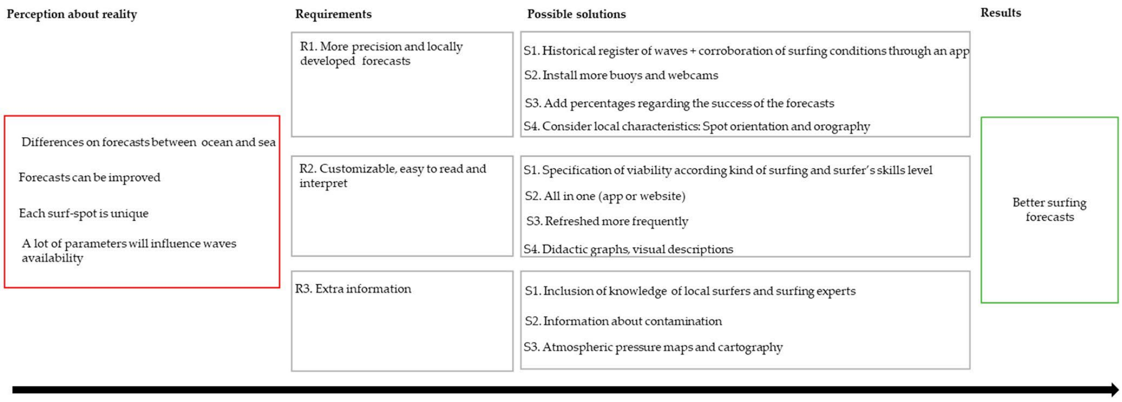

Figure 26. Suggested improvements for surfing forecasts from surfers' perspectives

Source: author's own production

Therefore, different requirements are presented from the surfers' perspectives: (R1) there is a need for more precision and locally developed forecasts, and (R2) forecasts should be customizable and easy to read and interpret. Surfers also emphasize the transversality of information that they require; and thus, (R3) they would like to have additional information in their SCS such as contamination state and sea-bank locations.

In this vein, surfers also identify possible solutions to address all these requirements. Regarding R1, possible solutions could be: (S1–R1) to manage the historical register of waves and corroborate surfing conditions through an app and establish patterns for specific areas; (S2–R1) to install more buoys and webcams; (S3–R1) to add percentages regarding the success of the forecasts; and (S4–R1) to consider local characteristics such as spot orientation and orography. R2 can be addressed by the following solutions: (S1–R2) specification of surfing viability according to kind of surfing and surfer's skills level; (S2–R2) all in one app or website; (S3–R2) information that is refreshed more frequently; and (S4-R2) didactic graphs and visual descriptions. R3 can be improved by: (S1–R3) the inclusion of knowledge of local surfers and surfing experts; (S2–R3) information about contamination in surf spots; and (S3–R3) inclusion of atmospheric pressure maps and cartography. From surfers' perspectives, if all these requirements are met, together they will make it possible to have better surfing forecasts.

Surfers were asked if they would use seasonal forecasts. The results show that 57.66% think that being able to check a seasonal forecast would be useful for them in planning surfing trips; conversely, 20.43% do not think they would use a seasonal forecast. Other surfers, 13.62%, do not know if this kind of forecast would be useful for them or not, and 8.09% have other opinions about this. The majority doubt the possibility of producing worthwhile seasonal surfing forecasts.

The required channels for receiving seasonal forecasts for surfers are apps for smartphones (64.47%), websites (45.11%), newsletters in mail accounts (9.15%), and SMS (6.81%); others were not interested in seasonal forecasts or gave other answers (17.87%).

4.3.2.1 Future Needs for Surf-Forecast Delivery for Private Surfing Businesses

In the case of surfing businesses, the preferred channels for receiving surfing forecasts for companies and surfing instructors are apps for smartphones (47.88%), websites (33.33%), newsletters in mail accounts (7.88%), and SMS (5.45%); 1.82% were not interested in seasonal forecasts.

Private surfing businesses were asked about the value of seasonal surfing forecasts. The results show that usability can be profitable for deciding where to locate the activity (50%), for managing clients (48.05%), for managing employees (34.42%), and for managing logistical permits (15.58%). Nevertheless, 15.58% would not use seasonal forecasts, and 4.55% gave other answers, such as being unsure whether they would use such forecasts because they do not expect that they would be useful to them.

As stated in the methods section, an aim of the present study is to discover whether surfing businesses' incomes depend on wave availability (Figure 31). The results show that 56.34% of participants believe that the income of the company/department varies depending on the availability of waves. They identified two factors that can cause a decrease in income: (1) periods with no waves and (2) periods with very large waves. However, 35.92% stated that income does not vary. The remaining 7.75% gave other answers, which included the following: (1) tourists come to surf when they have holidays, regardless of the wave quality; (2) income varies according to good or bad weather instead of according to wave quality; (3) stand up paddle (SUP) schools do not require waves; and (3) there is always some activity that tourists can practice or train for in the water.

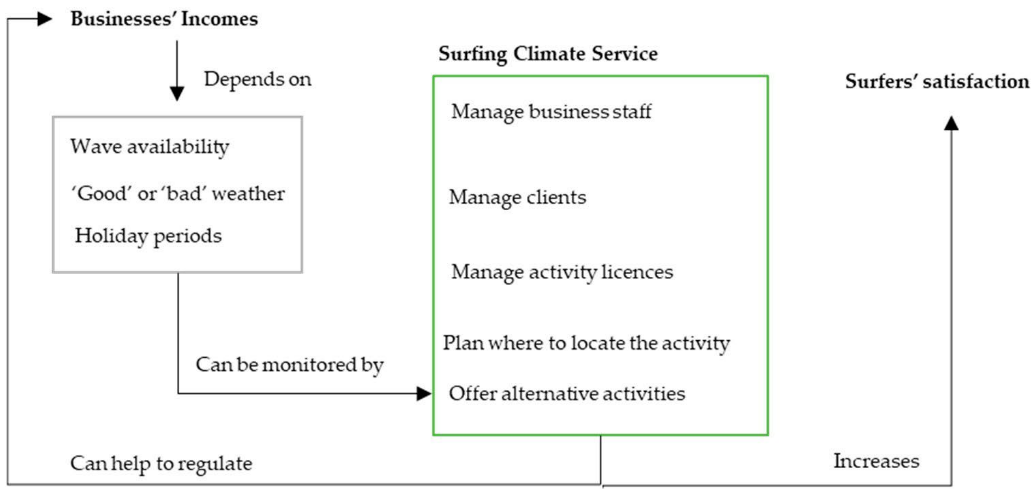

Figure 27. How SCS can help to regulate business income, according to surf schools

Source: author's own production

In regard to those who do not believe that income varies depending on wave availability, their opinion is usually related to the fact that some companies are associated with glamping resorts and that clients will also go surfing when they are on holiday. Some stated that during the summer when the waves are not good for surfing, they actually have increased income.

Currently, 61.11% of surfing companies on the Iberian Peninsula offer other water activities besides surfing, and the remaining 38.89% offer only surfing as the company's unique activity. However, 43.42% would diversify their offerings of water activities if they had adequate information to assist good decision-making, and 25% would probably offer other water activities. The remaining 31.58% would not diversify their offerings. Referring to willingness to pay, 60.13% would not be willing to pay to receive seasonal forecasts; 32.28% might be willing to pay; and the remaining 7.59% would be willing to pay.

To conclude, we can extract the following statements about the usability of seasonal forecasting for surfing companies: (1) Companies see the potential of seasonal surfing forecasts for managing clients, employees, the location for their activity and for managing licenses and permits. (2) Companies identify the relationship between wave availability and income. Nevertheless, other factors also influence income, and these include: (F1) tourists' holidays and (F2) good or bad weather. (3) Over half of companies, 61.11%, offer water activities besides surfing, but they would like to receive customized information to assist in decision making. Related to this, companies would be able to manage and plan other water activities when surfing is not possible. (4) The main channels desired for receiving information are apps for smartphones and websites.

4.3.2 Environmental Problems that Harm the Surfing Experience

In previous sections, we have identified the types of meteorological and climatological information surfers require for a better surfing experience. However, environmental problems are also a factor that affects the quality of the surfing experience. In this sense, surfers identify general environmental problems in surf spots (Figure 32), then they reveal several actual examples of these problems in their usual surf spots.

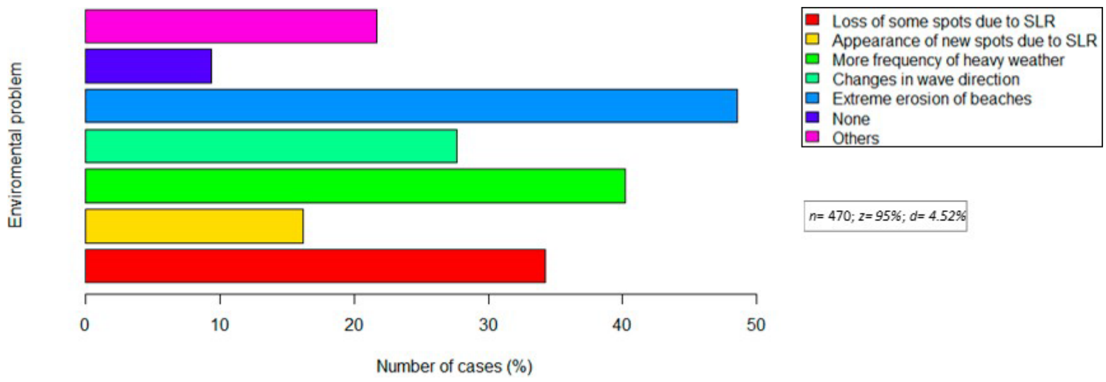

Figure 28. Theoretical environmental problem perception from surfers' point of view

Source: author's own production

Respondents could choose from among five different environmental impacts and could identify and describe other nonenvironmental impacts affecting surfing (multiple choice option). Referring to general environmental problems, the results show that extreme erosion of beaches (48.51%), greater frequency of extreme weather events (40.21%), and loss of some spots due to sea level rise (34.26%) are the main environmental impacts that affect surfing from surfers' perspectives. Some (27.66%) stated that changes in wave direction are an environmental impact that affects surfing, and 21.70% mentioned other kinds of environmental impacts. The appearance of new spots due to sea level rise is the least of the environmental problems identified (16.17%), and 9.36% reported no environmental impacts that affect their surfing.

The answers focusing on detecting other theoretical environmental problems can be summarized as follows: (1) building harbors, dikes; (2) contamination; (3)

massification; (4) loss of flora and fauna; (5) changes in climatology (ocean currents, sea temperature) ;(6) tourism; (7) and modifications of the sea floor and/or dune system. Surfers identified multiple environmental changes to their usual surf spots (Table 12); the majority of these are interconnected. Using the problem-tree process, a conceptual model used as a diagnostic tool to analyze a sequence of events that eventually leads to a problem (Fussel, 1995), it is possible to identify the major facts/problems and their corresponding causes and consequences. The main problems or factors in their usual surf spots highlighted by surfers are as follows: (1) pollution; (2) overtourism; (3) beach erosion, sea level rise, and dune system erosion; (4) changes in surfing availability; and (5) the presence of fewer tourists. The presence of people in surf spots is reflected in their impacts on human and natural systems. (1) Pollution in surf spots is fed by discharges from outfalls, inefficient pollution systems, increased population in the tourism season in tourist areas, and chemical pollution from factories. All these causes can be translated into human health problems as well as negative impacts on biodiversity. For example, some specific pollution problems are detected in Carcavelos for the presence of plastics and microplastics; and polyurethane balls in La Pineda. (2) Overtourism is also an identified problem in some surf-destination regions; this happens when a world surfing reserve is created to promote surfing—like in Ericeira—but no environmental protection plan is executed. This situation produces changes in water security as more people tend to increase pollution. In addition, sun and beach tourism development sometimes involves the construction of artificial beaches that modify genuine surf spots. (3) Beach erosion, sea level rise, and dune system erosion are three major threats for surfing activities; these may result in changes in wave breaks' characteristics and sea floor characteristics, and can result in the loss or appearance of surf spots. All these changes are results of the construction of breakwaters and dikes, massive construction on the coast, little sedimentary contribution, seasonal variability, and sand drainage or other massive movements of sand. In this line, some examples of sea level-rise impacts are detected in Salinas and Badalona. (4) Surfers also identified several changes in surfing-wave availability, due mainly to changes in primary swell direction and wind direction, and these facts can be translated into changes in the number of expected surfing days. (5) Some surfers identified that, at the present time, there are fewer surfing tourists due to the COVID-19 pandemic and its related travel and mobility restrictions. Thus, there has been a reduction in business income related to this group of tourists. Nevertheless, this situation is seen as an opportunity to gain greater water security, offer surfing activities to local surfers or inhabitants, and, as a result, increase the well-being of the population.

Table 12. Environmental problems observed in usual surf spots from surfers' perspectives

Source: author's own production

FACT PROBLEM	**Pollution**	**Overtourism Too many Tourists in the Water**	**Beach Erosion, Sea Level Rise, and Dune System Erosion**	**Changes in Surfing-Wave Availability**	**Fewer Tourists**
CAUSES	Discharges from outfalls Inefficient management of pollution systems Increase in population in tourism season Chemical pollution from factories	Increase in tourism flows before COVID-19 pandemic Promotion of surf destination with no environmental protection plan	Construction of breakwaters and dikes Massive construction on the coast Little sedimentary contribution Seasonal variability Sand drainage/massive sand movements	Changes in primary swell direction. Changes in wind patterns	COVID-19 pandemic: restricted mobility
CONSEQUENCES	Human health problems (gastritis, otitis) Affects the biodiversity of surf spots	Changes in security in the water Increase in pollution Construction of artificial beaches for sun and beach tourism	Changes in wave breaks' characteristics such as shape and height Sand beaches with increasing presence of rocks in relation to sand Loss or appearance of surf spots Changes on sea floor	Changes in the number of expected surfing days.	More security in the water Reduce local income from tourists New opportunities to offer surfing activities to local surfers Increase well-being of the population Boost the local economy

4.3.2 Usual Surf Spots and Surf Tourism on the Iberian Peninsula

A total of 40.90% of survey respondents affirmed that the place they chose to live was selected because of the availability of surfing. This confirms that surf spots are popular not only with tourists who surf but also local surfers. Figure 33 shows the location of usual surf spots (left) versus surf spots related to travel destinations (right).

