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FACULDADE DE CIÊNCIAS

IMPROVING THE TRANSFER OF COASTAL SCIENTIFIC KNOWLEDGE: FROM CONCEPT TO IMPLEMENTATION

Doutoramento em Geologia

Especialidade em Geodinâmica Externa

Ana Mafalda Marques Carapuço

Tese orientada por:

Professor Doutor Rui Pires de Matos Taborda

Professor Doutor César Augusto Canelhas Freire de Andrade

Documento especialmente elaborado para a obtenção do grau de doutor

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Ao Francisco, Emília, Rui, Tomás e Rita.
A minha casa.

To meet the challenge of sustainability scientists must transfer their knowledge outside the scientific community. This is not only desirable but also a social responsibility of scientists (UNESCO, 2000).

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Abstract

Achieving coastal sustainability requires a comprehensive knowledge of the coastal environment. In this context, scientific knowledge plays a major role in understanding coastal processes at a wide range of spatial and temporal scales, as well as in the integration of different types of knowledge. However, scientific knowledge as not been used in full for the development of science-based coastal policies and management strategies, and ineffective scientific knowledge transfer arises as a major obstacle in knowledge integration. Several reasons for ineffective knowledge transfer have been suggested in the literature, most of which related with communication gaps.

The main objective of the present work is to find means to improve the transfer of coastal scientific knowledge fostering its incorporation into coastal management. This study was based upon a conceptual approach supported in a comprehensive literature review and grounded in theoretical developments. Results benefits from the author's experience gathered from different projects developed under the framework of the present study.

The first step to achieve the main objective of this work was to identify who are the key coastal actors and understanding the way they interact: this is of paramount importance in a knowledge-transferring framework as they are the audience that scientists aim to reach. Beside scientists, two other key coastal actors are policy-makers and managers, and society. Policy-makers and managers are responsible for the regulation of the coastal zone uses by establishing and implementing the policy framework for the coast. Society arises also as a key coastal actor as people benefit from the services provided by the coastal environment. Although society is frequently regarded as a passive intervenient, the fact is that the role of society in the definition of coastal strategies is increasing. Key coastal actors, their roles and links are schematized in *The Coastal Knowledge Triangle*.

The second step was to identify the challenges faced by scientists in fostering scientific knowledge. Two major challenges were identified: the need to foster engagement among coastal actors, and the need to properly frame the message to be delivered. Engagement is grounded on empathy and goes beyond simple awareness of the problem. Four key enablers for successfully building engagement were identified: willingness, trust, competence and commitment. Framing the message helps turning scientific data into meaningful information for the target audience, and implies choosing the more adequate language (i.e., the manner in which scientific knowledge is traduced) and channels of communication (i.e., the manner in which the message is sent) according to the audience's specificities. Interpersonal communication, video and websites are examples of widely used channels in science communication. The most adequate languages to traduce scientific knowledge are discourse (i.e., conceptual generalization of conversation), images (including photographs and graphical representations) and indicators.

This study suggests that indicators the most efficient way to transmit inherently complex information in a simplified and applicable form, a conclusion in line with several international organizations. Considering their relevance, a common framework for the establishment of coastal geoindicators for sandy coast environments was developed in the scope of the present work.

The third step was to identify mechanisms that scientists can adopt to connect with their audience. Each mechanism accounts for the audience specificities and conveys the message in a different way leading to different types and quantity of feedback. If adequately used, mechanisms improve the transfer of scientific knowledge by fostering engagement, minimizing framing effort and optimizing audiences' feedback. The most widely known (and adopted) mechanism to transfer scientific knowledge is outreach (as formal education is not encompassed in the scope of this work). However, scientists' must be aware that other mechanisms are available: crowdsourcing, managers-oriented tools and co-production. These mechanisms although in earlier stages of development are promising alternatives and should be considered as major opportunities to foster knowledge transfer. In the scope of the present work, a conceptual model was developed to help scientists in selecting the most adequate mechanism to convey the coastal message. In this selection, scientists must weigh the level of engagement of the audience and account for the feedback raised by each mechanism: outreach leads to coastal awareness; crowdsourcing to data generation; management-oriented tools generate information, and co-production boosts knowledge. The application of each mechanism and related feedback is thoroughly discussed in this work grounded in real-world applications. The adequate use of these mechanisms will lead to a knowledge-based society and will increase the participation of key coastal actors in decision-making. Therefore, scientists should actively pursue the goal of transferring their knowledge outside of the scientific community, by adopting the proper mechanisms to connect with their audience, developing their framing skills and acknowledging the benefits of engaging with others. Not only this is a social responsibility of scientists but, ultimately, it will also benefit the value of research endeavors towards [coastal] sustainability.

Keywords: knowledge transfer; coastal actors; engagement; outreach; crowdsourcing; management-oriented tools; co-production; coastal sustainability.

Resumo

A sustentabilidade da zona costeira só é possível através da integração do conhecimento (*lato sensu*) na definição de estratégias de planeamento e gestão. Neste contexto, o conhecimento científico apresenta uma importância fundamental na compreensão dos processos que condicionam a evolução costeira, mas também na integração de outras fontes de conhecimento (não científico) associados à zona costeira. No entanto, presentemente, a integração do conhecimento científico na gestão da zona costeira é geralmente efetuada de forma não-sistemática e, na maioria dos casos, em contextos reativos. Esta situação deve-se essencialmente a constrangimentos associados à transferência do conhecimento científico entre as comunidades científicas e não científicas, relacionados com limitações na comunicação entre as partes.

O principal objectivo deste trabalho é definir estratégias que potenciem a transferência do conhecimento científico, entre as comunidades científica e não científica, promovendo a sua integração no planeamento e gestão da zona costeira. Este trabalho é baseado numa abordagem conceptual suportada em vasta pesquisa bibliográfica e no desenvolvimento de um conjunto de projetos que foram desenvolvidos e implementados no âmbito deste estudo.

A primeira fase deste trabalho consistiu na identificação dos principais atores da zona costeira. Para além dos cientistas, responsáveis pela geração do conhecimento científico, foram identificados os decisores políticos e gestores, e a sociedade em geral: os decisores políticos e gestores enquanto responsáveis pela regulação da zona costeira através do estabelecimento e implementação dos instrumentos legais de ordenamento da orla costeira; a sociedade uma vez que beneficia, direta e indiretamente, dos serviços fornecidos pela zona costeira e pelo ao seu papel cada vez mais interventivo e de maior relevância na tomada de decisão. De forma a conceptualizar as relações entre os principais atores da zona costeira foi desenvolvido o "Triângulo do Conhecimento Costeiro" (*The Coastal Knowledge Triangle*).

A segunda fase constituiu na identificação dos desafios que os cientistas encontram na transferência do conhecimento científico. Neste contexto foram identificadas duas ações que podem atuar como catalisadores da transferência do conhecimento: promover o engajamento (*engagement*) entre os principais atores e enquadrar (*framing*) a "mensagem" num formato que considere as especificidades da audiência. O engajamento implica o envolvimento dos cientistas não só na identificação do problema mas também na sua resolução e beneficia da existência de (maior) empatia entre as diferentes partes envolvidas. O enquadramento da mensagem implica a tradução e disponibilização do conhecimento científico em dados e informação relevante para os outros atores (receptores da mensagem) através da utilização de uma linguagem (forma como a informação é traduzida) e de canais de comunicação adequados. No âmbito do presente trabalho, foram identificadas com linguagens mais adequadas para a transferência do conhecimento científico, o discurso, as imagens (incluindo fotografias e gráficos) e os indicadores.

Os indicadores foram considerados como a linguagem mais adequada para transmitir informação inerentemente complexa de uma forma simples e aplicável. Esta constatação está de acordo com as orientações de várias organizações internacionais de reconhecido mérito. Neste sentido, no âmbito do presente trabalho foi desenvolvido um quadro de referência para o estabelecimento e reporte de geoindicadores orientados para a descrição do estado e evolução de litorais arenosos.

Por último foram identificados diferentes mecanismos para os cientistas se relacionarem com a audiência e que têm como objetivo potenciar a transferência do conhecimento. Cada um dos mecanismos pressupõe o estabelecimento de diferentes tipos de ligação com a audiência gerando, por sua vez, diferentes tipos de resposta. Adicionalmente, se devidamente utilizados, estes mecanismos não só promovem a transferência do conhecimento mas também promovem o engajamento, minimizam os esforços no enquadramento da mensagem e otimizam a resposta da audiência. O mais conhecido, e utilizado, mecanismo de transferência do conhecimento científico é a divulgação científica (*outreach*). No entanto, existem outras formas para transferir conhecimento científico: a aquisição coletiva de dados (*crowdsourcing),* ferramentas de apoio à gestão e co-produção. Estes mecanismos, apesar de se encontrarem numa fase mais inicial de desenvolvimento e aplicação, constituem alternativas de elevado potencial na transferência do conhecimento. Neste estudo, todos estes mecanismos são apresentados e discutidos com base em projetos concretos desenvolvidos no âmbito deste trabalho.

Para orientar os cientistas na seleção do mecanismo mais adequado para transferirem a sua mensagem foi desenvolvido um modelo conceptual. Nesta seleção, os cientistas devem considerar o nível de engajamento entre os atores e o tipo de resposta que os cientistas desejam gerar na audiência: enquanto a divulgação científica promove a literacia e a sensibilização, a aquisição coletiva de dados promove a geração de dados, as ferramentas orientadas para o apoio à gestão promovem a geração de informação e a co-produção a geração de (novo) conhecimento. Verificou-se que a adoção dos diferentes os mecanismos tem um vasto potencial na promoção uma sociedade baseada no conhecimento e potencia a participação dos diferentes atores costeiros no processo de decisão. Neste sentido, os cientistas devem promover ativamente a transferência do conhecimento científico para além das fronteiras da comunidade científica. É ainda fundamental que os cientistas desenvolvam as suas competências no enquadramento da mensagem e reconheçam os benefícios de interagir com os outros atores. Esta atitude é uma responsabilidade social dos cientistas que, em última instância, irá valorizar os seus esforços na geração do conhecimento científico e contribuir para a sustentabilidade da zona costeira.

Palavras-chave: transferência do conhecimento; atores da zona costeira; engajamento; divulgação científica; aquisição coletiva de dados; ferramentas de apoio à gestão; co-produção; sustentabilidade costeira.

IMPROVING THE TRANSFER OF COASTAL SCIENTIFIC KNOWLEDGE: FROM CONCEPT TO IMPLEMENTATION

Chapter 1

Introduction

Chapter 1

1. Introduction

1.1 Motivation

Moving towards sustainable development implies the incorporation of scientific knowledge in the management framework. The importance of scientific knowledge is acknowledged by major international organizations and highlighted in strategic documents such as the Agenda 21 (UN, 1992), and the Declaration on Science and the Use of Scientific Knowledge (UNESCO, 2000). Here, scientific knowledge integration is considered as being indispensable aiming at sustainability and, beyond desirable, it is stated as a social responsibility of scientists.

The integration of scientific knowledge has been growing in importance in coastal management as the coast is one of the most dynamic and vulnerable Earth's environments highly susceptible to human demands and to global climate change (*e.g.,* Hinkel *et al.*, 2015; IPCC, 2014; UNESCO, 2007; Agardy *et al.*, 2005). However, only a small part of scientific endeavor has been effectively used in the development of coastal management strategies (*e.g.,* Nursey-Bray *et al.*, 2014; van Koningsveld *et al.,* 2005). In the past, the inability to recognize coastal change has led to serious errors in terms of management practice (*e.g.,* Douglass, 2002). These errors are particularly obvious in highly populated coasts, were unwisely occupation collides with the inherent dynamics of the coast (*e.g.,* MacFadden, 2007; Hsu *et al.*, 1999). Nowadays, the rate of population growth and urbanization in coastal areas is still increasing and this trend is expected to continue into the near future (*e.g.,* UNESCO, 2007; Brown *et al.*, 2008). Neumann *et al.* (2015) estimate that the number of people living in low-lying coastal areas will grow between 2000 and 2060 from 625 million in 2000 up to 1.4 billion people in 2060. This increase will most likely put additional pressure on the coast and might thus endanger sustainability (Sekovski *et al.,* 2012). Adding to this scenario, the expected climate change-related effects may increase the intensity and frequency of risk-prone events throughout the 21st century and beyond (Hinkel *et al.*, 2015; IPCC, 2014). Attaining coastal sustainability has been a difficult goal in the past and, given that, at present, this goal should consider cumulative impacts of climate change an even bigger challenge lays ahead. Nevertheless, while the importance of scientific knowledge integration is widely recognized, significant gaps still remain in the effective incorporation of science outputs in the management agenda.

1.2 Gaps in scientific knowledge transfer

[This subchapter is based on: Carapuço, M.M., Taborda, R., Andrade, C., de Jonge, V.N. 2016a. Coping with coastal change: from scientific knowledge to implementation (*Submitted*)]

Several reasons for ineffective scientific knowledge transfer have been suggested in the literature. According to Anderson (1992) the problem mainly depends on scientists often allowing for much more interest, time, and effort to the production of new knowledge than to the dissemination of their research results. For van Koningsveld *et al.* (2005), scientific knowledge transfer has been hindered due to the complexity of the data available. This translates in the inherent difficulty in applying straightforwardly the research findings into the coastal management process. According to de Jonge (2007) many scientists fail to translate their data-rich research output into information that is understandable, useful and appealing to managers. Stone (2002) pointed out the lack of dialogue as the cause for the inadequate or insufficient use made of research findings. Carapuço *et al.* (2014a) identified as the major gap the inefficiency of the channels used for scientific data dissemination, which are not adequate to reach coastal managers. Jones *et al.* (2008) and Diedrich *et al.* (2010) noted that research is often conducted disregarding the needs of decision-makers, and this limits the responsiveness of research to current policy concerns. However, these authors also pointed lack of political will, limited researcher credibility in the eyes of policy-makers, and decisions being taken based on political premises rather than science, as reasons hindering the effectiveness of scientific knowledge transfer. In fact, several authors claim that the reasons for gaps in scientific knowledge transfer exclusively fall under the responsibility of policy-makers and managers. The resistance to adopt new knowledge, the motivation to seek and use information, and their often-limited competencies and skills in "translating" scientific knowledge are some of the main handicaps reported in the literature (Becheikh *et al.*, 2010; Kirst, 2010; de Jonge, 2007; Hemsley-Brown and Oplatka, 2005). For Nielson (2001) the problem lies "somewhere in the middle" and the non-use of research has been largely explained as an outcome of the cultural gap between scientists and non- scientists in relation to their values, jargon, time-frames, reward systems and professional affiliations to such an extent that they live in separate worlds.

The central issue is that, regardless on which side relies the responsibility of barriers in scientific knowledge transfer, communication gaps arise as the major obstacle to scientific knowledge transfer. Furthermore, it should be noted that scientific literature devaluates the role of society in scientific knowledge transfer (Bonne *et al.*, 2014). Thus, the amplitude of communication gaps in knowledge transfer is probably wider than expectable. The consequence is that this communication gap must be approached from both the scientists' and non-scientists' "sides". Scientists should acknowledge that their role does not end when scientific knowledge is developed and that they also have a role in its successful delivery to non-scientists. In this sense, scientists should take the first step in the direction towards knowledge transfer and should actively pursue this objective.

1.3 Objective of the work

The objective of the present work is to find means to improve the transfer of coastal scientific knowledge. This work aims to be a contribution in strengthening the links among scientists and other key coastal actors, a vital step towards sustainability.

This objective lead to the following research questions:

- Who are the key coastal actors and what are their roles?
- What are the challenges faced by scientists in knowledge transfer?
- What strategies can help scientists to connect with their audience and improve knowledge transfer?

This study was based upon a conceptual approach supported by a comprehensive literature review and critical thinking. Notwithstanding its theoretical approach this work was developed under the premise that to be useful to scientists a tangible result should be put forward. To achieve this objective, a conceptual model presenting guidelines for scientists to improve the transfer of scientific knowledge was developed. This model benefited from the author's experience gathered from different projects developed under the scope of the present study supported by real-world case studies undertaken and tested in the scope of this thesis.

1.4 Outline of the thesis

The thesis is divided into seven chapters, with a structure consistent with the research questions formulated above.

Chapter 1 presents the motivation and defines the objective of the work.

Chapter 2 focuses on key coastal actors, their roles and links.

Chapter 3 addresses the challenges that arise in scientific knowledge transfer. In this chapter, the identification of the existing gaps in coastal knowledge transfer is supported by results from a worldwide survey targeting coastal scientists, policy-makers and managers. Based upon these results, conditions for fostering scientific knowledge transfer are put forward.

Chapter 4 focuses on coastal indicators as one of the most adequate languages to improve the transfer of coastal scientific knowledge. A common framework for the establishment of coastal geoindicators for sandy coast environments developed in the scope of this work is presented.

Chapter 5 presents mechanisms that can be adopted to help scientists to connect with their audience. Each mechanism conveys the coastal message in a different way and accounts for the audience specificities. Real-world applications of the different mechanisms are presented and thoroughly discussed.

Chapter 6 presents a conceptual model to guide scientists in the selection of the most effective mechanism to convey their science-based message. This selection will depend both on audience's engagement and aspired feedback.

Chapter 7 presents the conclusions of the work and provides an outlook for moving forward in scientific knowledge transfer.

This thesis includes approaches and results that have been published in encyclopedias, books and peer-reviewed scientific journals. In order to assure fluency to the thesis small changes were introduced, when appropriate, to the original contents of those contributions. Specific reference to those publications is made in each chapter or subchapter.

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Chapter 2

Coastal actors, their roles and links

Chapter 2

2. Coastal actors, their roles and links

[This subchapter is based on: Carapuço, M.M., Taborda, R., Andrade, C., de Jonge, V.N. 2016a. Coping with coastal change: from scientific knowledge to implementation (*Submitted*)]

The identification of the coastal actors, taken as those who have a role in the coastal agenda, and understanding the way they interact is of paramount importance in the development of a scientific knowledge-transfer framework and a critical factor in the successful coastal management (Brown *et al.*, 2002). Moreover, coastal actors (other than those directly involved in coastal research) make the audiences that scientists aim to reach and knowing the audience is vital to ensure that communication is successful. In addition, and as put forward by Stocker and Wood (2014), "…coastal actors do not function alone but in existing networks and in legal, policy, political, social, technological, economic and cultural contexts. Coastal actors share links and can collaborate with each other to share power and available resources, such as knowledge". Therefore, understanding the links between scientists and the other coastal actors is also fundamental in moving forward knowledge transfer and implementation.

2.1 Coastal actors and their roles

Scientists are those who pursuit knowledge and the understanding of the natural and social world entailing unbiased observations and systematic experimentation, following a systematic methodology based on evidence (EEB, 2016; TSC, 2016).

Scientists generate knowledge based on the scientific method and aim to transfer it to other coastal actors. As scientific knowledge allows for the understanding of the natural world, it gives scientists a unique perspective on the coastal system. The ability to consider the processes driving coastal dynamics at different spatial and time scales makes scientists capable of supporting the functioning of that system under different forcing scenarios and evaluate different short- to long-term coastal management strategies. Moreover, scientific knowledge is not only relevant *per se* but also necessary in the integration of "all types of knowledge" (Nursey-Bray *et al.*, 2014), which also includes bureaucratic and local knowledge (*e.g.,* Edelenbos and van Buuren, 2011; Rinaudo and Garin, 2005; Hunt and Shackley, 1999). Benefits in the mobilization of bureaucratic and local knowledge are highlighted by Rinaudo and Garin (2005), and include "improving the quality of the identification of the issues at stake, the formulation of a generally complex and unstructured problem, and the identification of a large panel of alternative solutions".

Policy-makers and managers are responsible for the regulation of the coastal zone uses by establishing and implementing the policy framework for the coast. These actors detain bureaucratic knowledge, which is heavily intertwined with administrative and governmental practices (Edelenbos and van Buuren, 2011). When scientists aim to implement their findings policy-makers and managers are usually their primary audience.

Society arises also as a key coastal actor as they benefit from the services provided by the coastal environment. Society is a very heterogeneous actor encompassing several clusters of people sharing similar goals and activities (*e.g.,* surfers, fishermen, tourists). While a common understanding within these [sub]groups can ease knowledge transfer, scientists need to be aware that different clusters may have different coastal interests or expectations for the coast. This can favor the emergence of conflicts and constitute a barrier to science communication.

Society is linked with the generation of local knowledge grounded in the experience gathered from physical proximity. Local knowledge is strongly associated with the day-to-day activities of coastal users and derives from the practices in which people (inhabitants, entrepreneurs, etc.) are involved (Eshuis and Stuiver, 2005). Although society has been and still is frequently regarded as a passive intervenient, the fact is that the role of society in the definition of coastal strategies is increasing. In fact, to ensure broad support for the implementation of management strategies, society must adhere to the proposed ideas and solutions.

In summary three major groups - scientists (coastal researchers), policy-makers and managers (coastal regulators), and society (coastal users) - arise as key players in the coastal agenda and each group has a specific role to play in that agenda.

Table 1 presents the profile typology of the key actors. The information presented is based upon the results of the Socientize project (Socientize Team, 2013).

Table 1. Profiles of the key coastal actors: scientists, policy-makers and managers, and society.

Key actors	**Role**	**Short description**	**Typical functional organization**
Scientists	Research	Those who pursuit scientific knowledge and understanding.	Academia, research institutions, museums, laboratories.
Policy-makers and managers	Regulate	Those who defines policies and enforce their application to the coastal zone.	Inter-national, national and state/regional agencies, municipalities, funders.
Society	Use	A very heterogeneous actor that benefits from the services provided by the coastal environment (*e.g.,* surfers, fishermen, tourists).	Civil society organizations, local associations, non-governmental organizations, scholar and media networks.

2.2 The "Coastal Knowledge Triangle"

The Coastal Knowledge Triangle (Figure 1) aims to summarize and illustrate the key coastal actors, their roles and links. This model is based upon the works of Röckmann *et al.* (2015) and Hunt and Shackley (1999). Röckmann *et al.* (2015) present *The Interaction Triangle* as a tool for understanding stakeholder interactions in marine ecosystem-based management. Hunt and Shackley (1999) present *The Climate Knowledge Triangle* with possible forms of associating different types of knowledge in the scope of climate change.

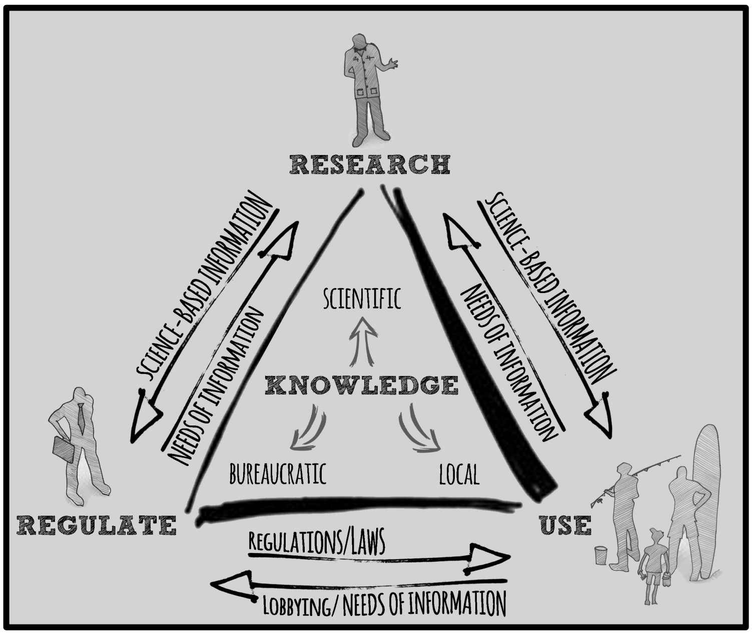


Figure 1. The Coastal Knowledge Triangle: coastal actors, their roles and links. Scientists use research methods to develop scientific knowledge and aim to transfer it. Policy-makers and managers, who detain bureaucratic knowledge, regulate the use of the coastal zone and convey their needs of information to scientists. Society benefits from the services provided by the coastal environment (e.g. fisheries, surfing, beach activities) and acquire local knowledge in relation to day-to-day activities; it influences policy-makers and managers by lobbying, and convey their needs of information to both policy-makers and managers, and scientists.

The Coastal Knowledge Triangle (Figure 1) shows that the understanding of links among the different key coastal actors is a fundamental step in fostering knowledge transfer. The existence of weak bounds, or even disconnection, among coastal actors can seriously prejudice knowledge transfer. It must be stressed, however, that the links among them depend not only on their willingness but also on societal organization. This can be put in evidence through the consideration of some basic forms of governance and their implications in knowledge integration, where politicians, a subset of policy-makers group, detain a critical role in implementation.

In participatory governance schemes where decision-making disregards scientific knowledge, management strategies emerge from the interaction between regulators and society (users). This scheme ensures that immediate societal expectations are integrated within the spirit of regulations and management decisions. However, disregarding scientific knowledge, results in a disproportionally large influence of lobbying in the decision-making process that can threaten sustainability. In fact, the demands of society frequently do not encompass an adequate perception of coastal risk, especially at medium- to long-term time scales. For example, the uninformed occupation of a seafront, which may not be perceived as problematic in the short-term, may disregard or even lead to severe coastal erosion and flooding on a longer time scale, and compromise future management options. However, a governance system exclusively driven by scientific and bureaucratic knowledge, generally fails to consider the different points of view and needs of society. Such a technocratic system has well-known limitations in the ability to manage conflicts inherent to the different interests of coastal users (for example, as in the case of nuclear power plants located on the coast). Finally, under centralized governance schemes, policy-makers and managers (regulators) are decoupled from every other actor. In the case of centralized schemes, not only there is no independent control of management decisions, but there are also no countervailing mechanisms to assure coastal sustainability and the incorporation of society's expectations. These considerations highlight the importance of the political environment, in its broadest sense, in providing the adequate settings to foster scientific knowledge transfer. In this context, the influence of politicians goes beyond policy-making and knowledge implementation, as they can also have a fundamental role in strengthening the links among key coastal actors.

Chapter 2 |Key messages:

- The identification of the coastal actors and understanding the way they interact is of paramount importance in the development of a scientific knowledge-transferring framework: they are the audience that scientists aim to reach and knowing the audience is vital to make communication successful.
- Three key actors arise in the coastal agenda: scientists, policy-makers and managers, and society. Each actor has a specific role in the framework for the coast namely in contributing with specific types of knowledge to the overall objective of sustainability.
- Key coastal actors, their roles and links are summarized and illustrated by the *Coastal Knowledge Triangle*.
- The *Coastal Knowledge Triangle* stresses that the understanding of links among the different key coastal actors is a fundamental step in fostering knowledge transfer and that the existence of weak bounds, or even disconnection, among coastal actors can seriously prejudice knowledge transfer.
- The political environment influences the establishment and the strength of the links among key coastal actors. Nevertheless, scientists should always seek an active role in fostering knowledge transfer, even in an adequate political environment favoring the incorporation of scientific knowledge in decision-making.

IMPROVING THE TRANSFER OF COASTAL SCIENTIFIC KNOWLEDGE: FROM CONCEPT TO IMPLEMENTATION

Chapter 3

Fostering scientific knowledge transfer

Chapter 3

3. Fostering scientific knowledge transfer

Improving the integration of scientific knowledge in the development of coastal strategies implies that scientists must have an active role in fostering knowledge transfer. However, in doing this, scientists face several barriers hindering knowledge transfer, as described in sub-chapter 1.2 *Gaps in scientific knowledge transfer*. To overcome these barriers it is first necessary to acknowledge that the process of [science] communication involves a sender [scientist] delivering a message to a receiver (or receivers) [the other coastal actors] (Figure 2). Scientists must translate their message using a language that other coastal actors can understand and select the most adequate communication channel (or channels). This process is called framing (Figure 2). If scientists successfully frame their message, they will get feedback from their audience. Feedback indicates if and to what extent the message has been successfully transferred and is considered the essence of two-way communication (Hattie and Timperley, 2007). Engagement can be perceived as a "distance" between the sender and the receiver. If the sender and receiver are closer, the effort needed to convey the message (framing) is lower. For example, if the receiver understands scientific language, the framing effort in is smaller.

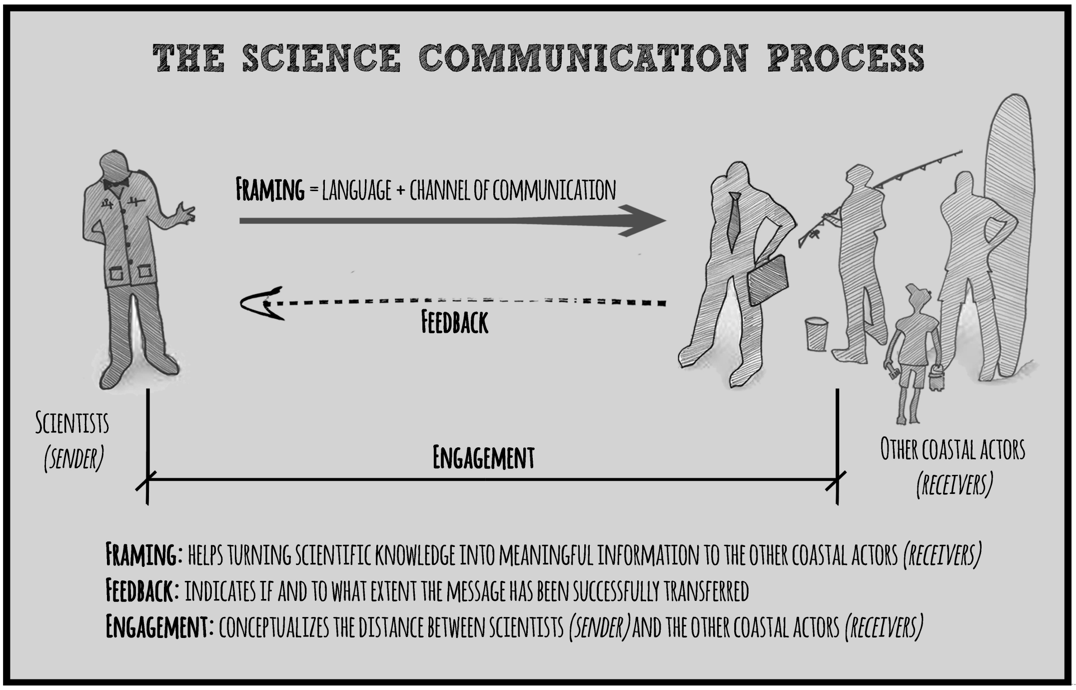


Figure 2. The science communication process: scientists aim to deliver the coastal message to the other actors and to be successful they need to frame their message. If scientists are able to connect with their audience and convey their message, receivers will give feedback. Engagement conceptualizes the distance that scientists need to overcome in delivering the message: shorter distances imply smaller framing efforts.

Fostering engagement and framing the coastal message arise as two conditions that scientists can act upon to overcame barriers in knowledge transfer. Scientists also have to find means to connect with the receivers choosing which of the following four mechanisms would provide the most effective linkage: outreach, crowdsourcing, managers-oriented tools and co-production (these mechanisms are further discussed later in Chapter 5. *Mechanisms to transfer scientific knowledge: from concept to implementation*).

In any case, and despite the level of scientists' motivation to communicate science, they should initiate the communication process by knowing their audiences and, ideally, by listen to them. Scientists have been responsible for almost all of the investigation addressing gaps in scientific knowledge transfer. Thus, most of the gaps identify in the literature have been inferred from their own experience (*see* sub-chapter 1.2). Actually, the literature lacks contribution on this subject accounting for the view of other coastal actors. Devaluating the opinion of the other coastal actors narrows the chance of identifying barriers to the communication process and this may reduce the effectiveness of strategies to narrow these barriers resting solely with scientists. To overcome this issue, and transform the "business as usual" one-way communication scheme into a broader two-way avenue, a worldwide web survey targeting coastal experts, including both scientists and policy-makers and managers, has been designed and conducted under the scope of this thesis. Results are presented and discussed below and were used to put forward conditions to improve knowledge transfer complementing previous studies.

3.1 The need to listen

[This subchapter is based on: Carapuço, M.M., Taborda, R., Andrade, C., Freitas, M.C. 2014a. Improving coastal knowledge transfer between researchers and managers: a two-way route. *In:* Cessa, M. (Ed), Beaches: Erosion, Management Practices and Environmental Implications. ISBN 978-1-63117-239-7.]

Knowledge transfer involves sharing data and information (CEC, 2007). In such a procedure, it is assumed that those who generate knowledge are familiar with the types and formats of the information to be share and with whom. However, scientists and policy-makers and managers frequently have different, and occasionally divergent, understandings of the meaning of "relevant information": scientists every so often focus on the state of the art, and policy-makers and managers usually expect translated data and information able to directly support management decisions.

A worldwide survey was conducted between September and November 2013 using the SurveyMonkey® platform in order to assess the opinions of coastal scientists and policy-makers and managers about gaps in the transfer of coastal scientific knowledge. A total of 174 enquiries were gathered. Coastal scientists provided 107 answers *(n=107)* and coastal policy-makers and managers (involving in local to national authorities, non- and governmental organizations, tourism, fisheries and port authorities, provided 67 answers *(n=67)*.