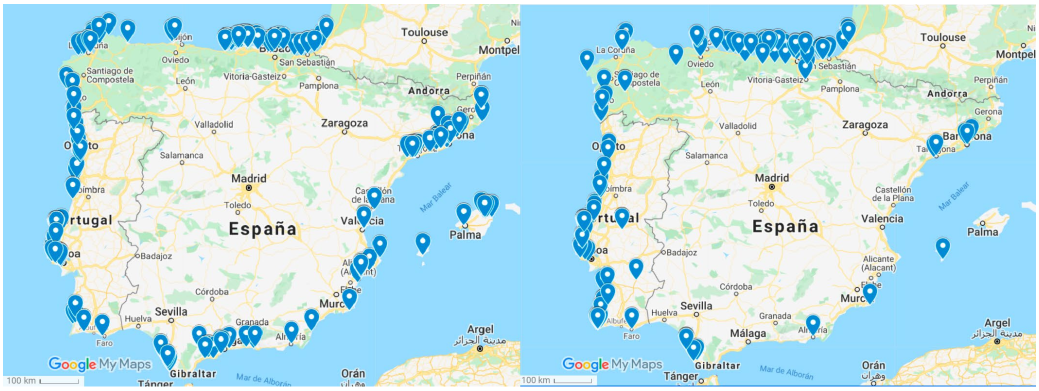

Figure 29. Usual surf spots (left) versus travel surf spots (right) located on the Iberian Peninsula.

Source: author's own production

We understand travel surf spots as places where surfers need to spend a minimum of one night away from their usual place of residence, whereas local surf spots work the other way. In relation to this, we can see that usual surf spots are distributed more homogeneously all around the Iberian Peninsula compared to travel surf spots. In relation to surf tourism, we can detect areas that are losers and others that are winners. The winners are located around the northern and western shores. The losing areas are those located around the eastern and southwestern shores.

Surfers stated that the information most frequently used when deciding where to surf is wave availability. As Boqué Ciurana & Aguilar (2020) have noted, the western and northern shores are the locations that offer more expected surfing days per year; then, this information is translated into which areas surfers visit most frequently for the purpose of surf tourism.

4.3.3 Design of SCS Prototype

According to the results of the survey, surfers requested one channel where they could access all the various pieces of information that they consult when making decisions about where to surf. This survey, therefore, has identified a market opportunity for an app-packaged climate service for surfers.

Figure 34 represents a mock-up layout of an SCS prototype identifying the climate service marketplace (Mysiak et al., 2018). Based on our results, this app, which, for convenience, we will call Surf Better, should contain the following items: first, end-users have to register (users will be asked to provide demographic information such as age, surfing skills, usual surf spots, and whether they are employed by a surf school). After registering, users can search specific surf spots and check for different items such as (1) forecasts, (2) real-time nowcasts, (3) users' shared surfing experiences, (4) surf tourism, and (5) local information. In this regard, specific items based on the forecast section include all the parameters mentioned in the previous section; in addition, forecasts will present the percentage of success and a comparison between the different models of prediction.

The real-time section includes all information related to nowcasts, including webcams and access to buoy data. Users can also post videos and/or photographs of their surf spots by indicating time and location.

The section for sharing surfing experiences will work as a registry of surfing sessions. Users should indicate day, time, surf-quality rating, pollution level, crowd level, and any environmental problems they observe. All this information will remain registered and will then be used as (a) a validation source for surfing forecasts and surf-wave climatology and (b) a registry of environmental problem perception.

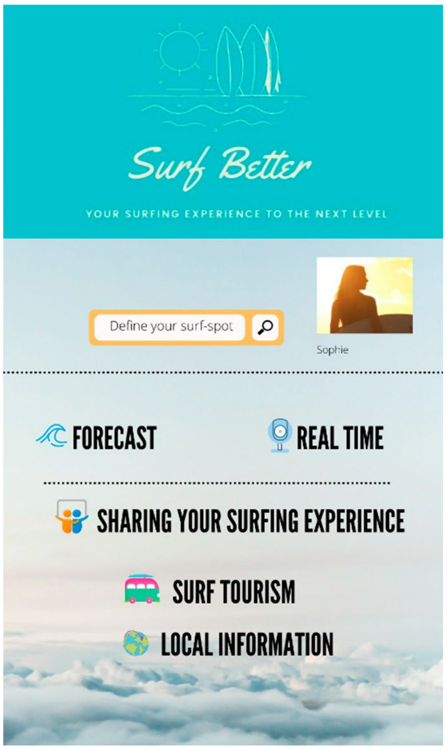

Figure 30. SCS app prototype.

Source: author's own production

When surfers are planning to travel for surfing, they can check the main source to assist their decision-making in regard to surf information about wave availability at the site

(67.02%) as well as information from friends and acquaintances (61.91%). Cartography is also a source that helps surfers decide where to go on a surfing trip (38.72%). Conversely, the least-checked information is that provided by tourist offices/tourist brands (7.45%). The surf-tourism section includes seasonal forecasts, and explanations for them will be present with recommendations for surf schools in order to manage employees and clients in terms of where to establish their business, and for surfers to decide where they should go for surf tourism. This section will also include water tourism offers as information for surfers.

In the end, the local information section provides the surfer with information about the specific conditions needed for surfing that vary from surf spot to surf spot; these can include swell direction, wind direction, bottom type, surfbreak type, recommended level of surfing, and the best season for surfing at a particular location. This section can be enhanced by information contributed by app users.

4.4 Discussion and Conclusions

The purpose of this paper was to determine the main characteristics required for inclusion in the development of a new prototype for an SCS tailored for surfing practitioners and companies who offer surfing services.

The present research represents an advance in the knowledge about the requirements needed for developing weather services targeted at surfing activities. This information was obtained from the data extracted from the online survey. Following Buckley (2002) and Ponting (2008), we identify surf tourism as occurring when surfers travel to enjoy this activity and spend at least one night away from their usual place of residence. In addition, we consider information from surfers who do not spend one night or more away from their place of residence. This is because, as Reineman (2016) and Reineman et al., (2017) presented, local surfers' knowledge is relevant to understanding each surf-spot's mechanism. The results of the survey allow us to validate the knowledge of local surfers and its value. In this sense, the results show that one of the requirements for a new SCS is to include location-specific information contributed by local experienced surfers. This information can include—but is not limited to—the type of tide that works better in the surf spot, the localization of surfbreaks and main currents, the level of surfing at different surfbreaks, and the best season of the year to surf at that location. As shown in the results section, the analysis reveals that 84.47% of surfers always consult sea-state information, 15.53% sometimes do, and 0% never do. This demonstrates that sea-state information is a key element for planning, developing, and managing surfing activities. This reality confirms the need for surfers to seek the right combination of swell size, swell direction, wind strength, wind direction, tide, sand, and rock, as surfers are always hunting the ephemeral wave (Groves et al., 2016).

In order to improve SCS, several factors that can provide new opportunities to develop more-advanced SCS must be considered. These should be focused on: (1) developing greater accuracy and precision and locally developed forecasts; (2) designing a customizable format that is easy to read and interpret for all levels of surfing; and (3) adding information that is based on the knowledge of local surfers and surfing experts, as well as information about pollution and atmospheric maps and cartography.

The present research provides information about the need to assist different surfing user-communities, specifically surfers and companies that offer surfing activities. It has also been shown that, when surfers decide to travel for surfing purposes, the information used most often is that related to wave availability. The information used least often is that provided by tourist offices/tourist brands. Regarding this certainty, further research should focus on exploring whether this limitation is due to a lack of available information from these organizations or due to poor communication between tourism boards and surfers. In regard to this, we encourage the alliance of tourism boards, surf schools, tourist-accommodation establishments, and surfers—both local and those who travel to go surfing—in order to empower and better manage surfing destinations.

In a global tourism context, it is important to mention that some surfing apps— like Magicseaweed—used in the Iberian Peninsula are also consulted abroad, such as in Australia and Hawaii. This is because they are designed for a global coverage. Even so, there are some more locally developed surfing apps, such as Medswells, which focuses its predictions only on a specific area of the Mediterranean coast.

Future research might focus on developing a seasonal forecast for surfing activity, as it has been shown that this kind of prediction does not currently exist. As stated by Cool

(2003), as with any forecast, the further out the prediction, the lower the tolerance for accuracy. Nevertheless, a significant number of surfers reported that if they could access such information, it might be useful for planning their surfing trips. Surfing companies also report that they would take advantage of this kind of forecast; seasonal forecasting would be useful to them for managing their clients, employees, and licenses. It would also help them in their decision-making to know where to locate their business for the greatest amount of activity and whether they should consider offering complementary activities that do not require wave availability, for example, standup paddleboarding and kayaking. In this sense, a short-term forecast is useful for surfers and companies; even so, it requires some improvements. However, seasonal forecasts could play another role in managing surfing activity in the medium term.

As noted by Groves et al. (2016), surfers are aware of the negative impact of human activity on marine environments. The present study affirms that surf spots present important environmental problems. In some cases, promoting surfing tourism can lead to exacerbating those problems or creating new ones. For this reason and in regard to our results, we propose adding to the SCS a register of observed environmental problems such as CoastSnap (User, 2021) based on citizen science and creating community surf-spot monitoring. In doing so, the service can present a historical data registry that looks at (1) surfing-session registry evaluation and (2) environmental problem detection, and then processes this in- formation to manage the surf spot. The outcomes of this monitoring would contribute to implementing measures for protecting surf-spot environments and improving local forecasts based on machine learning. This structure will help to feed the validity and accuracy of the forecast and contribute to raise the credibility of it.

It is important to rethink the needs of surfers and surf companies. The requirements of the two groups are quite different, with individual surfers wanting to know if it is worth travelling to a location, and the companies being interested in expenditures and numbers likely to be present. These differences may be considered when developing SCS.

Surfing tourism research is in its early stages (Valencia et al., 2020). Research has explored advances in climate services in different sectors, including mainly the priority areas defined by the Global Framework for Climate Services: agriculture and food security; disaster risk reduction; and energy, health, and water. Some research focusing on CS has highlighted other sectors such as tourism, but research in the field of surfing tourism that analyzes SCS has not been conducted before now.

To conclude, we can affirm that our results clearly define the first steps in how an SCS should be developed in the framework of surf spots on the Iberian Peninsula. When an effective SCS has been developed, it will have clear implications for the management of these tourism areas and will provide insights into whether surfing activities in these areas may be successful. The survey model used for the research presented in this article can be found online (Boqué Ciurana & Aguilar, 2020): see Appendix A.3.

5. Surfing Tourist Destination Management

Exploring the Climatic Potential of Somo's Surf Spot for Tourist Destination Management

Boqué Ciurana, A., Ménendez, M., Suárez Bilbao, M., & Aguilar, E. (2022). Exploring the Climatic Potential of Somo's Surf Spot for Tourist Destination Management. *Sustainability*, *14*(14), 8496.

Highlights

- Climatological information for having a better surfing experience is developed considering users' needs for surfing climate service
- Hybrid downscaling is applied to a global hindcast dataset to obtain high spatial resolution data
- A Series of indicators are designed to assess surfing activity in tourist destinations
- Indicators are computed for Somo surf spot case study to show the applicability of them
- Surfers and businesses that offer surfing activity will be able to make more climate resilient actions thanks to the information developed in this study

Abstract

Surfing is one of the most popular activities in coastal tourism resorts. However, the sport depends strongly on the met-ocean weather conditions, particularly on the surface wind-generated waves that reach the coast. This study provides examples of how users' needs and user perspectives are considered by climate data specialists to develop needed, highly useful information addressing human and social needs. In this vein, the climate analysis of such data can provide input on the expected length of a surfing season, according to the surfer's level of expertise. In addition, other water sports, such as SUP Wave and windsurfing, among others, might be indicated when surfing conditions are not optimal. Finally, the safety of surfers and other tourists who venture into the sea is also dependent on those conditions. We collaborated with the surfing community to define a series of indices for quantifying surfing days (SD), surfing days stratified by surfers' skills (SDS), alternate offers (AOs), and surfers' and swimmers' safety (SuS and SwS). These are of general applications but require wind and wave data at a very fine scale as the input. To illustrate the potential of our indices, we applied them to the Somo beach (Cantabria, Spain). We downscaled a global wave hindcast dataset covering a 30-year period to a spatial resolution of 100 m to obtain wave-surfing information at Somo's surf spot. The results confirmed Somo's status as a year-round surf spot, with SD values of 229.5 days/year and monthly values between 22 days/month and 16 days/month. SDS showed different seasonal peaks according to the surfers' skills. Beginners' conditions occurred more often in the summer (18.1 days/month in July), intermediate surfers' conditions appeared in the transitional seasons (14.1 days/month in April), and advanced and big-wave riders in the winter (15.1 days/month in January and 0.7 days/month, respectively). The AO index identified the SUP wave values of 216 days/year. Wind water sports presented values of 141.6 days/year; conversely, SUP sports were possible on only 7.4 days/year. SuS and SwS identified different seasonal hazard values, decreasing from the winter, autumn, and spring to minimum values in the summer.

Keywords: resilience, wave climate, tourism management, surfing, climatology, climate service, sustainability, adaptation

5.1 Introduction

Climate services are defined as the provision of climate information to help individuals and organizations make climate-resilient decisions. The World Climate Conference-3 (WCC-3), organized in 2009 by the World Meteorological Organization, established the Global Framework for Climate Services (GFCS) (World Meteorological Organization, 2014). Climate data and information are transformed into customized products to provide decision makers in climate-sensitive sectors with better information to adapt to climate variability and change (Hewitt et al., 2012). The goal of climate services is to provide access to scientific knowledge and, thereby, to reduce vulnerability and create opportunities to promote innovation, business opportunities, and employment, highlighting the importance of involving users in developing climate services (Swart et al., 2021). Research has revealed (Mahon et al., 2021) that peer-reviewed literature on the availability and use of climate services in the operations and management of tourism is scarce, and that a need exists for a new generation of specialized climate information products that can enhance climate risk management amongst tourism suppliers. Adaptation to climate change is becoming more urgent, but the wealth of knowledge that informs adaptation planning and decision making is currently not being used to its full potential (André et al., 2021). In this context, climate services can provide valuable information that can help society enhance resilience, survival, and even prosperity in the face of climate risk (Ibarra et al., 2021).