Results are available at a University of Lisbon website (http://disepla.fc.ul.pt/ktransfer/index.htm) excluding personal data to ensure participants' anonymity. Data management and processing was done using IBM® SPSS® Statistics and ESRI® ArcGIS applications. Figure 3 shows the geographical distribution of the population targeted.

Both the majority of scientists, and policy-makers and managers have been conducting their work in Portugal (57 and 82% respectively) followed by United States of America (12 and 16% respectively).

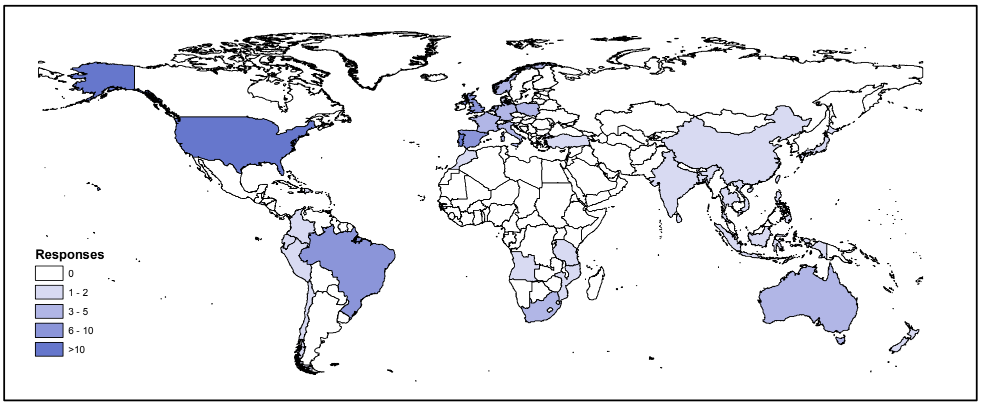


Figure 3. Geographic distribution of the scientists *(n=107)*, and policy-makers and managers sample *(n=67)*.

Results of the survey indicate that the majority of scientists (more than 80%) aim at incorporating their scientific findings in coastal zone management. It was also possible to conclude that the incorporation of scientific knowledge in coastal management is becoming "business as usual", as almost 40% of the policy-makers and managers stated that they always use scientific knowledge in their work (Carapuço *et al.*, 2014a). These results are a positive sign in the scope of scientific knowledge transfer, allowing deducing a favorable environment to foster knowledge transfer and showing willingness of scientists and policy-makers and mangers to move forward knowledge transfer and integration.

Different means of science dissemination are depicted in Figure 4 and Figure 5. Figure 4 shows the effort/time spent by scientists in each science dissemination instrument revealing that research papers and technical reports are the means preferred by scientists, while non-technical outputs received less attention and merited less effort. Figure 5 shows that technical reports and papers are the means more often used by policy-makers and managers to access to scientific and technical contents.

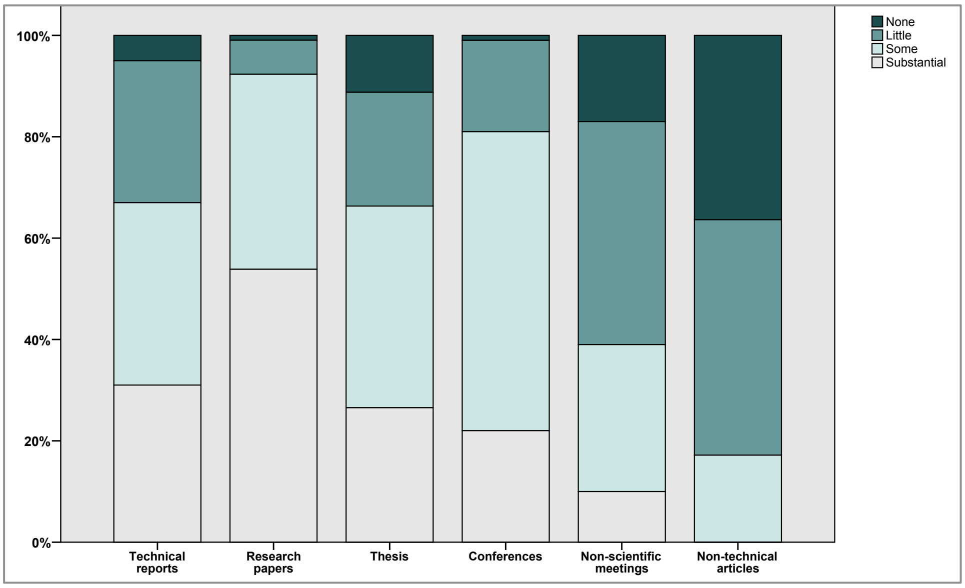


Figure 4. Effort/time put by scientists *(n=107)* in different means of scientific knowledge dissemination.

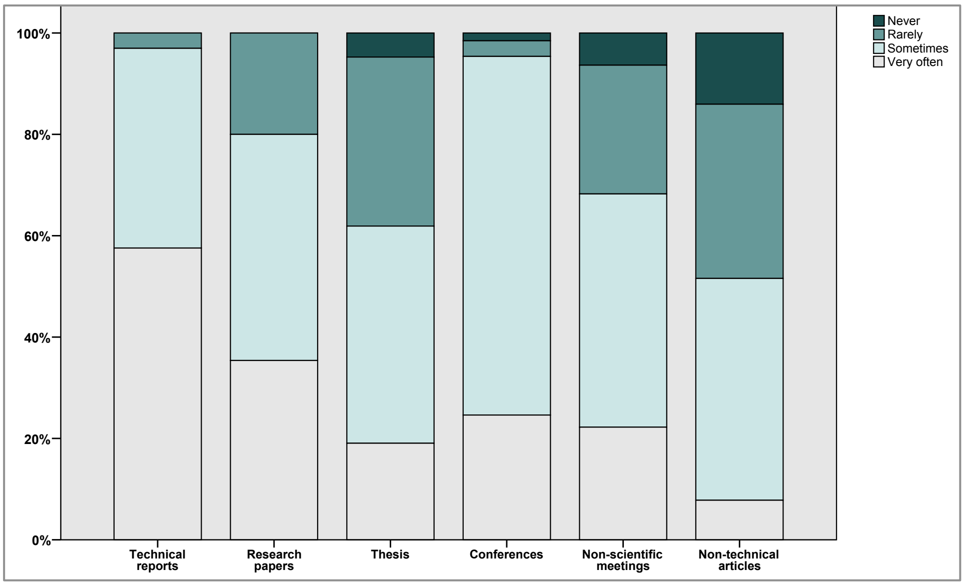
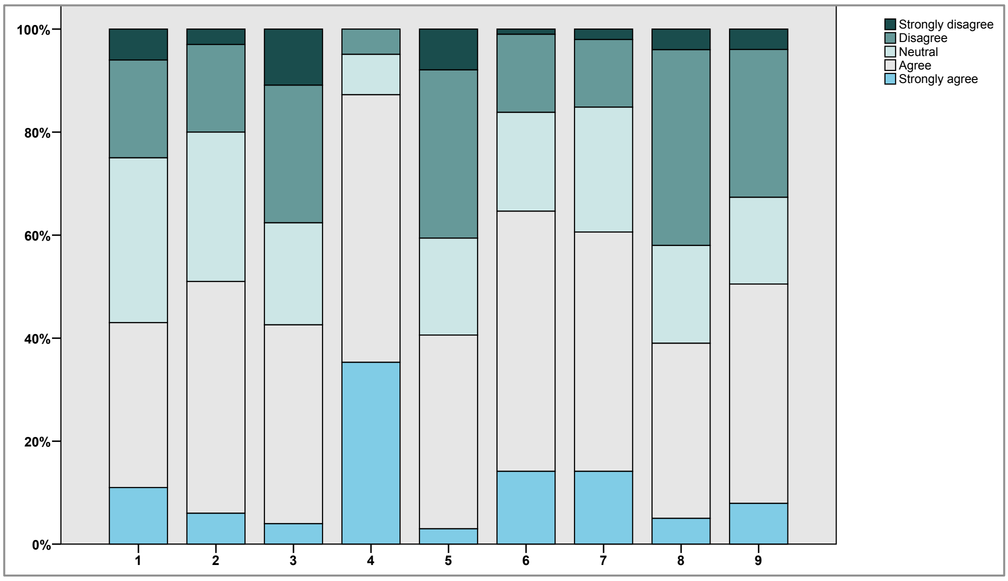


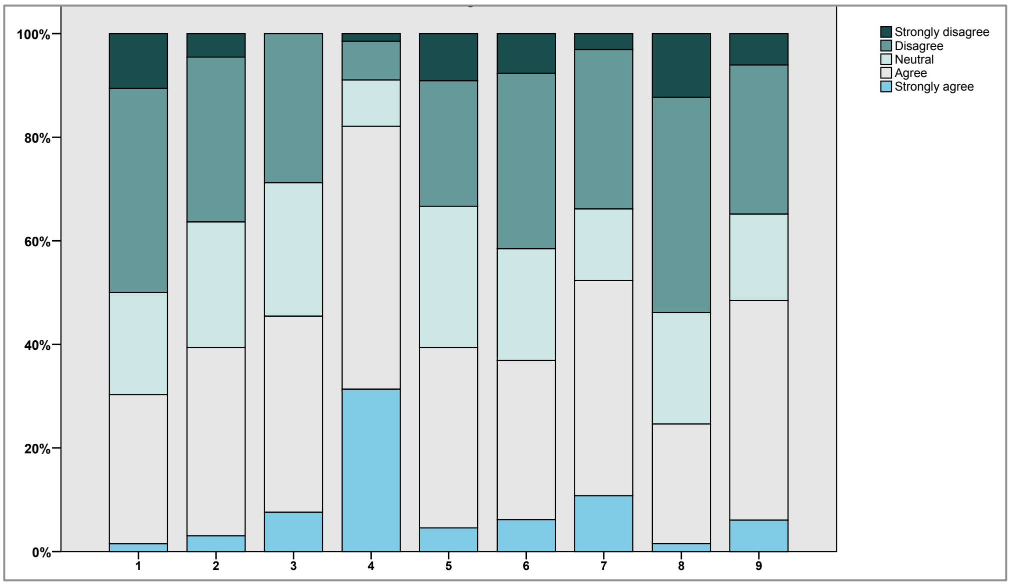
Figure 5. Means of scientific knowledge dissemination adopted by policy-makers and managers *(n=67)* to access to scientific information.

The analyses of Figure 4 and Figure 5 reveals similarity between the dissemination means preferably chosen by scientists an the policy-makers and managers means to access scientific contents. The general agreement noted above suggests the absence of communication problems between both groups. However, and as illustrated in Figure 6 and Figure 7, scientists and policy-makers and managers recognize the existence of relevant obstacles in knowledge transfer.



1. Policy-makers and managers are not motivated to seek and use new information. **2.** Policy-makers and managers do not clearly identify their management needs. **3.** Coastal scientists are not motivated to share information. **4.** The channels used in data dissemination (e.g. scientific articles) are not adequate to reach policy-makers and managers. **5.** The data sets and results are too complex to be understood and used by policy-makers and managers. **6.** There is a lack of policy-makers and managers' competencies to integrate scientific knowledge in management. **7.** There is a lack of policy-makers and managers' time to integrate scientific knowledge in management activities. **8.** There is a lack of scientists' competencies to generate and deliver useful data to managers. **9.** There is a lack of scientists' competencies to traduce scientific knowledge in simple information.

Figure 6. The opinion of scientists *(n=107)* concerning gaps in scientific knowledge transfer.



1. Policy-makers and managers are not motivated to seek and use new information. **2.** Policy-makers and managers do not clearly identify their management needs. **3.** Coastal scientists are not motivated to share information. **4.** The channels used in data dissemination (e.g. scientific articles) are not adequate to reach policy-makers and managers. **5.** The data sets and results are too complex to be understood and used by policy-makers and managers. **6.** There is a lack of policy-makers and managers' competencies to integrate scientific knowledge in management. **7.** There is a lack of policy-makers and managers' time to integrate scientific knowledge in management activities. **8.** There is a lack of scientists' competencies to generate and deliver useful data to managers. **9.** There is a lack of scientists' competencies to traduce scientific knowledge in simple information.

Figure 7. The opinion of policy-makers and managers *(n=67)* concerning gaps in scientific knowledge transfer.

Analysis of Figure 6 and Figure 7 indicates that the major obstacle hindering scientific knowledge transfer identified by both parties is the channel preferred by scientists when it comes to dissemination of data, information and knowledge. Research papers are the preferred means of dissemination by scientists and this inherently implies using technical vocabulary (and frequently specific jargon), which may not be adequate to reach policy-makers and managers. Moreover, research papers follow a reasoning outline that may transform a fine scientific paper into a tedious document from the point of view of the "non-initiated" reader.

This suggests that policy-makers and managers are indeed constrained in their ability to use the information made available in scientific papers and technical reports. This empathizes the need of scientists to find the time and resources to disseminate their knowledge in non-scientists terms or, in alternative, the incorporation of knowledge brokers or resorting to boundary organizations as facilitators (as discussed further in sub-chapter 3.3 *Framing the message*). This is depicted by the two bars on the right side of figures Figure 4 and Figure 5.

Results also reveal that both scientists and policy-makers and managers identified a wide range of causes for gaps in scientific knowledge transfer besides the adequacy of channels used in data dissemination (Figure 6 and Figure 7, respectively). This may be due to differences in the respondents' profile (*e.g.,* different skills, responsibilities, experiences, competencies). However, the overall perception of scientists and non-scientists concerning this matter reflects an unexpected general agreement, expressed by the similarity between the bars diagram depicted in Figure 6 and Figure 7.

As a side thought this result raises relevant issues concerning the policies of scientific data dissemination and evaluation systems of scientists and scientific institutions that may be contributing to "getting apart" scientists and science from policy-makers and managers and society. In too many cases, rakings and measure of performance of scientists and institutions are to a large extent based upon indexes and activities of outreach have been somewhat underestimated.

In conclusion, results from this survey corroborate the major outcome of the literature review presented in sub-chapter 1.2 *Gaps in scientific knowledge transfer*: communication gaps are the major obstacle in scientific knowledge transfer (regardless the scope being restricted to coastal issues or other aspects of scientific knowledge). The critical issue contributing to communication gaps is the channel of communication. Both scientists and non-scientists converge in identifying a large suite of reasons justifying the existence of communication gaps, besides the channels of communication, and both communities rank them in a similar way. This similarity constitutes a major opportunity in bridging together both key coastal actors.

3.2 Fostering engagement

[This subchapter is based on: Carapuço, M.M., Taborda, R., Andrade, C., de Jonge, V.N. 2016a. Coping with coastal change: from scientific knowledge to implementation (*Submitted*)]

The science communication process conceptualized in Figure 2 evidences that overcoming communication gaps is more likely to happen with effective engagement of coastal actors. Engagement is grounded on empathy and goes beyond simple awareness of the problem: it includes caring, motivation, willingness to act, and action itself (Lorenzoni *et al.*, 2007).

Engagement is not a simple task: it is an ongoing process, not confined within the timeframe of a particular project and there is no simple best way to engage with an audience (or audiences) (Cormick, 2012). "Get-together" opportunities, ranging from small informal meetings and workshops to conferences and seminars, are one way to foster engagement and maintain the linkages among the actors beyond project timeframes, enabling conditions to reach compromise and clearing ways for future co-operation. Willingness, trust, competence and commitment can be regarded as key enablers for successfully building engagement (*e.g.,* Röckmann *et al.*, 2015; Schmidt *et al.*, 2014) (Figure 8). Achieving these conditions implies that scientists should be prepared to promote open and honest dialogues about their findings, including the benefits but also the limits, perils, and pitfalls (Lsehner, 2003). This practice is grounded in the principles of the precautionary principle (Carapuço, 2015a) and of the "best available knowledge", meaning the latest state of knowledge or "state of the art". According to the latter scientists acknowledge the existence of changes and limitations in scientific knowledge and understanding. Moreover, scientists should also be prepared to move forward and be expose to the public opinion something much more familiar to managers.

Figure 8. Key enablers of engagement: willingness, trust, competence and commitment.

Engagement is a major and serious challenge but it will enhance understanding of the scientific approach to coastal issues, raising awareness of the value of scientific output and help in decision-making. Engagement fosters the acceptance and longevity of science-based policies, targeting coastal sustainability (Hines, 2010). Early engagement has the additional benefits of avoiding polarized positions, and helps to broaden consideration of issues.

3.3 Framing the message

[This subchapter is based on: Carapuço, M.M., Taborda, R., Andrade, C., de Jonge, V.N. 2016a. Coping with coastal change: from scientific knowledge to implementation (*Submitted*)]

Framing also arises as another fundamental condition to overcome gaps in communication (Figure 2). Framing helps turning scientific data into meaningful information for the target audience. It involves encoding scientific findings into a simple and clear language, anticipating and eliminating likely causes of confusion and misunderstanding, so that the audience can decode the message and understands the idea being conveyed. In the scope of the present study, language is defined as the manner in which scientific knowledge is traduced (coded) attending to the audience's specifies. It encompasses the discourse, images (including photographs and graphical representations) and indicators (further discussed in Chapter 4. *Coastal indicators: a common language*). Framing goes, however, beyond translating scientific data into a "common" language between scientists and their audiences. Framing also implies choosing the proper channels of communication, i.e., the manner in which the message is, or will be, sent. Communication channels include, among others, interpersonal communication, books, audio, video, websites and mobile applications (Estrada and Davis, 2015; Andrews *et al.*, 2005). Channels of communication can be used individually or combined in order to support narratives and storytelling and easily capture the audience's attention, to achieved increased comprehension and to make the message more appealing (Dahlstrom, 2014).

Figure 9 depicts the importance of framing to successfully deliver the coastal message and highlights that scientists may now be facing a new paradigm: framing the message is no longer centered in the subject, but is shifting to be centered in (different types of) audiences.

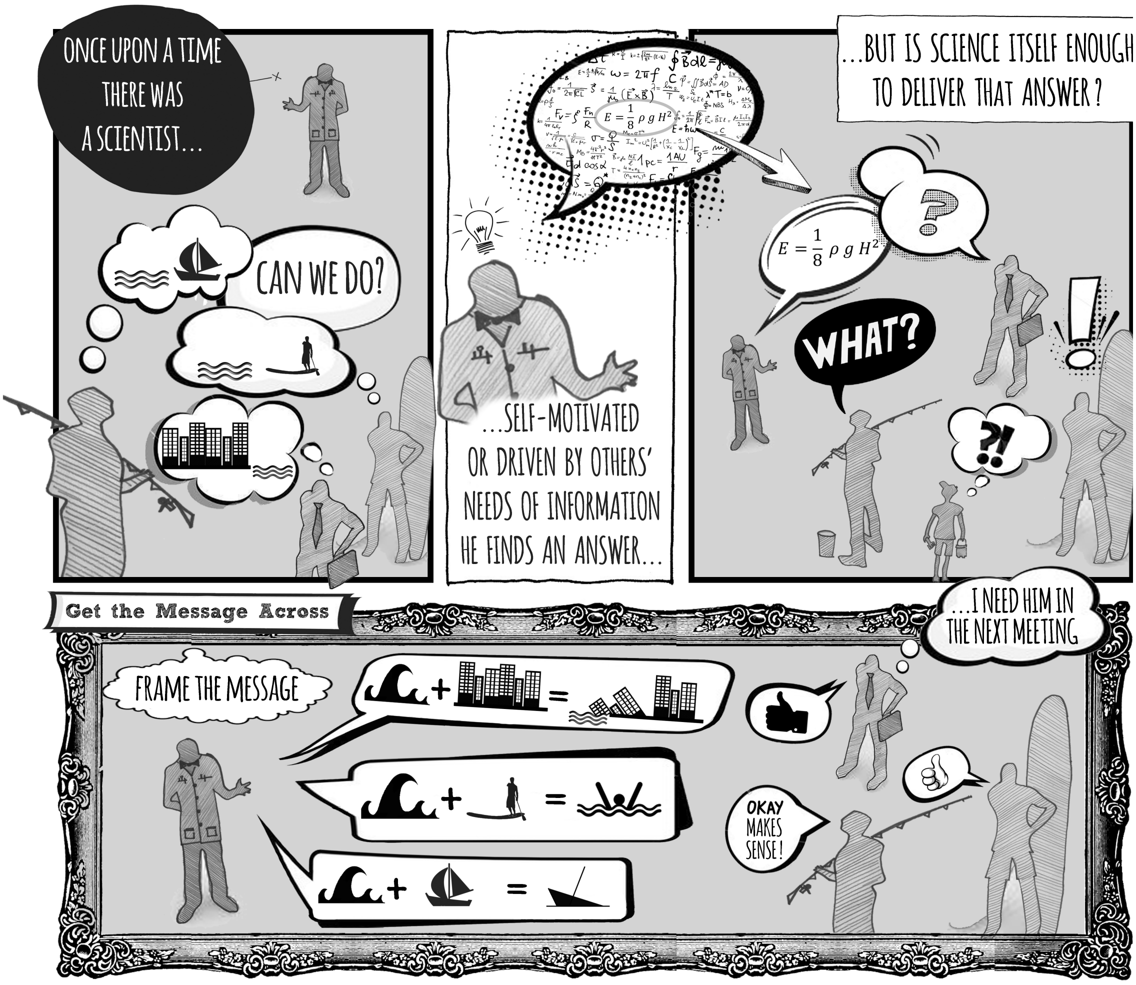


Figure 9. Scientists have to properly frame the coastal message to get it across and reach their audience. Once the content of the message is identified, scientists have to find the proper language and channels of communication to make it understandable and appealing. This figure illustrates the different reactions from the audience when the scientist refers to wave energy in formal terms and when he properly frames his message attending to the audience' specificities.

Any coastal actor driven by the identification of a relevant coastal issue can trigger the communication process: "Can we build here? Are their good waves for surfing in this area? Can I safely fish tomorrow?". Scientists themselves may identify important issues that can compromise coastal sustainability (*e.g.,* increasing storminess, destruction of habitats, increasing erosion). Although scientific knowledge plays an important role in answering these questions, "science itself" is not sufficient to ensure that the answer is successfully conveyed and understood. Scientists should preferably frame the message themselves taking into account the needs of information and expectations of their audience (Doumont, 2010). As an alternative to making scientists accountable for the design of the whole communication process, knowledge brokers or boundary organizations can be integrated to assist and facilitate the task of framing the message (*e.g.,* Cvitanovic *et al.*, 2015; Dilling and Lemos, 2011; Vogel *et al.*, 2007). Knowledge brokers, also referred in the literature as linkage agents or professional facilitators (*e.g.,* de

Jonge and Giebels, 2015; Carapuço et al., 2014a; Becheikh *et al.*, 2010; Pielke, 2007; Huberman, 1990), are persons acting as intermediaries between scientists and non-scientists and are fluent in both worlds (Dilling and Lemos, 2011). They have been successful in the U.S. Pacific Island region in "creating usable science" under the scope of climate knowledge (Dilling and Lemos, 2011). A boundary organization serves the function of working between the worlds of research and of the use or application of science. However, given their size and capacity, they may have more resources to tailor information and produce value-added products than individual brokers (Cash, 2001). Under adverse circumstances both knowledge brokers and boundary organizations can be further helpful in achieving consensus (for example, in overcoming difficulties in coordination and cooperation between different parties involved in a coastal issue) or for accomplishing a project within narrow time boundaries.

Framing the coastal message requires effort and this implies that scientists are engaged in the communication process. Framing is an unavoidable reality within the task of scientific knowledge dissemination. It helps to capture audiences' attention, makes the message understandable and assists scientists in communicating the relevance of their findings (Bubela *et al.*, 2009). Framing helps scientists to communicate why an issue may be a problem, who or what might be responsible for it, and what should or could be done.

Chapter 3 |Key messages:

- ❖ Communication gaps are the major obstacle in scientific knowledge transfer in the opinion of both scientists and policy-makers and managers.
- ❖ Channels used in data dissemination (*e.g.,* scientific articles and implicit scientific wording and symbols) were identified as the major barrier within the process of communication between scientists and policy-makers and managers.
- ❖ To overcome gaps in communication, the engagement of coastal actors and message framing arise as conditions of vital importance.
- ❖ Engagement is grounded on empathy and, beyond simple awareness of the problem, implies action in itself enabled by coastal actors' willingness, trust, competence and commitment.
- ❖ Framing helps turning scientific data into meaningful information for the target audience and involves translating scientific findings into languages understandable by the audience, as well as choosing the proper communication channels.

Chapter 4

Coastal indicators: a common language

Chapter 4

[This chapter is based on: Carapuço, M.M., Taborda, R., Silveira, T.M., Psuty, N.P., Andrade, C., Freitas, M.C. 2016b Coastal geoindicators: Towards the establishment of a common framework for sandy coastal environments. Earth-Science Reviews. DOI: 10.1016/j.earscirev.2016.01.002.]

4. Coastal indicators: a common language

Science communication poses additional challenges in finding a language adequate to foster mutual understanding between sender and receiver. Whatever the language selected it must be comprehensible to the target audience and, simultaneously, ensure rigorous reporting.

Several international organizations forwarded guidelines on this matter and have stated that indicators constitute the most efficient way to transmit inherently complex information in a simplified and applicable form, allowing for the establishment of reference situations and quantitative assessment of evolution trends (*e.g.,* EU, 2014; NOAA, 2010; UNESCO, 2006, 2003). In this sense, indicators arise as the universal language in coastal science communication facilitating the dialog among coastal actors (*e.g.,* NOAA, 2010). However, concerning the coastal zone, the development of indicators is still in an emergent stage. The aim of the present chapter is to present an innovate contribution to the development of a common framework on coastal geoindicators.

4.1 Motivation

The coastal zone is a complex environment that encompasses several geomorphological features with specific dynamics. Beaches, in particular, are one of the most mutable environments where morphologic variations can occur at a wide range of temporal and spatial scales. Often, human interference with such a complex and dynamic system leads to negative impacts. To cope with coastal use-related conflicts, the integration of scientific knowledge is of vital importance. To achieve this objective, several coastal monitoring programs aiming to deliver scientific data to the management process have been developed worldwide, with specific data acquisition procedures and reporting methods, according to their aims and scopes (*e.g.,* Lynch *et al.*, 2014; Psuty *et al.*, 2012; 2010; MESSINA, 2005; Bradbury *et al.*, 2002). Though valid for the specific environments and objectives they were designed for, information derived from these programs may not be suitable for use and comparison with other coastal areas. To improve data sharing and comparability, it is important to promote procedures that enlarge the scope of applications of the acquired data with minimum additional effort, and provide data and information in a standardized form. Indicators have been put forward as the most efficient form to do so (*e.g.,* Carapuço, 2015b; NOAA, 2010).

However, the coastal zone lacks a widely accepted and normalized framework of basic definitions, common designations and measurement criteria to assist in choosing a set of coherent and consistent indicators to described the coastal state.

4.2 Scope

The environments and morphological domains herein considered are schematized in Figure 10. Their physical boundaries were defined aiming to make them useful for different areas of expertise (*e.g.,* coastal engineering, management, research), and are defined as follow:

Beach: accumulation of wave reworked unconsolidated sediment (usually sand and/or gravel) extending from the closure depth to inland up to a physiographic change such as a dune field or sea cliff or to the point where the permanent vegetation is established (Komar, 1983).

Coastal dunes: hills or ridges of sand deposited by the wind and/or wave action, or can be artificially deposited, and are often covered with beachgrass (NOAA, 1994).

Coastal barriers: a narrow low-lying strip of land consisting of beach and dunes extending parallel to the trend of the coast and separated from the mainland by a fresh, brackish or salt water body or marsh (NOAA, 1994).

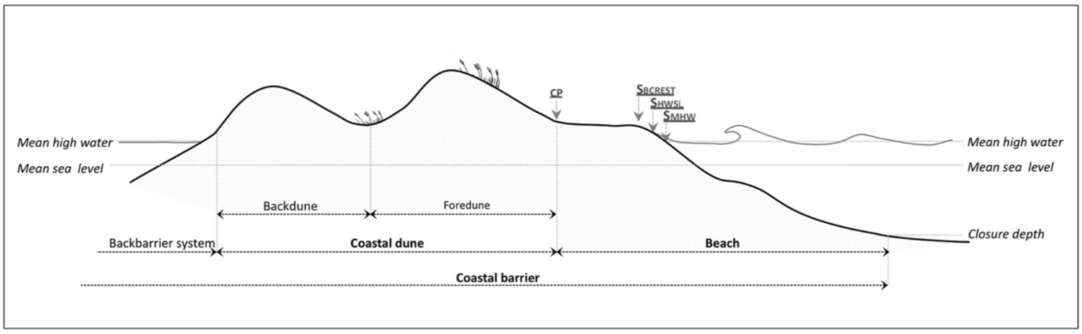


Figure 10. Sandy coast environments and morphological domains; underlined labels refer to coastal geoindicators: CP - coastline position; SBCREST - shoreline based on the berm crest; SHWSL - shoreline based on the high water swash line; SMHW - shoreline based on the mean high water line.

4.3 Definition and background

Historically, the term indicator has been used as a statement with the ability to measure or describe variables; a parameter that indicates some characteristic or metric. One of the commonly used definition of indicator is from UNESCO (2006): "indicator is a quantitative/qualitative statement or measured/observed parameter that can be used to describe an existing situation and measure changes and trends over time".

According to Cobb and Rixford (1998), indicators have been used "*since the dawn of history, and the first reference of human's self-conscious use of indicators dates back to the 1830s referring to the judgment of social conditions using statistical indicators to improve public health and social conditions*". Cohn, in 1899, refers to the use of indicators associated to the disciplines of chemistry and pharmacy. In the 20th century, indicators emerged in other areas: in the 1920s, economic indicators, such as the gross domestic product (GDP), the rate of inflation, or public sector borrowing and debt, were considered essential tools to measure the state of economies (Keating, 2001). More recently, in the 1970s, specific indicators were developed and used in the description of the state of environment (SoE). In what concerns to indicators related to the description of coastal features, the earliest reference is even more recent (Berger, 1996). A significant number of essays, reports and projects focused on indicators in the scope of coastal zone management have since been produced (*e.g.,* SUSTAIN, 2012; Ciavola *et al.*, 2011; Marchand, 2010; NOAA, 2010; EPA, 2008; Davidson *et al.*, 2007; Martí *et al.*, 2007; van Koningsveld *et al.*, 2007; UNEP, 2006; UNESCO 2006, 2003; OECD, 2003; UAB-GIM, 2002; SECRU, 2001). Table 2 presents a chronological summary of the use of indicators to describe the SoE focusing on the ones that describe the geomorphological state of the coastal environment.

Analysis of Table 2 leads to the conclusion that during the first years, SoE reporting focused on gathering and reporting as much knowledge and information as possible. These early reports constituted valuable reference works. However, they were extensive, too complex and almost impenetrable to anyone searching for a quick synopsis of key issues and trends (Keating, 2001). The demand for critical environmental snapshots was later achieved through the use of indicators, and SoE reporting evolved from encyclopedic tomes to indicator-based reports, often grouped under specific issues (*e.g.,* air and water quality). Concerning the state of the coast, geoindicators emerged in 1996 as high-resolution measures of short-term (<100 years) surface or near-surface changes in earth processes and phenomena that are significant for environmental monitoring and assessment (Berger, 1996).

Since 2000, coastal indicators started to be developed and used as a tool to support coastal management, aiming to promote the interaction between coastal researchers and managers in application-oriented knowledge-based development. Projects EUROSION (UAB-GIM, 2002); CoastView (CoastView Team, 2002; Davidson *et al.*, 2007; van Koningsveld *et al.*, 2007; Jiménez *et al.*, 2007), DEDUCE (Martí, *et al.*, 2007), CONSCIENCE (Marchand, 2010; Jiménez, 2010), MICORE (Ciavola, 2011; Ciavola *et al.*, 2011), SUSTAIN (SUSTAIN, 2012) and PEGASO (Santoro *et al.*, 2014) are examples of efforts to enhance the integration of the results of scientific research in the process of coastal decision-making through the use of coastal indicators. However, the indicators emerge from these studies were project- or site-specific and their performance limited to few specific management settings, with little or no transferability potential to other realities.

Table 2. Chronological summary of the SoE and coastal geoindicators.