Climate assessment for recreation and tourism have increasingly become dynamic research topics, especially in the age of the anthropogenic climate crisis (Demiroglu et al., 2020). Coastal destinations can offer different tourist activities in the same territory and all of them are influenced by meteo-climatic conditions to a specific degree (Font Barnet et al., 2021). We assert that there is a need to explore the climatic viability of different activities. By doing so, the development of climate services with tailored climate information about particular destinations can shed light on system changes.

The results of this research, specifically all the information generated with the indicators, imply an improved capacity for destination managers to promote particular destinations. This can lead to a destination being promoted in a more resilient way, not only by knowing which season is better for a specific level of surfing but also by knowing the viability of offering complementary activities. Thus, destination managers can plan tourist offers better and can be prepared to adapt activities when surfing is not possible. This will lead to investing in resources, from hiring staff to planning surfing championships, that will be planned more efficiently and sustainably. Definitively, using this information will enable destination managers to apply informed climate-resilient actions in their sector.

The present research bridges the gap between users and producers of climate information in line with our previous study, in which surfers and surf companies identified which meteorological and climatological information they need access to for better surfing experiences (Boqué Ciurana & Aguilar, 2021). The new contacts that were gained through the survey conducted in the previous study helped the researchers of this study refine its focus.

Climate index application and validation for tourism is a complicated topic and presents several challenges (De Freitas et al., 2008; Scott et al., 2016; Rutty et al., 2020). In this context, the significance of this study is the need to transform meteo-oceanic data into information that can assist decision making in coastal destinations that need sustainable development. As coastal tourist destinations can offer different activities, we focus on surfing, one of the water activities that is offered at several destinations. Following the scientific literature, we have identified a gap in this specific activity and a need to develop a climate service that addresses it. Therefore, this research aims to contribute to the development of a specific climate service for surfing by considering specific users' needs and also by developing high-resolution meteo-oceanic data. The paper's primary objective is to present a set of climate indices for surfing destinations, taking as its experimental area the well-known Spanish surf spot of Somo (see the next section for details). With our analyses, we achieve two secondary objectives: (1) to obtain a downscaled dataset of wave data and (2) to describe with climate data the surfing potential of Somo's surf spot. As our results will specifically define the surfing potential of the spot, this information will assist surfing destination managers in promoting climate-resilient pathways for sustainable development in surfing tourism. In this regard, we intend to contribute modestly to the achievement of the various UN 2030 Agenda Sustainable Development Goals (SDGs), namely (3) good health and well-being, (8) decent work and economic growth, (12) responsible consumption and production, (13) climate action, (14) life below water, and (15) life on land.

5.2 Literature Review

Several authors have defended the idea (Terrado et al., 2021) that climate change communication and user engagement can work as a tool to anticipate climate change. The visual communication of climate information is one of the cornerstones of climate services; there-by, the characteristics that make a climate service self-explanatory rely on the type of representation used. In this context, guidance on the climate information published by official bodies should adopt a consistent approach, with a clear narrative that describes the transition from science to guidance (Terrado et al.,2021). The form in which climate services information is needed for the required end-user decisions requires careful thought, including appropriate communication of the associated uncertainties using best practices and experiences from related sectors (Simm et al., 2021).

Numerous authors have discussed the importance of climate (WTO & UNEP, 2008), weather (Álvarez-Díaz & Roselló-Nadal, 2010; Roselló-Nadal et al., 2011; Førland et al., 2013; Day et al., 2013; Falk, 2013), and extreme weather (Forster et al., 2012; Hamzah et al., 2012; Tsai et al., 2012) in the establishment and choice of tourism destinations. Outdoor recreation is strongly and increasingly affected by climate change and its impacts present marked seasonal and geographical variations that determine its viability (Arent et al., 2014). In the past, the Tourism Climate Index (TCI) (Mieczkowski, 1985; Becken & Hay., 2007) has been used in suitability analyses. Several studies calculated this index to determine the climatic comfort conditions for tourism in different areas (Adiguzel et al., 2021; Tanana et al., 2021). Specific research has focused on exploring the state of weather and climate information for tourism and explored sustain-able tourism and the grand challenge of climate change (Scott & Lemieux, 2010; Scott, 2021). Regarding the idea of the TCI, other studies have developed the Holiday Climate Index (HCI) (Terrado et al., 2018; Terrado et al., 2021) and computed it, in a reshaped formulation, for beach and urban destinations with climate data downscaled dynamically (Scott, 2021). Other studies Font Barnet et al., (2021) have proposed the co-creation of specific indices for each specific activity/destination. One such study described indices for beach and snow tourism (Olano et al., 2020), while others developed indices for skiing (Rice et al., 2021; Köberl et al., 2021), and still others have focused on surfing (Boqué Ciurana & Aguilar, 2020). Sports tourism, based either on attending a sports event or on practicing the sport, has experienced considerable growth in the last several decades. Surfing as a tourist activity has traditionally been labeled as sports tourism (Martin & Assenov, 2012) or nautical, maritime, or marine tourism (Amorim et al., 2016). Most recently, researchers defined it as 'blue tourism', a concept intimately related to the blue economy and the blue growth strategy (Martínez Vázquez et al., 2021). Blue tourism highlights the sea as the central resource for leisure and recreation activities and leisure and tourism industries (Portugal et al., 2017; Chen et al., 2020).

Surf and surfing tourism affect the environment and depend on its preservation and there is a concern regarding not only the quality of the activity but also its sustainability. New research has ranked Cape Town beaches in terms of sustainability by using surf tourism related indicators (Martin, 2010). Similarly, other authors have used the Driving Forces-Pressures-State-Impacts-Responses (DPSIR) framework to propose indicators to measure human activities affecting surf breaks (Arroyo et al., 2020). Similarly, it has been affirmed that surf breaks are finite, valuable, and vulnerable natural resources that not only in-fluence community and cultural identities but are also a source of revenue and provide a range of health benefits (Atkin et al., 2020). Despite this, surf breaks lack recognition as coastal re-sources and, therefore, the associated management measures required to maintain them. It has also been recognized that conserving biodiversity and ecosystem services requires diverse models that empower communities to act steward of such resources and also to benefit from them. They investigate the potential of surfing resources and the consciousness of surfing communities as beacons of environmental and marine biodiversity preservation. In fact, the sustainable management of these resources ensures their ability to provide for the character, economy, and development of coastal communities worldwide (Reineman et al., 2021). Valencia et al. (2021) studied how surfing tourism's effects are perceived by local residents; the results of their research have implications for surf tourism management at the destination.

Fox et al. (2021) focused their research on recreational ocean users, specifically surfers, and how their blue space activities may inform the understanding of ocean processes and human–ocean interconnections. They presented novel insights about the opportunities for integrating ocean sustainability strategies through blue space activity mechanisms and coastal community engagement. They defined the surfing social-ecological system adapted from McGinnis et al. (McGinnis et al., 2014) and demonstrated how the human (social) and ocean (ecological) systems provide opportunities for interactions between surfers (users) and waves (resource units), producing ocean literacy understanding and awareness.

Another aspect that has an impact on the perception and development of surf is the safety of the practitioners. Mindes (1997) analyzed hazards perceptions among surfers in Southern California. Rip currents are a primary mechanism associated with dangerous situations (Brander, 2015) and have been the focus of beachgoer education and awareness strategies (Brander et al., 2011). Surfers and lifeguards often utilize rip currents to expedite their journey across the surf zone (Dalrymple et al., 2011). Attard et al. (2015) found that 63% of surfers believe they have saved a swimmer's life. The enjoyability and safety of the surfing experience are enhanced when the right information is communicated in the right way. Boqué Ciurana and Aguilar (2021) surveyed surfers in Spain to explore which meteorological and climatological in-formation they find necessary for a better surfing experience.

De Andrés et al. (2016), who studied surfers' balance during surfing activity be-tween competitive surfers and non-competitive surfers in Somo, in collaboration with Escuela Cantabra de Surf and Somo Surf Center, defended that surfing in training and competition is characterized by a great variability of environmental factors such as different sizes and breaking shapes of the waves and changing weather conditions. Nevertheless, there are limitations and possibilities for the world surfing reserves (López Sariego & Melgarejo, 2015) that can be assessed by surfing climatology and surfing forecasts (Boqué Ciurana & Aguilar, 2021).

5.3 Study Area, Data and Methods

5.3.1 Study Area

The pilot area of the Somo surf spot is part of the municipality of Ribamontán al Mar Municipality. Ribamontán al Mar is located on the northern shore of the Iberian Peninsula in the Cantabria region (Figure 35) close to its capital of Santander. It hosts Spain's first surfing school, established in 1991. Ribamontán al Mar (declared in 2012 as a World Surfing Reserve, the first in Spain and the second in Europe) is a pioneering territory in its commitment to surfing tourism through its Surfing Competitiveness Plan (2009–2014) and in promoting territorial balance through the competitiveness of destinations, international projection, specialization of tourism products, and deseasonalization (Sariego López & Moreno Melgarejo, 2015).

The area is characterized by an oceanic climate, specifically Cfb, in the Köpen Climate Classification (Köppen, 1931). The Cfb type is defined as being temperate mesothermal, without a dry season, and with a mild summer. Using monthly values, the annual thermometric regime is regular, with the highest average values in August and the lowest in January. Precipitation is significant even in the drier months (Rafael, 1992). Wind variations are present throughout the year. Northwest and southeast winds dominate in the winter. In the spring, northerly winds usually blow and then shift to a northeasterly direction in the summer. High intensity winds are more frequent in the winter and at the end of autumn (Hellín Medina, 2009).

Figure 31. Somo surf spot location: global and local context

Source: author's own production

5.3.2 Data and Methods

Data for our analysis were obtained after applying the high resolution downscaled ocean waves (DOW) approach (Camus et al., 2011; Camus et al., 2013) to the global ocean waves hindcast (Reguero et al., 2012) data. This hindcast is a historical hourly wave reconstruction generated with the WAVEWATCH III model (Pérez et al., 2017), using the atmospheric forcing from the Climate Forecast System Reanalysis (CFSR) global reanalysis from 1979 to 2010 (Saha et al., 2010) and extended to the present by CFSv2 (Saha et al., 2014) with a ~0.2° resolution. GOW2 has global coverage with a spatial resolution of 0.5° × 0.5° and a resolution of 0.25° × 0.25° in zones near the coast. The DOW approach is a global framework to downscale waves to coastal areas, which takes into account a correction of open sea significant wave height (directional calibration). The approach combines numerical models (dynamical downscaling) and mathematical tools (statistical downscaling). First, a regional hindcast is numerically simulated with the Simulating Waves Nearshore (SWAN) model using high-resolution winds from the Cantabrian domain of downscaling winds (a 3 km historical reconstruction from global CFSR reanalysis) and the GOW2 spectral data as the boundary conditions.

Then, the DOW Cantabria database is used, which is based on regional waves as initial conditions for waves in the contours of high-resolution numerical domains, at ~100 m resolution.

Our methodological approach (Figure 36) used significant wave height (*Hm0*), peak period (*Tp*), wind speed (*Ws*), and wind direction (*Wd*) downscaled climate data from DOW in the Somo surf spot in the definition of a climate service for the management of surfing destinations. In addition, using *Hm0* and *Tp* as input from DOW, we computed the wave energy flux (*We*) with the following formula (Holthuijsen, 2010):

$$We = Hm0^{2} * Tp \tag{4}$$

$We = wave\ energy\ flux$

$Hm0$ = significant wave height

$Tp = peak\ wave\ period$

We designed the surfing management indicators by combining the variables previously described and constraining hourly data to daylight time (obtained through the R package suncalc, https://cran.r-project.org/web/packages/suncalc/suncalc.pdf) when surfing activity was concentrated. We obtained (1) a daily surf climatology, (2) a surfer-skill climate indicator, (3) an index for alternatives to surfing, and (4) a hazard climate indicator for surfers and swimmers.

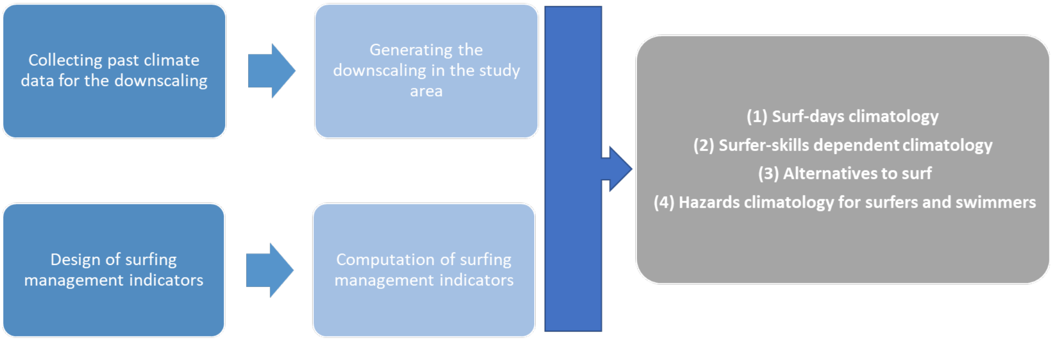

Figure 32. Development workflow of the climate service for surfing destination management.

Source: author’s own production

Surfing climatology yields the number of expected surfing days per year, i.e., days when, following Espejo et al. (2014) and Boqué Ciurana and Aguilar (2020), $Hm0 \geq 0.5$, $Tp \geq 6$, and $Ws < 20$. Days that do not meet these requirements are considered non-surfing times. For these periods, we described and indexed combining *Hm0* and *Ws* to suggest to surfers and surf schools the best surf-related alternatives (e.g., other water sports), according to the state of the wind and the sea. We considered a surf-related activity to be any activity requiring the use of a board. We grouped them as (1) Stand Up Paddle Surf (SUP) activities, for which waves are not required, e.g., SUP yoga, SUP Pilates on board, or a water polo match using surfboards (Yukawa et al., 2015); (2) SUP activities that require waves and are similar to surfing—called SUP Wave; and (3) sports such kitesurfing, in which wind speed is the key element (Vermeersch & Alcoforado, 2013). These activities and their optimal values of Hm0 and Ws are shown in Table 13.