Date	Accomplishments	References
1972	The United Nations Conference on the Human Environment urged the international community to prepare periodic reports on the SoE.	[1]
1972 to 1987	SoE reports: focused on describing environmental conditions and trends in environmental issues (*e.g.,* air quality, marine resources), aimed primarily at raising awareness; These reports were often encyclopedic tomes containing a large amount of information difficult to digest; in consequence, they did not appear to have much influence on decision-makers; Canada played a key role in helping to report the state of environment.	[1] [2]
1987 to 1992	The Bruntland Report (1987) and, subsequently, both the G7 Economic Summit in Paris (1989) and the Earth Summit in Rio de Janeiro (1992) drew attention to the need for indicators to gauge progress towards sustainable development.	[1] [3]
1992 onwards	The construction and use of sustainable development indicators has proceeded apace; the dominant trend in SoE reporting shifts away from comprehensive reports towards more focused indicator-based reports to serve the needs of, or to influence, specific users, especially decision-makers.	[1]
1992	The International Union of Geological Sciences (IUGS) identified a gap in SoE reporting: the absence of measures describing abiotic, surface and nearsurface geological processes. In response to this need, the IUGS established a working group to develop, what was designated as geoindicators.	[4]
1996/7	Berger (1996) presented the first definition of geoindicators. A list of geoindicators was compiled and made available in the internet in the IUGS website. Geoindicators are the first reference to indicators that aim to describe the state of the coast, among other geo-environments.	[4]
2000s	A series of coastal geomorphological indicators are described in the literature. Several projects use indicator-based approaches focused on coastal zone management: EUROSION; CoastView; CONSCIENCE; DEDUCE; MICORE; SUSTAIN; PEGASO.	*e.g.,*[5] to [16] [17] to [24]
2012 to present	Despite the relevance of coastal indicators, indicator-based reports addressing development and implementation of climate change adaptation strategies, at national and international levels, do not consider coastal indicators to describe the state of the coastal zone. The adoption of coastal indicators is limited to a few management settings and particular projects.	[25] [26]

[1] UNEP, 2006 **[2]** Keating, 2001 **[3]** WCED, 1987 **[4]** Berger, 1996 **[5]** Bush *et al.*, 1999 **[6]** SECRU, 2001 **[7]** CoastView Team, 2002 **[8]** Diedrich *et al.*, 2010 **[9]** EPA, 2008 **[10]** Harrington and Mooney-seus, 2007a **[11]** Harrington and Mooney-seus, 2007b **[12]** Moore *et al.*, 2006 **[13]** Ruggiero *et al.*, 2013 **[14]** Sutherland, 2010 **[15]** van Koningsveld *et al.*, 2005 **[16]** van Rijn, 2010 **[17]** Ciavola *et al.*, 2011 **[18]** Davidson *et al.*, 2007 **[19]** Marchand, 2010 **[20]** Martí *et al.*, 2007 **[21]** Santoro *et al.*, 2014 **[22]** SUSTAIN, 2012 **[23]** UAB-GIM, 2002 **[24]** van Koningsveld *et al.*, 2007 **[25]** EEA, 2012 **[26]** EPA, 2014.

4.4 Identified gaps

The appraisal of coastal indicators-related literature reveals that a myriad of indicators have been used to report the state of the coastal environment. In this review, numerous inconsistencies in the reporting process were found, including the use of different indicators' designations to report the same geomorphological feature, the use of different indicators' categories for the same purpose and paradoxes in wording. Moreover, even the meaning of the word "indicator" is not consensual. These discrepancies make an all-inclusive analysis on this topic an almost unfeasible task, especially when adopting a top-down approach.

For example, attempting to compile a review on coastal indicators, using the key word "indicator" will exclude a significant number of contributions that have adopted other designations, such as "criteria" (*e.g.,* CZMA, 1972), "index" (*e.g.,* Bukata, 2005), "parameter" (*e.g.,* Baptista *et al.*, 2011), "proxy" (e.g. Farris and List, 2007), "standard" (*e.g.,* CZMA, 1972), "variable" (*e.g.,* Thieler and Hammar-Klose, 2000) and "vital sign" (*e.g.,* NPS, 2005; Stevens *et al.*, 2005), are excluded. This exclusion includes, for example, works related to well-established and extremely valuable coastal monitoring programs that rely upon indicator-based approaches (*e.g.,* NPS, 2005).

Concerning the categories of indicators, five designations were identified in literature: geoindicators (Carapuço *et al.*, 2013a; Bush and Young, 2009; Berger, 1997, 1996), coastal state indicators (Marchand, 2010; Sutherland, 2010; van Rijn, 2010; van Koningsveld, 2003), science coastal state indicators (Giardino *et al.*, 2014; van Koningsveld *et al.*, 2005; van Koningsveld, 2003), issue-based coastal state indicators (van Koningsveld *et al.*, 2005; van Koningsveld, 2003), and geomorphological indicators (Bernatchez *et al.*, 2011).

Additionally, different indicators were found to refer to the same target-features. For example, the width of the beach is referenced to using three different designations: beach width (Marchand, 2010; Sutherland, 2010; van Rijn, 2010; Bush and Young, 2009; van Koningsveld *et al.*, 2005; van Koningsveld, 2003; Bush *et al.*, 1999), backshore width (Marchand, 2010; Sutherland, 2010) and berm width (van Rijn, 2010).

Furthermore, whereas some indicators are supported by very detailed measurement criteria, in other cases the criteria have been poorly defined. Without this information, the usefulness of indicators is prejudiced and transferability other realities very limited.

This lack of specificity and consistency described above reflects the need for a normalized scheme and calls for a standard approach describing the state of the coastal environment reporting through the use of indicators targeting universality, simplicity and unambiguity.

4.5 Development of a common framework

The development of a common framework constitutes a first step towards the establishment of a set of coastal geoindicators aiming and using a consensus-based approach. This effort is grounded in previous works, and relies upon a compromise that aims to normalize indicator concepts and designations. "Geoindicator" is herein proposed as the most suitable term to encompass the category of indicators pertaining to surface or near-surface changes in earth processes and phenomena, as discussed above (see 4.3 *Definition and background*). This designation is simultaneously the oldest and still in-use term having been original proposed by the IUGS (Berger, 1996).

4.5.1 Indicator properties

Indicators should share a set of fundamental characteristics in order to provide a simplified form to communicate complex data and information among stakeholders. In order to assure relevance of the indicators, they must embed the following proprieties, and be:

Specific: indicators should yield a clear representation of the system characteristic they are intended to reflect.

Measurable: indicators should be quantifiable.

Achievable: indicators should rely upon implementation and collection methods that are feasible with available resources and intellectual capital.

Relevant: there must be a direct link between the indicator and the underlying key issue or target-question to be answered.

Time-bound: indicators should be responsive to changes in time and provide timely information.

These characteristics have been put together under the acronym SMART (Specific, Measurable, Achievable, Relevant, Time-bound). SMART indicators play an important role in result-based management strategies (MDF, 2005). Several organizations and authors acknowledge these properties as the most relevant in indicators' selection in order to assure that they are comparable (*e.g.,* NOAA, 2010; Sutherland, 2010; van Rijn, 2010; UNESCO, 2006; OECD, 2003; CoastView Team, 2002).

4.5.2 The challenge

The process of simplification in reporting the state of the coastal environment using indicators poses a real challenge because of the local and often site-specific nature of the coastal features and management issues addressed. For this reason, the adoption of a common measurement criterion, applicable worldwide and to different geomorphological settings, can be controversial (*e.g.,* NRC,1990) for further discussion on this topic). This drawback is shared by all indicators and is particularly well documented in the case of the shoreline position (*e.g.,* Galgano and Douglas, 2008; Boak and Turner, 2005; Byrnes *et al.*, 2003; Kraus and Rosati, 1997). In fact, this is one of the major reasons that have hindered the adoption of a common and widely accepted criterion that could be used at every location of world's coast. However, and despite these difficulties, other scientific areas have shown that the process of simplification in reporting is not only a possible task but also a vital one. For example, the GDP reports financial information from different countries with very different realities, and despite the difficulties associated with its estimation and associated uncertainty (Xianchun, 2002), it has come to be a well-established and accepted indicator, useful to convey in a simple form a complex economic setting, not only to economic professionals but also to non-experts. A similar approach was followed in this work, relying upon a compromise attitude among the different schools of thought, targeting a consensus-based approach.

4.5.3 A common framework

A common framework on coastal geoindicators focusing on sandy coastal environments is presented in Table 3. The baseline information for this work includes a thorough analysis of the scientific papers and reports addressing coastal indicators and metrics therein incorporated. From the literature analyzed, a total of forty-three indicators were found. However, in reality, they target only sixteen different coastal features (Table 3) as several indicators with different names target the same issue (identified in Table 3 as "Other common designations").

The majority of the key issues addressed by indicators, as found in the literature, are related to "risk assessment" and "coastal protection" (Table 3), a situation that highlights the relevance of coastal indicators in providing useful information for coastal management, in particular, and to society in more general terms.

The proposed framework does not introduce additional designations, but derives from the application of the existing ones. In the cases where the same indicator has been referred by more than one designation, the one that has a clear cross-discipline meaning prevailed.

The proposed measurement criteria target a consensus-based approach, adopting the most widely recognized standards and aiming to be globally assessable. For the majority of the indicators, it was possible to identify a single and rather consensual criterion. In the case of the physical interface of land and water (*sensu lato*), related to coastline and shoreline concepts, it was not possible or suitable to achieve a consensus. In the present study, the coastline and shoreline are considered to be related to different morphological elements: the coastline position refers to the landward limit of the backshore (taken as the toe position of the dune, cliff or structure confining the beach) (Figure 10) whereas shoreline refers to the physical interface of land and water (Dolan *et al.*, 1991). The first concept is more conservative in spatial location and useful for different purposes than the latter. Additionally, in selecting an indicator concerning the shoreline position, it should also be considered that data may derive from very different sources (*e.g.,* field surveys, LiDAR, historical maps, air photos, satellite and video imagery), and can be either feature-based (*e.g.,* Psuty *et al.*, 2010) or datum-based (*e.g.,* Hess, 2003). To overcome this obstacle without losing valuable information and, at the same time, to eliminate confusion, it is suggested that the shoreline indicator designation should include the variable used.

Therefore, it is proposed the adoption of the following proxies and notations for the shoreline indicator, according to the method of collection used (Figure 10):

S_{BCREST}: to be used when the shoreline is morphology-based. It is suggested the adoption of the active berm crest (BCREST) because it is a feature commonly used as a shoreline proxy (Kraus and Rosati, 1997) that can be extracted from topographic data.

S_{HWL}: to be used when the shoreline is imagery-based. It is suggested the adoption of the high water swash line (HWSL), because high water line is the most commonly-used shoreline indicator (Boak and Turner, 2005).

S_{MHW}: to be used when the shoreline is elevation-based. It is suggested the adoption of the mean high water (MWH) level because it matches a standard tidal datum (Hess, 2003).

The measurements expressed in Table 3 are relative to cross-shore profiles and the units are: length - L -, time - T - and qualitative - Q.

Table 3. Common framework on coastal geoindicators for sandy coast environments (quantitative scale: length (L) and time (T); qualitative scale (Q)). *Other common designations* and *key issues* as identified in the literature.

Geoindicator	Other common designations as found in the literature	Key issue as found in the literature	Proposed measurement criteria	Units
For sandy environments in general				
1. Shoreline position	-	Coastal erosion, sediment transport and deposition, land use, sea levels, climate related-issues [10] Preserve and protect natural resources [11] Beach evolution trend [12] Beach erosion [13]	S_{BCREST} is defined as the most seaward-berm crest S_{HWSL} is defined as the high water swash line S_{MHW} is defined as the mean high water level	L
2. Shoreline evolution	Accretion [1] Coastal erosion [1] Erosion rate [2] Shoreline change [3] Shoreline stability [3]	Risk assessment and management [2] [14] [12] [9] Coastal protection [16] Coastal flooding and erosion hazards [17] To make available and promote sustainable environmental practices [18]	Shoreline position change over time	L/T
3. Coastline position	Dune erosion point [4] Dune foot location [4] Dune foot position [4] Dune location [5] Length of dynamic coastline [1] Momentary coastline [1] [6] [4] Position of the dune foot [7]	Standard of protection [1] [6] Perception of safety [1] [6] Sustainable maintenance of safety [19] Sustainable maintenance of dunes [19]	Coastline is defined as the landward limit of the backshore (taken as toe position of the dune, cliff or structure)	L
4. Coastline evolution	Accretion [1] Changes in coastal erosion [8] Coastal erosion [1] Erosion rate [2] Presence of coastal erosion [8]	Risk assessment and management [2] [14] [20] Coastal protection [15]	Coastline position change over time	L/T
5. Sediment size	-	Sand type [12]	Median grain size	L
6. Sediment composition	-	Sand type [12]	Dominant composition	Q
For beaches				
7. Beach elevation	Beach height [5] Berm level [4] Elevation [2]	Risk assessment and management [2] [14]	Average elevation measured between the coastline and shoreline positions	L
8. Beach volume	Total beach volume [4] Total profile volume [4]	Beach resilience [12]	Volume (per unit of length), measured above MSL, and limited by the coastline position	L^3/L
9. Beach width	Backshore width [1] [6] Berm width [1] [6]	Standard of protection [1] [6] Beach carrying capacity [12]	Distance between the coastline and shoreline positions	L
10. Beach slope	Beachface slope [9] Coastal slope [1] [6]	Flood and coastal erosion risk [1] [6] Bathing hazard [11]	Slope between the shoreline position and MSL contours	-
For coastal dunes				
11. Dune elevation	Dune crest height [4] Dune zone height [1] [6]		Maximum elevation of the foredune dune, relative to MSL	L
12. Dune volume	Dune strength [1] [6]	Standard of protection [1] [6]	Volume (per unit of length) above the foredune toe elevation and across the dune width	L^3/L
13. Dune width	Dune zone width [1] [6]		Distance between the seaward and landward limits as defined in a case by case basis.	L
For coastal barriers				
14. Barrier elevation	-		Maximum elevation, relative to MSL	L
15. Barrier volume	Total barrier volume [1] [6]	Standard of protection for storm [1] [6]	Volume above MSL	L^3/L
16. Barrier width	-		Distance between the back-barrier and ocean shorelines	L

[1] Sutherland, 2010 **[2]** Bush *et al.*, 1999 **[3]** NPS, 2005 **[4]** van Rijn, 2010**[5]** van Koningsveld *et al.*, 2005**[6]** Marchand, 2010 **[7]** van Koningsveld, 2003**[8]** UAB-GIM, 2002 **[9]** Reis and Gama, 2009 **[10]** Berger, 1997 **[11]** Stevens *et al.*, 2005**[12]** Carapuço *et al.*, 2013a **[13]** Ruggiero, 2013 **[14]** Bush and Young, 2009 **[15]** NRC, 1990 **[16]** Martí *et al.*, 2007 **[17]** Bernatchez *et al.*, 2011 **[18]** SUSTAIN, 2012 **[19]** Giardino *et al.*, 2014 **[20]** Santoro *et al.*, 2014.

4.6 Conclusions

The adoption of a framework of indicators as a tool to describe the state and trends of evolution of the coastal zone has been applied inconsistently. The major cause of the delay in the generalized adoption of a widely accepted framework is the existence of a myriad of indicators that are frequently poorly defined. Inconsistences were found related with the indicators' designations, categories and measurement criteria. These shortcomings call for a standardized approach in coastal indicators' measurement and reporting, targeting simplicity and unambiguity. To address this issue, a common framework for the establishment of coastal geoindicators for sandy coast environments is proposed. Sixteen indicators are identified as relevant for beach, coastal dune and coastal barrier environments. This effort aims to contribute to the widespread adoption of coastal indicators as common language in the dialogue between coastal actors.

Chapter 4 |Key messages:

- Indicators provide a simplified form to communicate complex data and information, and arise as the most adequate common language in the dialog among costal actors.
- The existence of a myriad of indicators, frequently poorly defined, was identified as a major cause that has their generalized adoption.
- A standardized approach in coastal indicators' measurement and reporting, targeting simplicity and unambiguity was lacking.
- A first contribution to the development of a common framework on coastal geoindicators is presented and sixteen indicators are identified as most relevant for communicating the dynamic and evolution of beach, coastal dune, and coastal barrier environments.

IMPROVING THE TRANSFER OF COASTAL SCIENTIFIC KNOWLEDGE: FROM CONCEPT TO IMPLEMENTATION

Chapter 5

Mechanisms to improve knowledge transfer

Chapter 5

5. Mechanisms to transfer scientific knowledge: from concept to implementation

Scientists can adopt different mechanisms to connect with their audience. Each mechanism provides a different route for scientists to link with the audience, leading to different types of feedback. If adequately used, mechanisms to improve the transfer of scientific knowledge can foster engagement, minimize the framing effort and optimize audiences' feedback.

The most widely known and adopted mechanism to transfer scientific knowledge is outreach (as formal education is beyond the scope of this work). However, scientists must be aware that other means are also available: crowdsourcing, managers-oriented tools and co-production. These latter three mechanisms, although in earlier stages of development, are promising alternatives and should be considered as major opportunities to foster knowledge transfer. In this chapter the concept associated of each of the four mechanisms and examples of their application to real-world developed under the scope of this thesis are presented.

5.1 Outreach

Outreach in coastal science aims to raise coastal literacy and awareness. These are important political and societal issues characterizing a knowledge-based society engaged with science. Two outreach projects were developed in the scope of the present work: "The Beaches of Cascais: past and present" and "The Nazaré Wave: a trigger for learning". These projects focus on the two key-elements of beach dynamics, sand and waves. The implementation of both projects returned valuable insights on the audience responsiveness and also on to what extend lay audiences can effectively be motivated, influenced and engaged in coastal issues.

5.1.1 The concept

Outreach is a "meaningful and mutually beneficial collaboration with partners in education, business, public and social service. It represents that aspect of teaching that enables learning beyond the campus walls, that aspect of research that makes what we discover useful beyond the academic community, and that aspect of service that directly benefits the public" (Ray, 1999). Outreach aims at fostering public awareness and understanding of science, thus developing comprehension of both the meaning and knowledge implications (Burns *et al.*, 2003).

In outreach, the message to be conveyed can be framed resorting to a wide range of channels of communication, including tutoring, giving formal presentations and also supporting teachers, developing resources and so forth (Andrews *et al.*, 2005).

5.1.2 "The Beaches of Cascais: past and present" project

[This subchapter is based on: Carapuço, M.M., Taborda, R., Silveira, T.M., Andrade, C. 2016c. Upstream Public Engagement On Coastal Issues: Audience Response To A Science-Based Exhibition. *In preparation*]

"The Beaches of Cascais: past and present" project was an outreach initiative developed with the goal of upstream public engagement on coastal issues. It was the outcome of a collaborative initiative involving the Faculty of Sciences of University of Lisbon, the Municipal Council of Cascais and the Portuguese Environmental Agency.

5.1.2.1 Motivation

Public understanding of coastal dynamics and coastal change is fundamental in supporting the implementation of sustainable coastal strategies. However, in addition to the challenges previously discussed in subchapters 3.2 *Fostering engagement* and 3.3 *Framing the message*, when scientists address the dynamics of beach systems a further challenge arises: preconceived ideas. For many people beaches are places of memories built during childhood and emotional memories play an important role in the public response in later stages of life (Zadra and Clore, 2011). Perception of size of both objects and distances varies substantially from childhood to, and over, later stages of life and both perceptions may also differ from the true dimension of the entities brought to our conscience. The true dimension of the beach of our infancy is very often different from what we perceived it to be. Objects that we found gigantic in early stages of our existence were in fact considerably smaller (Banakou *et al.*, 2013). This illusion is due to the size of the physical world being perceived in relation to the size of the perceiver's body (Banakou *et al.*, 2013; Linkenauger *et al.*, 2010). For example, as a person grows and gets taller, fewer steps and less effort are required to cover a certain distance (van der Hoort *et al.*, 2011). The sense of our own body affects how we visually experience the world and plays an important role in perceiving our surroundings and their dimensions. Traditionally, our infancy memories recall us of larger and wider beaches. This leads to a sense of feeling and believing that beaches are getting smaller as we grow taller and older.

To this size-illusion effect adds the human tendency to generalize and overvalue negative things (Baumeister *et al.*, 2001) and the notion that "it was better in the good old days". Media can also magnify this negative bias, as it often emphasizes bad news (*e.g.,* coastal erosion *vs.* coastal accretion). Research and its outputs are also generally focused on erosional behavior as it dominates the evolutional trend of coastlines worldwide in the recent past and because retreating coastlines are more prone to risk (*e.g.,* Pilkey, 2008).

Society perception of coastal evolution is built upon all the aforementioned biases. So it is natural that there is a generalized assumption that all beaches are eroding – even if they are not. In fact, coastline evolution depends on many factors, including the geomorphological setting, sediment budget and human intervention so, contrary to what is often deeply rooted in public [mis]perception, many coastal stretches are stable or under accretion. The project "The Beaches of Cascais: past and present" arose with the aim of shifting the public perspective on the generalized assumption that all beaches are eroding.

5.1.2.2 A science-based exhibition as a platform for public engagement

An outdoor science-based exhibition, developed in the scope of this work, was the platform designed to trigger public's attention and foster society engagement with coastal issues (Figure 11). The exhibition focused on the evolution of the beaches of Cascais municipality (Portugal) that have been mostly stable in the last decades and, in some cases, increased in area. Photographs taken from the early to mid-20th century and recent ones were adopted as the language to convey a coastal message of "beach invariance", aiming to shift the public perspective on the generalized assumption that all beaches are eroding.

THE BEACHES OF CASCAIS: PAST AND PRESENT

AUDIENCE: SOCIETY (IN GENERAL)
LANGUAGE: IMAGES (PHOTOGRAPHS)
CHANNEL OF COMMUNICATION: EXHIBITION
MECHANISM: OUTREACH

Figure 11. "The Beaches of Cascais: past and present": project's audience, language, channel of communication and mechanism adopted to get the message across and reach the audience.

Study area

Cascais is a cosmopolitan area with a high touristic demand located in the west coast of Portugal (Figure 12). Since the mid-19th century the beaches along the Cascais coastline, the so-called Portuguese Sunshine Coast, have been very popular amongst those who live in Cascais and Lisbon areas, and tourists all over the world. Today, most of Cascais' eighteen beaches still preserve much of their original charm, and remain one of the icons of this municipality.

Figure 12. Location of Cascais' beaches (Cascais, Portugal).

Beaches of Cascais correspond mainly to small pocket sand beaches. On the landward side, these beaches are usually limited by low cliffs or manmade structures aiming to protect sea front property or infrastructures (*e.g.,* roads) and used for recreation purposes (*e.g.,* seaside promenade). Cascais coastline can be divided in two littoral segments with different orientation and contrasting wave exposure: a western segment, more exposed to the prevailing northwest waves generated in the Northeast Atlantic Ocean, where the beaches of Abano, Guincho, Água Doce and Cresmina are included; and a southern segment, sheltered from the prevailing wave regime and thus experiencing a milder wave regime, encompassing the beaches from Santa Marta to Carcavelos (Figure 12).

Analysis of aerial photographs, maps and historical postcards, dated from the early 20th century to the present allowed deducing the past evolution of Cascais' beaches. It was possible to identify changes in position of the shoreline in the vast majority of beaches, related with seasonal to interannual variations in oceanographic forcing, but excluding a perceptible long-term trend. Beach areas updrift of groins are exception to this, and Moitas, Tamariz and Avencas beaches have experienced localized accretion following the constructing of groins. Accretion lasted until the saturation of their retention potential (Carapuço *et al.*, 2012). The long-term stability of the beaches of Cascais makes them an ideal study site to evaluate the influence of outreach initiatives aiming to raise public understanding on coastal issues. In this case, the shift in peoples' opinion from the generalized assumption that all beaches are eroding to an understanding of long-term beach stability, regardless seasonal to interdecadal reversible changes, can be a valuable indicator of successful receptivity and assimilation of information by the public.

As a word of caution, it must be noted that the behavior of the Cascais beaches throughout the last 100 years should not be straightforwardly used to forecast their evolution into the near future. There is an increasing consensus that an accelerating sea-level rise (SLR) scenario due to climate warming will have significant impacts on the coastal zone (Church *et al.*, 2013). For example, the work of Taborda and Ribeiro (2015) suggest that, in relation to acceleration of SLR, a reduction in the exposed area of all Cascais beaches is expected.

The exhibition

The exhibition "The Beaches of Cascais: past and present" focused on the changes of the beaches along the Cascais coastline (Figure 13). The concept of the exhibition was thought to maximize public engagement. This objective was accomplished by adopting the following strategies in framing the message:

Location: the exhibition took place outdoor, in an attractive and pleasant seaside promenade where hundreds of people walk every day. This setting allowed reaching a wider audience and contacting in "their own ground".

Storytelling: the narrative of the evolution of the beaches of Cascais was supported mainly upon the comparison of present-day photographs with ones from the early to mid-20th century. Supporting the narrative format on photographs allows audiences with different backgrounds to "find the answer on their own". Not imposing a solution makes easier for people to accept it and to retain their own findings.

Design: large panels with appealing design, supported by large-format printed photographs triggered the public attention.

The exhibition was set up along the seaside promenade that starts at Cascais village (Figure 12) and consisted of thirty large prints (2x1m) (Figure 13). Twenty-eight prints showed the same beach as captured by old and recent photographs, with the pictures displayed side-by-side. One print displayed a map with the name and location of the beaches, and another one contained a brief description of beach dynamics.

Figure 13. Images illustrating the exhibition "The Beaches of Cascais: past and present".

Old photographs were entirely retrieved from the Cascais' Historical Municipal Archive because of authorship issues. Two photographs from each beach were selected, based on the oldest age and the largest beach coverage, ensuring the needed print quality except for Guincho, Azarujinha, Bafureira and Carcavelos, because there was only one photograph available fulfilling the aforementioned requisites. There were no available old photographic records for the Água Doce and Moitas beaches.

The present-day photographs were taken by a professional photographer working for the Municipal Council of Cascais (on the 21st and 22nd of May 2015), guided by the author of this work, aiming to reproduce, as closely as possible, the image captured by the old records. The photographs were acquired from the same point of view of the old pictures, except where the original location was no longer accessible either because of cliff retreat or coastal development. The stage of the tide was also taken into consideration, and the timing of images acquisition selected so that the uncovered beach area in old and new pictures was broadly the same.

Photographs displayed in the panels were complemented with small bilingual texts (Portuguese and English) describing the geomorphological and geographical setting of each beach, as well as noticeable architectural and social features. Texts avoided references to evolutionary trends allowing for the audience to infer their own conclusions about the system behavior.

The panels were installed on the 4th of June 2015, and the opening of the exhibition took place the next day. The exhibition remained available to residents and those visiting Cascais coast and beaches until the end of September 2015.

5.1.2.3 Drifting from assumptions to understanding

The impact of the exhibition on the public understanding about the evolution of Cascais' beaches was assessed by a two-phase survey: a first phase took place just before the exhibition and the second phase after people watching the panels. The survey was conducted anonymously and was based upon short and simple questionnaires available in Portuguese and English. A total of 682 answers were obtained (n=341 previous to the exhibition, and n=341 after the exhibition). Questionnaires and responses are available for download at http://beachphotomonitoring.campus.ciencias.ulisboa.pt/exhibition.html.

Evaluation of the impact of the exhibition

The first phase of the survey took place between May 12th and June 3rd 2015 (Table 4). A five-question questionnaire was made available online at the website of Municipal Council of Cascais, and was also publicized through the websites of the Faculty of Sciences of the University of Lisbon, the Portuguese Environmental Agency, and internet social media.

Table 4. Information related with the surveys conducted to assess the impact of the "The Beaches of Cascais: past and present" exhibition.

Phase	When	How	Questions
First [before the exhibition]	Between May 12th and June 3rd 2015	Online questionnaire	1. *Do you live in Cascais?* yes; no 2. *Age:* less then 18; 18-30; 31-50; more than 50 3. *Which is your favorite beach in Cascais?* 4. *How many beaches there are in Cascais?* 5. *In your opinion, the beaches of Cascais are:* increasing; stable; decreasing?
Second [after people watched the exhibition]	Between June 22nd and August 13th 2015	Face-to-face interviews	1. *Do you live in Cascais:* yes; no 2. *Age:* less then 18; 18-30; 31-50; more than 50 3. *In your opinion, the beaches of Cascais are:* all increasing; the majority is increasing; stable; the majority is decreasing; are all decreasing? 4. *In your opinion, the use of old and actual photographs to illustrate beach evolution is:* an adequate option; neutral option; an inadequate option. *Why?* 5. *What other type of information about the Cascais beaches would you like to have access?*

The first two questions were related with the participants' characteristics: their age and if they were living or visiting Cascais. Two questions followed aiming to assess the public's familiarity with the coast of Cascais: participants were requested to indicate their favorite beach and how many beaches exist in the Cascais municipality. The last question was a closed-format and multiple-choice question about the perception on the evolution of the beaches of Cascais: beaches are increasing, stable or decreasing.

The second phase of the survey took place during the exhibition, between June 22nd and August 13th 2015 (Table 4). This phase consisted of face-to-face interviews carried out at the exhibition site, targeting people that were observing the panels. A team of volunteers*, Marézinhas*, clearly identified as working for the Municipal Council of Cascais*,* conducted these interviews.

The main objectives of the second phase of the survey were to collect a sample size equal to the first phase and to increase the level of detail provided in the previous phase the multiple-choice question about the perception on the state of the beaches. The change on the questions about beach evolution was based upon the fact that the participants were *in situ,* and watching photographs off the beaches concern. This made the three response options made available in the first phase somewhat limitative. Thus, five options of response for the same question were made available in the second phase (see Table 4). Two other items were added in the second questioners. Participants were asked if the use of old and present-day photographs was an adequate framing option to illustrate beach evolution, and why. Participants were also requested to express their opinion concerning other type of information on the Cascais beaches that they would like to access. Both these two latter questions created the opportunity for participants to express their opinion and share ideas.

The results of the survey were all compiled in electronic format and organized for data analysis. Data management and processing was done using IBM® SPSS® Statistics and ESRI® ArcGIS applications. Pearson's chi-square test was used to test the independency of the variables.

Before the exhibition: appraising assumptions

Regarding the first phase of the survey 68% of 341 participants lived in Cascais and 32% were visitors. The majority (49.6%) were 31 to 50 years old and those were followed by those with more than 50 years of age (25.5%); 23.5% of the participants were between 18 and 30 years old, and only 1.5% were under 18. Guincho was voted the favorite beach of Cascais, followed by Carcavelos (Figure 14). These beaches are the widest of Cascais, and are very popular for surf and other water-related sports. Less favorite beaches, Água Doce and Santa Marta, correspond to very small beaches, only reachable during low tide.

About 36% of the respondents answered that the number of beaches in Cascais ranges from 15 to 20, followed by 35% that responded 10 to 15 beaches. As the Cascais coastline encompasses 18 beaches, these results showed that the majority of the audience had a fair good perception about the number of beaches.

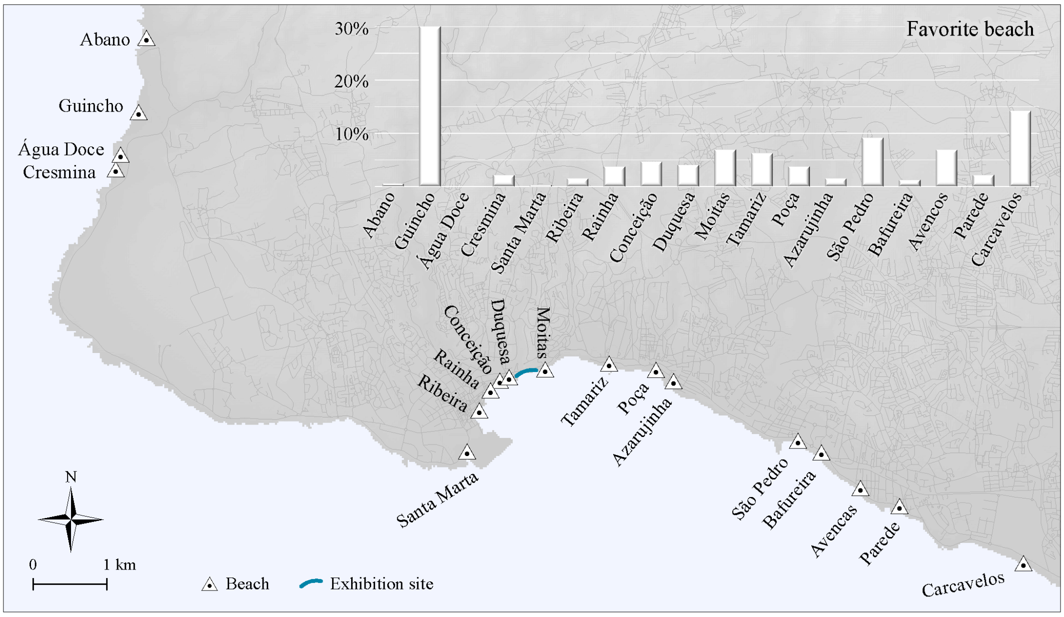


Figure 14. Favorite Cascais beach according to the results of the survey.

Concerning beach evolution, the majority of the audience (57.8%) believed that the beaches in this municipality were decreasing (meaning that beaches have been losing sand); 38.7% answered that Cascais' beaches were stable, and only a small percentage (3.5%) answered that beaches were increasing (Figure 15).

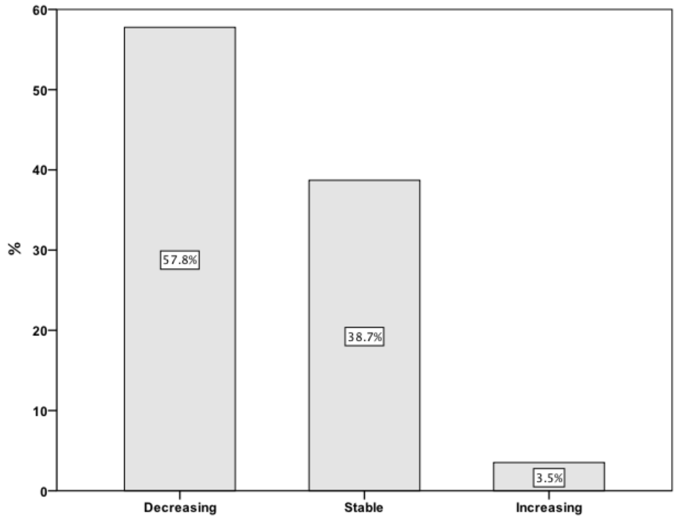


Figure 15. People's opinion concerning the evolution of the beaches of Cascais before the exhibition.