Table 13. Alternative surf activity definition

Source: author's own production

Alternative Surf Activity		
Categorization	**Conditions Required**	**Explanation**
SUP/SUP yoga/SUP Pilates/Surf polo better than surfing	$Ws < 10$ $Hm0 < 0.5$	Waves are not high enough for surfing, but wind conditions allow the practice of other related activities
SUP Wave	$Ws < 20$ $Hm0 > 0.5 \leq 1.5$	Significant wave height and wind speed will probably make SUP Wave possible
Kite surfing, windsurfing, wing better than surfing	$Ws > 20$	Wind speed is too extreme for surfing but is suitable for other related activities

The second index (Table 14) categorizes the Hm0 values as different surf-skill levels (i.e., beginner, intermediate, advanced, or big wave rider). The values of the different intervals are an adaptation of Hutt et al. (2001), who defined the maximum and mini-mum values of wave height according to the surfers' skills. We also combined these values for the peak period following the thresholds suggested by Espejo et al. (2014).

Table 14. Surfing skill-oriented climatology definition

Source: author's own production

Surfing Skill-Oriented Climatology		
Categorization	**Conditions Required**	**Explanation**
Beginner/Longboard/Fatty boards	*Hm0 ≥ 0.5 < 0.9* *Tp ≥ 6*	Small waves useful for beginners, longboarders, or fatty board riders
Intermediate	*Hm0 ≥ 0.9 < 1.5* *Tp ≥ 6*	Wave height is useful for intermediate surfers (in green waves) but also for beginners in white water
Advanced	*Hm0 ≥ 1.5 < 3* *Tp ≥ 6*	Wave height is so high that the surfers require advanced skills to arrive at the peak zone and to surf
Big wave rider	*Hm0 ≥ 3* *Tp ≥ 6*	Wave height is suitable only for big wave riders and tow-in surfers

To compute these two monthly indices from hourly observations, we used our own formula as follows:

$$I(m) = \frac{\sum obs_{crm}(m)}{\sum obs(m)} n(m) \qquad (5)$$

where $I(m)$ (Equation (5)) corresponds to the monthly indicator for a specific month and expresses the number of complete days that meet a set of given conditions, regardless of how they are distributed within the month; $obs_{crm}(m)$ is the number of hourly observations that meet the required conditions; $obs(m)$ is the total number of observations per month; and $n(m)$ is the number of days in that month (e.g., 31 in January, 28/29 in February, etc.).

For the hazard indicator, we followed Attard et al. (2015), who demonstrated that surfers do well in locations that can be hazardous to swimmers. In line with Attard's et al., approach (2015), we used *Hm0, Ws, Wd*, and *We*, according to formula 5. Following Koon et al. (2018), Mazzone (1961), Whitcomb (2008), and Miloshis and Stephenson (2011), we computed hazard scores for intermediate surfers, the third general degree established by the surfing Spanish federation framework, and intermediate swimmers, according to the classification of the Real Federación Española de Natación achieving the level fry 2. As swimmers' and surfers' interactions with the ocean are intrinsically different, we defined specific cut-off points for each, as reflected in Table 15, and attribute values from 0 to 4 to each condition to create a composite index that can take values between 0 and 10. Maximum values (10) relate to hazardous conditions; minimum values (0) relate to conditions without hazards.

Table 15. Hazard management: surfers' versus swimmers' definition

Source: author's own production

Hazard Management: Surfers versus Swimmers Definition				
Variable Based	**Conditions Required (Swimmers)**	**Value (Swimmers)**	**Conditions Required (Surfers)**	**Value (Surfers)**
Wind-based	$Ws < 10$ Wd = all directions	0	$Ws < 15$ Wd = all directions	0
	$Ws \geq 10 < 15$ Wd = onshore	1	$Ws \geq 15 < 20$ Wd = all directions	3
	$Ws \geq 10 < 15$ Wd = offshore	2	$Wd \geq 20$ Wd = all directions	4
	$Ws \geq 15 < 20$ Wd = onshore	1	NA	NA
	$Ws \geq 15 < 20$ Wd = offshore	3	NA	NA
	$Ws \geq 20$ Wd = all directions	4	NA	NA
Significant wave-height-based	$Hm0 > 0.5 < 0.9$	1	$Hm0 > 1.5 > 3$	1
	$Hm0 \geq 0.9 < 1.5$	2	$Hm0 \geq 3$	2
	$Hm0 > 1.5$	3	NA	NA
Wave energy flux-based	$We < 45$	0	$We \geq 500 < 1000$	1
	$We \geq 45 < 100$	1	$We \geq 1000$	4
	$We \geq 100 < 1000$	2	NA	NA
	$We \geq 1000$	3	NA	NA

We obtained each daily hazard indicator by selecting the maximum hourly value of the hazard score per day. These values were packaged (1) in the form of calendars and in graphical time series where maximum monthly values are shown, as we will present in Section 5.4.

For SD, SDS, and AO, we represent the monthly values as boxplots, and we also show the annual values in a graphical time series to observe the evolution for the 1985-2015 period. For all sets of indicators, the Mann–Kendall test was calculated to explore the trends. For SuS and SwS, we represent the annual mean of the monthly mean of the daily maximum value in the time series.

5.4 Results

5.4.1 Surf climatologies

Figure 37 presents the monthly climatology of the expected surfing days computed from 1985-2015 at the Somo surf site. The annual number of expected surfing days was 229.5. The highest monthly value corresponded to July (22 days), followed by August (21.7 days/month) and June (21 days/month). Lower values corresponded to November (16.3 days/month), February (16.9 days/month), December (17.8 days/month), and April (17.9 days/month). The winter months (December, January, and February) showed larger interquartile ranges.

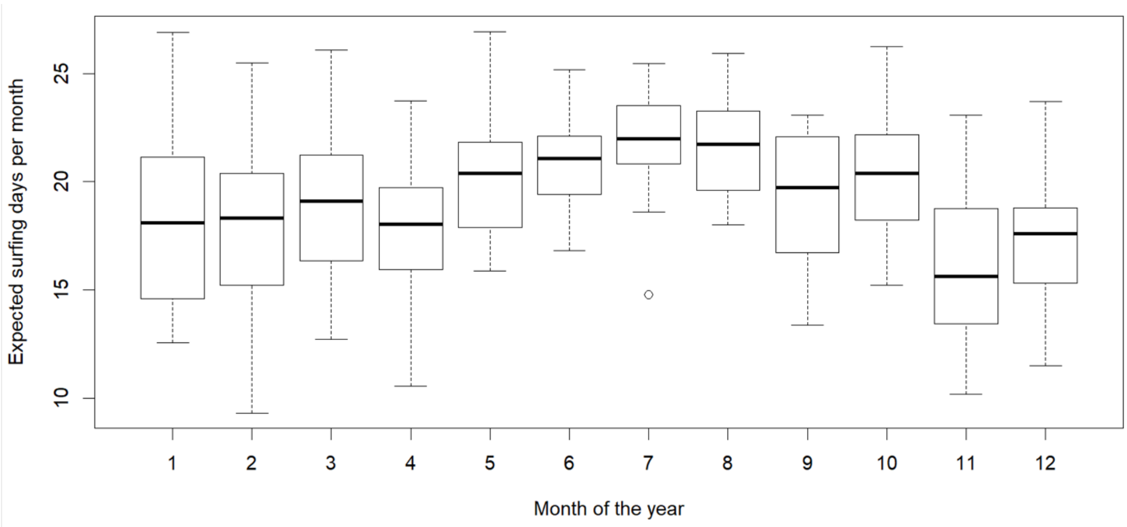

Figure 33. Expected distribution of surfing days per month, Somo, 1985-2015

Source: author's own production

Figure 38 shows the evolution of the annual SD for the 1985–2015 period. The SD annual values ranged from 247.8 days (the year 2015) to 206.19 days (the year 2010). The plot shows the variation of the annual SD between the years; the standard deviation corresponded to 10.09 days.

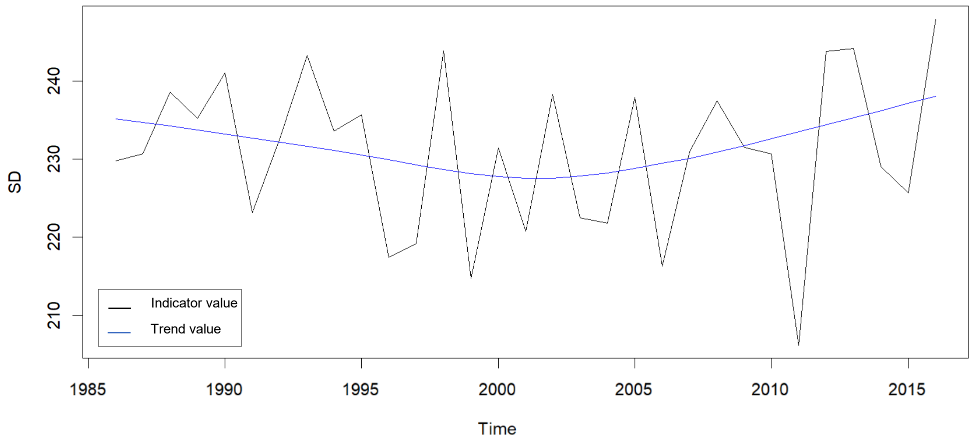

Figure 34. Evolution and trend of annual surfing days; reference period is 1985-2015 in Somo

Source: author's own production

Figure 39 adds the consideration of the surfer's skill level. Our results showed that, depending on the practitioner's skills, the season shifted from summer to winter, opening the door to the deseasonalization of tourist resorts. In this regard, the peak number of the expected days for the beginners clustered again in the summer: June (17.3 days/month), July (18.19 days/month), and August (17.2 days/month). By contrast, intermediate surfers should expect to find a larger number of optimal days in the transition seasons, with peaks in April (14.4 days/month) and September (13.4 days/month). Finally, advanced surfers and big wave riders will find better conditions in the winter. For advanced surfers, the expected days peaked in January (15.1 days) and December (12.3 days/month). Big wave riders should expect < 1 day/month, concentrated throughout the period of the November–April semester and peaking in January (0.7 days/month).

Figure 40a–d show the SDS annual evolution and trend for the 1985–2015 period. The maximum SDS were detected on surfing days for intermediate surfers at 167.02 days (in 2011), followed by beginners with 157.36 days (in 1985), 108.21 days (in 1986) for advanced surfers, and 10.02 days (in 2014) for big wave riders. The minimum SDS annual values were ranked from big wave riders with 0 days (in 1992), advanced surfers with 43.16 days (the year 2010), beginners with 94.94 days (the year 2011), and intermediates with 114.5 days (in 1989). The standard deviation ranged from 2.19 days (big wave riders) to 17.41 days for advanced surfers. The case for intermediates was 11.89 days and for beginners was 16.2 days.

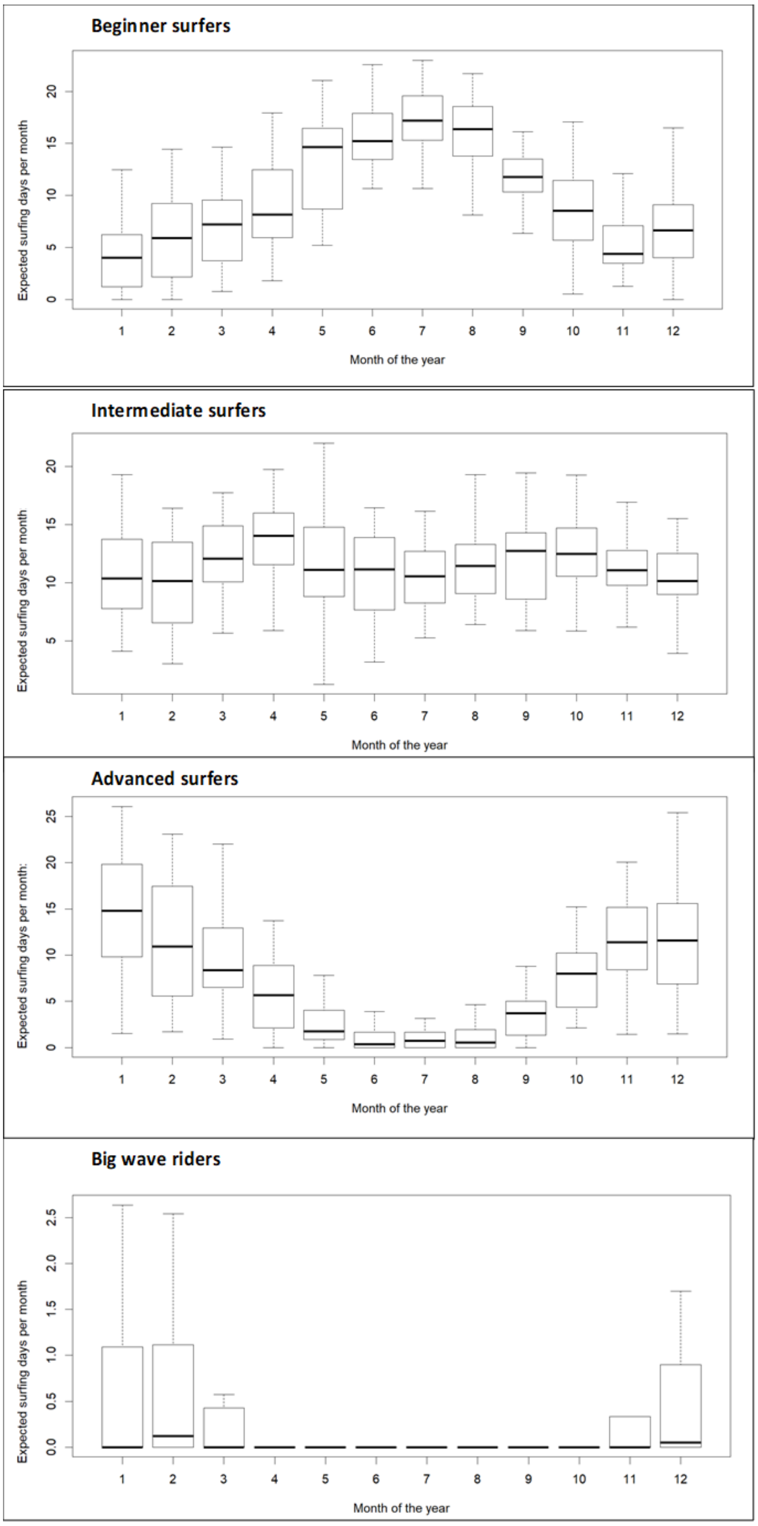

Figure 35. Expected distribution of surfing days per month sorted by surfer's skill level; reference period is 1985-2015 in Somo