After the exhibition: assessing understanding

In the second phase of the survey 60.4% of the 341 participants were people living in Cascais and 39.6% visitors. Almost half of the participants were over 50 years old (49.3%), and 21.4% were between 31 to 50 years old. About 15.2% of the responders were under 18 years, and 14.1% were between 18 and 30 years.

After watching "The Beaches of Cascais: past and present" exhibition, the opinion of the audience concerning the evolution of the beaches of Cascais was as follows: 36.1% answered that the beaches were increasing (all increasing - 15%; and majority increasing - 21.1%); 34.9% responded that beaches were stable; and 29% that beaches were decreasing (all decreasing - 5.3% and majority decreasing - 23.8%). This opinion is shared by those living and visiting Cascais and amongst respondents with different ages.

Figure 16 shows the comparison of the results on the public perception on beach evolution before and after the exhibition.

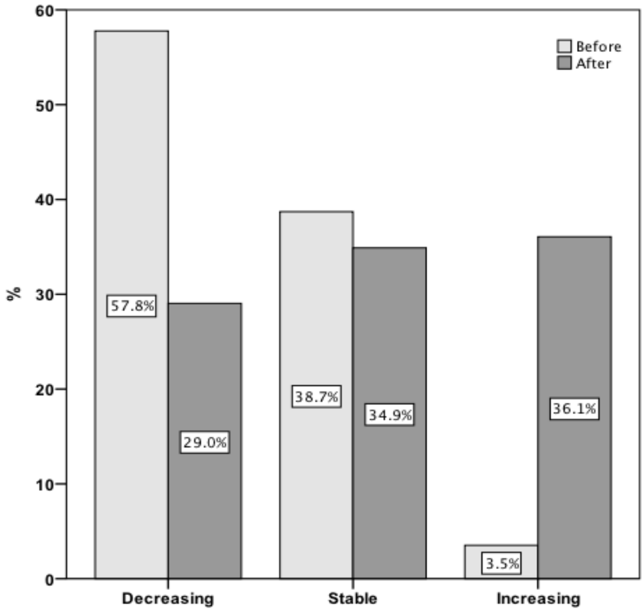


Figure 16. People's opinion concerning the evolution of the beaches of Cascais before and after the exhibition.

There was a noticeable change in public opinion regarding perception of trends in beach change: before the exhibition most people believed that beaches were decreasing (57.8%), while after watching the exhibition most people considered that beaches are stable or increasing (34.9% and 36.1%, respectively). Pearson's chi-square test was performed to compare the data acquired before and after the exhibition (Figure 16) and the result was found to be highly significative (test statistics 124.4; $p < 0.001$). The shift in public opinion indicates the successful transfer of science-based information to the public and highlights that the goal of the exhibition was attained.

The use of old and present-day photographs to illustrate beach evolution was considered adequate by a large majority (93.3%) of the participants, while only 2.6% considered this media inadequate. "*Allowing observing beach evolution*", "*Beautiful and useful*", and "*It presents additional information related with other issues (historical, architectural)*" illustrate comments related to this question. These results indicate that photographs performed well as a good language supporting the narrative.

Concerning the last item of the questionnaire the majority of the responders commented that the information portrayed by the exhibition was adequate. Nevertheless some people made comments outside of the scope of the exhibition mentioning that they would like to have easier access to information on quality issues (water and sand quality parameters) and to the history of the beaches of Cascais (heritage, architecture).

A 7-minute movie compiling the several elements of the "The Beaches of Cascais: past and present" exhibition and these results is available in the website: http://beachphotomonitoring.campus.ciencias.ulisboa.pt/movie.html.

5.1.2.4 Conclusions

Communicating beach dynamics to the public is a difficult task. Challenges arise, not only related with the need to capture the public's attention to science, but also in dealing with people's assumptions. "The Beaches of Cascais: past and present" exhibition was designed to upstream public engagement on coastal issues. The exhibition concept considered location, storytelling and design as key framing strategies in overcoming the challenges faced by communicating science to the public. A survey conducted before the exhibition reveals that the majority of the public believed that the beaches of Cascais were under erosion. However, after watching the exhibition, the public's perspective on the evolution of Cascais beaches shifted towards stability and accretion trends, a perspective in line with their real long-term trend. Results show that the "The Beaches of Cascais: past and present" exhibition was a highly valuable science outreach initiative as it contributed to raise public understanding about the coastal system.

5.1.3 "The Nazaré Wave: a trigger for learning" project

"The Nazaré Wave: a trigger for learning" project was developed with the goals of raising ocean literacy and capture the attention of young students (in particular) and society (in general) to the importance of scientific knowledge integration in ocean and coastal management. This project was developed in the framework of the present thesis by the Faculty of Sciences of University of Lisbon and was funded by the European Economic Area Financial Mechanism in the framework of the Programme PT02 – Integrated Marine and Coastal Water Management (#PT02_2ºRPS_0008).

5.1.3.1 Motivation

Ocean and coastal management face relevant sustainability challenges. It is consensual that a wiser governance of both environments can only be achieved by the involvement of all key actors. In this scope scientists, as knowledge generators, have a vital role in transferring their knowledge and in raising awareness and understanding beyond the scientific community. The project "The Nazaré Wave: a trigger for learning" was designed with the purpose of transferring scientific knowledge about the physics of waves using the Nazaré Wave as the trigger, a gigantic wave that takes place at Norte beach (central western Portuguese coast, Portugal,) (Carapuço *et al.,* 2016d). Moreover, waves are not only important by themselves but also represent a dominant source of energy in the nearshore zone. Wave energy is ultimately the driving force behind coastal morphological change (Masselink and Huges, 2003).

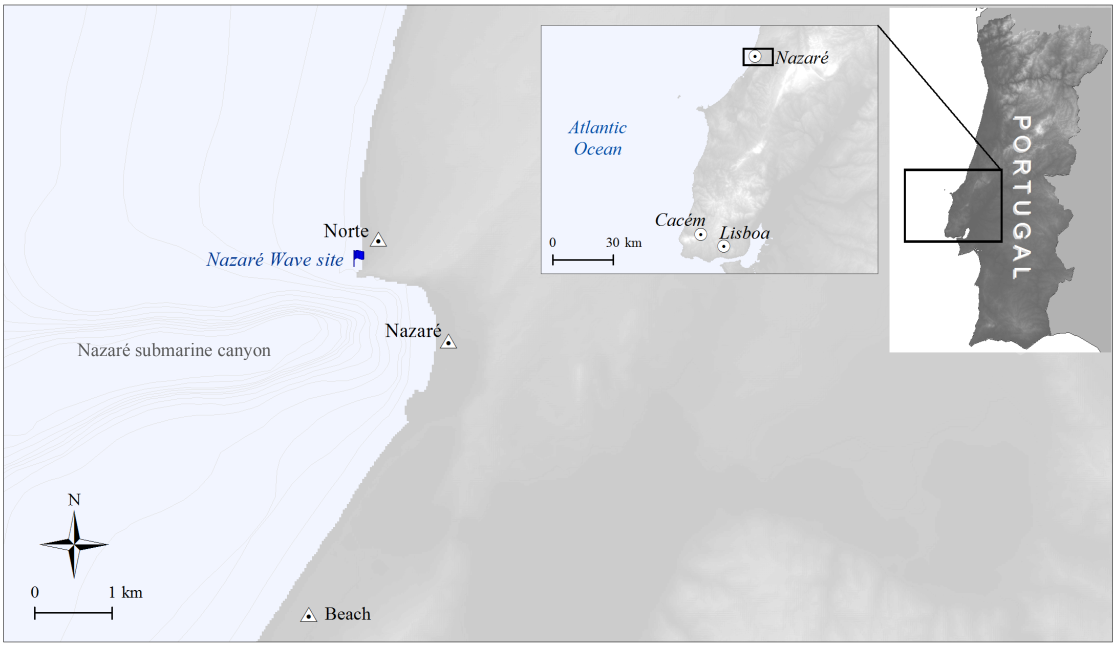


Figure 17. Location of Norte and Nazaré beaches (Nazaré, Portugal).

5.1.3.2 Project development

The project "The Nazaré Wave: a trigger for learning" was framed under Responsible Research and Innovation approach (EC, 2013) where different actors work throughout during the whole process in order to better align both the process and outcomes with their needs and expectations.

The project was based upon the following framing strategies:

Triggers in communication: the Nazaré Wave was used as the communication trigger. This option was based upon the fact that this particular wave has recently became quite fashionable, appealing to the spirit of adventure of youngsters and thus revels to easily capture the attention of the target-audience: high-school students.

Storytelling: short scientific animations where blend in "The Nazaré Wave" movie voice-over by high-school students. Students' discourse and the movie were combined and used as the communication channels to support the narrative. This choice was based upon the fact films are seen as one of the media that easily captures the audience's attention (*e.g.,* Ismaili, 2015; Xhemaili, 2013) (Figure 18).

Making audience a part of the process: a group of forty-six high-school students were challenged to actively contribute to the project, including performance takes in the "The Nazaré Wave" movie (Figure 19).

THE NAZARÉ WAVE: A TRIGGER FOR LEARNING

AUDIENCE: STUDENTS (IN PARTICULAR) AND SOCIETY (IN GENERAL)
LANGUAGE: DISCOURSE AND IMAGES (GRAPHICS)
CHANNEL OF COMMUNICATION: VIDEO
MECHANISM: OUTREACH

Figure 18. "The Nazaré Wave: a trigger for learning": project's audience, language, channel of communication and mechanism adopted to get the message across and reach the audience.

Figure 19. Images illustrating the filming session on the 15th December 2015 (left) and a frame of the movie "The Nazaré Wave" (right).

The Nazaré Wave

The Nazaré Wave corresponds to an occasional, though predictable, sea state that is related with the occurrence of a gigantic wave at Norte beach, in the vicinity of and up to hundreds of meters of the Nazaré headland. Here, the submarine morphology is complex and dominated by the presence of the Nazaré submarine canyon that deeply incises the continental shelf. When incident waves correspond to long period Northwest and West swells, the particular geomorphological setting of the continental shelf strongly modifies the nearshore wave pattern (IH, 2016; Silva, 2014). This modification leads to an abnormal and localized increase of wave height in relation to the cumulative effects of shoaling, convergence and interference culminating in gigantic breakers when the deep-water wave height is already large.

As Nazaré Wave became a very popular subject in the media and social networks it has drawn the interest of society and in particular, of young students. The reason for such popularity is that the Nazaré Wave is considered to be the highest wave ever surfed according to Guinness World Records. Here, it is mentioned that on the 1st November 2011, Garrett McNamara surfed a *circa* 24 m-high wave. Offshore conditions on that day were 5.3 m wave height, 13.8 s wave peak period and wave direction of 307° (Silva, 2014). This ride has been filmed and for a certain time became viral in communication network.

As recognized by the teachers that participate in this project, from *Escola Secundária de Gama Barros,* and in literature movies can easily catch the learners' interest and it can positively affect their motivation to learn. Taking the impact of films in capturing audiences, short scientific animations illustrating the physical processes affecting the Nazaré Wave (generation, propagation, refraction, shoaling, convergence, interference and breaking) and the influence of the Nazaré submarine canyon in modulating the local wave patterns (Silva, 2014) were merged into the "The Nazaré Wave" movie to get the science content of the message across.

The participation of the audience in the project was materialized by the inputs of forty-six students of the 10th grade and three Science teachers of *Escola Secundária de Gama Barros* (Cacém, Portugal). Besides performing in "The Nazaré Wave" movie, students and schoolteachers helped scientists to build the concept of the project and commented several drafts of the scripts (written by scientists) assuring that the language was comprehensible and that the essential principles and fundamental concepts of waves reached the audience. They also and actively participated in the dissemination of the project, namely by participating in scientific meetings given interviews to regional newspapers and by more informally using social networks.

The movie

The principal output of project "The Nazaré Wave: a trigger for learning" is a 5-minute movie entitled "The Nazaré Wave" available at the YouTube platform since 15th February 2016 (Figure 20).

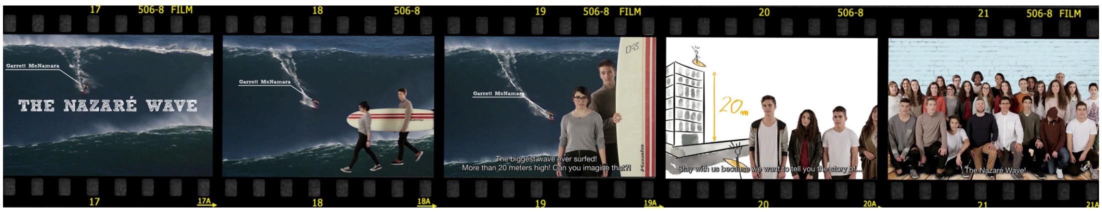


Figure 20. Initial frames of "The Nazaré Wave" movie.

As social media are being increasingly used in science outreach and engagement of scientists with the general public (McClain and Neeley, 2014) and considered a success factor in ensuring successful dissemination of projects' outputs (Stiver *et al.*, 2015) a website and a facebook page for the "The Nazaré Wave: a trigger for learning" project were created. The latter was a fundamental mechanism in the dissemination of "The Nazaré Wave" movie: it reached over 6.000 views in the first month of its release and in a three months time window, had been watched in more than 95 countries and was promoted or recommended in more than 30 communications platform (national and international; science and non-science related) (Figure 21).

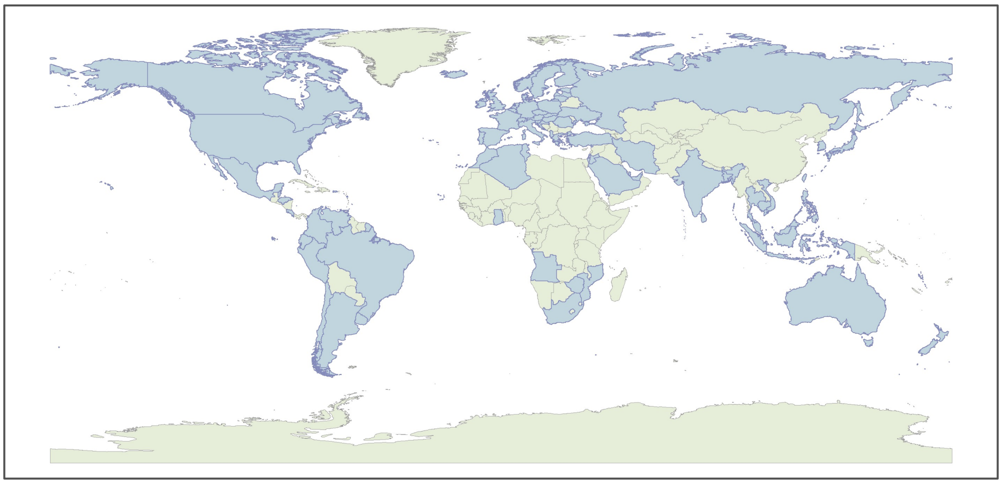


Figure 21. Identification of the 97 countries (in blue) where "The Nazaré Wave" movie was visualized after three months of its released (between 15th February and 15th May 2016) (source: YouTube statistics).

Facebook revealed also to be an excellent mean to receive feedback from the audiences and in fostering engagement. The project has been receiving very good feedback from a varied suite of societal [sub]groups. Some examples of comments posted on-line are presented below. Moreover, Facebook also allows for students and professors to share posts thus boosting their active role in the project.

~*~

"How do you get high school students interested in science? Teach them about the highest wave ever surfed!" AGU Blogosphere

"How do you explain the giant wave of Nazaré? "The Nazaré Wave: A Trigger for Learning" aims to teach and involve everyone: young students, the general public, and academics." SurferToday.com

"Portugiesische Forscher haben zusammen mit Schülern der Gama Barros High-School die Entstehung der Wellen vor Nazaré untersucht und ein Erklärungsvideo veröffentlicht." Funsport.de *[in German]*

"Jovens alunos decidiram explicar de forma simples e pormenorizada o fenómeno das ondas gigantes da Nazaré (...) Fácil de entender até para os mais pequenos. (...) Um trabalho muito interessante que vale a pena ver! SurfPortugal *[in Portuguese]*

"Nazaré, Portugal. Where surfers flock to surf some of the most formidable waves in the world. But what makes Nazaré so special? Well let this awesome group of Portuguese High School students explain it to you. Shoaling! Refraction! Interference! This video has got All The Physics." Deep Sea News

~*~

5.1.3.3 Conclusions

In science communication it is often necessary to capture the public's attention to scientific contents. Results of the "The Nazaré Wave: a trigger for learning" project show that the triggers in communication can ease this task. The Nazaré Wave was an excellent trigger to capture students' attention to science and highlighted the importance of scientific knowledge transfer between scientists and society (in a broad sense). Additionally to the theme itself, it was found that short scientific animation videos on basic wave dynamics performed very well as the communication channel re-enforcing the advantages of using movies to enhance student's motivation and understanding. "The Nazaré Wave: a trigger for learning" revealed to be a highly successful outreach initiative and similar strategies adopted can be used in the development of other science communication projects.

Chapter 5.1 | Key messages

- Outreach aims at fostering public awareness and understanding of science.
- Two outreach projects were developed: "The Beaches of Cascais: past and present" and "The Nazaré Wave: a trigger for learning". In both cases, the message was carefully framed attending to audiences' specificities. Both initiatives cases were highly successful.
- "The Beaches of Cascais: past and present" exhibition was successful in contributing to raise public understanding about the coastal system, and allowed to shift peoples' beliefs about beach evolution.
- "The Nazaré Wave" movie had over 6.000 views in the first month of its release and, after three months, had been seen in more than 95 countries and was promoted in more than 30 platforms demonstrating excellent performance of the selected languages and channel of communication.
- Outreach efforts can be highly valuable in moving forward public engagement and are major opportunities in developing a knowledge-based society.

5.2 Crowdsourcing

Crowdsourcing has the objective of involving of a high number of people in the generation of large sets of data. Although still in its early stages of development, this mechanism presents a high potential on society engagement. Moreover, crowdsourcing can influence on the success of a wide range of projects (Stiver *et al.*, 2015). In the framework of the present study the "Cascais Beach Photo Monitoring" project was designed and have been conducted since May 2015.

5.2.1 The concept

Crowdsourcing can be descried as an open call for voluntary assistance from a large group of individuals (Kalil and Wilkinson, 2015). Crowdsourcing benefits society by encouraging society to participate in the scientific process by collecting data and helping in advance scientific knowledge (Kalil and Wilkinson, 2015). Some initiatives under the Citizen Science framework have already been developed namely in the context of public participatory monitoring (*e.g.,* Tulloch *et al.*, 2013; Stojanovic and Ballingerv, 2009), and volunteered geographical information by the development of mapping tools and web applications (Leidig and Teeuw, 2015). Citizen Science is a broad term, covering a part of open science in which citizens can participate in the scientific research process in different possible ways: as observers, as funders, in identifying images or analyzing data, or providing data themselves (SCU, 2013).

Crowdsourcing and Citizen Science are powerful approaches for engaging the public in the scientific process and in addressing societal needs. Multiple benefits of these approaches include increased knowledge, positive impact on the participants in terms of enhancing their [coastal] awareness, empowerment and improved communication between the actors involved, and better adherence to [coastal] regulations (Holdren, 2015; Wagner, 2004).

5.2.2 "Cascais Beach Photo Monitoring" project

Beach photo monitoring consists on the systematic acquisition of photographs targeting the beach area. The Coastal Photo Monitoring project is an example of a crowdsourcing initiative, conducted in Australia by volunteers, since 2006, aiming at providing a visual record of changes of priority sites within the Southern Perth Metropolitan coastal zone (Perth Region NMR, 2016). Results available at the website of the CPM project depict morphological changes occurred in the study areas and are readily noticeable and perceived by people with different backgrounds (both scientists and non- scientists).

The CPM project and the "The Beaches of Cascais: past and present" exhibition (sub-chapter 5.1.2) highlight the importance of using images (photographs) as the language to communicate beach dynamics. Based upon these initiatives, the Cascais Beach Photo Monitoring (CBPM) project was developed and has been conducted from May 2015 onwards. This project aims to be a proof of concept approach designed to demonstrate the feasibility of systematic acquisition of photographs to support the development of a crowdsourcing tool targeting beach monitoring. The CBPM project was developed upon the mutual agreement between the Faculty of Sciences of University of Lisbon and the Municipal Council of Cascais, that it was interesting to establishing guidelines towards the development of a crowdsourcing tool helping supporting a beach photo monitoring programs while, at the same time, upstream public engagement on coastal issues.

5.2.2.1 Motivation

One key element in coastal zone management is correct understanding of coastal zone evolution. However, the evaluation of morphological changes of a coast, namely beaches, is a non-trivial task due to the complex and intrinsically non-steady nature of the coastal processes (Taborda and Silva, 2012). Beach monitoring, the continuous or periodic process of collecting and analyzing data to measure the dynamic of the beach (UNESCO, 2006), should be see as an integral and continuing element of the coastal management agenda, because it provides to managers regular feedback on implementation and progress towards the attainment of environmental objectives. However, some monitoring programs fail due to lack of capacity to assure the continuity of data acquisition. In this context, crowdsourcing arises as a major opportunity in enhancing and accelerating scientific research through co-generation of data. For instance, volunteers can collect data over large areas and long periods of time, and sometimes increase the frequency of observations, in ways that coastal management agencies or research institutions may not be able to do, given geographic and resource constraints (Holdren, 2015). In addition, this author highlights that community-based monitoring led to improved links amongst the actors involved, a vital step towards sustainability.

Different fields of knowledge are at present developing crowdsourcing platforms to support research and foster engagement among participants. In the program did you feel it? volunteers report experiences felt during earthquakes using a web platform of the U.S. Geological Survey, providing "a collection of citizen science data". The National Oceanic And Atmospheric Administration (NOAA)'s mPING mobile application, allows for volunteers to submit weather-related observations, appealing that "We need your weather reports for our research!".

In the scope of beach photomonitoring, the Photomon application, developed by the Northern Agricultural Catchments Council, was designed to support systematic acquisition and storage of photographs in order to improve the quality of data collected by environmental [beach] photo monitoring programs. Recently, in March 2016, the code of this application became publically available, and this allowed for its adoption in the scope of other beach monitoring programs.

The above emphasizes the potential of beach photomonitoring initiatives supported by crowdsourcing and in upstream public engagement.

5.2.2.2 Project development

The development of the CBPM project encompasses four main tasks:

Task #1: which implies a 1-year systematic acquisition of photographs targeting the beaches of Cascais (Portugal) (Figure 12) to test and validated photographs as a good mean to assess short- to medium-term morphological changes of the beach of Cascais.

Task #2: the development of approaches to extract costal geoindicators from photographs.

Task #3: the development of a smartphone application to support crowdsourcing beach photomonitoring.

Task #4: the development of web-based platforms to archive and to allow access to acquired photographs and other outputs of the CBPM project.

In the scope of the present thesis, efforts were performed targeting the implementation of *Task #1* that has been conducted from May 2015 to July 2016 so far. Systematic acquisition of photographs targeting the eighteen beaches of Cascais (Figure 12) was performed on a monthly basis. Two additional surveys were performed on 20th and 30th October 2015 to assess post-storm morphological changes. The methods and procedures adopted during the surveys were based on the works of Carapuço *et al.*, 2014b, DaSilva, 2012 and Silveira *et al.*, 2012 and are the following:

Photo monitoring points: a monitoring point was selected for the acquisition of each photograph. The establishment of the viewpoint network took into consideration accessibility and the field of view - a good perspective of the target area and, if possible, of the entire beach. In every field campaign, the objective was to acquire photographs from the same points and with the same field of view. Beside a standard photograph of each beach, a panoramic photograph (with elongated field of view) was also acquired.

Equipment: a Nikon® D90 digital single-lens reflex camera equipped with a Nikon® 18-200 mm vibration-reduction lens features 12.1-megapixel was used. The camera was set with automatic focus, and a focal length of 18 mm. For the acquisition of panoramic photographs, 8-megapixixel digital camera of an iPhone 5s was used.

Periodicity and stage of the tide: field surveys were taken at low tide on a monthly basis from May 2016 to July 2016 (as an example, Abano beach photographs are presented in Figure 22). In addition, after the 17th October 2015 storm that hit the Cascais coast, two additional surveys were carried out on October 20th and 30th (as an example, São Pedro beach photographs illustrating pre- and post-storm conditions are presented in Figure 23).

Archiving: after each campaign, photographs were named using a previously agreed code (P1: Abano to P18: Carcavelos), the name of the beach, and the date of the photograph (*e.g.,* P1_abano_2015mai21.jpg). Photographs were also tagged with the name of the beach allowing constructing flexible and easy metadata that made the pictures easily searchable.

Data availability: photographs are available in Flickr, an image and video hosting web platform. In addition, results from monthly surveys are also available in a University of Lisbon website: Beach Monitoring.

Figure 22. Photographs of Abano beach between 21st May 2015 and 06th June 2016.

Figure 23. São Pedro beach photographs in pre-storm (16th October 2015) and post-storm conditions (20th and 30th October 2015, and 12th November 2015).

5.2.2.3 Moving forward

Results obtained so far in the scope of the CBPM project allow putting forward that images (photographs) are a valuable resource in beach monitoring as they can be considered a adequate "language" to communicate beach changes in a simple manner (Figure 24). Examples herein presented (Figure 22 and Figure 23) for the beaches of Cascais, revels that photographs illustrated both seasonal variations that took place at Abano as well as storm erosion and post-storm recovery that took place at São Pedro do Estoril. Moreover, the information portrayed by the image conveys additionally information useful to understand and evaluate major morphodynamic drivers, such as incident wave characteristics.

Results achieved also highlight the potential of the CBPM project to support the widespread use of simple photogrammetric techniques can upgrade the acquired information from qualitative to quantitative allowing to extract costal indicators (*Task #2*) following the work of Carapuço *et al.*, 2014.

In addition, as beach monitoring will largely benefit from the involvement of volunteers in the enlargement of data sets which can be of vital importance in cases where coastal agencies are not be able to assure the longevity of coastal monitoring programs, crowdsourcing can be considered as a valuable resource in beach monitoring. Furthermore, crowdsourcing can, not only upstream public engagement on coastal issues, but also benefit from society's local knowledge enhancing the value of the outputs coastal monitoring programs and further enriching the value of crowdsourcing as a mechanism to improve knowledge transfer (Figure 24) (stressing the importance of *Task #3*).

Moreover, in moving forward the development and adoption of crowdsourcing tools (beach- or non-beach related), it should be underlined the need for easy access to the data collected and related-outputs. If society is willing to participate in crowdsourcing the data, information and knowledge generated should be open, and easy to, access. The development of web-based platforms (*Task #4*) arises as the simplest and low-cost solution to assure that these conditions are meet.

CASCAIS BEACH PHOTO MONITORING

AUDIENCE: SOCIETY (IN GENERAL)
LANGUAGE: IMAGES (PHOTOGRAPHS)
CHANNEL OF COMMUNICATION: SMARTPHONE APPLICATION/WEBSITE
MECHANISM: CROWDSOURCING

Figure 24. "Cascais Beach Photo Monitoring": project's audience, language, channel of communication and mechanism adopted to get the message across and reach the audience.

5.2.3 Conclusions

Crowdsourcing covers a part of open science in which society can participate in the scientific research of the coastal zone by providing data. Further benefits of this approach include strengthening and reinforcing the links amongst all actors involved (see *The Coastal Knowledge Triangle* (Figure 1)): society benefits from having an active role in the coastal management framework, leading to empowerment; scientists, policy-makers and managers benefit from the [co]generation of data, increasing the longevity of monitoring programs enhancing management and scientific research.

In the scope of beach monitoring, crowdsourcing is still in its early stages of development. However, existing initiatives as the Coastal Photo Monitoring (Perth Region NMR, 2013) and Photomon (NACC, 2014) are positive signs of change towards a wider adopting of beach monitoring supported in crowdsourcing tools. Both examples are photographs-related reinforcing the importance of images in a simple identification of beaches changes. Results of the CBPM project highlighted this same conclusion. Moreover, images are also considered a "universal language" being also very useful in communicating beach dynamics and evolution to different audiences. Altogether, these results suggest that scientists should support the development of image-related approaches to foster the use of crowdsourcing tools. It is expected that in the near future these tools can constitute a valuable complement to official (and traditional) coastal monitoring programs as they can provide high resolution (both in time and space) data at a very low cost-benefit ratio.

Chapter 5.2 | Key messages

- ❖ Crowdsourcing can be a valuable mechanism the in scientific knowledge transfer as it encourage the participation of society in the scientific process.
- ❖ Crowdsourcing can strengthen and reinforce the links amongst the actors' involved, which can encompass all key coastal actors identified in *The Coastal Knowledge Triangle* (Figure 1).
- ❖ Crowdsourcing can have a major positive impact in supporting beach photo monitoring programs while, at the same time, upstream public engagement on coastal issues. Moreover, crowdsourcing can not only increasing the frequency of observations, but also contributing to reducing costs associated with coastal monitoring.
- ❖ Preliminary results from "Cascais Beach Photo Monitoring" emphasize that photographs are a valuable resource in beach monitoring as they easily provide a reliable qualitative identification of beach changes.

5.3 Management-oriented tools

The coastal management community has specific needs of information that is required to address specific management issues (*e.g.,* Goldsmith *et al.*, 2015; Carapuço *et al.*, 2013b; van Koningsveld *et al.*, 2005). This principle drives the development of management-oriented tools as a mechanism to improve scientific knowledge transfer. More than providing access to coastal data, management-oriented tools aim to turn data into helpful and readily usable information. In this chapter "Wave Transformation Matrices" are presented as a management-oriented tool for computing site-specific nearshore wave characteristics.

5.3.1 The concept

Management-oriented tools are designed to support the generation of specific information directly useful to policy-makers and managers. The largest compilation of coastal management-oriented tools is "The Digital Coast" (NOAA, 2016) a web platform "developed to meet the unique needs of the coastal management community". This platform provides access to a significant number of science-based GIS (Geographic Information System) tools capable of generating spatial information targeting different coastal issues. Available tools include web applications to compute the rate of shoreline change, and to create maps of potential ecological, social, and economic impacts from rising seas and changing climate. Despite any coastal actor can use these tools their purpose is to directly support coastal management.

5.3.2 "Wave Transformation Matrices"

The use of wave numerical models constitutes an eminently cost-effective, efficient, and rational approach to generating the desired estimates of wave parameters for a specific end (Panchang *et al.*, 1999). However, the process of transforming several thousands of individual wave recordings from deep-water to the nearshore can be a weighty and time-consuming procedure. Wave transformation matrices (WTM) constitute a more efficient method to achieve similar objectives, as they are able to produce forecast products for the oceanographic parameters and make them timely available.

5.3.2.1 Definition and goal

Delivering accurate nearshore wave data and information to coastal managers is of paramount importance in coastal zone management, namely to support the development and routine operation of beach activities, water sports and warning systems for coastal storms.

However, in most cases, wave data and information is only accessible as *1)* deep-water wave data sets requiring further processing to account for wave transformation during propagation and breaking, *2)* refraction and diffraction diagrams picturing transformation of a limited number of previously selected wave conditions, and *3)* extensive lists of numbers on diverse wave attributes computed from increasingly complex numerical models. These "formats" are very difficult (if not impossible) to use by managers in their daily activities. Moreover, often, the physical processes and uncertainty involved in processing wave data from the offshore to the coast are frequently hindered. This may lead to a decrease of trust in scientific results, which can be triggered, for example, by cases where forecasts depart from observations (Carapuço *et al.*, 2014d).

A WTM is a look-up table prepared to quickly deliver elementary nearshore wave parameters (Deltares, 2016). It consists of graphical solutions for computing site-specific nearshore wave characteristics, yielding results at an accuracy level compatible with most of the needs related with management of the coastal area and risks. Here, the performance of different modeling strategies considering standard bi-dimensional (2D) WTM, and three-dimensional (3D) WTM, is presented. The approach developed in this work was applied to the characterization of nearshore wave regime for a sector of the western Portuguese coast.

5.3.2.2 Physical background

As waves propagate from deep to shallow waters, they experience changes in height and direction of travel due to the uneven bathymetry and coastal sheltering (as illustrated in the movie "The Nazaré Wave", sub-chapter 5.1.3.2). The primary processes affecting wave propagation are shoaling, refraction and diffraction (CERC, 2002). Wave shoaling is the change in wave height when they enter shallower water. Wave refraction is the bending of the wave crest due primarily to depth changes and can result in convergence or divergence of the wave energy. Diffraction of waves is a phenomenon in which energy is transferred laterally along the wave crest. As waves move into shoaling water they eventually become unstable and break. Wave breaking is the prominent method of wave energy dissipation but waves also lose energy due to bottom friction when they propagate over intermediate and shallow waters (FEMA, 2005). Refraction, shoaling and diffraction are phenomena that have been approached and studied as linear problems and are resolved in the same manner by numerical models (Fassardi, 2004).

The standard approach to WTM

In standard approach to WTM the nearshore wave height (H) at a specific depth is assumed to be linearly proportional to the deep-water wave height (H_0) (Fassardi, 2004). This is an important consideration because it assumes that the wave transformation process is independent from H_0 and thus allows to estimate H considering only the deep-water wave period (T_0) and deep-water wave direction (Dir_0). Using this approach, a wave height transformation coefficient (WTC_H) can be defined by the ratio between H and H_0 (Fassardi, 2004):

$$WTC_H = H/H_0 \qquad \textit{(equation 1)}$$

This coefficient can be estimated by the product of the shoaling (Ks) and refraction (Kr) coefficients, which depend only on T_0 and Dir_0:

$$WTC_H = f\ (T_0, Dir_0) = Ks \times Kr \qquad \textit{(equation 2)}$$

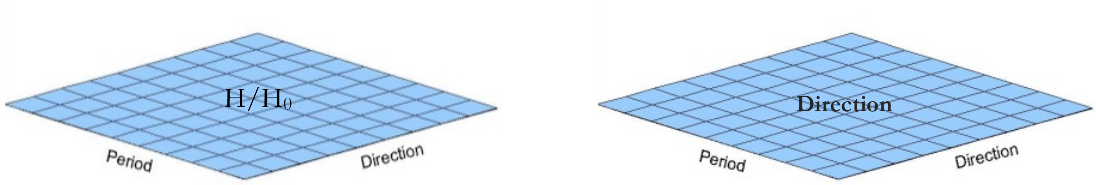
Nearshore wave direction (Dir) can be estimated by a similar processes as it also depends on T_0 and Dir_0:

$$Dir = f\ (T_0, Dir_0) \qquad \textit{(equation 3)}$$

As in linear wave theory the wave period (T) remains unchanged during propagation, the nearshore wave period equal the deep-water wave period (T_0).

$$T = T_0 \qquad \textit{(equation 4)}$$

From the above it is possible to conclude that all relevant nearshore wave parameters can be estimated using only two independent variables: T_0 and Dir_0. This approach supports the use of 2D WTM (a 2D matrix for wave height - WTM_H and a 2D matrix for direction - WTM_{Dir}) to transfer deep-water wave conditions to the nearshore (Figure 25).

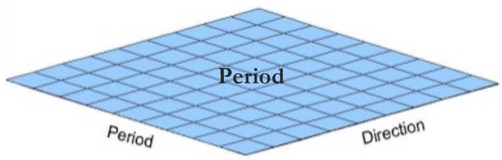


a) 2D WTM_H **b)** 2D WTM_{Dir}

Figure 25. Bi-dimensional wave transformation matrices: a) relative nearshore wave height (2D WTM_H) and b) nearshore wave direction (2D WTM_{Dir}).

An improved approach to WTM

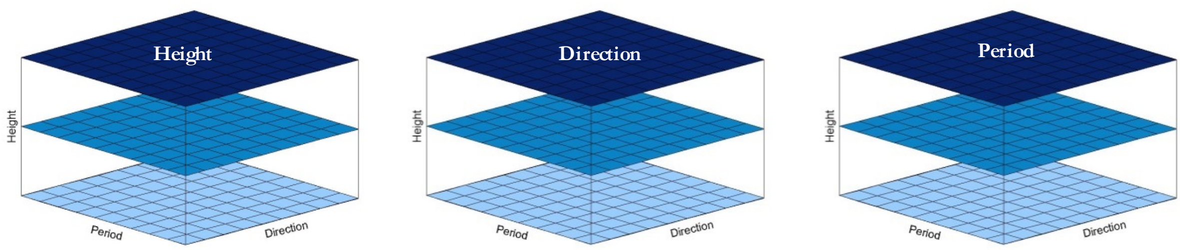
The standard approach to WTM (described above) is valid for both monochromatic and polychromatic waves. In the case of polychromatic waves, the sea state is described using standard wave parameters (*e.g.,* significant wave height (Hs), peak period (Tp) and mean wave direction (Dir)). In this case, the WTM_H and WTM_{Dir} must be estimated using a spectral wave model. In addition, when waves are polychromatic significant changes in wave period may occur such as when propagating in sheltered coastal sections or areas of convergence/divergence. In these cases, the use of *equation 4* can lead to significant errors and a wave transformation matrix for period (WTM_T) should be considered.



a) 2D WTM_T

Figure 26. Bi-dimensional wave transformation matrix for period: 2D WTM_T.

Furthermore, in the standard approach H is considered linear dependent of H_0. In shallow water, this assumption can lead to relative large errors in cases where breaking and bottom friction are important. Under these circumstances, H_0 should be considered explicitly in the transformation matrix. Three-dimensional WTM (3D WTM) are herein presented to address this issue, as they explicitly consider wave height as a third independent variable (Figure 27 a) to c)).



a) 3D WTM_H **b)** 3D WTM_{Dir} **c)** 3D WTM_T

Figure 27. Three-dimensional wave transformation matrices: a) height (3D WTM_H), b) direction (3D WTM_{Dir}) and period (3D WTM_T).

5.3.2.3 Methodological approach

Figure 28 displays the methodological approach followed in this study for wave propagation using the WTM approach. A comparison with the main steps using a conventional wave-by-wave propagation approach is depicted.

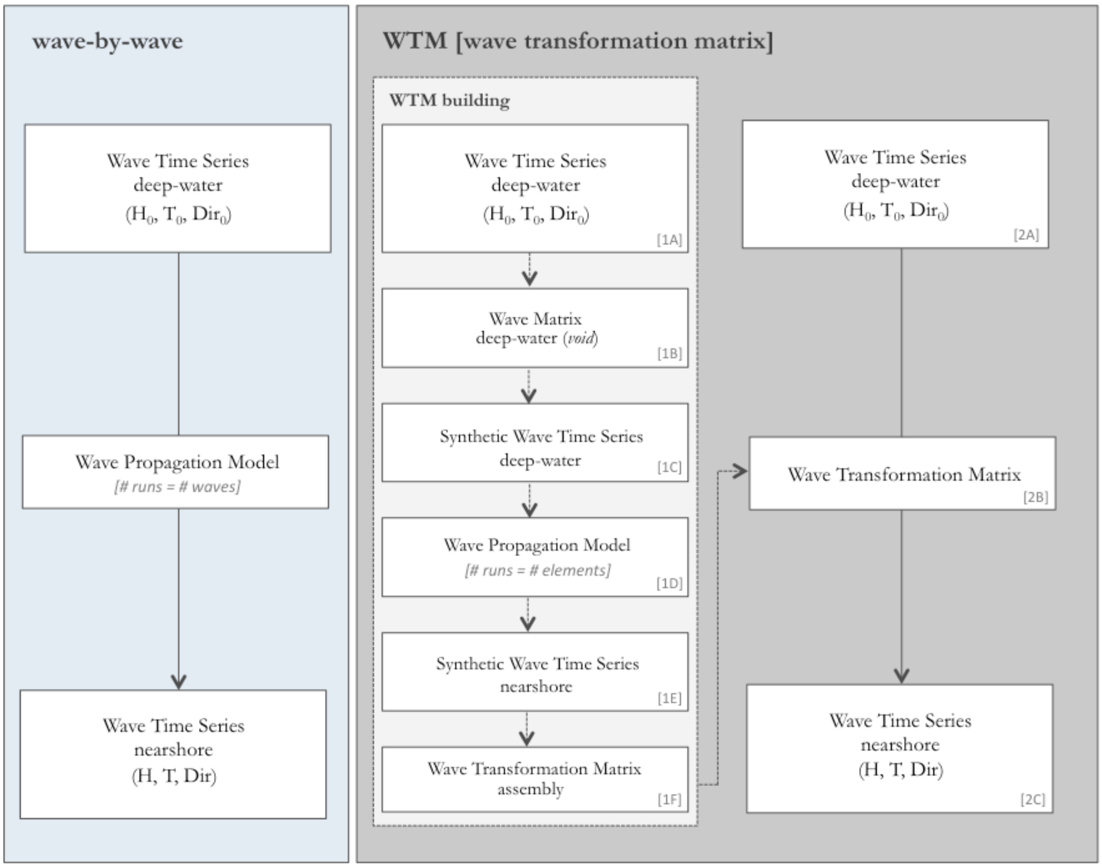


Figure 28. Methodological approach for wave propagation using the wave-by-wave (left panel) and the WTM (right panel) approaches.

The WTM approach involves a two-step procedure: 1) building the WTM, and 2) wave transformation from deep-waters to nearshore through the use of this matrix (Figure 28). The first phase of building the WTM implies creating a matrix covering the range of most likely, or relevant, periods and directions (Figure 28, 1B) (departing from the deep-water wave time series (Figure 28, 1A)). In the case of a 3D WTM, the matrix also covers the range of most likely values of deep-water wave height. Then, all possible pairs of T_0 and Dir_0 (for 2D WTM) are computed to create a synthetic deep-water time series with wave parameters (Figure 28, 1C). In the case of 3D WTM, triples combinations also considered H_0. A wave propagation model then runs for each condition defined in the synthetic wave time series (Figure 28, 1D and Figure 29), creating a synthetic nearshore wave time series (Figure 28, 1E) and allowing assembling the nearshore WTM (Figure 28, 1F) for height (WTM_H), direction (WTM_{Dir}), and period (WTM_T).

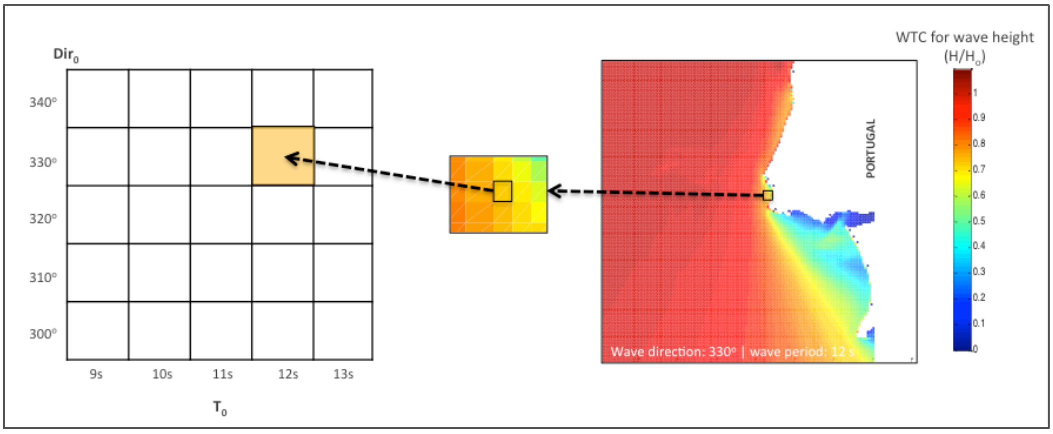


Figure 29. Procedure to build the WTM_H from the wave propagation model results obtained at the target location. The figure depicts an example for Dir_0=330º and T_0=12s.

The second phase implies wave transformation from deep-waters (Figure 28, 2A) to nearshore (Figure 28, 2C) by using the WTM (Figure 28, 2B). Wave transformation values are bilinearly interpolated from the WTM nodes. An example of a WTM_H and its use is presented in Figure 30.

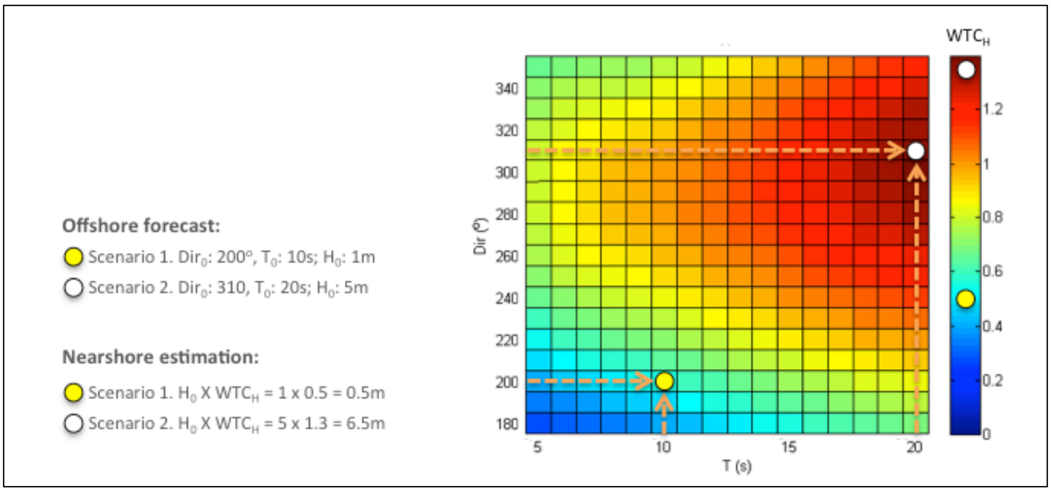


Figure 30. Example of using a WTM_H for two offshore wave conditions. The figure depicts an exercise that coastal managers, with no specific technical skills, can perform to convert two scenarios of wave conditions from deep-waters to nearshore.

From the above, it is clear that WTM approach is intrinsically more complex than the conventional wave-by-wave approach. However, the computational effort required to compute calculation of a WTM is almost independent of the size of the deep-water time series, whereas in the wave-by-wave approach computational effort is proportional to length of the time series (Figure 31). In addition, despite building the WTM requires a certain amount of time, which depends on the resolution of the WTM, this is a one-time action, and correspond to an effort done by scientists. Therefore, for coastal managers WTM can be considered as a ready-to-use solution.

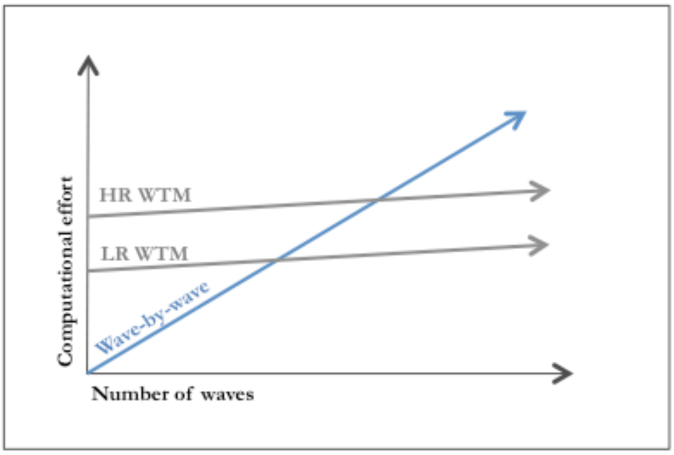


Figure 31. Schematic relation between computational effort and number of waves for wave-by-wave and WTM approaches. The computational efforts in WTM approach vary according to WTM resolution [HR WTM: high resolution wave transformation matrix; LR WTM: low resolution wave transformation matrix].

Wave propagation model

In this study, the assembly of WTM was based on the SWAN (acronym for Simulation WAves Nearshore, Booji *et al.*, 1999) wave propagation model (Booji *et al.,* 1999), version 40.85, developed by the Delft University of Technology. This phase-averaging (or spectral) wave model was designed to obtain realistic estimates of wave parameters in coastal areas and, as it is very flexible, it can be used in a wide range of coastal applications at a wide range of spatial scales. SWAN performs effectively and that is why it was denoted as the "…community wave model" (Rusu, 2011). Several application of the SWAN model along the western coast of Portugal are described in the literature, namely, in thesis, scientific papers and technical reports (*e.g.,* Reis *et al.*, 2013; Rusu, 2011; Rusu *et al.*, 2011; Neves *et al.*, 2010; Silva, 2009; Capitão et al., 2009).

The SWAN model was forced along its open boundaries using wave time series parameters obtanied a 57-year hindcast (1953 to 2009) obtain by Dodet *et al.* (2010). Data are available at http://disepla.fc.ul.pt/Micore/WaveDownload.html. The model run in stationary mode, assuming that the JONSWAP spectrum adequately represented the spectrum of ocean waves in all simulations. It was also assumed that the energy dissipation due to bottom friction is adequately represented by the formulation proposed by Madsen et al. (1998, in SWAN Team, 2011) (friction coefficient equal to 0.05) and ignoring the nonlinear wave-wave interactions (triads and quadruplets). A constant tide level equal to mean sea level was considered. The breaking coefficient followed SWAN default value of 0.78. The model ran in MATLAB® environment through the SwanAuto toolbox developed by the Coastal Processes team of the Geology Department of the Faculty of Sciences of Lisbon University.

Bathymetric data

The bathymetric data used in the wave propagation model result from the compilation of different source of information (Figure 12).

- Source 1: European Marine Observation and Data Network (EMODnet) (sea floor domain not covered by source 2);

- Source 2: Instituto Hidrográfico (IH);

- Source 3: Direção-Geral do Território (DGT) (with Light Detection And Ranging (LiDAR) data for the coastal zone domain).

This representation was complemented with Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (version 2) data (source 4, land domain) developed jointly by the U.S. National Aeronautics and Space Administration and Japan's Ministry of Economy, Trade and Industry.

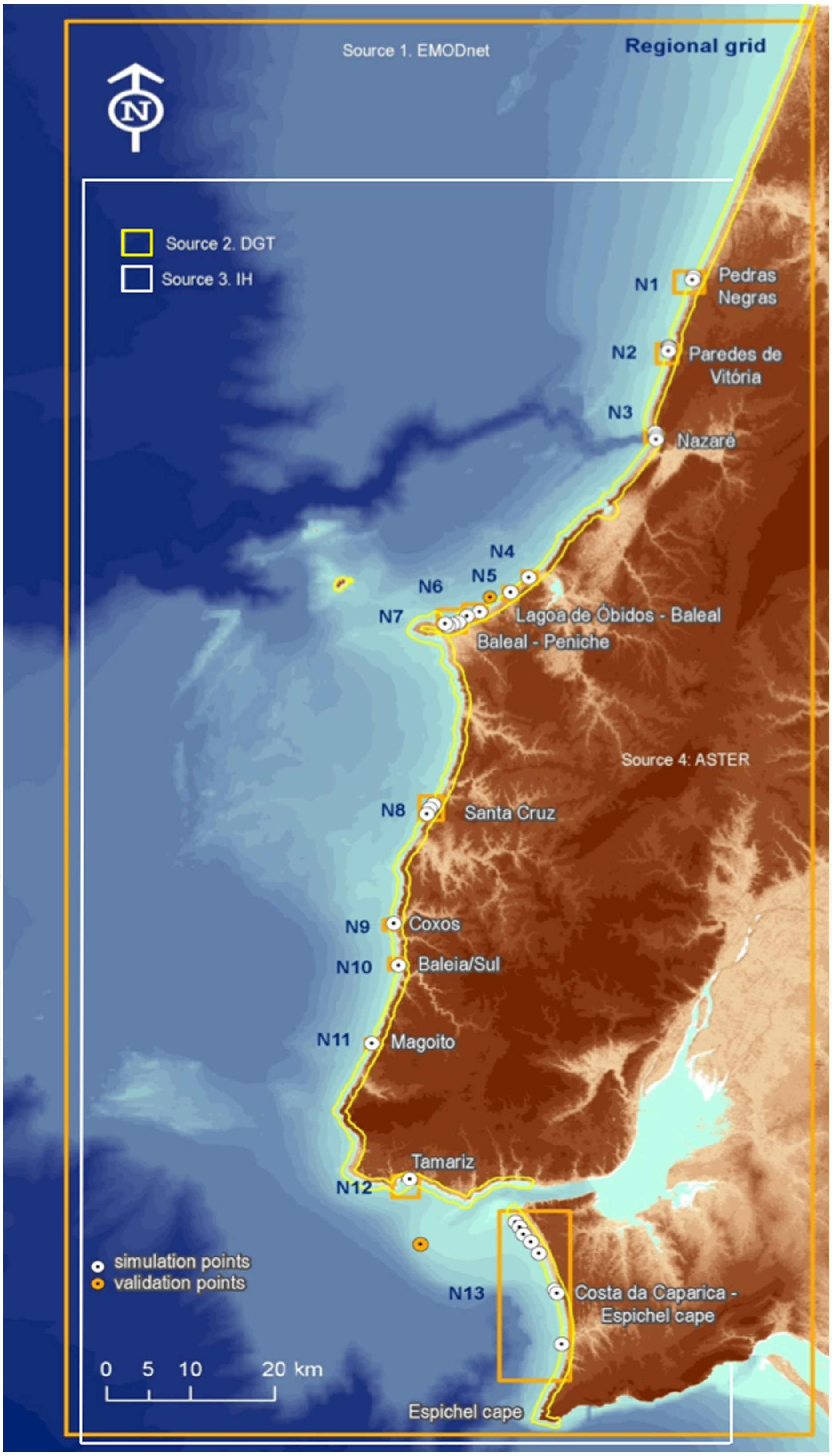


Figure 32. Identification of the bathymetric data sources used in the wave propagation model (EMODnet, IH (white rectangle) and DGT (yellow polygons)). Identification of regional (orange rectangle) and nested grids (orange rectangles - N1 to N13). Location of the target-points used in validation (orange dots) and simulations (white dots).

5.3.2.4 Validation

Validation implies determining whether the simulation model is an accurate representation of the real system (Kleijnen, 1998) and comparison with a real system is considered the most reliable and preferred way to validate a simulation model (Etessami and Gilmore, 1998). Nevertheless, in the present work, the performance of WTM in simulating wave propagation was validated by two methods: absolute performance by the comparison of the simulated data with *1)* field data (real system), and *2)* relative performance by the simulated data acquired through a wave-to-wave modeling strategy.

Field data

Validation of wave parameters yielded by WTM was based on the comparison of H_S, T_p and Dir computed by the SWAN model, and data acquired by equipment's installed offshore in two different locations (Figure 32).

- An acoustic doppler current profiler (ADCP) deployed at 28 m depth offshore Almagreira beach by the IH (data from 29 October 2009 to 11 October 2011) available at Ribeiro (2013) (Point VAL1: location: X = -101002; Y = -29128 ETRS89 PT-TM06);
- The directional wave buoy moored at the depth of 30 m at the edge of the Tagus ebb delta maintained by the Lisbon Port Authority (data between 31 July 2005 and 31 December 2008) (Point VAL2: location: X = -109094; Y = -115320 ETRS89 PT-TM06).

Boundary conditions imposed to the model consisted of two wave time series of integral parameters for the same location in the open sea (lat: 39.31ºN, long: 9.38ºW, 2000 m depth) obtained from two different sources:

- An oceanographic buoy installed by the IH under the MONItoring the Nazaré CANyon (MONICAN) project; and,
- Hindcast data provided by the National Data Buoy Center of the National Oceanic And Atmospheric Administration (NOAA) that were interpolated to that location. This procedure aim to test if the influence of different boundary conditions exceeds the differences obtained using different wave transformation strategies (WTM *vs.* wave-by-wave).

In the simulations, wave periods ranging from 5 to 21s and directions from 180º to 360º, and different combinations of time- and direction-steps were tested (Table 5). For 3D WTM wave heights ranged from 1 to 13m, every 4m. Simulations settings and corresponding validation designations are presented in Table 9. Statistical error parameters (bias, root mean square error (RMSE), scatter index (SI) and Pearson correlation coefficient (R)) for the different 24 validation settings were computed.

Table 5. Wave period, direction and height ranges and steps used in 2D WTM and 3D WTM approaches.

Ranges and steps [for T_0, Dir_0 and H_0]	2D WTM			3D WTM		
	High resolution [HR]	Low resolution [LR]	Very low resolution [VLR]	HR	LR	VLR
T_{0Min}	5	5	5	5	5	5
T_{0Max}	21	21	21	21	21	21
T_{0Step}	1	4	8	1	4	8
Dir_{0Min}	180	180	180	180	180	180
Dir_{0Max}	360	360	360	360	360	360
Dir_{0Step}	10	20	45	10	20	45
H_{0Min}	-	-	-	1	1	1
H_{0Max}	-	-	-	13	13	13
H_{0Step}	-	-	-	4	4	4

Table 6. Simulations settings and corresponding designations to each validation (V1 to V24).

Simulation	2D WTM			3D WTM			Offshore wave data		Validation	
	HR	LR	VLR	HR	LR	VLR	MONICAN	NOAA	ADCP	APL buoy
S1	X						X		V1	V2
S2	X							X	V3	V4
S3		X					X		V5	V6
S4		X						X	V7	V8
S5			X				X		V9	V10
S6			X					X	V11	V12
S7				X			X		V13	V14
S8				X				X	V15	V16
S9					X		X		V17	V18
S10					X			X	V19	V20
S11						X	X		V21	V22
S12						X		X	V23	V24

Results displayed in Table 7 and in Table 8 show that no significant differences when contrasting resolutions for 2D WTM and 3D WTM were found. In fact, the major difference found was in relation to the time to build the matrices, which ranged from 4 to 449 minutes. Nevertheless, it was found that very low resolutions WTM are, in general, related with the worst performances. As an example, RMSE for H_S ranges from 0.28m (V2, V6 and V10) to 0.52m (V23), for Tp ranges from 1.60s (V13) to 2.06s (V4, V8 and V12), and for Dir ranges from 7.11º (V21) to 21.67º (V12).

Table 7. Statistical error parameters for different validation settings for 2D WTM.

Wave parameter	Statistical error parameters	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12
Hs (m)	Bias (m)	0.03	-0.04	0.01	0.09	0.02	-0.04	0.00	0.09	-0.05	-0.06	-0.06	0.06
	RMSE (m)	0.29	0.28	0.40	0.30	0.29	0.28	0.40	0.30	0.30	0.28	0.41	0.29
	SI	0.16	0.19	0.22	0.22	0.16	0.19	0.23	0.22	0.17	0.19	0.23	0.22
	r	0.95	0.95	0.89	0.94	0.95	0.95	0.89	0.94	0.94	0.95	0.89	0.94
T_p (s)	Bias (s)	0.23	0.01	0.22	-0.12	0.26	0.04	0.26	-0.07	0.14	0.14	0.35	0.02
	RMSE (s)	1.62	2.02	1.87	2.06	1.63	2.03	1.87	2.06	2.03	2.03	1.88	2.06
	SI	0.15	0.19	0.18	0.19	0.15	0.19	0.18	0.19	0.19	0.19	0.17	0.19
	r	0.81	0.73	0.72	0.71	0.81	0.73	0.72	0.71	0.73	0.73	0.72	0.71
Dir (º)	Bias (º)	3.04	-4.48	-1.72	-5.89	2.83	-4.68	-1.95	-6.05	-5.94	-5.94	-2.56	-7.36
	RMSE (º)	7.73	15.69	11.06	21.23	7.57	15.71	11.06	21.26	16.08	16.08	11.16	21.67
number of observations		*5400*	*15329*	*7057*	*33680*	*5400*	*15329*	*7057*	*33680*	*15329*	*15329*	*7057*	*33680*
time to build WTM (min)		*79*	*79*	*79*	*79*	*12*	*12*	*12*	*12*	*4*	*4*	*4*	*4*

Table 8. Statistical errors parameters for different validation settings for 3D WTM.

Wave parameter	Statistical error parameters	V13	V14	V15	V16	V17	V18	V19	V20	V21	V22	V23	V24
Hs (m)	Bias (m)	-0.10	-0.11	-0.10	0.03	-0.13	-0.12	-0.13	0.02	-0.24	-0.19	-0.23	-0.06
	RMSE (m)	0.35	0.31	0.44	0.30	0.37	0.32	0.46	0.30	0.46	0.37	0.52	0.32
	SI	0.18	0.20	0.24	0.21	0.19	0.21	0.25	0.21	0.24	0.24	0.28	0.22
	r	0.92	0.95	0.86	0.93	0.92	0.94	0.86	0.93	0.89	0.93	0.84	0.92
T_p (s)	Bias (s)	0.26	-0.02	0.22	-0.15	0.29	0.02	0.26	-0.11	0.39	0.13	0.37	0.00
	RMSE (s)	1.60	1.94	1.83	1.93	1.61	1.94	1.84	1.93	1.62	1.94	1.85	1.93
	SI	0.15	0.18	0.17	0.18	0.15	0.18	0.17	0.18	0.15	0.18	0.17	0.18
	r	0.82	0.74	0.73	0.73	0.82	0.74	0.73	0.73	0.82	0.74	0.73	0.73
Dir (º)	Bias (º)	3.09	-5.09	-1.20	-6.91	2.85	-5.30	-1.45	-7.08	1.99	-6.53	-2.21	-8.35
	RMSE (º)	7.58	14.70	10.67	18.95	7.42	14.73	10.67	19.00	7.11	15.18	10.81	19.51
number of observations		*5125*	*14409*	*6614*	*30670*	*5125*	*14409*	*6614*	*30670*	*5125*	*14409*	*6614*	*30670*
time to build WTM (min)		*449*	*449*	*498*	*498*	*100*	*100*	*103*	*103*	*36*	*36*	*36*	*36*

According to the results obtained, the factor that seems to most affect the quality of the outputs is the source of the offshore wave data, with better performances with MONICAN (measured) data than NOAA (hindcast) data as depicted in Figure 33.

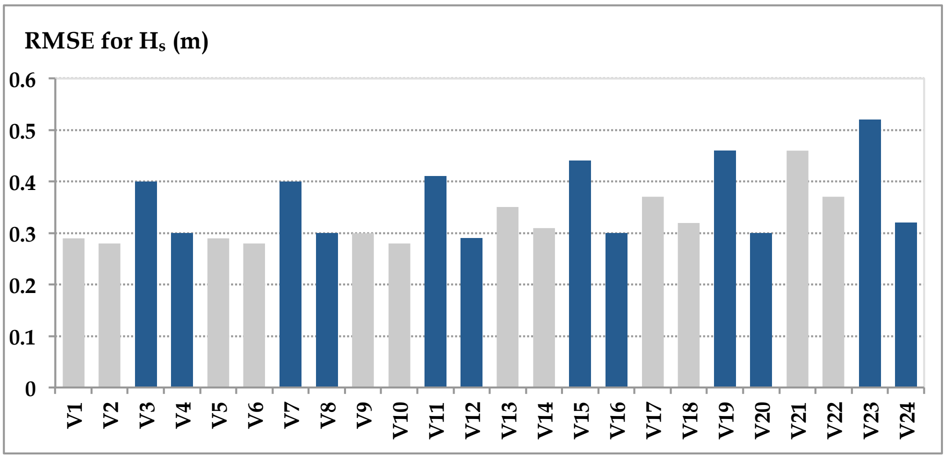


Figure 33. RMSE for Hs for the different validations settings (V1 to V24). Grey bars: MONICAN data | Blue bars: NOAA data.

In order to test the performance of WTM_T, simulations of V1 to V4 were reiterate considering the period unchanged ($T = T_0$). Results presented in Table 9 show smaller RMSE when $T \neq T_0$. In this sequence, it is recommended the adoption of WTM_T in areas where the wave period is more likely to change.

Table 9. Statistical errors parameters for validation settings V1 to V4 including and excluding WTMT.

Wave parameter	Statistical error parameters	V1	V2	V3	V4	V1	V2	V3	V4
		Period changed ($T \neq T_0$)				Period unchanged ($T = T_0$)			
T_p (s)	Bias (s)	0.23	0.01	0.22	-0.12	0.31	0.09	0.33	-0.01
	RMSE (s)	1.62	2.02	1.87	2.06	1.75	2.19	1.93	2.09
	SI	0.15	0.19	0.18	0.19	0.16	0.21	0.18	0.20
	r	0.81	0.73	0.72	0.71	0.80	0.71	0.72	0.71

From the results obtained, it is possible to conclude that:

- WTM are excellent tools to simulate effects of wave propagation, and in predicting changes in wave parameters;
- 2D WTM have a very good performance in the characterization of nearshore wave regime providing good results in a simpler and faster manner (Table 7);
- 3D WTM_H should be used in target-areas where wave breaking or where bottom friction leads to significant energy dissipation seaward of the simulation point (Table 8);
- 2D WTM_T is recommended in sheltered or strong refraction areas where the wave period is more likely to change (Table 9);
- The nature of offshore wave data (hindcast *vs.* measured) is more relevant than the resolution adopted in the WTM, in determining the quality of the results (Figure 33).

Wave-by-wave modeling strategy

Validation of wave parameters yielded by WTM was based on the comparison of Hs, Tp and Dir computed by the SWAN model, and the results of a wave-to-wave simulation exercise by Silveira *et al.* (2013). In this assessment bias, RMSE, SI and R for validations V3, V4, V15 and V16 (corresponding to the best 2D WTM and 3D WTM performance for hindcast forcing using NOAA data) were computed. The results of the comparison between the WTM approach and wave-by-wave modeling strategy are presented in Table 10.

Table 10. Statistical errors for comparison between the wave transformation matrices and the wave-by-wave modeling approach.