Source: author's own production

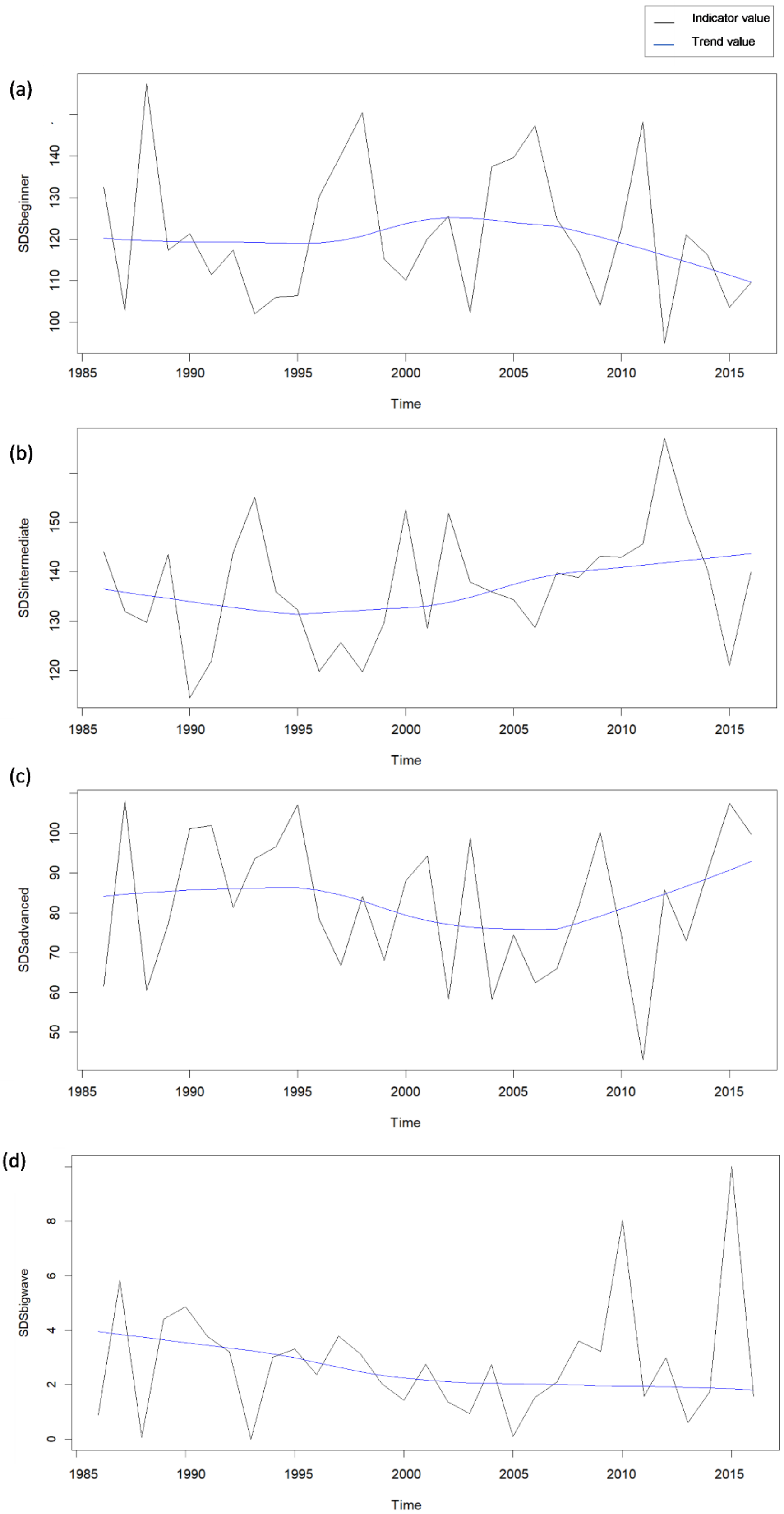
Indicator value
Trend value
(a)
SDSbeginner
Time
(b)
SDSintermediate
Time
(c)
SDSadvanced
Time
(d)
SDSbigwave
Time

Figure 36. (a) Evolution and trend of annual surfing days for beginner surfers; reference period is 1985-2015 in Somo. (b) Evolution and trend of annual surfing days for intermediate surfers; reference period is 1985-2015 in Somo. (c) Evolution and trend of annual surfing days for advanced surfers; reference period is 1985-2015 in Somo. (d) Evolution and trend of annual surfing days for big wave riders; reference period is 1985-2015 in Somo.

Source: author's own production

5.4.2 Alternative Offer

Days when environmental conditions do not favor surfing might still be suitable for alternative water sport activities (Figure 41a–c). From the series of activities considered in Section 5.3, in the case of the Somo surf spot, the surf activity offered most frequently was SUP Wave (216 days/year); specifically, July (22.7 days/month) had the largest number of expected days. Kitesurfing was the alternative surf activity offered second most frequently (141.6 days/year), and the spring and summer months present-ed the lowest values for expected kitesurfing days per year, linked with summer's calm winds. SUP yoga (7.4 days/year) was the alternative that offered lower possibilities, which indicates that if the activity needs to be promoted, it should probably ubi-cate in rivers next to the main surf spot. SUP Wave and kitesurfing seemed to be complementary, as when there is so much wind to practice SUP Wave, there is enough wind to practice kitesurfing, wing, or windsurfing. The high values for these wind activities were present specifically in autumn and winter: November (15.8 days/month), December (16 days/month), and January (16.8 days/month). A good period for practicing SUP Wave is during the spring and summer, and at the beginning of autumn: May (21 days/month), June (22 days/month), July (22.7 days/month), August (22.4 days/month), and September (19.6 days/month).

Figure 42a–c shows the annual AO evolution and trend for the 1985–2015 period. The Mann–Kendall test denoted the absence of a trend in the data. For the annual AO values, SUP-related activities presented the lowest values of annual days: a minimum of 3.35 days in 1986 and a maximum days of 11.81 days in 1997. SUP Wave presented a maximum of 207.74 annual days in 2001 and a minimum of 165.23 days in 1993. Wind and water sports such as windsurfing, wing surfing, or kitesurfing presented high maximum annual values in 2010, corresponding to 138.71 days, and lower values were in 1998, corresponding to 102.89 days.

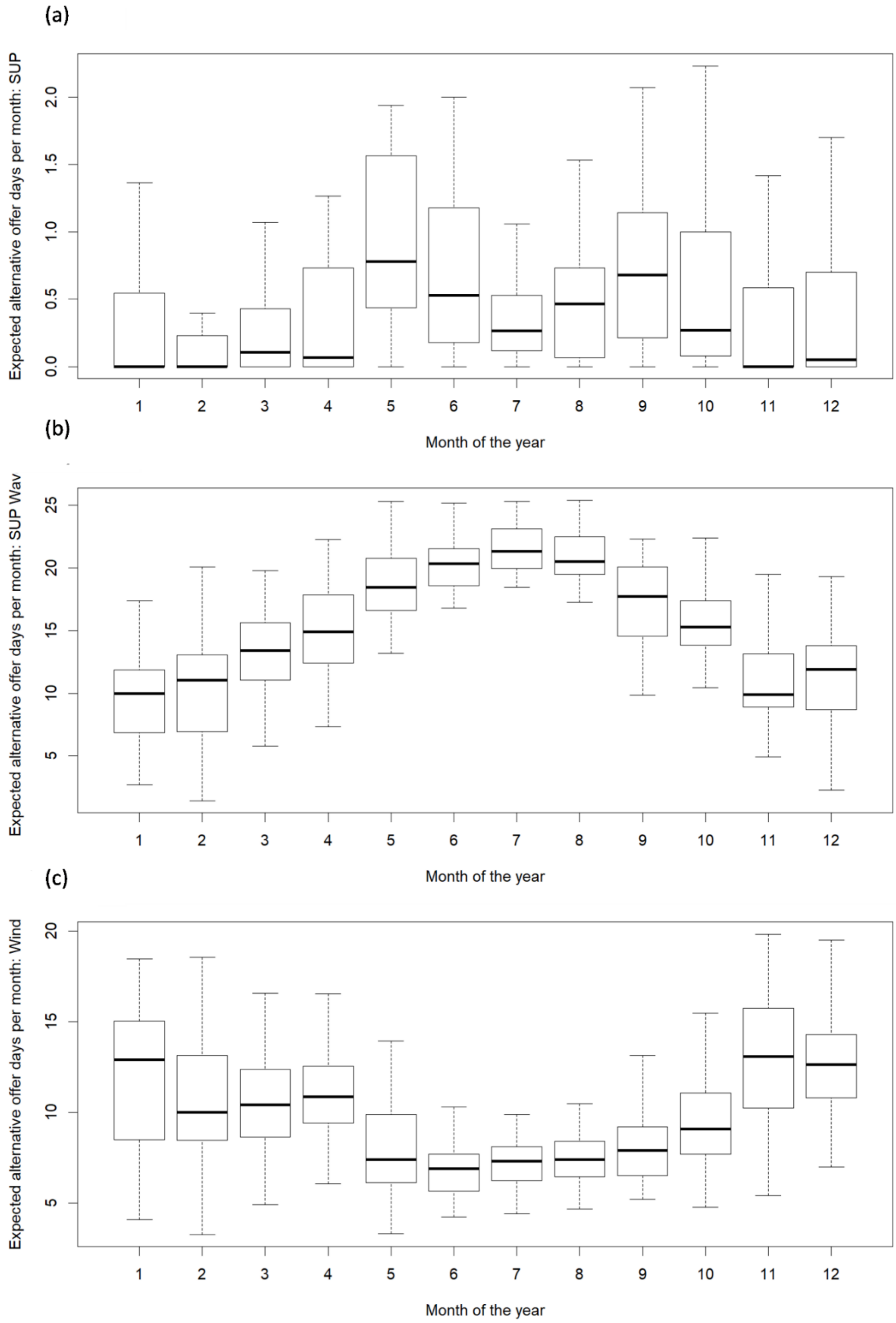

Figure 37. (a) Expected distribution of alternative offer monthly days for SUP-related sports; reference period is 1985-2015 in Somo. (b) Expected distribution of alternative offer monthly days for SUP Wave sport; reference period is 1985-2015 in Somo. (c) Expected distribution of alternative offer monthly days for wind-related sports, i.e., windsurfing, kitesurfing, wing surfing; reference period is 1985-2015 in Somo

Source: author's own production

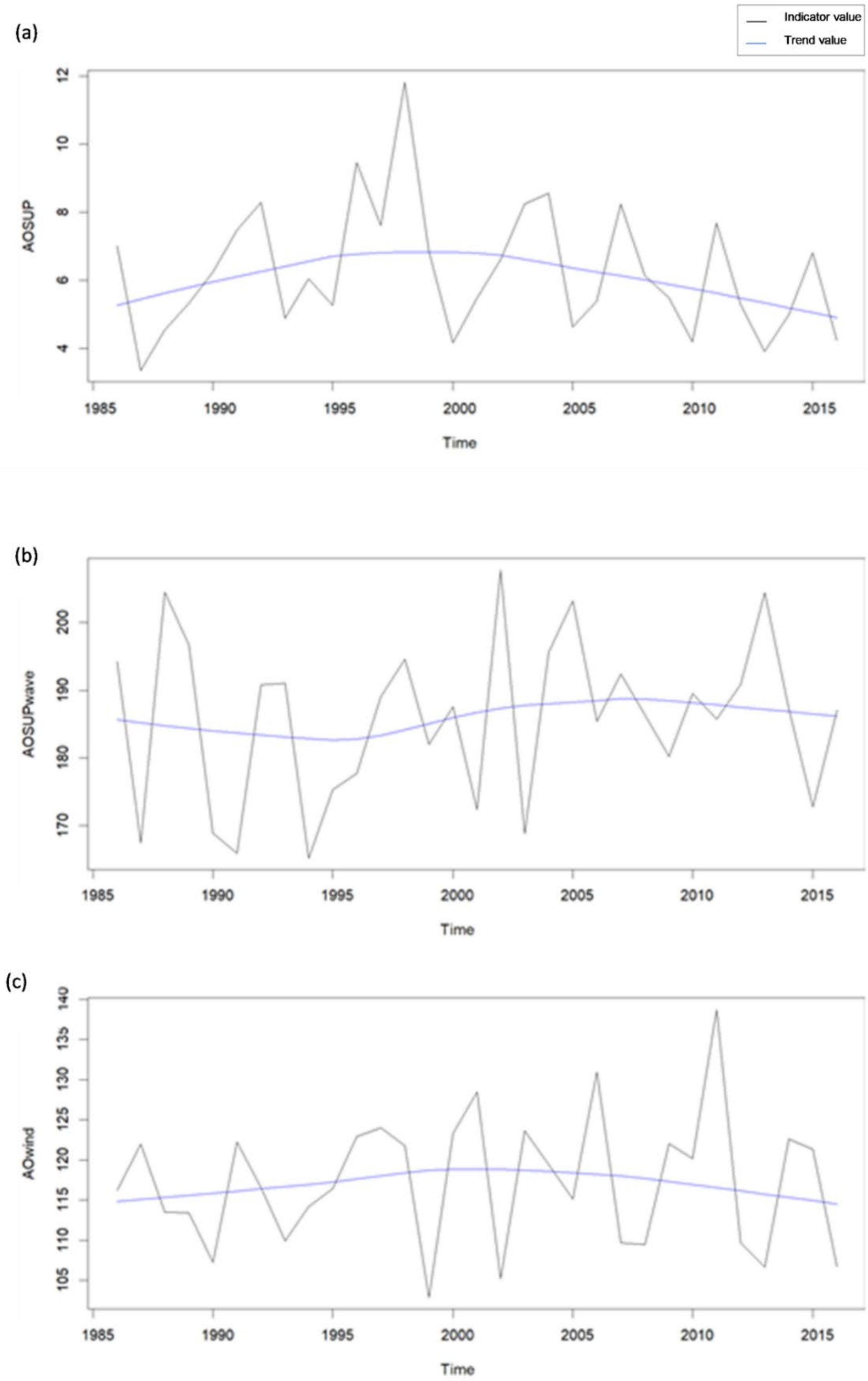

Figure 38. Evolution and trend of annual alternative offer days for SUP-related sports; reference period is 1985-2015. (b) Evolution and trend of annual alternative offer days for SUP Wave sport; reference period is 1985-2015. (c) Evolution and trend of annual alternative offer days for wind-related sports, i.e., windsurfing, kitesurfing, wing surfing; reference period is 1985-2015

Source: author's own production

5.4.3 Hazards Management for Surfers and Swimmers

As expected, the results showed that, in the coordinates of the Somo surf spot, the hazard score was higher for swimmers than for surfers (Figure 43). The maximum possible values were 10 for both swimmers and surfers, and even so, at any time of the studied period, a score of 10 was reached. The scores for surfers were always lower than those for swimmers (Figure 43). Higher hazard values were present in the winter, autumn, and spring; lower values corresponded to the summer season. After analyzing higher scores for surfers versus swimmers year round, we found the following values: January (4.1 vs. 7.3), February (4.2 vs. 7.3), March (3.9 vs. 7), April (3.7 vs. 6.7), Novem-ber (4.4 vs. 7.8), and December (3.9 vs. 7).