Wave parameter	Statistical error parameter	2D WTM V3 and V4		3D WTM V15 and V16		Wave-by-wave(*)	
		ADCP	APL	ADCP	APL	ADCP	APL
H_S (m)	Bias (m)	0.01	0.01	-0.10	0.03	0.00	-0.02
	RMSE (m)	0.40	0.40	0.44	0.30	0.42	0.30
	SI	0.22	0.22	0.24	0.21	0.23	0.26
	r	0.89	0.89	0.86	0.93	0.88	0.88
T_p (s)	Bias (s)	0.22	0.22	0.22	-0.15	-1.51	2.88
	RMSE (s)	1.87	1.87	1.83	1.93	2.41	3.30
	SI	0.18	0.18	0.17	0.18	0.22	0.58
	r	0.72	0.72	0.73	0.73	0.70	0.56
Dir (º)	Bias (º)	-1.72	-1.72	-1.20	-6.91	1.89	-4.98
	RMSE (º)	11.06	11.06	10.67	18.95	9.14	17.64
	number of observations	*7057*	*33680*	*6614*	*30670*	*14409*	*15728*
	computational time	*7 seconds (**)*		*14 seconds (***)*		*circa* of 15 days	

(*) Silveira *et al,*. 2013

(**) the time to build transformation matrix is 79 minutes; however, this is a one-time action.

(***) the time to build transformation matrix is 449 minutes; however, this is a one-time action.

Results show that the performance of the WTM is excellent for the propagation of waves when comparing with the wave-by-wave strategy. Dir, H_S and T_p present similar (sometimes lower) RMSE in the 2D WTM strategy in comparison with the wave-to-wave strategy. Best results for T_p were obtained using 3D WTM strategy. Therefore, considering both 2D and 3D WTM *vs.* the wave-by-wave, WTM present better results in wave propagation. However, 2D WTM have to be used carefully in areas with significant bottom friction or wave breaking in line with the conclusions above mentioned for validation with field data (5.3.2.4 *Validation*).

Figure 34 depicts a plot of nearshore Hs for a nearshore simulation point computed using wave-by-wave *vs.* 2D and 3D WMT strategies. These results put in evidence that for H_{S0}>5m the 2D WTM_H overestimated H_S because 2D WMT fail to adequately reproduce wave breaking effects over wave height. Thus, under this circumstance, the use of 3D WTM_H should be considered.

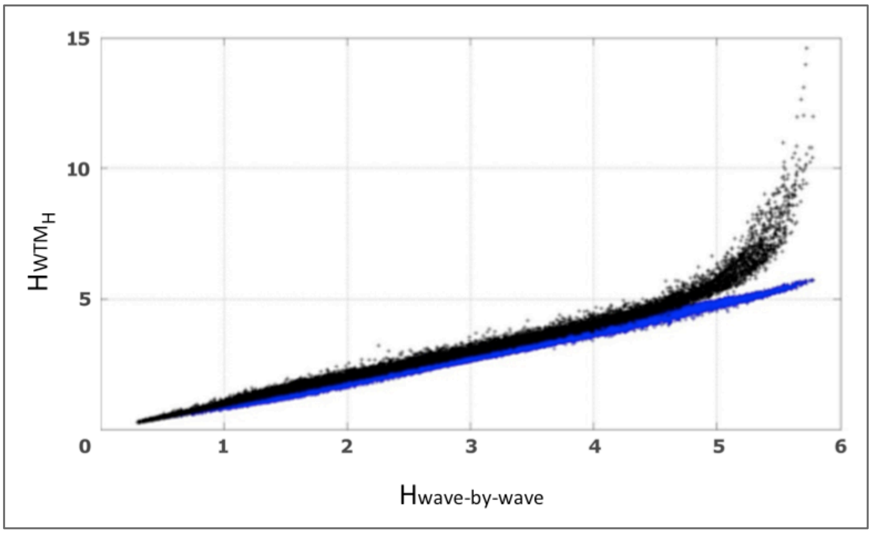


Figure 34. Relation between Hs obtained by the wave-by-wave strategy and 2D WTM_H (black markers) and wave-by-wave strategy and 3D WTM_H (blue markers).

5.3.2.5 Case study

Validation procedures indicate that WTM is an excellent strategy for wave propagation, allowing accurate prediction of nearshore wave parameters and regime. In this subchapter, characterization of the nearshore wave regime is performed for a specific coastal sector using the 2D WTM approach. This option relied upon the fact that 2D WTM's performed very well in the characterization of the wave regime for modal conditions and requires smaller computational times.

Study area

The study area is located in the western Portuguese coast (Figure 32) and encompasses the coastal ribbon between Pedras Negras beach and cape Espichel. This sector is exposed to an offshore wave regime generated far in the North Atlantic, and dominated by swell, and overlapped by waves generated by local winds (sea). North of Tagus river, the coast is predominantly rocky, and characterized by small embayed beaches, with different exposure to the incident waves. South of Tagus, the study area corresponds to a continuous sand strip that develops between the cliffs of cape Espichel and Tagus estuary, in the north.

Eleven target-areas were selected for the characterization of the nearshore wave regime (Figure 32; see also Annex "*Wave Transformation Matrices*", Table A2), which are representative of coastal sections with different exposure to the incident waves, contrasting morphological setting and different sedimentary content. 31 target-points at 10 m depth were considered with the exception of target-point TM2 defined at 5 m depth (see Annex "*Wave Transformation Matrices*", Table A2).

Model settings

In the numerical simulations wave spectrum was segmented in 22 classes of frequency (5 to 20 s) and 36 directional classes (180º to 360º and 0º to 20º).

The computational domain was divided into grids, one regional and 13 nested, to improve accuracy and enhance computational effort and time (Figure 32). Grid characteristics used in the wave propagation model are presented in Annex "*Wave Transformation Matrices"* (Table A1).

Further information about the SWAN propagation model and the bathymetric data used are described in sub-chapter 5.3.2.3 *Methodological approach*.

Results and discussion

Obtained results for the 31 simulation points are present in Table 11. Results show that Hs_{Mean} ranges from 1.91m (Paredes de Vitória) to 0.68m (Tamariz), T_{Mean} ranges from 10.0s (Tamariz) to 8.38s (Costa da Caparica – Espichel cape stretch) and Dir_{Mean} ranges from 210º (Tamariz beach) to 353º (southernmost location of Lagoa de Óbidos – Baleal stretch).

Table 11. Results obtained through the use of 2D WTM to characterize the nearshore wave regime in the study area.

Target-areas	Target-points	Hs_{Mean}	H_{max}	$H_{sP97.5}$	Hs_{P75}	Hs_{P50}	Hs_{P25}	T_{PMean}	Dir_{Mean}
Pedras Negras beach	PN1	1.86	14.66	5.03	2.26	1.52	1.10	9.00	298
	PN2	1.83	13.99	4.88	2.21	1.50	1.09	8.96	297
Paredes de Vitória beach	PV1	1.91	14.37	5.18	2.32	1.55	1.11	9.07	293
	PV2	1.86	13.83	5.01	2.26	1.51	1.09	9.03	292
	PV3	1.75	12.57	4.63	2.12	1.43	1.05	8.93	296
Nazaré beach	NZ1	0.70	4.77	1.93	0.88	0.57	0.38	8.54	253
	NZ2	1.10	6.70	2.84	1.35	0.92	0.65	8.70	275
	NZ3	1.22	7.09	3.05	1.49	1.04	0.76	8.66	286
Lagoa de Óbidos – Baleal stretch	LOB1	1.68	10.94	4.26	2.02	1.41	1.04	8.85	315
	LOB2	1.73	11.03	4.39	2.09	1.46	1.07	8.94	317
	LOB3	1.53	9.32	3.78	1.84	1.31	0.96	8.87	326
	LOB4	1.23	7.94	3.30	1.53	1.04	0.71	9.49	353
Baleal - Peniche	BP1	1.43	8.90	3.56	1.73	1.22	0.89	8.92	327
	BP2	1.48	9.60	3.79	1.80	1.26	0.91	9.08	332
	BP3	1.21	6.95	3.08	1.50	1.05	0.73	9.11	342
	BP4	1.09	6.38	2.68	1.33	0.95	0.68	8.92	346
Santa Cruz beach	SC1	1.75	14.61	4.76	2.12	1.42	1.03	8.97	298
	SC2	1.75	14.37	4.71	2.11	1.43	1.04	8.95	299
	SC3	1.69	13.80	4.50	2.03	1.38	1.01	8.87	302
Coxos beach	CX1	1.81	14.41	5.00	2.22	1.46	1.03	9.07	288
Baleia/Sul beach	BS1	1.56	12.51	4.21	1.90	1.27	0.91	8.87	286
Magoito beach	MG1	1.71	13.23	4.51	2.06	1.41	1.04	8.86	296
Tamariz beach	TM2	0.68	7.60	2.38	0.89	0.49	0.27	10.00	210
Costa da Caparica – Espichel cape stretch	CC1	1.37	14.15	4.38	1.75	1.03	0.61	9.58	240
	CC2	1.39	13.54	4.29	1.77	1.07	0.66	9.48	245
	CC3	1.34	12.66	4.05	1.69	1.04	0.66	9.34	248
	CC4	1.20	10.83	3.57	1.50	0.94	0.61	9.17	250
	CC5	1.13	8.84	3.22	1.41	0.91	0.60	8.96	253
	CC6	0.96	9.17	3.04	1.18	0.72	0.49	8.34	259
	CC7	0.98	9.39	3.10	1.20	0.73	0.50	8.38	260
	CC8	1.26	10.04	3.60	1.55	1.00	0.69	8.69	276

H_{sMean}: average significant wave height (m), H_{Max}: maximum wave height (m), $H_{sP97.5}$: 97.5 percentile for significant wave height, H_{sP75}: 75 percentile for significant wave height, H_{sP50}: 50 percentile for significant wave height, H_{sP25}: 25 percentile for significant wave height, T_{PMEAN}: average peak period (s) and Dir_{Mean}: average mean direction (º).

The longshore distribution of H_{SMean} and Dir_{Mean} are depicted in Figure 35 and is possible to acknowledge, in a simple manner, asymmetries in H_{SMean} and $Dir_{Mean.}$ Exposed beaches, such as Pedras Negras and Paredes de Vitória, present higher Hs_{Mean}. In contrast, beaches located in sheltered environments present the lowest values of Hs_{Mean}, as in the case of Tamariz.

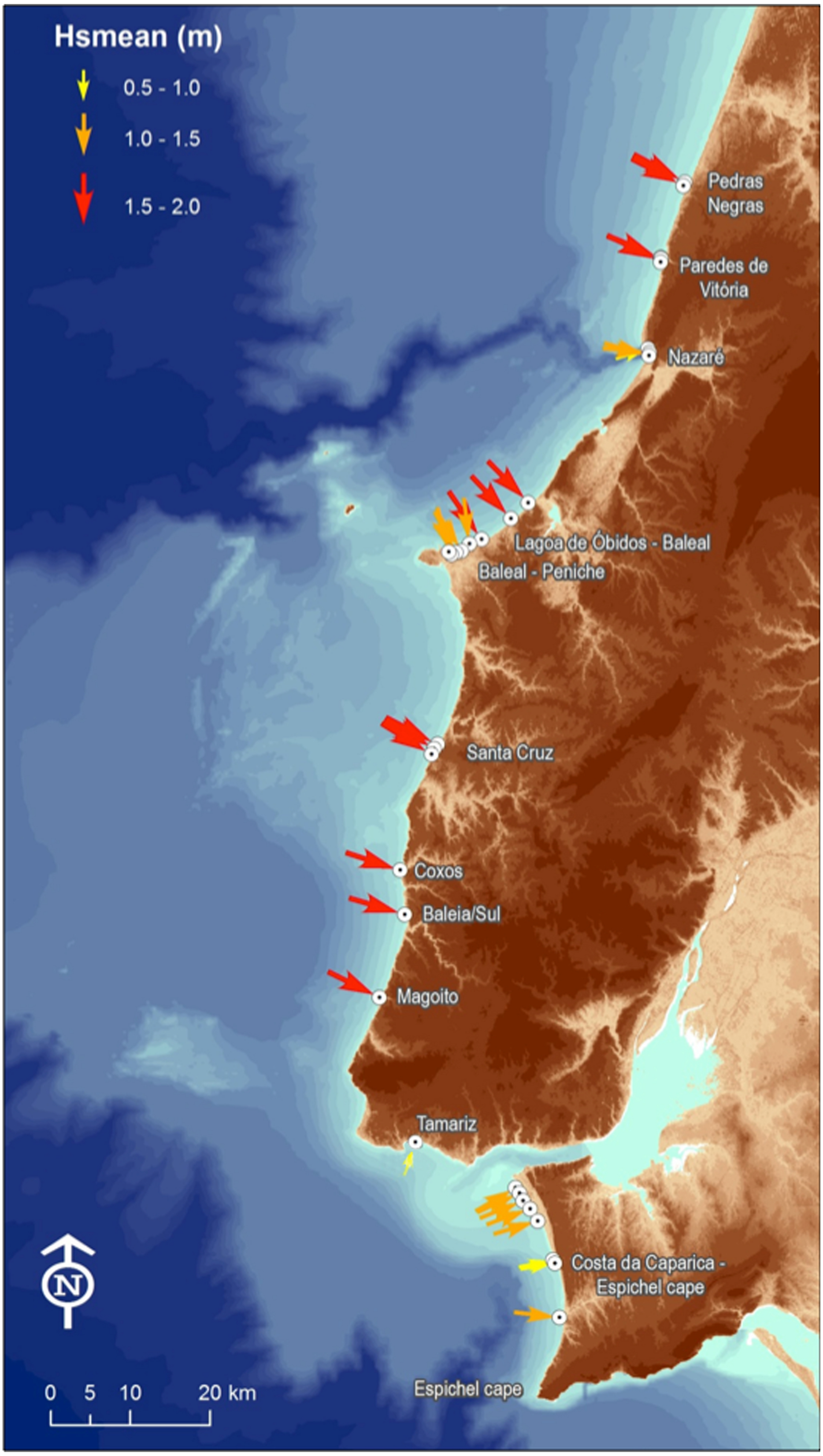


Figure 35. Longshore distribution of average H_{SMean} and Dir_{Mean} obtained using WTM strategy in all simulation target-points.

Results obtained for 2D WTM_H in all simulations points are presented in Annex "*Wave Transformation Matrices* (Figure A1 to A13)". Nevertheless, a number of 2D WTM_H are herein presented aiming at illustrate paradigmatic situations:

- *Paredes de Vitória beach*: the second northernmost beach of the study site with the highest Hs_{Mean} of all the simulated points (Figure 36). This can be explained because Paredes de Vitória is highly exposed to offshore waves. In addition, the linear development of the beach and coast explains the similarity of all WTM for all simulations points.
- *Nazaré beach*: an embayed beach at the head of the Nazaré submarine canyon (Figure 37). The WTM yield different nearshore patterns along the same beach area and is evident that the northernmost simulate point (PNZ1) corresponds to the most sheltered beach ribbon. This result is in agreement with those obtained by Silveira *et al.* (2016).
- *Tamariz beach*: lowest Hs_{mean} of all the simulated points (Figure 38). WTM reveal lower Hs_{Mean} due to coastal sheltering.

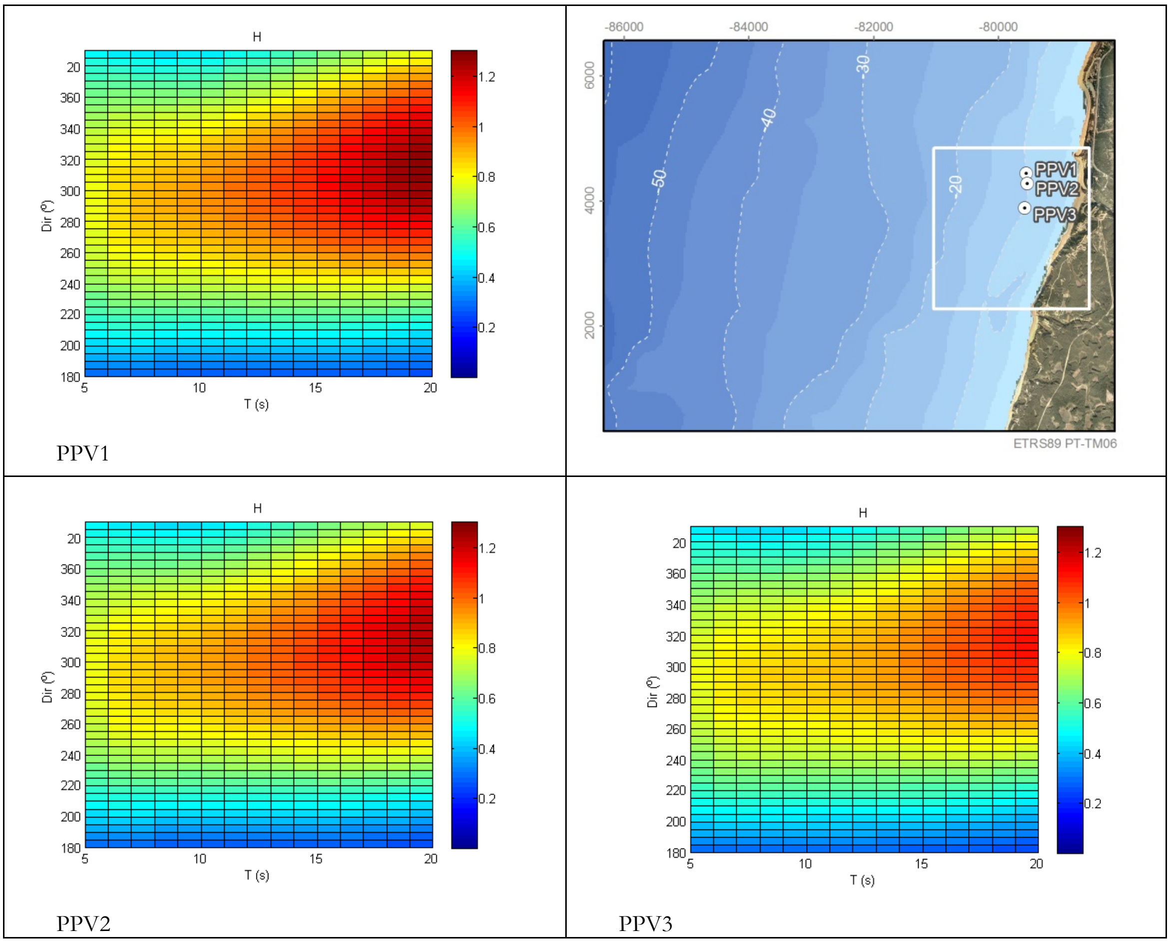


Figure 36. 2D WTM_H for target-points PPV1, PPV2 and PPV3 at Paredes de Vitória beach.

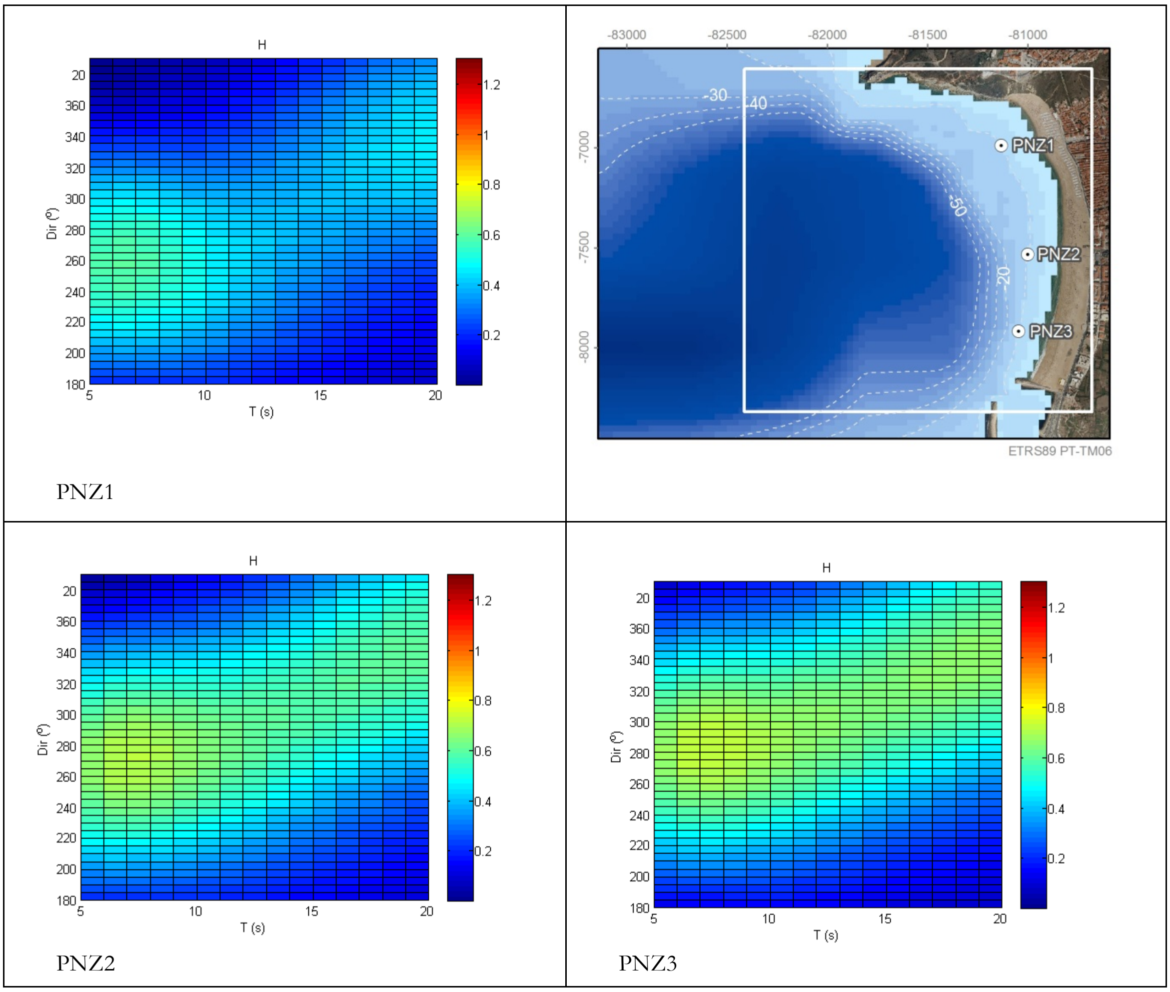


Figure 37. 2D WTM_H for target-points PNZ1, PNZ2 and PNZ3 at Nazaré beach.

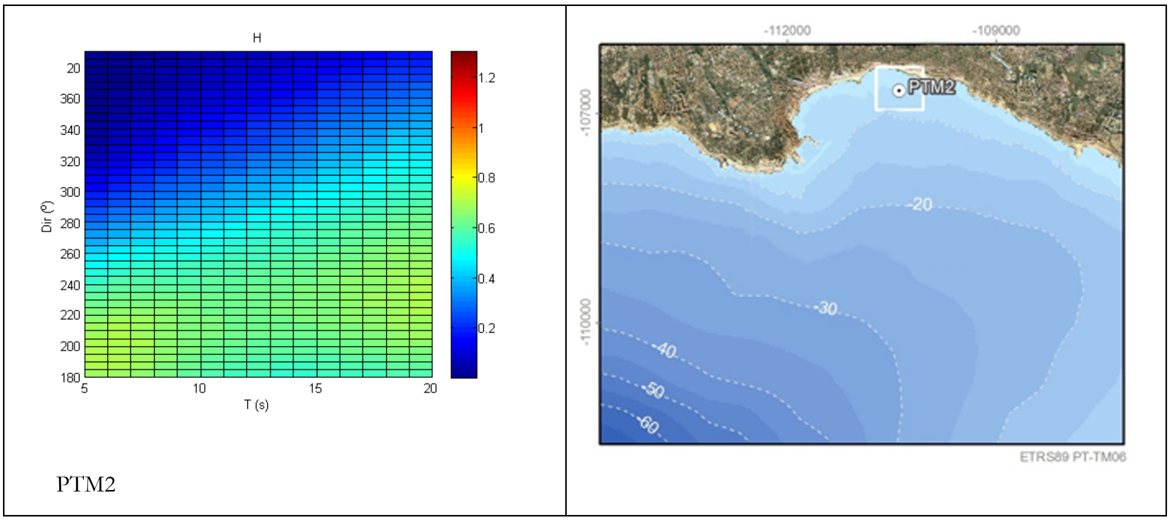


Figure 38. 2D WTM_H for target-point PTM2 at Tamariz beach.

Results for this case study allow concluding that not only WTM are reliable in the characterization of the nearshore wave regime but also in varied nearshore and coastal settings. They are also are very helpful in providing visualization of the changes experimented by waves when propagating in progressively shallow water towards a specific coastal location.

5.3.2.6 Setting an agenda for future research

The availability of reliable data concerning the nearshore wave regime is fundamental in coastal zone planning and management. Numerical models of waves propagation are able to produce hindcast and forecast products describing waves parameters. They can make available in a useful time scales the oceanographic data necessary to support decision-making process.

In this context, WTM revealed to be an excellent approach to deliver nearshore wave data. Results obtained allow concluding that *1)* 2D WTM have a very good performance in the characterization of nearshore wave regime providing good results in a simpler and faster manner, *2)* 3D WTM_H should be used in target-areas where wave breaking or where bottom friction leads to significant energy dissipation seaward of the simulation point and 3) 2D WTM_T should be used under circumstances where the wave period is likely to change, such as sheltered coastal stretches or areas with strong refraction. The findings herein presented also allowed to conclude that the WTM *1)* imply significantly smaller computational and interpretation effort and time, in comparison with a conventional wave-by-wave modeling strategy, and *2)* are very helpful in the visualization of the physical processes related with waves propagation.

In this sense, WTM offer a high potential as a management-tool as their adoption allows for coastal managers (and other users) to simulate wave conditions for specific target-area in a simple and intuitive manner. An offshore wave forecast with an adequate WTM allows predicting wave conditions or interpret the wave regime at a certain beach, by any WTM-user, as no specific technical skills are required. Moreover, WTM allow users to acknowledge the wave transformation processes and inform on uncertainty involved in processing wave data from the deep-waters to nearshore.

Future works should consider optimizing the potential of WTM by investing in the development of friendlier user-interfaces. As WTM approach implies smaller computational time (in comparison with a conventional wave-by-wave modeling strategy) it makes WTM approach suitable for the development of website and smartphone applications. These developments can set the agenda for future research (Figure 39).

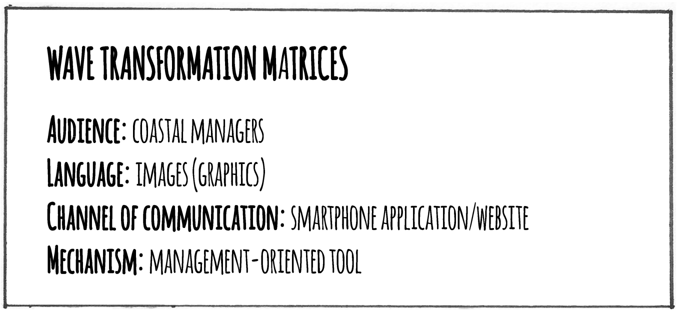


Figure 39. "Wave Transformation Matrices": project's audience, language, channel of communication and mechanism adopted to get the message across and reach the audience.

5.3.3 Conclusions

Management-oriented tools aim to turn science-based data into helpful information directly useful to policy-makers and managers. They constitute a major opportunity to foster scientific knowledge integration in decision-making, acting as catalyzers in the science-management interface. In fact, some of these tools can even be useful to other coastal actors. In agreement with this, the tool presented in this sub-chapter, WTM, besides being useful for coastal managers, are also suitable to address the needs of information of sub-groups of society with varied interests in the coastal zone (*e.g.,* surfers, fishermen). Management-oriented tools may also have a role in allowing users to be informed on physical processes acting upon the coast and acknowledge uncertainty. The latter issue is of major importance in foster engagement among coastal actors as it is grounded in the principle of the "best available knowledge", where scientists assume the existence of changes and limitations in scientific knowledge and understanding.

Chapter 5.3 | Key messages

- ❖ Management-oriented tools are designed to support the generation of specific information directly useful to policy-makers and managers: more than providing access to coastal data, management-oriented aim to turn data into helpful information.
- ❖ WTM are management-oriented tools that allow computing reliable and timely information concerning the nearshore wave regime or particular state of the sea. This information is of vital importance in coastal zone management.
- ❖ WTM allow users to acknowledge physical processes upstreaming their understanding on the coastal system and of uncertainty. The latter issue, combined with the principle of the "best available knowledge", is of major importance in building engagement among coastal actors.
- ❖ Future work such consider to optimize the potential of WTM by the development of friendlier user-interfaces: website or smartphone applications can set the agenda for future research.

5.4 Co-production

Co-production emerged in social sciences in the 1970's. The idea was first articulated by Elinor Ostrom (2009 Nobel prize winner for economics) (Boyle and Michael, 2009) who, in 1996 (Ostrom, 1996), defined co-production as a "…process through which inputs from individuals who are not in the same organization are transformed into goods and services". The concept has been evolving and, in 2011, Armitage *et al.* have (re)defined co-production "as the collaborative process among [coastal] actors bringing a plurality of knowledge types together to address a specific problem, aiming at building an integrated solution for that problem".

In the scope of the present study, co-production is represented by the "CIS - Coastal Information System for the municipality of Cascais" project, co-designed in close collaboration with technicians from this municipality aiming the establishment of a coastal monitoring program targeting Cascais' beaches.

5.4.1 The concept

Co-production is often described as a process where people "contribute to" and "collaborate in" the generation of the outputs. Despite the lack of agreement of a "universal" definition (Boyle and Harris, 2009) five core elements of co-production can be identified according to Heaton *et al.* (2016): (1) all participants are regarded as active parties and not merely passive subjects or recipients of outputs; (2) there is greater equality in the relations between co-production participants, with outputs becoming more user-driven, and users' knowledge and experience being valued on an equal basis; (3) working together allows for achieving more (and better) outcomes than working apart; (4) continued participation of parties involved transforms the ways in which outputs are designed and delivered; this helps in developing the capacity for users' to identify and present their needs of information; and (5) participation in co-production should be encouraged and facilitated by networks and organizations that support their involvement - nevertheless, it is recognized that it is people, not systems, who create change (Heaton *et al.*, 2016).

From the above, it is possible to conclude that co-production contains intrinsic benefits for those involved, creating the possibility for coastal actors to share their knowledge and motivations and to shape consensual or best-compromise solutions around their needs. LARCI (2010) stated that co-production fosters mutual trust and communication, generates reciprocal and mutual benefits, and alters attitudes. In recent years, co-production has also been linked to describe the growing engagement of policy-makers and managers in driven research motivated to solve societal problems (Martin, 2010; Nutley, 2010).

5.4.2 "Coastal Information System for the municipality of Cascais" project

The "Coastal Information System for the municipality of Cascais" project (designated by CIS project from this point forward) emerged with the objective of designing a roadmap towards the implementation of a coastal monitoring program targeting the beaches of Cascais. This program addresses specific needs of the managers of this municipality, based upon de implementation of an indicator-based coastal monitoring program.

The trigger for this collaboration was the positive experience and high levels of engagement achieved under the framework of the outreach initiative "The Beaches of Cascais: past and present" (see chapter 5.1.2. *The Beaches of Cascais: past and present*).

5.4.2.1 Motivation

The coastal zone of Cascais is characterized by beaches, cliffs and sand dunes that play an important role as environmental, economical and social values of this municipality. Beaches, in particular, are a major asset of Cascais and a key driver of local economy. Acknowledging their importance, the municipality of Cascais aims to establish a monitoring program to raise the present-day level of understanding of beaches change and evolution at seasonal to long-term time scales. Beside the data and science involved the program also aims to support the definition of measures aiming at beach conservation. Actually, projects of beach changes under scenarios of climate change and sea level rise indicate that a significant reduction in the beach area of all Cascais beaches is expectable if no conservation actions are taken (Taborda and Ribeiro, 2015). Furthermore, it is an ambition of those who participate in the design of the CIS project to foster communication of results of the monitoring program in a systematic manner. The goal is to make the CIS project a linkage initiative amongst the different coastal actors contributing to raise their engagement in coastal issues.

5.4.2.2 Approach

To support the development of a monitoring program targeting Cascais coastline, the "Frame of Reference" approach was adopted aiming to structure the interaction of scientists, and policy-makers and coastal managers in application-oriented knowledge development according to van Koningsveld (2003). Within this approach, the starting point for knowledge development is to get the big picture of the information and knowledge needed by policy-makers and coastal managers. In addition, a key element is the definition of "fit-for-purpose" indicators.

According to van Koningsveld (2003) the "Frame of Reference" is potentially useful in any situation where miscommunication arises in interaction between interdependent coastal actors, with different states of knowledge, working on different parts of the same overall problem.

"Frame of Reference" is represented in Figure 40 and involves the six key-steps:

- *Strategic objective:* that expresses the long-term management vision and policy;
- *Operational objective(s):* that describes how the strategic objective will be achieved in a four stage process:
- *Quantitative state concept*: a means of quantifying the problem in hand. The application of indicators is relevant at this stage of the process;
- *Benchmarking process:* a means of assessing whether or not action is required. At this stage indicators are compared to threshold values;
- *Intervention procedure:* defines in detail what action is required if the benchmark values are exceeded;
- *Evaluation procedure:* assesses the impact of the action taken. If the action has not been successful it may be necessary to revise the strategic/operational objectives and hence the feedback loops indicated in Figure 40.