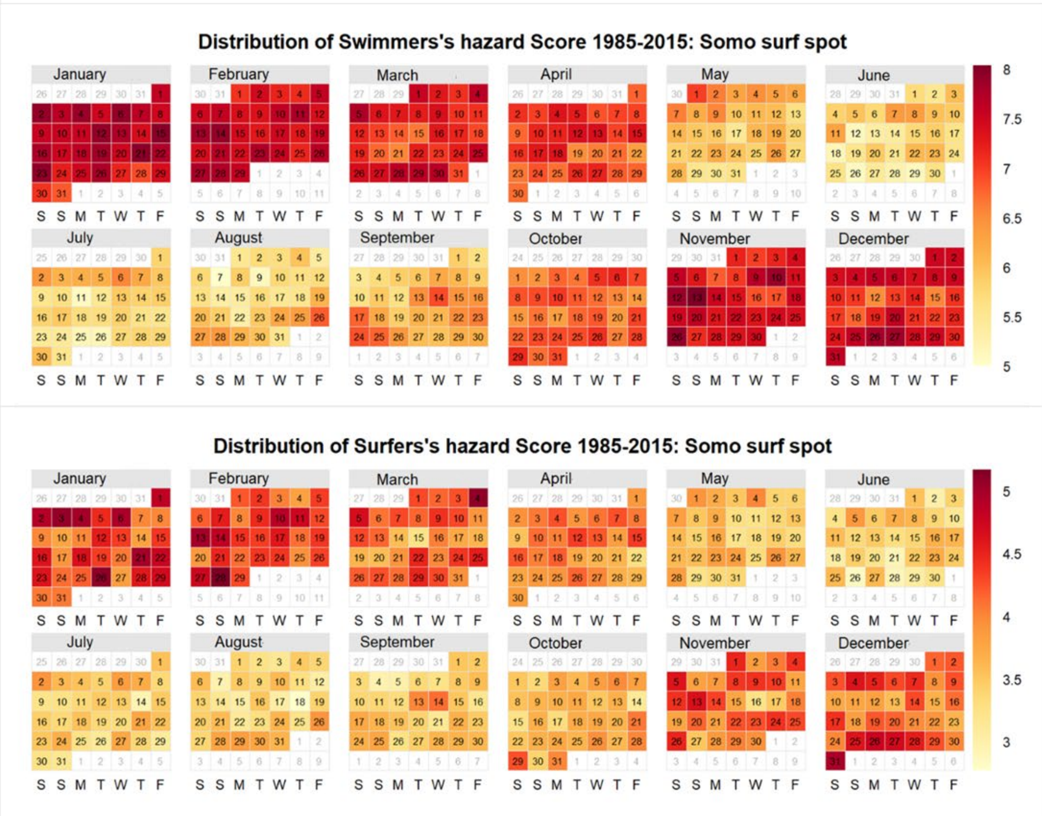

Figure 39. Distribution of swimmers' and surfer' hazard score, 1985-2015: Somo surf spot.

Source: author's own production

Figure 44a,b presents the evolution and trend of the annual values of SwS and SuS for the 1985–2015 period. The highest values for SwS and SuS were in 2014 (a score of 9.21 vs. 7.07) and the lowest happened in 1987 (a score of 7.32 vs. 4.25).

The Mann–Kendall test denoted the absence of significant trends in the series of all the indicators, characterized by interannual variability.

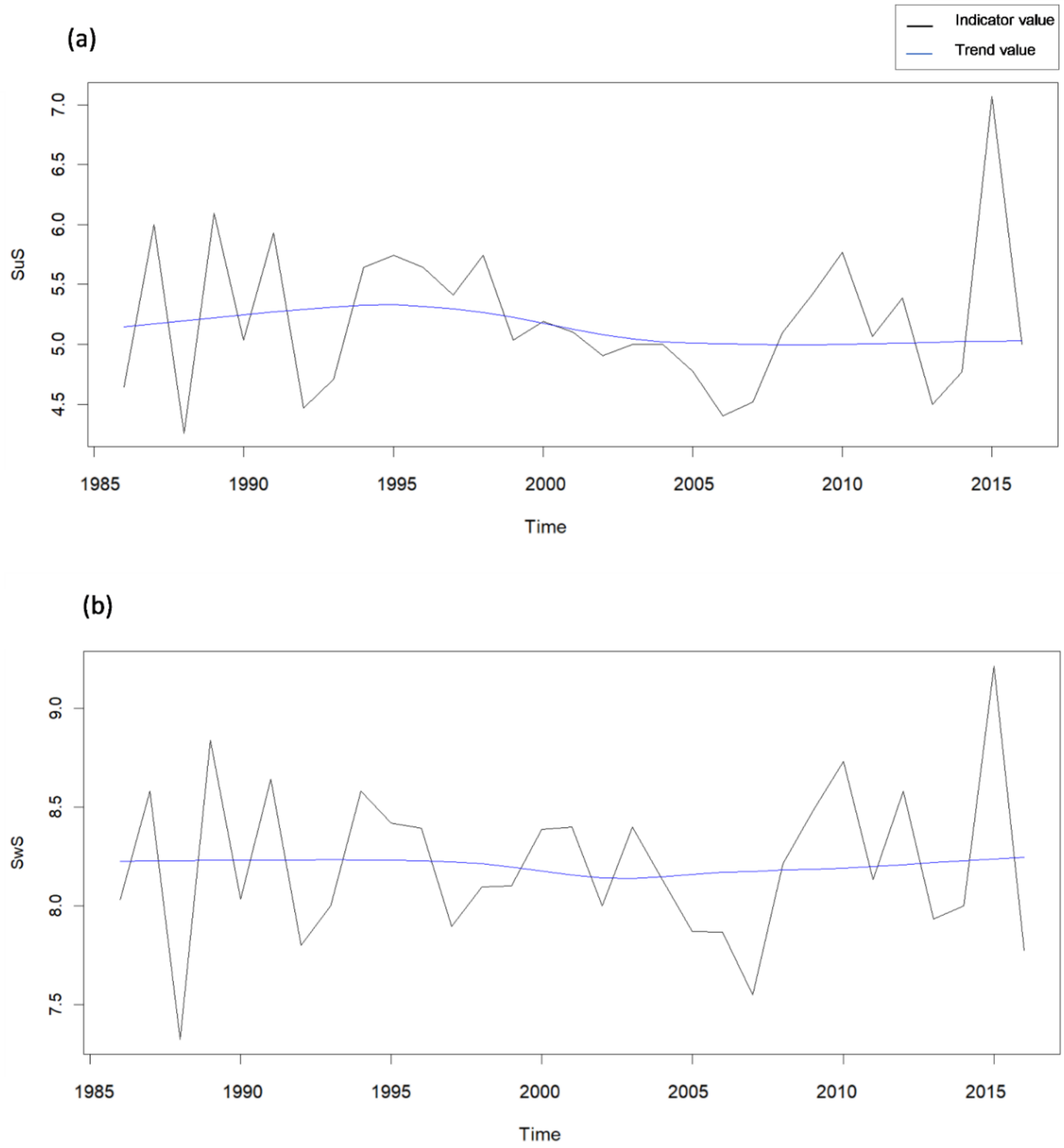

Figure 40. Evolution and trend of annual maximum SuS from 1985 to 2015 in Somo. (b) Evolution and trend of annual maximmum Sws.

Source: author's own production

5.5 Discussion

As described in Section 5.3, surfing days were computed considering peak period (*Tp*), significant wave height (*Hm0*), wind direction (*Wd*), and wind speed (*Ws*) parameters. The highest values in the summer will probably be linked to the period of calm winds in the area.

Nevertheless, the months in the winter that presented lower values will probably present high values in other spots of the east of the beach where the wind speed is not as high as in this region due to orientation and exposure factors. These results improved those of Boqué Ciurana and Aguilar (2020), who calculated expected surfing days without considering wind direction and wind speed, basing their calculations only on buoy data information from Puertos del Estado and Instituto Marinha Portugal.

As Scarfe et al. (2009) suggested, we have developed a surfing wave climatology in-tended as an information resource for surfing management. Espejo et al. (2014) developed a global index for analyzing surfing climatic potential, but the horizontal spatial resolution of oceanic data was coarser than ours. Espejo et al. (2014) based their analysis on a global scale, while we focused on the local scale by utilizing downscaled data with a hybrid method. Tausía (2020) studied the surfing conditions in the Somo surf spot with a slightly coarser spatial resolution of 100 m, focusing on the numerical simulation of the physical processes that affect surfing waves.

Advanced surfers had a higher number of expected days per month from October to April. Intermediate surfing days per month had fewer fluctuations year round. As suggested by Hutt et al. (2001), surf breaks were classified according to surfing skills. In this sense, we followed Barlow et al. (2014), who examined the effect of wave conditions and surfer ability on performance and the physiological response of recreational surfers. Hence, by combining climatic conditions and surfing levels as defined by Hutt et al. (2001), we see that we can contribute to the knowledge about expected surfing days by considering surfers' skills. Thus, we have more evidence about how different sizes of waves are associated with the balance of surfers during surfing activities, which will depend on surfers' skills as De Andrés et al. (2016) stated.

These results provide important insights into demonstrating the different capacities for offering water-related activities for a specific territory. In some cases, lectures on the deseasonalization of the tourist activity are supported by the offer of other kinds of tourist products. Peñas de Haro (2015), defended deseasonalizing sun and beach tourism in Mallorca, which is typically concentrated in the summer months. The deseasonalization proposal is based on the offer of surfing and body surfing activities, as these activities are possible when sun and beach climatic requirements are not in their best conditions. Martín González & Gil (2014) also presented a proposal for the diversification of products in consolidated tourist destinations, giving special mention to the possibility of promoting Costa del Sol as a surfing destination. Even so, these studies did not specifically analyze climate data to determine the exact climatology of the products that can diversify the tourist offer, which is one of the aims of our study.

Regarding the hazard information from swimmers, as stated by Short and Hogan (1994), rip currents and beach hazards have an impact on public safety and have implications for coastal management. We believe that surfers and lifeguards can assist swimmers in a hazardous situation and that swimmers should have lessons on rip current escape strategies (Miloshis & Stephenson, 2011). In the event that a swimmer does not know how to escape from a rip current, surfers and lifeguards, who know how rip currents work (Brander et al., 2011), can perform a rescue (Dalrymple et al., 2011). Surfers possess this ability because they usually use rip currents to arrive at the surfing waiting-area zone for surfing (Brander et al., 2011). Therewith, we consider in which moments surfers present the highest hazard score because, in that situation, they are not going to be able to rescue swimmers. During these times, lifeguards should check on both surfers and swimmers. Based on climatic conditions, our results reveal the difference between swimmers' and surfers' hazards, and thus, this information can assess lifeguards' decision making related to which periods are better for assisting only swimmers and which are important for assessing the safety of both swimmers and surfers. In Somo, lifeguards are only present during the summer months; therefore, this information can be of value when deciding whether to extend the period of lifeguards' presence if required.

5.6 Conclusions and Perspectives

León et al. (2021) explained that the tourism sector is recognized as being highly vulnerable to climate change, and research supporting destinations to enhance their resilience capacities is still considered scarce. As Bradshaw (2021) found, a review of the related tourism literature raises awareness of surfing as a sport, tourism, and innovation opportunities for policymakers in the context of a highly entrepreneurial country, highlighting the benefits that surf tourism offers for sustainable growth and positioning surf tourism as an innovative product.

Our research represents an advance in the knowledge of (1) the expected surfing conditions, (2) the expected surfing conditions related to surfers' skills, (3) the ex-pected conditions for alternative surf offers, and (4) the expected hazard conditions and their differences for surfers and swimmers. Our case is applied in Somo's surf spot but the general framework can work as a model for other specific surfing destinations, specifically sandy beaches. Surfing destinations with point breaks and estuaries propagations of swell should follow another approach; nevertheless, surfing management indicators can be applied in the same way.

Following Borne (2018), who defended the functions of academic and more-popular literature within different language games, academic accounts can seem turgid, dense, and overcomplicated, while popular media may sometimes be seen as repeating banal and superficial observations. However, the scope for surfing-related authors to seek to bridge the gap between scholarship and surfing culture is exceedingly broad. For this reason, we developed specific indicators and represented them to assist surfing destination managers to be better prepared to make climate-smart decisions as recommended by the Global Framework for Climate Services (Hewitt et al., 2012). In this vein and following Kumar et al. (2021), who explored how the visualization and communication of the forecast support the end users' decision making, our graphics in the results section are de-signed to be simple and easy to interpret for surfing destination managers, surf schools, and surfers, among others.

Our results contribute to the blue economy knowledge, as Spinrad (2021) highlighted that the new blue economy is realized as the commercialization of value-added data, information, and knowledge about the marine environment. The economic benefits are enabled by dramatic improvements in observational capabilities and the development of predictive models. Increases in the volume, diversity, and quality of data, as well as more skillful methods of forecasting and nowcasting, make possible the pro-duction of products and services enhancing traditional components of the blue economy.

Surf tourism development provides economic opportunities to residents in coastal destinations, yet it has also been criticized for associations with gentrification, pollution, and inequality. The pandemic exacerbated existing sustainability challenges by accelerating development near surf breaks in Bocas del Toro, Panama. Mach (2021) also found that there is an urgent need for stakeholders in surf communities, and particularly surf tourism business owners, to cooperate to preserve surf experiences that are vital to residents' mental and physical health and well-being as well as attractiveness as a surf tourism destination. As Mach and Ponting (2021) explained, we defend the idea that surfing tourism deserves a more significant place in funding initiatives, discussions, and research related to fostering sustainable development from ocean resources in the rapidly changing world.

Our research can modestly contribute to Spain's goals for its Sustainable Tourism Strategy 2030. This is because, in 2019, the general guidelines of the Sustainable Tour-ism Strategy were presented, but surfing tourism was not mentioned.

This study presents a foundation for surfing climate service surfing. Future work will apply our indices to other surf spots and will validate the predictability of the in-dices. In addition, more indicators can be generated to assess surfing activities if more variables are added; an example is wetsuit recommendations if seawater temperature is analyzed. The present study has focused on surf tourism, but the methodology can be applied to other outdoor and sport-tourism-related activities following Silva et al. (2021) and other dimensions of adventure tourism (Janowski et al., 2021).

As surfers have their experiential standards for the surfability of particular places and conditions, and following Hutt et al. (2001), research can affirm that, depending on surfing skills, surfers will be able to perform in specific meteo-oceanic conditions or not. The general idea is that the advanced surfers can surf in all conditions when they are not adverse. Conversely, beginning surfers cannot perform in all situations. Nevertheless, when high waves that are beneficial for advance surfers occur, beginners may sometimes also surf, but not in the same area. Advanced surfers will surf in the green wave area and beginners will surf in the white water area. The standards of surfers will depend on the level of practice, i.e., beginner, intermediate, advanced, and big wave rider, and on style, i.e., body board, skim, shortboard, longboard—for this reason, in general terms, some beaches are better for beginners and others for advanced surfers. Even so, as meteo-conditions are constantly changing, there is no general surf clue that can help the surfing community. For this reason, the present research has focused on developing those different needs identified from the survey profiling different kinds of surfers: beginners, intermediates, advanced, and big wave riders (Boqué Ciurana & Aguilar, 2021). Relatedly, future research may explore the provision of an app with reactive programming for surfers that could help them to set preferences for meteo-oceanic variables.

Future research may also explore the needs of actual resort managers and/or developers by means of focus groups, adapting Font Barnet et al.*'s* (2021) methodology to better re-design a climate service. The development of this kind of research will promote the maximization of the usage of surfing resources.

Research has explored the advances in climate services in multiple fields but determining a climate service for surfing destination management through downscaled wave data with a 100 m horizontal spatial resolution has not been done before. Further research may focus on developing the same/similar indicators but while also combining surfing forecasting with the downscaling method employed in the present re-search. This forecast data would help destination managers formulate better marketing plans and development. The next steps of the investigation can apply the computation of the same indicators with projection data considering the different climate scenarios to study how surfing resources will change in the future.

PART III. DISCUSSION AND CONCLUSIONS

6. Discussion and conclusions

This chapter discusses our results and drafts a series of derived conclusions, aligned with to the research objectives presented in Chapter 1. Finally, we propose further research possibilities.

6.1 Discussion

This doctoral thesis proposes a methodology for developing a surfing climate service.

The first objective was to identify the expected surfing days per year in specific surf spots in the Iberian Peninsula employing oceanic buoys and the validation of that indicator with surfing session records registered through Glassy app data. We describe and compute an index composed of parameters reported by the buoy's sensors, based on Butt et al. (2004), Butt (2009), and Holthuisjsen (2010), we use it to define a surfing climatology.

. Once the computation is done, we validated the expected surfing days using Costa de Tarragona's surfing sessions as a benchmark.

We then explored the main preferred wind direction and wave direction for all surf spots identified for the Glassy app, observing the differences in those parameters depending on the locations of the surf spots, evidencing the role of surf spot orientation for presenting surfable waves.

Thus, the results of the first article highlight the importance of defining a specific methodology that helps to define regional surfing climatologies. This research expands the knowledge of Espejo et al. (2014), who studied the spatial and temporal variability of surfing resources around the world. They used global models for waves, wind, sea surface temperature, and tides. We follow and complement Peñas de Haro (2015), who examined the expected surfing days per year by means of REDCOS buoy of *Puertos del Estado* and WANA wave interpolation model. Our methodology was adapted from those previous studies; even so, we only used oceanic buoy data from Iberian Peninsula's coast. We agree with Peñas de Haro (2015) that the expected surfing days indicator design computed with the wave mean direction and significant wave height can be improved, as there are substantial differences in the morphology of each surf break. As Butt (2009) stated, wave direction is one of the parameters that determine the wave quality for surfing; in this sense, the optimal swell direction will depend—between other factors— on surf spot orientation. To fill this gap, Peñas de Haro (2015) solved the required wave direction for each surf spot with the help of fieldwork and 25 surveys taken by surfers. Peñas de Haro's (2015) research does not check the link between the surfers' perceptions and the real oceanic parameters. For this reason, our study has used citizen science information and a benchmark with these data and Tarragona's coast to validate the indicator proposal.

In the second publication, the main aim has been to explore the preferences on consulting sea-state information of the future users of the surfing climate service. Thus, co-creating the SCS and answering the real demands of the surfers and companies offers this activity along the Iberian Peninsula's surf spots. We followed the idea of Font Barnet et al. (2021) for user engagement and co-creation; even so, due to pandemic reasons, we decided to develop the co-creation process using an online survey instead of present co-creation workshops.

The article's results highlight the importance of weather information on surfers and businesses that offer this activity; we also discovered what key aspects must be improved regarding which meteorological and climatological information is requested for a better surfing experience. Outputs of the research evidence that differences in forecasts exist between ocean and sea. Research also states that forecasts must be improved and that each surf spot is unique. Furthermore, surveyed participants defend that many parameters will influence wave availability; thus, having good information about this is a difficult and complex task. In this vein, the main findings focus on the identification of the need for: (1) more precision and locally developed forecast; (2) customizable, easy to read and interpret information; and (3) extra information such as the inclusion of knowledge of local surfers and surfing experts and information about contamination.

As Amorim et al. (2016) stated, in the field of CS for surfing, studies about the efficient delivery of forecasting to nautical sports mobile application with semantic data services have demonstrated that weather and sea-related forecasts provide crucial insights for the practice of nautical sports, such as wave surfing and kitesurfing. Moreover, mobile devices are appropriate interfaces for the visualization of meteorology and operational oceanography data.

Along these lines, we explored the channel and format following users' needs. Our research found that the mobile phone is the first preferred channel for receiving information for surfers and companies. Our research has designed a mock-up of a mobile phone app to accomplish this statement.

The third publication has generated a high-resolution atmospheric-oceanic database with a spatial resolution of 100m through hybrid downscaling following Camus et al. (2011) and Camus et al. (2013). Thanks to the knowledge of Hutt et al. (2001), who defined a methodology for relating surf breaks to surf skills, and through the exploration of users' needs by the online survey, it also has been possible to design several indicators to assist decision-making in a tourist destination. The indicators are computed in Somo surf spot as a test, evidencing the strong value of this information for surfers and stakeholders who manage and/or promote this activity.

This third manuscript contributes directly to create high atmospheric-oceanic quality data never used before for surfing assessment purposes. Even so, previous attempts helped to frame this research and act as reference knowledge. An example of this is Espejo et al.'s (2014) research, which defined the global surf index by using global models for the different parameters required. However, in this approach with the wave model, the shallow-water wave propagation process was not considered. Furthermore, because of the grid model resolution, wave conditions were known for intervals of 100-100 km of open coast. Other attempts, such as Peñas del Haro (2015), used the WANA model for wave data, but data had 3h or 5h temporal resolution and 0.125º- 0.25º of spatial resolution. That data was computed in specific points generated by *Puertos del Estado*, and not with the purpose of analyzing specific areas when surf occurs and just analysed on 1999-2008 period—which was not enough period to be considered as a climatology.

In this regard, our knowledge fills the gap on the need for fine data resolution with two meanings temporal coverage by having hourly met-ocean hourly data from 1985 to 2015 and spatial coverage of 100m. And, our methodology allows us to extract the data from the precise location of the surf spot.

6.2 Conclusions

In general terms, answering the different research questions is viable after this research development. It is possible to determine the expected surfing days in the surf spots located in the Iberian Peninsula. Different distribution patterns of the expected surfing days are found; the maximum expected surfing days are present on the western shore, and the minimum values are present on the southern shore. Swell creation and waves' propagation play an enormous role in determining surfing conditions but also play wind direction and intensity in the location where surfing occurs. So main parameters to assess the climatic potential for surfing are: *significant wave height; peak wave period; mean wave direction; wind direction; and wind intensity*. We can compute other parameters, such as *wave energy*, that will also assess surfing conditions. After this research development, we know that CS can provide better information to surfing destinations by co-creating indicators that assist in developing surfing activity or alternate activities such as SUP and windsurfing, among others. In that way, it is confirmed that climate data can assess an alternative surfing offer when this sport is impossible to practice.

The characteristics needed from the SCS are explicitly defined by the end users: surfers, and companies that offer this activity. For the case of the Iberian Peninsula's surf spots, locally developed data is requested in terms of climatologies and forecasts. The primary need detected by end users is to have the data in high resolution, as now they only have the data in the open sea and 5 km spatial resolution in the case of the most precise model, in terms of spatial resolution.

The different indicators developed in this thesis work as information that constitutes the SCS. This way of providing information, by transforming atmospheric-oceanic data into information, will improve surfing experiences for surfers and surf schools, as seen in the answers of the online survey developed in the present research.

A prototype of the app—as end users requested through the online survey—has been developed to show how this climate-resilient information can be communicated to end-users.

As seen in the discussion section, through the development of three objectives, it has been possible to develop a methodology to define SCS. So, the present research has achieved the specific objective of developing a SCS to equip decision makers in the surfing tourism sector to better help the destination adapt to climate variability and change. In this line, it is possible to affirm the dissertation hypothesis, which defended that tourist destination management for coastal destinations can be improved through the development and use of a co-created SCS.

In specific terms, we can conclude that thanks to this research, we have learned that parameters to analyze waves are designed for navigation and not for surfing, so there is a need to transform or reinterpret these parameters to be useful for surfing activities.

Models of wave data from Copernicus (CMEMS) are a good source, such as Atlantic-Iberian Biscay Irish-Ocean Wave Analysis and Forecast (https://doi.org/10.48670/moi-00025); even so, the model does not present fine resolution data (spatial resolution 0.05ºx 0.05º).

Buoy register is a helping source; even so, for the resource wave availability, categorization for surfing is also needed to know the wind in the surfing area. Unluckily, not all the buoys present a meteorological station next to them; if it is present, the register periods do not match. This fact makes some limitations in the characterization of the surfing climatology by the only use of buoy—for wave parameters—and meteorological station data for wind parameters.

The second publication has demonstrated the utility of surfers' and surf companies' knowledge and the potential application of their information to co-create the Climate Service.

The third publication highlighted the differences in expected days of different sports considering different values of atmospheric-oceanic parameters. Peñas de Haro (2015) examined the expected surfing days for surfing and bodyboarding, but there was not any difference in the value of this indicator for those two different sports. We believe that with the involvement of surfers and bodyboarders, a specific indicator for each sport could be developed, as the present research has evolved with kitesurfing and stand-up paddle.

So, with this research, we have seen how scientists have linked weather and climate with different tourist activities using distinct approaches. It has also been stated which atmospheric-oceanic parameters influence surfability and explored how researchers had tried to determine climatic surfing potential. Through the exploration of the climate service co-creation background, it has been explored how important CS development is to face climate variability and change. The literature review evidences a gap in developing climate services for surfing activity. For this reason, this research contributes with a methodology to develop a co-created SCS to manage a surfing destination better, as the main objective stated.

6.3 Further research

Thanks to the knowledge gained through the development of this thesis, we have detected the need and opportunity to address a future research plan focused on:

➔ **Computing future surfing climatic potential:** Climate and weather conditions for outdoor recreation construct the basis to identify which activities are viable in certain territories and moments and which are not (Scott et al., 2005). Surf, snow, wind, and white water provide natural resources for adventure tourism. Both resources and their tourism access depend on weather and, hence, are affected by climate change (Buckley, 2017). The present research postulates the need to compute indicators generated in the third publication but calculated with climate projections applying the same hybrid downscaling method that Camus et al. (2011) and Camus et al. (2013) developed.

The present research has explored the present climate potential for surfing activity with the adaptation offered by exploring the possibilities of practicing other water sports. But it has not yet explored the future climate potential.

Cardell et al. (2021) explored the present and future climate potentials for several outdoor tourism activities in Spain, but they did not achieve the degree of spatial resolution as in the present research. They used ERA-5 data for past data, obtaining 30 km spatial resolution data. Further, RCM simulations were used for future data with 12 km spatial resolution.

Therefore, future research may address computing future surfing climatic potential with downscaled data.

➔ **Designing wave forecast with hybrid downscaled data:** Upcoming research may address the redesign and computation of indicators generated in the third publication of this thesis but with Copernicus 5km forecast data (https://doi.org/10.48670/moi-00025) with the application of the same hybrid downscaling method (Camus et al., 2011; Camus et al., 2013).

➔ **Computing the climatic potential indicators for other sea-based leisure activities:** Results of this research evidence that it would be interesting to expand this methodology framework to other coastal activities linked with the weather, climate, and climate change. There is the possibility of co-creation indicators following Font et al. (2021) with *in situ* workshops and also following Reineman (2016) who examined the utility of surfers' wave knowledge for coastal management.

➔ **Specifically, developing the implementation and communication of the SCS:** As improved climate services will become even more vital for travel, the travel and tourism industries and destinations will be required to adapt services and activities to meet the challenges of climate change in an economically, socially, and environmentally sustainable manner (Scott et al., 2011). For this reason, research states the importance of generating a deeper exploration of how to communicate the climate service and generation of a validation process of the Surfing Climate Service prototype with stakeholders.

➔ **Generating feedback with stakeholders of the tourist destination:** following Scott & Lemieux (2010) who defined the importance of weather and climate information for tourism, future research must address pathways to contact tourist destination managers to promote destinations with surfing climatology information.

CS does not generate economic and social value on their own. For having value, the most important point is that users benefit from decisions as a result of the information provided, even if the services are of the highest quality (WMO, 2015).