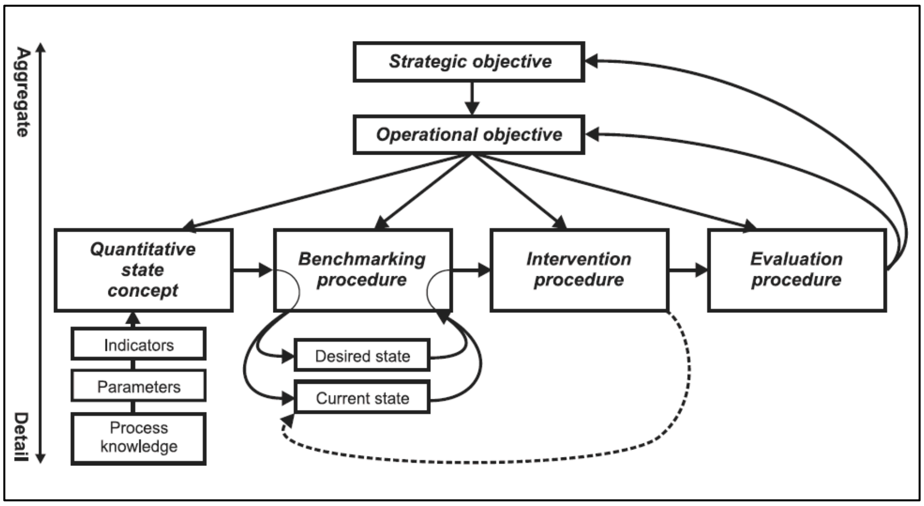


Figure 40. The "Frame of Reference" postulated by van Koningsveld (2003).

The "Frame of Reference" has been previously applied under the scope of a Portuguese project *Consultoria para a Criação e Implementação de um Sistema de Monitorização do Litoral abrangido pela área de jurisdição da ARH do Tejo* (Carapuço *et al.*, 2013c) as well as in several European projects, namely, CoastView (Davidson *et al.*, 2007; van Koningsveld *et al.*, 2007), Conscience (Marchand, 2010) and Morphological Impacts and COastal Risks induced by Extreme storm events (Micore) (Ciavola *et al.*, 2011).

In the framework of the CIS project, the *strategic objective* for Cascais municipality was identified as sustainability (in a broad sense), from which coastal sustainability and sustainable tourism arise as main concerns. The priority *operational objective* is the definition of beaches width accounting for variations at short- (tide level), medium- (seasonality) and long-term (sea-level rise) time scales. This objective was triggered by the need to establish management strategies attending to two particular situations: 1) minimizing conflict, during bathing season, between beach users and concessionaires due to competing interests in the use of the (available) beach area; 2) assessing the impact of sea level rise and the predicted reduction in beach area (Taborda and Ribeiro, 2015; PECAC, 2010). The coastal geoindicator selected as most relevant support *quantitative state concept* was identified as beach width, which implicitly implies the determination of other two geoindicators: coastline and shoreline positions (see Table 3 in Chapter 4. *Coastal indicators: a common language*).

As suggested in the literature (van Rijin, 2010; van Koningsveld, 2003), and within the spirit of co-production, selection of the indicator "beach width" reflects the input from both coastal managers and scientists. The importance of their involvement is that the former are able to assess what information will be of most value to the management, while the latter can determine what and when might be possible to measure based on existing or potential data and technology and how the scientific understanding of the data set may contribute to fulfill management or conservation needs. Indicators assume the role of the "common" language (see Chapter 4. *Coastal indicators: a common language*) between the different parties as they are comprehensible to all parties involved while, simultaneously, assure rigorous reporting (Figure 41).

COASTAL INFORMATION SYSTEM FOR THE MUNICIPALITY OF CASCAIS

AUDIENCE: POLICY-MAKERS AND MANAGERS (IN PARTICULAR), AND SOCIETY (IN GENERAL)
LANGUAGE: INDICATORS
CHANNEL OF COMMUNICATION: WEBSITE
MECHANISM: CO-PRODUCTION

Figure 41. "CIS – Coastal Information System": project's audience and language, channel of communication and mechanism adopted to get the message across and reach the audience.

CIS project will also allow identifying the best methodologies to monitor the changes in the width of the beaches of Cascais. Results from the project "Cascais Beach Photo Monitoring" (see 5.2.2. "*Cascais Beach Photo Monitoring" project*) will be a contribution in this direction by investigating the value of systematic acquisition of photographs to characterize the changes in the area of the beaches of Cascais. Implementation of CIS project will further allow the establishment of the following steps of the "Frame of Reference" contributing to the establishment of threshold values to support the definition of coastal interventions, and the assessment of the impact of those interventions.

At present time, Cascais municipality conducts small-scale and localized sand shifting operations amongst beaches aiming at solving problems related with the variations of beach width during beach session. However, these operations are performed on an *ad hoc* basis and do not benefit from scientific understanding of the sedimentary budget.

5.4.2.3 Roadmap of the CIS project

The roadmap presented in Figure 42 aims to provide a chronological overview of the four key-activities of the CIS project:

Design of the monitoring program: includes the establishment of key-areas (*i.e.,* beaches of Cascais) and key-issues (*i.e.,* variations in beaches width) according to the needs of information of managers from Cascais municipality. Still to be solved the most efficient techniques for data acquisition (*e.g.,* photo and video monitoring, cross-shore profile and topographic surveys) and data processing with may not be the same in all beaches. This step considers the evaluation of the resources available in Cascais municipality namely in terms of human resources, equipment and existing data sets, namely those available at Geo Cascais platform as well as the development of crowdsourcing initiatives. The goal is to optimize resources and increases [chances of] the longevity of the monitoring program. Crowdsourcing have the additional benefit of upstream society engagement in coastal issues.

Implementation of the monitoring program and skill development: includes putting into operation the routines for data acquisition, processing and making data and information available to all key coastal actors as well as training of technicians of the municipality of Cascais

Communication plan: includes the presentation of the project and its results to different audiences, by the development of outreach activities and "get-together" initiatives (workshops, conferences seminars). In addition to crowdsourcing, the implementation of the communication plan will further promote society engagement in coastal issues.

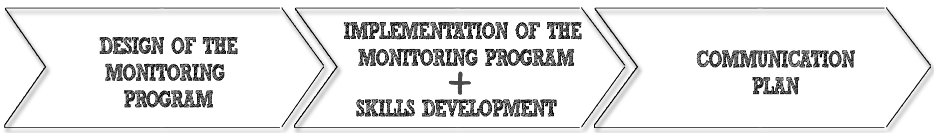


Figure 42. Roadmap towards the implementation of the CIS project.

Like other stages of the CIS project, this roadmap was co-produced with managers, technics and staff from Cascais Municipality. This option can make the difference in shifting the balance of responsibilities and resources, transforming the dynamics between participants and shortening the leap to the implementation of the CIS project.

5.4.3 Conclusions

Co-production is a collaborative process among [coastal] actors that take place in "middle ground". Co-production bridges a plurality of knowledge types together to address a specific problem and makes the solution for that problem to be more efficient, more effective and more responsive to the needs of coastal actors. The CSI project was designed using a co-production approach involving scientists and managers and technicians from Cascais municipality with the objective of establishing a roadmap towards the implementation of a coastal monitoring program targeting the beaches of this municipality. Despite the design of the project having been more time-consuming that under typical circumstances (*i.e.,* when projects are designed [almost] exclusively by scientists), the output is much more likely to address the managers' needs of information, to optimizing resources and to involve the non-scientists communities. This can increases the changes of implementation and success of the CIS project. It is worth to mention that the positive experience of the outreach initiative "The Beaches of Cascais: past and present" (see chapter 5.1.2. *The Beaches of Cascais: past and present*) enabled the conditions that facilitated the adoption of a co-production strategy for the CIS project. This highlights the importance of outreach in building higher levels of engagement among coastal actors, namely in enabling conditions for co-production.

Chapter 5.4 | Key messages

- Co-production is a collaborative approach amongst [coastal] actors, bringing different knowledge types together to address a specific problem, aiming at building an integrated solution.
- CIS project is an example of a project designed under the co-production approach, proving additional benefits in addressing the needs of those who participate, and in maximizing resources, thus increasing the changes of projects' implementation and longevity.
- The trigger for the development of the CIS project was the positive experience from the outreach initiative "The Beaches of Cascais: past and present". This highlights the importance of outreach in enabling conditions for fostering collaboration requiring higher levels of engagement.

Chapter 6

A conceptual model for successful knowledge transfer

Chapter 6

6. A conceptual model for successful knowledge transfer

[This subchapter is based on: Carapuço, M.M., Taborda, R., Andrade, C., de Jonge, V.N. 2016a. Coping with coastal change: from scientific knowledge to implementation (*Submitted*)]

It is widely acknowledged that to promote the integration of science in the decision-making process "a one size fits all" approach will not work (Bonne *et al.*, 2014). In this work, four mechanisms for transferring scientific knowledge were identified: outreach, crowdsourcing, management-oriented tools and co-production. The selection of the more adequate mechanism will depend both on audience's engagement and aspired feedback. The conceptual model depicted in Figure 43 aims to guide scientists in this selection.

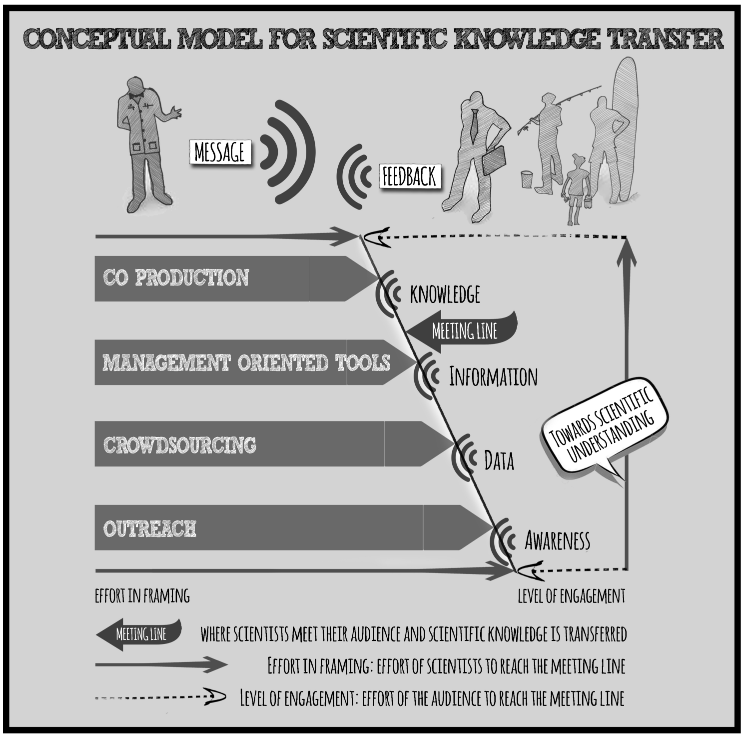


Figure 43. A conceptual model to guide scientists (on the left) in the selection of the best mechanism to transfer scientific knowledge to other key coastal actors (on the right). Four mechanisms for transferring scientific knowledge can be adopted: co-production, management-oriented tools, crowdsourcing and outreach. Each mechanism requires a different effort in framing by scientists, and its adoption is constrained by the level of engagement of the audience. This conceptual model highlights that in order to adopt higher-level mechanisms (*e.g.,* co-production) it is necessary to assure high levels of engagement; when these conditions are not met is necessary to previously implement lower-level mechanisms, fostering engagement.

Communication is only effective if both scientific and non-scientific actors are willing to converge and take the necessary steps to meet at some point of the communication process, which is conceptualized by the "meeting line" depicted in Figure 43 by the solid oblique line. This bridging effort can be approached from both sides in a proportion that will depend on the mechanism adopted (depicted in Figure 43 by the horizontal lines: effort in framing by scientists, and level of engagement by non-scientists). When the communication process is successful it not only increases receivers' scientific understanding on the coastal system but also fosters engagement and generates feedback. The quality and amount of feedback depends on the adopted mechanism with a complexity that increases from awareness (in response to outreach) to knowledge (in response to co-production). This conceptual model shows that, in order to adopt higher-level mechanisms (such as co-production for scientific knowledge transfer), it is necessary to assure high levels of engagement. If these conditions are not meet it is necessary to previously implement actions requiring lower level mechanisms (such as outreach), to foster engagement.

- When the objective of scientists is to raise awareness of an audience that is scarcely engaged into coastal science, outreach arises as the most adequate mechanism for scientific knowledge transfer (bottom of Figure 43). As the audience may not be tuned to scientific language and contents, outreach is the mechanism involving the highest framing effort by scientists. The feedback of a well-succeeded outreach initiative is raising awareness on coastal issues, thus contributing to trigger involvement of the audience. In addition, this helps to change receivers' attitude from passive to active, increasing their level of engagement. When society is engaged with science, it is no longer a mere spectator of coastal policies and development and is more capable and willing to influence the policy-makers and managers towards coastal sustainability, and also willing to offer useful contributions to coastal science and management.

- In crowdsourcing the audience plays an active role, thus the adoption of this mechanism requires some level of engagement. This mechanism has the advantage of contributing to the development of a participatory society, which is an important step towards coastal sustainability. Furthermore, the data generated by the use of this mechanism also create a positive feedback to the knowledge generation process.

- In management-oriented tools, it is expected that coastal actors become more autonomous in generating information according to their specific needs. This mechanism needs lower framing effort because coastal actors involved are, in general, more engaged and aware of the challenges of coastal sustainability. Information generated by using management-oriented tools also increases in relevance (as it refers to contextualized data) helping scientists to further understand the coastal system.

- Co-production can be regarded as highest-level mechanism in scientific knowledge transfer as the audience is closer to scientific language and issues, thus involving the lowest framing effort by scientists (top of the Figure 43). The adoption of this mechanism benefits from the knowledge (i.e., combined information leading to understanding) generated (also) by the audience. This mechanism stimulates the integration of different types of knowledge, thus promoting optimal conditions for implementation.

The conceptual model for scientific knowledge transfer aims to contribute towards a society where all key coastal actors are active asset-holders. The mechanisms portrayed in this model can be linked with their typical audiences and expected feedbacks: the lower-level mechanisms usually target society, and the higher-level mechanisms target policy-makers and managers. Notwithstanding, they can be used to reach all types of audiences with a success that mainly depends on the initial levels of engagement of the different parties.

Chapter 7

Conclusions and outlook

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7. Conclusions and outlook

Achieving coastal sustainability depends on the effective integration of scientific knowledge in the decision-making process. To do so, scientists need to be able to transfer their knowledge outside of the scientific community. However, communication gaps arise as a major obstacle to scientific knowledge integration. Communication barriers include differences in language adopted by different groups of coastal actors (*e.g.,* scientific *vs.* non-scientific language) and the channels of communication selected by the scientific community (*e.g.,* scientific articles) that do not account for specificities of non-scientific audiences. In overcoming these drawbacks, scientists need to acknowledge that their role does not end when scientific knowledge is developed. Scientists have also an indispensable role in its successful delivery to non-scientists.

In the development of a scientific knowledge-transferring framework, the identification of the coastal actors is of paramount importance. Coastal actors (other rather scientists themselves) make the audiences that scientists aim to reach and understanding and respecting their specificities is vital to make communication successful. Besides scientists, two other key coastal actors were identified and considered in this work: policy-makers and managers, and society. It was also found that understanding the ways coastal actors interact is a major issue in fostering knowledge transfer, as the existence of weak bounds, or even disconnection, among coastal actors can seriously prejudice knowledge transfer among them. This was put in evidence in the *Coastal Knowledge Triangle*, a model that conceptualize coastal actors, their roles and links.

Once the audience is clearly identified, knowledge transfer depends on coastal actors' engagement and adequate framing of the message to be delivered by scientists. Engagement is grounded on empathy and, beyond simple awareness of the problem it implies action in itself, enabled by coastal actors' willingness, trust, competence and commitment. Framing helps turning scientific data into meaningful information for the target audience. Framing involves translating scientific findings into an understandable language by different audiences as well as choosing the proper channels of communication to convey the message.

Indicators arise as the most efficient "common language" to communicate science. Moreover, proven to be useful to describe the state and trends of evolution of the coastal zone. However, a standardized concept and approach on coastal indicators' quantification and reporting was lacking. Therefore, in the scope of the present study, a common framework for the establishment of coastal geoindicators for sandy coast environments was developed. Sixteen indicators were identified as relevant for beach, coastal dune and coastal barrier environments.

Nevertheless, to effectively communicate science it is necessary to find means to relate with the audience in order to get the message across. In this work four mechanisms for knowledge transfer were identified based upon real world applications. In addition, a conceptual model was developed to guide scientists in the selection of the most adequate mechanism. Outreach is the most widely known and adopted mechanism to transfer scientific knowledge. However, other means are available: crowdsourcing, managers-oriented tools and co-production. With the exception of outreach these mechanisms are still in early stages of development and experimentation – but they all are promising alternatives and should be considered as major opportunities to foster knowledge transfer. Each mechanism accounts for the audience specificities and conveys the message in a different way leading to different types of feedback from the audience: outreach leads to coastal awareness; crowdsourcing to data generation; management-oriented tools generate information, and co-production generates knowledge. Moreover, and if adequately used, these mechanisms can foster engagement, minimize framing effort and optimize audiences' feedback.

In the scope of the present study the concepts of each mechanism are presented and discussed as well as the results obtained by real-world applications are put-forward. Two outreach initiatives were developed aiming at increasing literacy and awareness: "The Beaches of Cascais: past and present" and "The Nazaré Wave: a trigger for learning". Both case studies were highly successful outreach initiatives: "The Beaches of Cascais: past and present" exhibition was successful in raising public understanding about the coastal system, and promoting a shift in people' beliefs about beach evolution trends. The project "The Nazaré Wave: a trigger for learning" was designed with the purpose of transferring scientific knowledge about the physics of waves using the Nazaré Wave as the trigger. The principal outcome of this project - the "The Nazaré Wave" movie - had over 6.000 views in the first month of its release and, three months later had been viewed in more than 95 countries. Results' allowed concluding that outreach is a major opportunity in fostering engagement and in developing a knowledge-based society.

In relation with crowdsourcing, in which society can participate in scientific research by providing more data, the "Cascais Beach Photo Monitoring" project was design and the first task of the project, which implies a 1-year systematic acquisition of photographs targeting the beaches of Cascais, was implemented. This project aims to be a proof of concept approach designed to demonstrate feasibility of systematic acquisition of photographs to support further developments of crowdsourcing tools targeting beach monitoring. It was found that photographs are a valuable resource in beach monitoring as they easily provide a reliable qualitative identification of beach changes while, at the same time, can have a major positive impact in upstreaming public engagement on coastal issues. Moreover, results suggest that crowdsourcing can not only increase the frequency of observations, in ways that coastal management agencies may not be able to do, but also contribute to reducing costs associated with coastal monitoring programs.

Within management-oriented tools, it was developed the "Wave Transformation Matrices", a graphical solution that allows for estimating site-specific nearshore wave characteristics. Besides being demonstrated to be useful for coastal managers, WTM can also be suitable to address the needs of information of sub-groups of society (e.g., surfers, fishermen). In addition, WTM allows users to be informing on physical processes and acknowledge uncertainty and issue is of major importance in building trust among coastal actors, grounded in the principle of the "best available knowledge".

The "Coastal Information System for the municipality of Cascais" (CIS) project, aiming at establishing of a coastal monitoring program targeting Cascais' beaches, was co-design in close collaboration with technicians from this municipality. CIS project constitutes a successful example of co-production having benefits in address the needs of those who participated and in maximizing resources, thus increasing the changes of projects' implementation and longevity. Worth mention that the conditions for the development of the CIS project was base upon previous (positive) experience from the outreach initiative "The Beaches of Cascais: past and present". This highlights the importance of outreach in fostering engagement and in enabling conditions for moving forward closer collaboration.

Results from the above-mentioned projects allowed for the development and establishment of a conceptual model aiming at supporting scientists in the selection of the most adequate mechanisms for successful knowledge transfer. In this selection scientists must weigh the expected level of engagement of the audience, and expected feedback in both quantity and quality aspects. Using the adequate mechanism will help in overcoming the existent communication gaps and increase the participation of all key coastal actors in the decision-making process.

Scientists must also develop their framing skills and acknowledging the benefits of engaging with others. In addition, scientists need to (and sometimes, learn to) listen to their audience to find and understand their needs of information. Such an attitude will allow scientists and science to effectively inform decision-making as often society's (in a broad scope) needs of information differs from that which science routinely provides. This effort is time-consuming and challenges scientists to step outside their comfort zone and to take the necessary steps to reach non-scientists in their own ground. Whenever scientists are able and willing to make these additional efforts and to communicate more effectively with non-scientist audiences, the end-products extend beyond informed decision-making: it is now becoming widely acknowledged that when this interaction is effective science thrives. Furthermore, science is increasingly interdisciplinary and the ability to communicate more effectively across disciplines (*e.g.,* natural and social sciences) fosters scientists and institutions' collaboration, which certainly leads to better approaches and solutions towards sustainability.

The results obtained in the scope of this work and the conclusions herein presented allow putting forward a number of tangible considerations aiming at promoting and developing a culture of science communication in universities and research & development (R&D) institutions. This will narrow the communication gaps between scientists (and science) and other coastal actors and will improve the effectiveness of coastal scientific knowledge transfer:

- The establishment of science communication offices at universities and R&D institutions as an interface between institutions that generate scientific knowledge and the outside world.
- To assure science communication projects and initiatives into institutional planning and resources allocation enabling conditions for the design and implementation of outreach initiatives.
- To assure training in science communication for faculty, staff and students. Their involvement in science communication activities should be recognized, valued and rewarded.

As transferring scientific knowledge implies the existence of target-audiences, it is also important that governmental, regional and municipal institutions sharing responsibilities in science policies and in the management of the coastal zone develop their own resources to maximize the process of knowledge transfer.

This study relies on the premise that a knowledge-based society is needed to meet the objective of coastal sustainability. Therefore, scientists should actively pursue the goal of transferring science outside of the scientific community and fully embrace their role in this process. The implementation of the above-mentioned measures will contribute to improve the transfer of coastal scientific knowledge, from concept to implementation. Altogether, scientists and institutional efforts will shorten the leap from knowledge to implementation fostering the use of scientific knowledge as the rationale for costal sustainability.

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IMPROVING THE TRANSFER OF COASTAL SCIENTIFIC KNOWLEDGE: FROM CONCEPT TO IMPLEMENTATION

Annex

- Annex :: Wave Transformation Matrices -

Table A1. Characteristics of the grids used in the wave propagation model.

Grids	Resolution $(\Delta x, \Delta y)$	Origin (ETRS89 PT-TM06) x	y
Regional	500 x 500 m	-151294	-140730
Nested - NE 1	100 X 100 m	-78902	11638
Nested - NE 2	50 x 50 m	-81038	2269
Nested - NE 3	50 x 50 m	-82415	-8321
Nested - NE 4	50 x 50 m	-97057	-27268
Nested - NE 5	50 x 50 m	-99323	-29401
Nested - NE 6	50 x 50 m	-104097	-32098
Nested - NE 7	50 x 50 m	-107099	-33736
Nested - NE 8	50 x 50 m	-109292	-58794
Nested - NE 9	50 x 50 m	-113545	-73400
Nested - NE 10	50 x 50 m	-112873	-78683
Nested - NE 11	50 x 50 m	-115710	-89291
Nested - NE 12	100 X 100 m	-112499	-109050
Nested - NE 13	50 x 50 m	-99746	-133486

Table A2. Names and positions of the target-areas and target-points.

Target-areas	Target-points	Position ETRS89 PT-TM06 x	y
1. Pedras Negras beach	PN1	-76553	13872
	PN2	-76734	13435
2. Paredes de Vitória beach	PV1	-79548	4439
	PV2	-79534	4280
	PV3	-79570	3883
3. Nazaré beach	NZ1	-81131	-6991
	NZ2	-80997	-7535
	NZ3	-81043	-7918
4. Lagoa de Óbidos – Baleal stretch	LOB1	-96233	-26368
	LOB2	-98365	-28345
	LOB3	-102060	-30948
	LOB4	-103593	-31521
5. Baleal - Peniche	BP1	-104610	-32375
	BP2	-105279	-32608
	BP3	-105855	-32853
	BP4	-106187	-32525
6. Santa Cruz beach	SC1	-107596	-56685
	SC2	-108000	-57260
	SC3	-108344	-57953
7. Coxos beach	CX1	-112265	-72525
8. Baleia/Sul beach	BS1	-111680	-78128
9. Magoito beach	MG1	-114851	-88535
10. Tamariz beach	TM2	-110395	-106679
11. Costa da Caparica – Espichel cape strecht	CC1	-97787	-112380
	CC2	-97288	-113087
	CC3	-96853	-114005
	CC4	-95925	-115056
	CC5	-95001	-116570
	CC6	-93067	-121472
	CC7	-92864	-121922
	CC8	-92289	-128711

Figures A1 to A13 present the WTM for the simulation target-points listed in Table A2 (*in column* “Target-points”).

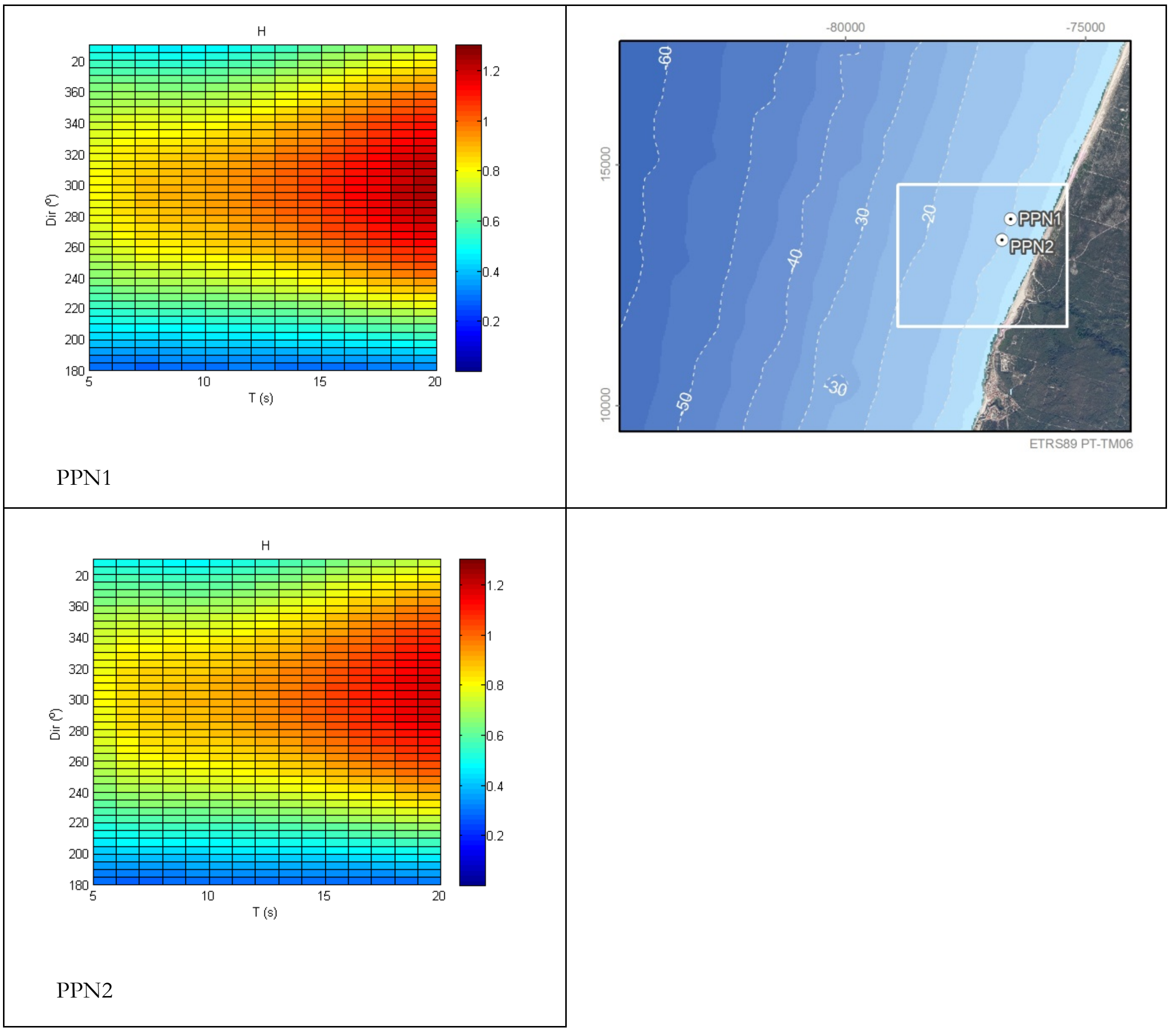


Figure A1. 2D WTM_H for target-points PPN1 and PPN2 at Pedras Negras beach.

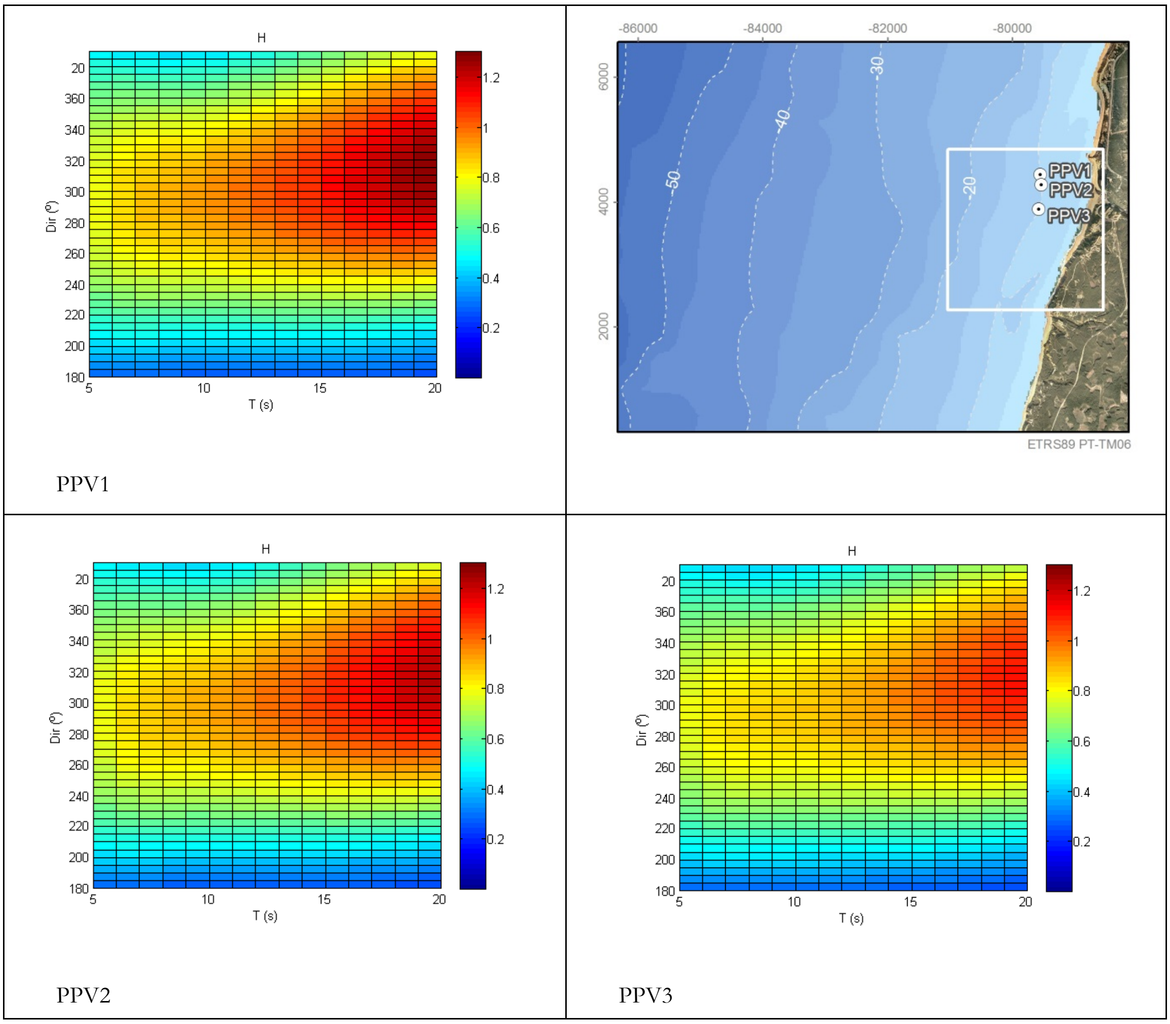


Figure A2. 2D WTM_H for target-points PPV1, PPV2 and PPV3 at Paredes de Vitória beach.

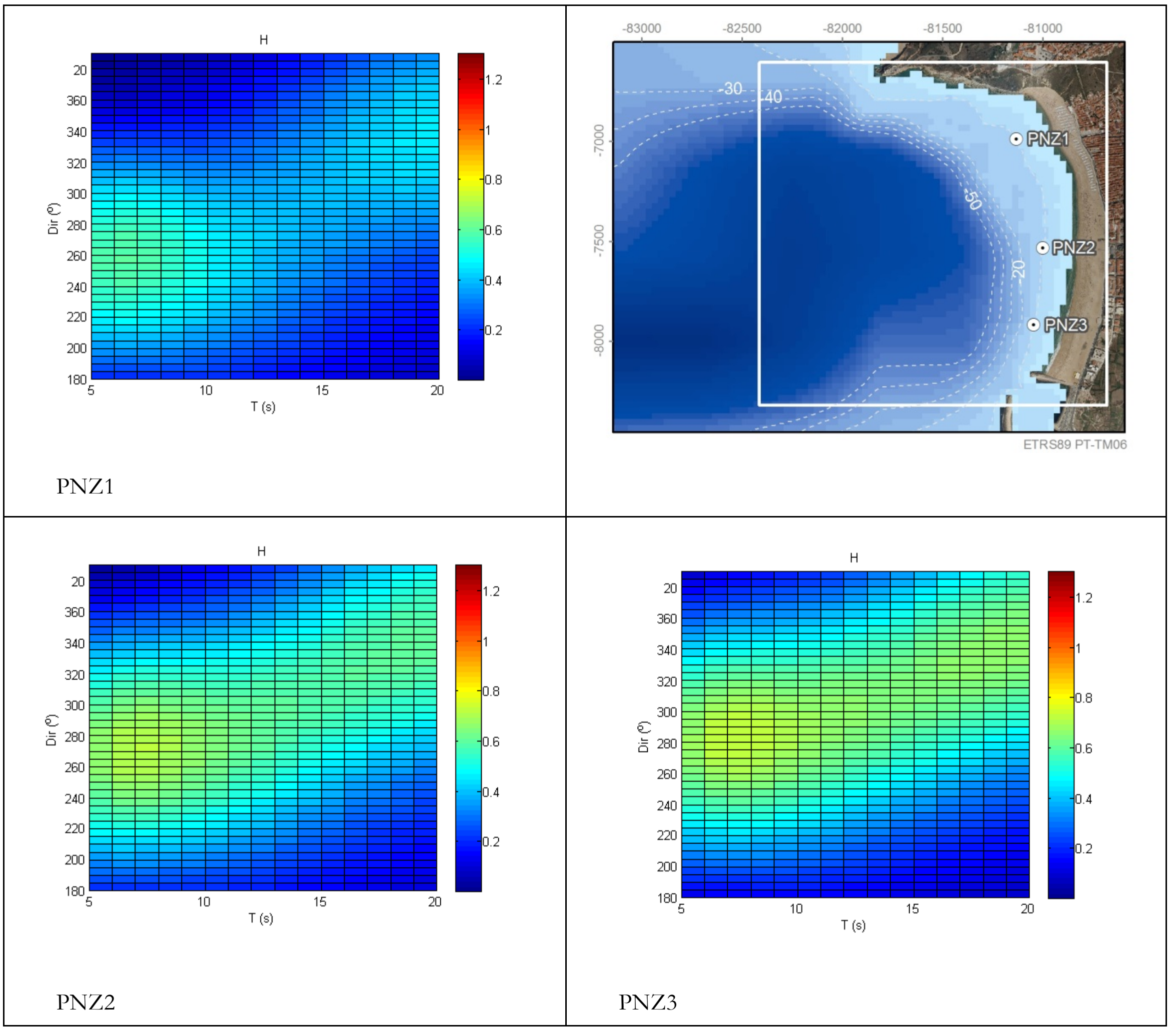


Figure A3. 2D WTM_H for target-points PNZ1, PNZ2 and PNZ3 at Nazaré beach.

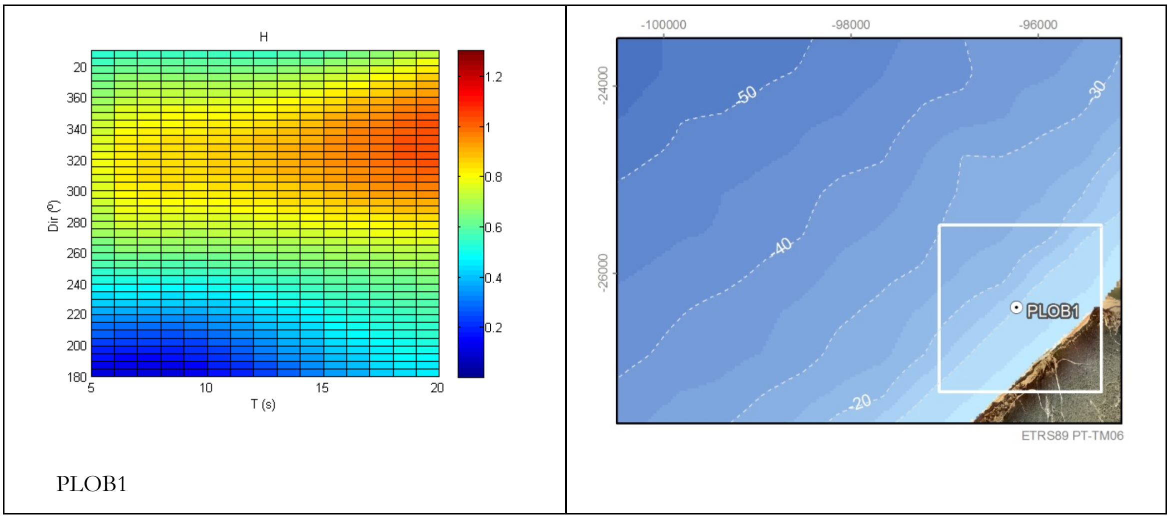
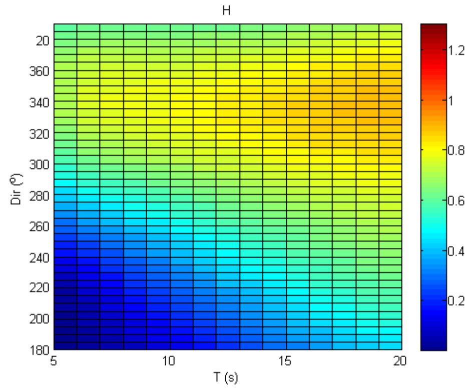
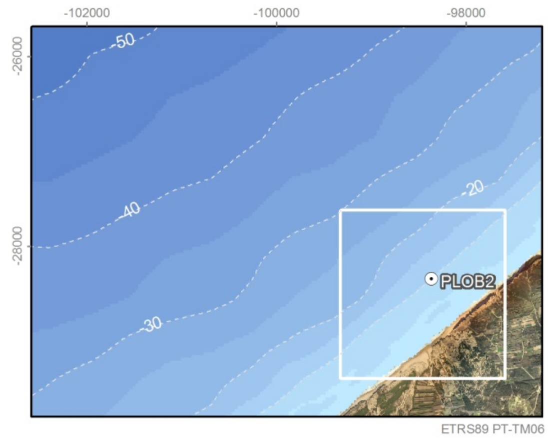


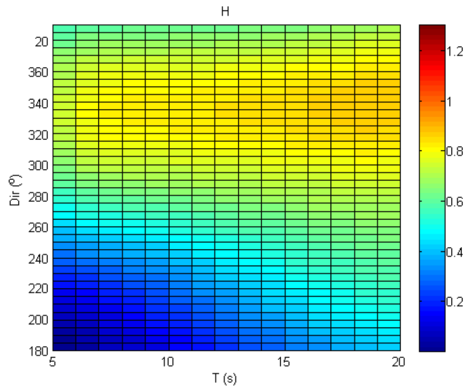
Figure A4. 2D WTM_H for target-point PLOB1 at Lagoa de Óbidos-Baleal coastal stretch.

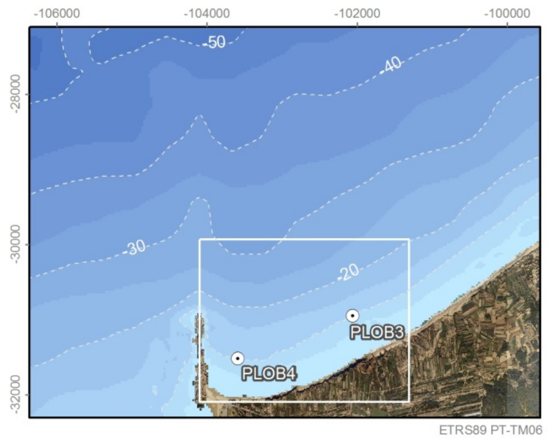




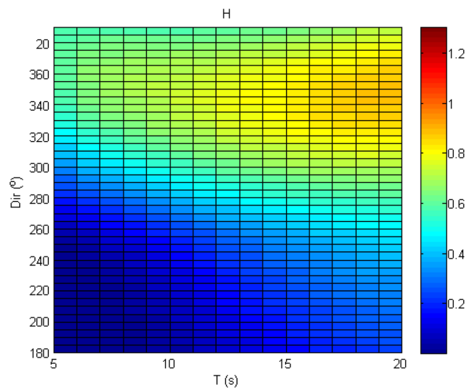
PLOB2

Figure A5. 2D WTM_H for target-point PLOB2 at Lagoa de Óbidos-Baleal coastal stretch.





PLOB3



PLOB4

Figure A6. 2D WTM_H for target-points PLOB3 and PLOB4 at Lagoa de Óbidos-Baleal coastal stretch.

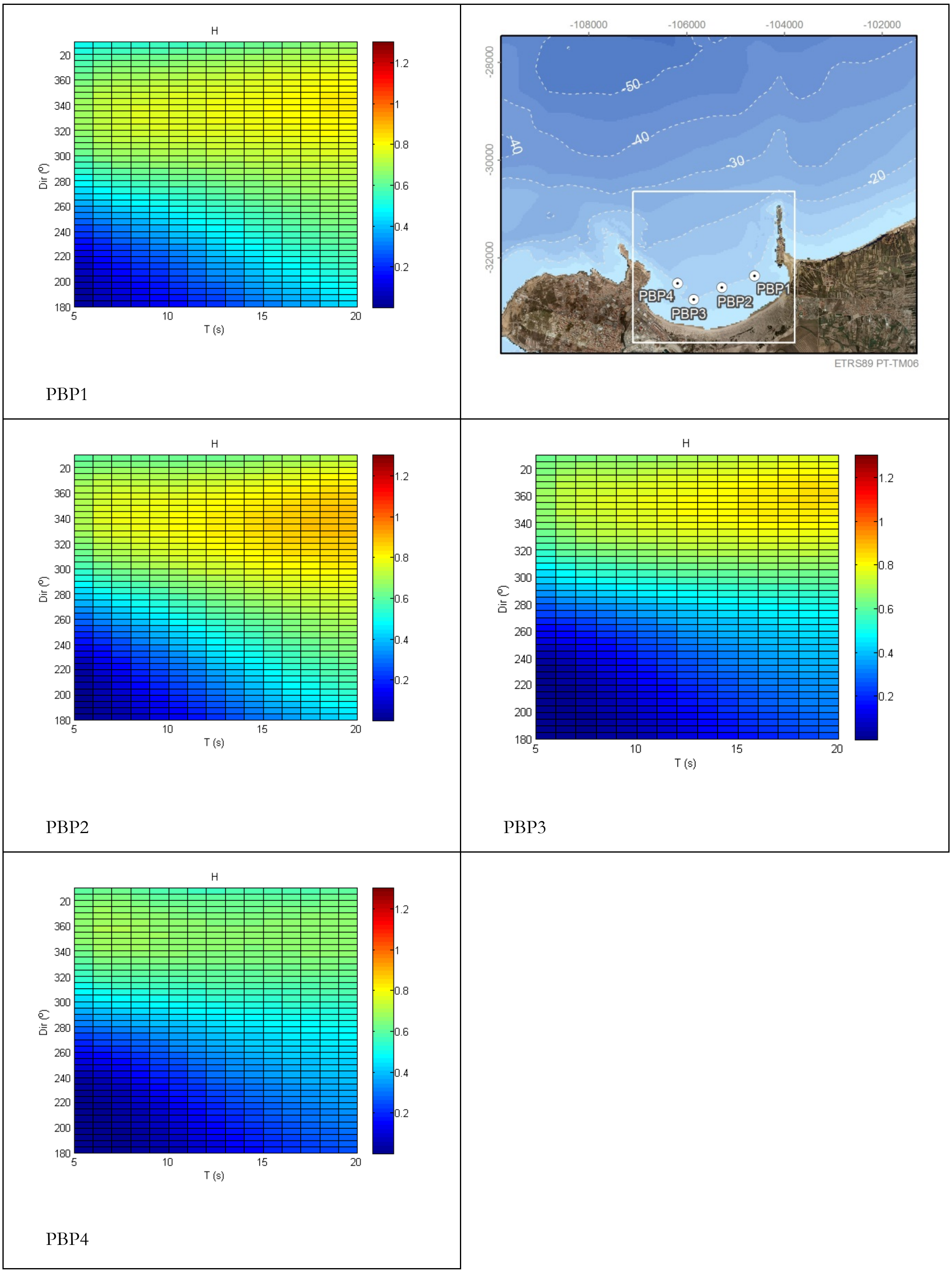


Figure A7. 2D WTM_H for target-points PBP1, PBP2, PBP3 and PBP4 at Baleal-Peniche coastal stretch.

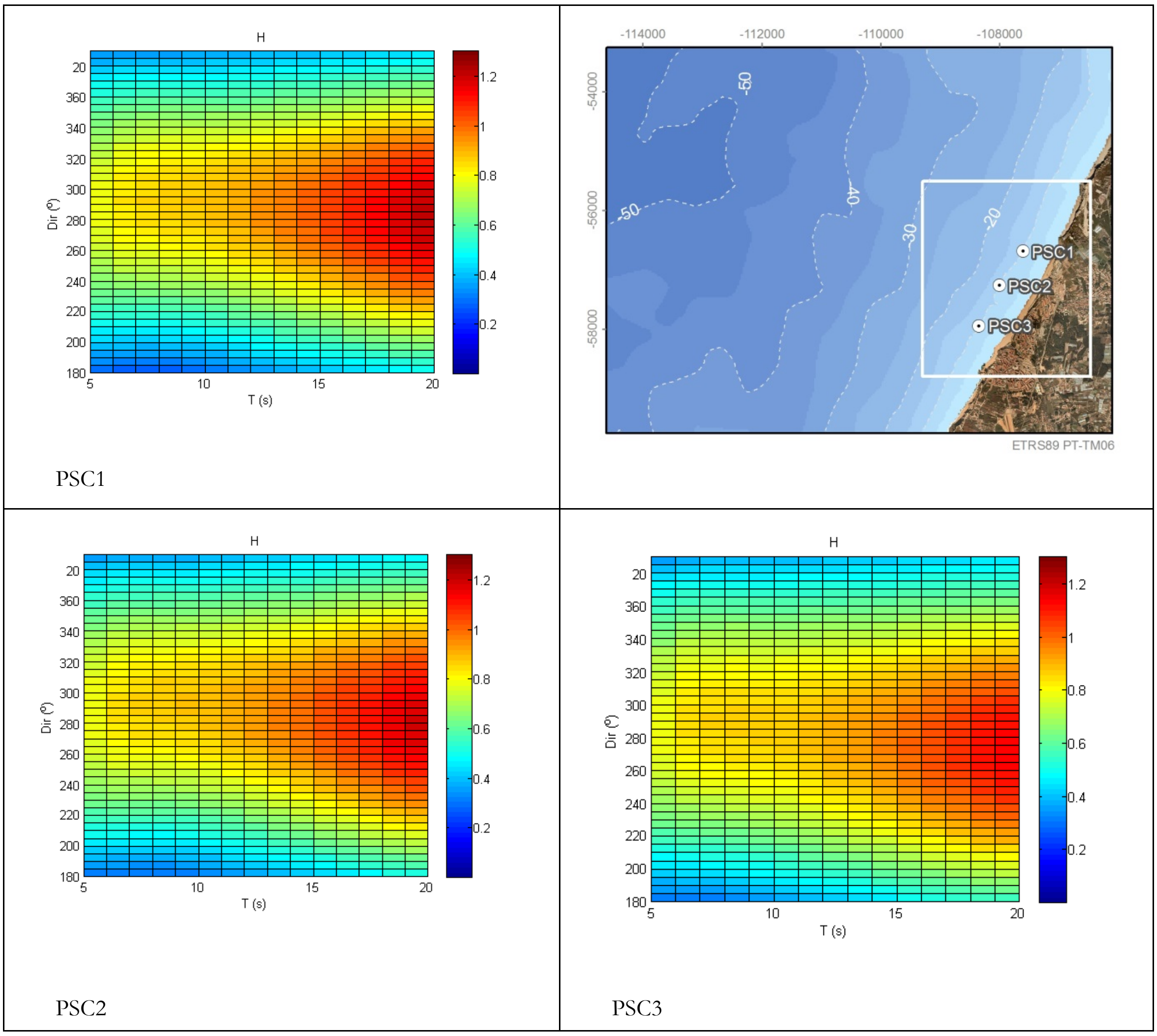


Figure A8. 2D WTM_H for target-points PSC1, PSC2 and PSC3 at Santa Cruz beach.

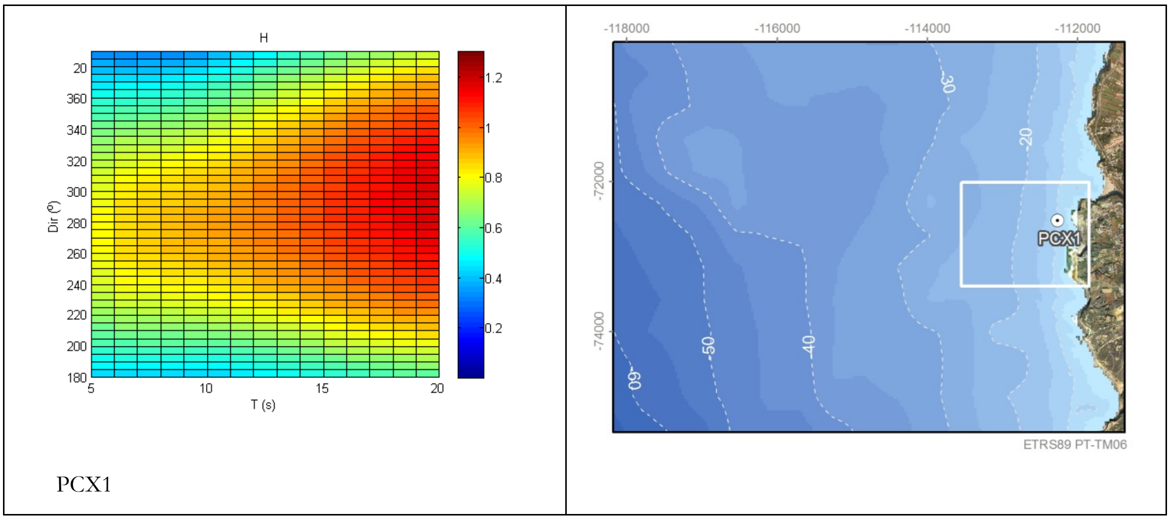


Figure A9. 2D WTM_H for target-point PCX1 at Coxos beach.

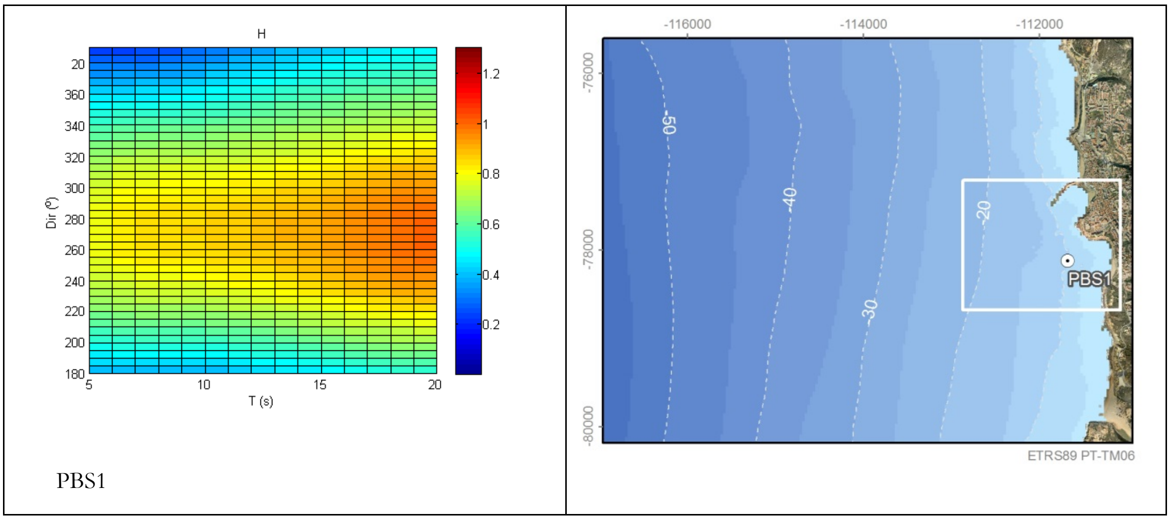


Figure A10. 2D WTM_H for target-point PBS1 at Baleia/Sul beach.

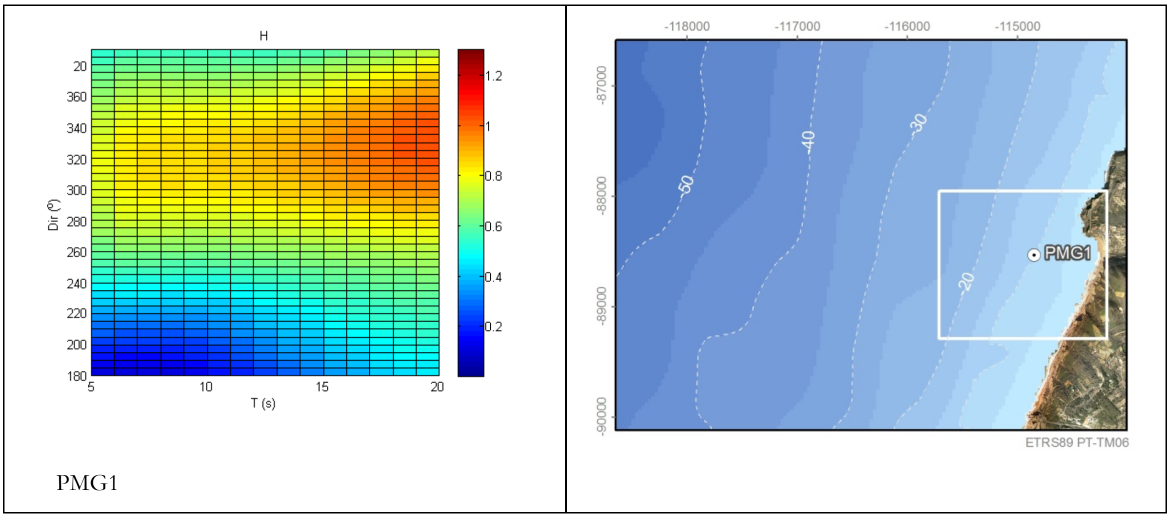


Figure A11. 2D WTM_H for target-point PMG1 at Magoito beach.

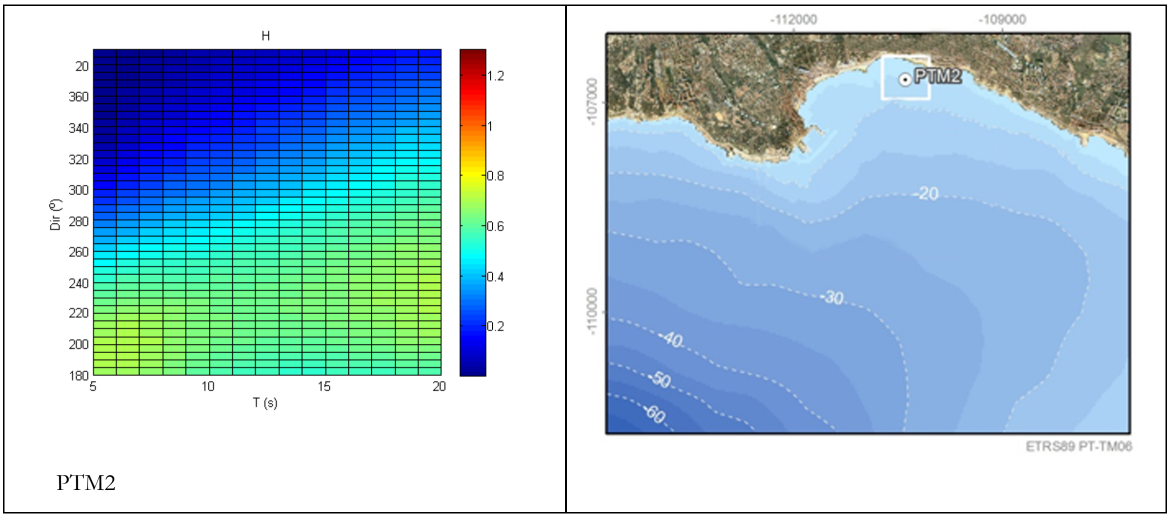


Figure A12. 2D WTM_H for target-point PTM2 at Tamariz beach.

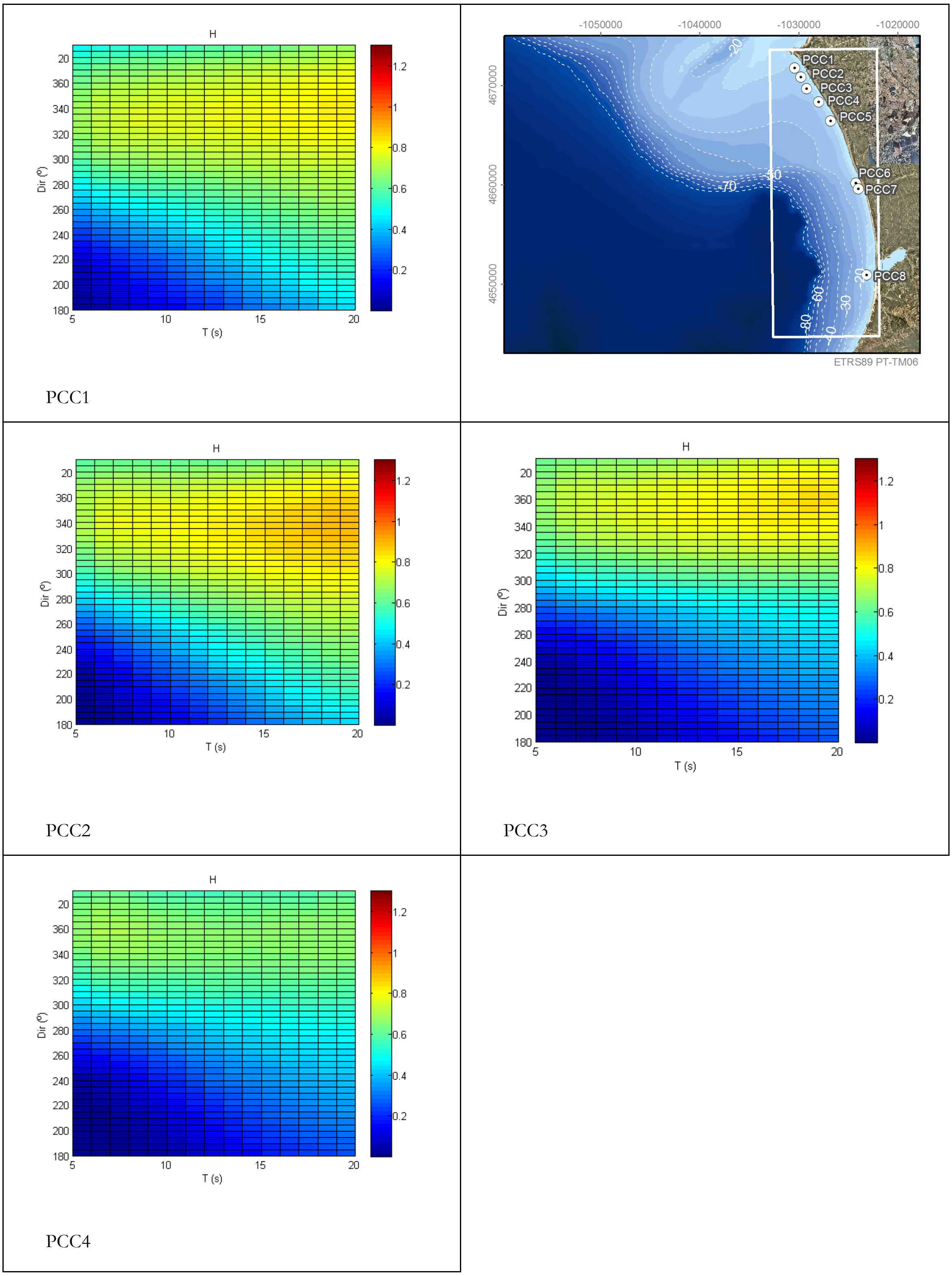


Figure A13. 2D WTM_H for target-points PCC1, PCC2, PCC3 and PCC4 at Costa da Caparica – Espichel cape coastal stretch.

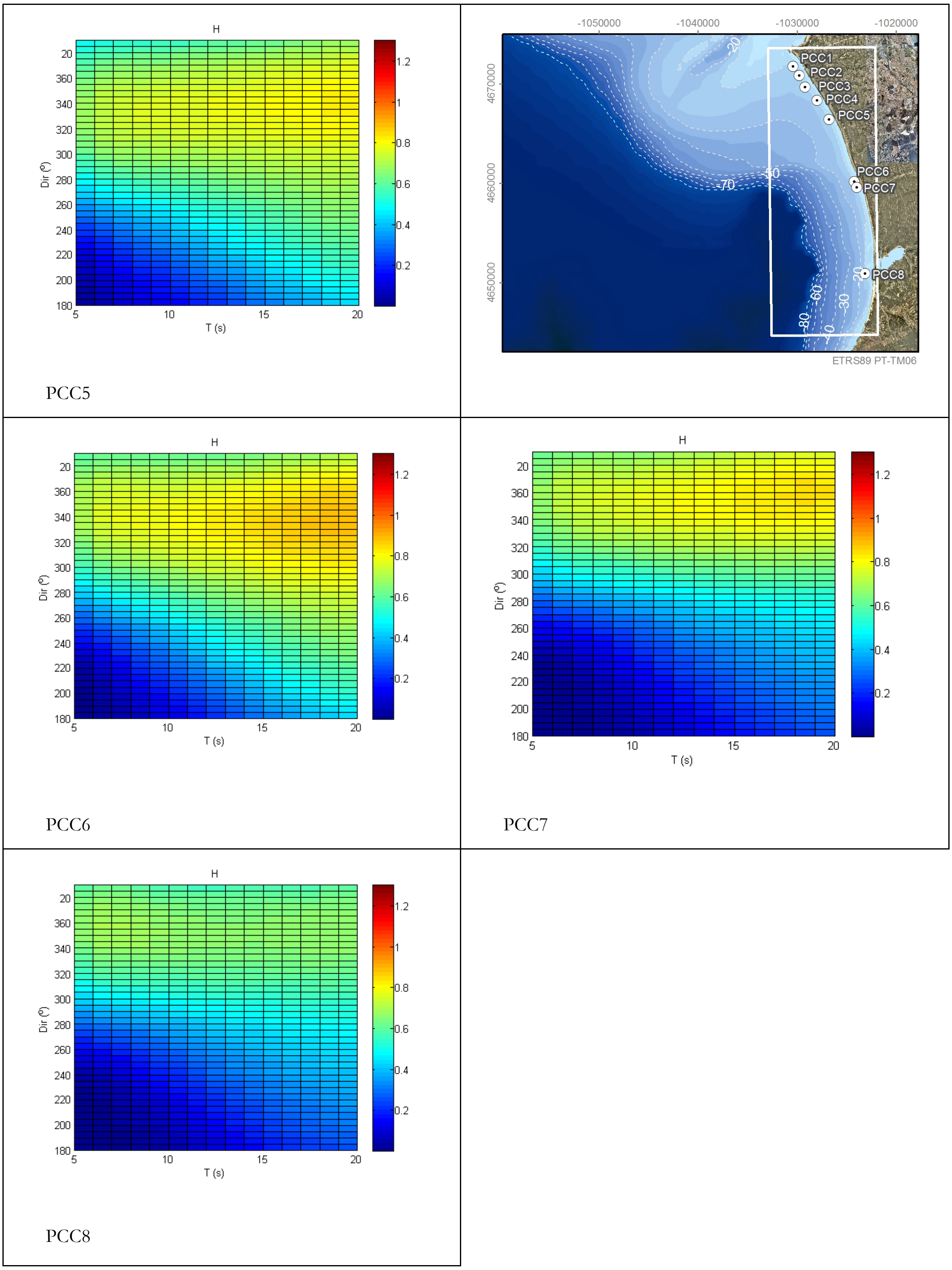


Figure A13 (cont). 2D WTM_H target-for points PCC5, PCC6, PCC7 and PCC8 at Costa da Caparica – Espichel cape coastal stretch.