➔ **Exploring the value of the SCS:** Peñas de Haro (2015) stated that the surf breaks' potential is a factor that usually goes unnoticed in consideration of economic factors. Still, surf breaks have an economic return for the local economy. The multiplier economic effect of the surf spot extends not only to active practitioners of this sport but also involves the mobility of visitors who are limited to observing surfers or who act as companions to those who surf.

According to Scott et al. (2011) there is a lack of research on studies about the financial or non-market benefits of specialized products for tourism or the willingness to pay for climate information among tourists and tourism operators.

For this reason, it can be of interest to explore the economic value of this surfing climate service.

➔ **The exploration of sensors' installation to help validate the model and monitor possible environmental problems**: in the surf spots. This would be following the ideas from projects like Coastnap based on citizen science (User, 2021).

➔ **Relating weather and climate conditions to surfers' performance:** Following de Andrés et al. (2016), who explored the performance in balance ability of competitive surfers in relation to the healthy non-surfer population. Their research stated that in this sport, training and competition is characterized by a great variability of environmental factors, such as different sizes and shapes of breaking of waves and changing weather conditions. The adaptation and control of these factors require the athlete to have adequate postural control and stability. For this reason, a future research plan may address the exploration of the relations between surfers' equilibrium performance and sea-state conditions.

➔ **Exploring mitigation and adaptation actions for sea-based leisure activities**: Pröbstl-Haider et al. (2021) analysed the climate change impacts on outdoor activities in the summer and shoulder seasons. The research found interesting results on specific activities: hiking; Nordic walking and walking; mountain hiking; climbing and high mountain tours; bathing in natural lakes and diving; fishing as a vacation and leisure activity; water sports activities (canoeing, rafting, and sailing); air sports (paragliding, gliding, ballooning, or hang gliding); mountain biking and cycling; golfing; and nature experience offered in connection with protected area tourism.

Along these lines, research found expected effects on tourism activities, such as season extension, improved overall conditions, or the other way round effect. The manuscript also investigates the climate-induced effects on tourism activities and links mitigation and adaptation actions.

For this reason, we consider that future research may address a similar approach to this manuscript, but including surfing sport and derivates such as windsurfing, wing, kitesurfing, and stand-up paddle, obtaining future climatic potential and linked adaptation and mitigation actions.

If those research topics are explored, tourism destinations could increase their resilience to climate variability and change and work as examples of how to develop and apply climate services to specific sectors.

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A. Appendix

A.1. Buoys Characteristics and Variables Formulas

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

Source: author's own production

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)) (Young *et al.*, 1995) where the peak frequency is the frequency which corresponds to the maximum of S(f) (Tomás Sampedro, 2010). Average of wave mean direction is recognized as D_{md} or θ_m (Equation (A3)) (Kellogg Brown & Root, 2022) maximum wave height occurring in a record is recognized as H_{max}. (Equation (A4)) (Laing *et al.*, 1998) 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)) (Tomás Sampedro, 2010).

$$T_P = f_p^{-1} \qquad \text{(A1)}$$

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

$$T_P = \frac{2\pi}{\omega_P} \qquad \text{(A2)}$$

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

$$\theta_m = \arctan\left(\frac{\int_0^{2\pi}\int_0^{\infty} \sin\theta\, S(\omega,\theta)\, d\omega\, d\theta}{\int_0^{2\pi}\int_0^{\infty} \cos\theta\, S(\omega,\theta)\, d\omega\, d\theta}\right) \qquad \text{(A3)}$$

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

$$Hmax = \overline{H_{m0}}\sqrt{0.5\, \ln N} \qquad \text{(A4)}$$

where $Hmax$ is maximum wave height, $\overline{Hm0}$ is mean of significant wave height, N is counted observations of waves.

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

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

A.2. Bottom Type and Surf Break Characterization

As described in Section 3.1, 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 least frequent being reef breaks (9.6%). The remaining 0.4 are unknown.

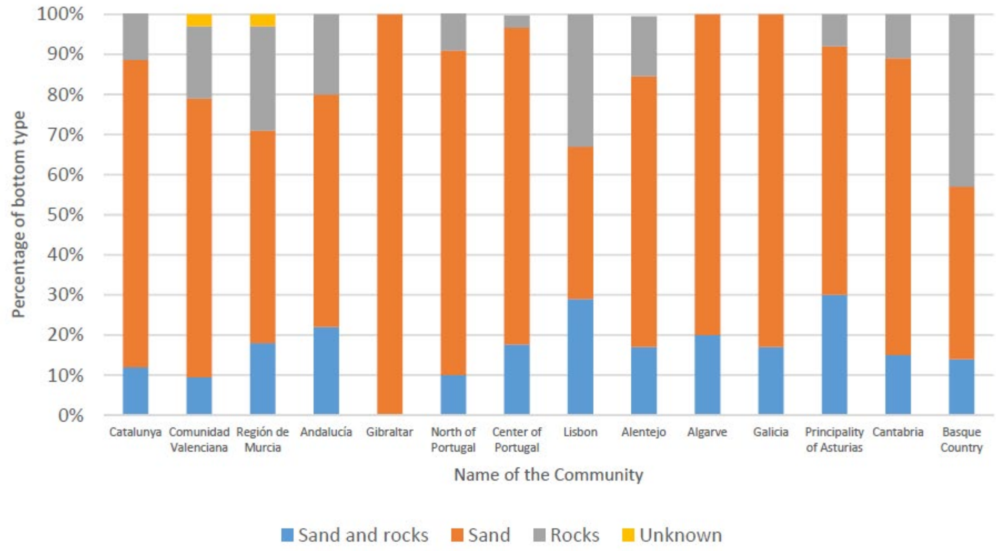

Figure A2. Distribution of bottom type grouped by NUTS 2 division (%)

Source: author's own production

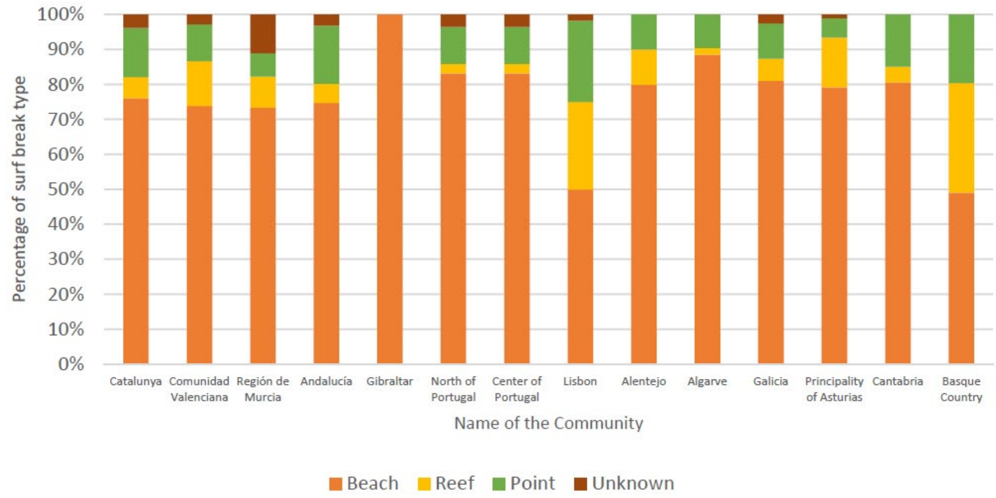

Figure A3. Distribution of surf break type grouped by NUTS 2 division (%)

Source: author's own production

A.3. Survey model

Survey model available online: https://forms.gle/yQrTeUARKaTaZy7z7.

A.4. Summary of Survey Responses

Table A2. Summary of Survey Responses

0. Have you ever surfer on the Iberian Peninsula?	Yes	No				
	97.77%	2.23%				
1. Gender	% Male	% Female				
	75.11%	24.89%				
2. Years of surfing	<5	[5-10)	[10,15)	[15,20)	>=20	
	20.85%	27.66%	14.47%	12.13%	24.89%	
3. Board water sport practiced more frequently	Bodyboard	Shortboard	Longboard	Stand up Paddle		
	11.49%	64.68%	17.66%	6.17%		
4. Level of surfing	Beginner	Intermediate	Advanced			
	5.74%	25.11%	69.15%			
5. Do you dedicate yourself or have you dedicated yourself professionally to surfing (competition, instructor, judge . . .)?	Yes	No				
	39.15%	60.85%				
6. Indicate your usual spots						Section 4.3.4 See Figure A5
7. What do you think are the environmental impacts that affect surfing? (multiple choice)						Section 4.3.3
8. Please list any changes you have observed in your usual spot (s) that harm or benefit the practice of the sport. Indicate in which surf spot						Section 4.3.3
9. Do you have to travel at a distance that involves you spending a night away from home in order to surf surf?	Yes	No				
	88.30%	11.70%				
10. Indicate some of you travel spots that you would like to highlight (if possible, within the Iberian Peninsula)						Section 4.3.4 See Figure A6
11. When do you travel (spend a minimum of 1 night away from home) do you consult the state of the sea in a different way? (multiple choice)						Section 4.3.1
12. Where do you surf most often?	Home	Not home				
	88.30%	11.70%				
13. Indicate what information you consult before going surfing and assess its quality (1 = very bad – 5 = very good) [Friends / family inform me]						Section 4.3.1
14. Before going surfing, do you consult information to know the state of the sea?						Section 4.3.1
15. How far long in advance do you check the forecast? (multiple choice)						Section 4.3.1
16. What website or application do you consult to look at the prediction?						Section 4.3.1
17. What parameters do you look at when checking at the wave forecasts?						Section 4.3.1
18. Do you know what the significant height of the wave is?	Yes	No	I have heard about it, but I don't know what it is			
	71.91%	13.19%	14.89%			
19. What do you think could be improved from the surf forecasts?						Section 4.3.2
20. If you had seasonal forecast * do you think it would be useful for you? * for example, if in the spring, you had the information of the summer						Section 4.3.2
21. In what format would you like to receive seasonal forecast information? (multiple choice)						Section 4.3.2

	Yes	No	I have heard about it, but I don't know what it is
22. Do you know what the significant height of the wave is?	71.91%	13.19%	14.89%
23. What do you think could be improved from the surf forecasts?			Section 4.3.2
24. If you had seasonal forecast * do you think it would be useful for you? * For example, if in the spring, you had the information of the summer			Section 4.3.2
25. In what format would you like to receive seasonal forecast information? (Multiple choice)			Section 4.3.2
26. Filter question			
28. In what format would you like to receive the information?			Section 4.3.2
29. Does the income of the company/department vary depending on the availability of waves?			Section 4.3.2
30. Does your company currently offer other water activities apart from surfing?			Section 4.3.2
31. Would you be willing to pay to receive seasonal information?			Section 4.3.2
32. Do you think you would diversify the offer of aquatic activities if you had adequate information on the state of the sea?			Section 4.3.2
33. Add comments that you think you can contribute extra information to the study:			
34. If you want to stay informed of the results of the investigation you can write your email here			

Figure A4. Place of residence.

Source: author's own production

Figure A5. Usual surf spots.

Source: author's own production

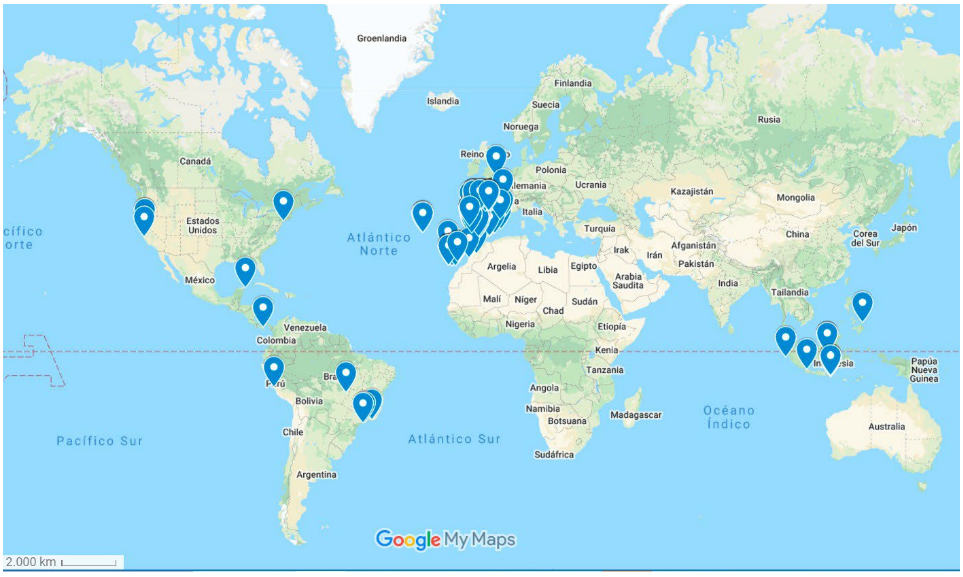

Figure A6. Travel surf spots

Source: author's own production

A.5. Letters of co-authors

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FA CONSTAR

que els següents articles dels quals és coautor no han format part de cap altra tesi doctoral, i RENUNCIA a presentar-los com a tal en el futur:

- Boqué Ciurana, A., & Aguilar, E. (2020). Expected distribution of surfing days in the Iberian Peninsula. *Journal of Marine Science and Engineering*, *8*(8), 599. https://doi.org/10.3390/jmse8080599
- Boqué Ciurana, A., & Aguilar, E. (2021). Which Meteorological and Climatological Information Is Requested for Better Surfing Experiences? A Survey-Based Analysis. *Atmosphere*, *12*(3), 293. https://doi.org/10.3390/atmos12030293
- Boqué Ciurana, A., Ménendez, M., Suárez Bilbao, M., & Aguilar, E. (2022). Exploring the Climatic Potential of Somo's Surf Spot for Tourist Destination Management. *Sustainability*, 14(14), 8496. https://doi.org/10.3390/su14148496

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HACE CONSTAR

que el siguiente artículo del cual es coautora no ha formado parte de ninguna otra tesis doctoral, y RENUNCIA a presentarlo como tal en el futuro:

- Boqué Ciurana, A., Ménendez, M., Suárez Bilbao, M., & Aguilar, E. (2022). Exploring the Climatic Potential of Somo's Surf Spot for Tourist Destination Management. *Sustainability*, 14(14), 8496. https://doi.org/10.3390/su14148496

Santander, 2 de septiembre de 2022

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HACE CONSTAR

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Santander, 2 de septiembre de 2022

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